Riparian vegetation diversity in the Sydney Catchment Authority's area of operation

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A report prepared for the Sydney Catchment Authority as a component of a synoptic biodiversity survey for developing a long-term biodiversity-monitoring program

CRC FOR FRESHWATER ECOLOGY

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Executive Summary

The CRC for Freshwater Ecology (CRCFE) undertook a Synoptic Biodiversity Survey funded exclusively by the Sydney Catchment Authority (SCA) in 2001. The over-arching purpose of the survey was to make a preliminary assessment of the distribution and variability of riparian and in-stream biodiversity across the catchments under the responsibility of the SCA, and to identify sites of scientific significance. The biological information necessary for achieving these two purposes was not available, necessitating the survey. The survey targeted three biotic groups: fish (Task 2a), macroinvertebrates (Task 2b and Task 2d) and riparian vegetation (Task 2c). This is the final report on the synoptic survey of riparian vegetation diversity (Task 2c).

This preliminary survey of riparian diversity had four objectives:

[1] to measure riparian plant diversity and its variation within and between sites sampled;

[2] to correlate species richness and vegetation structure measures with site physical characteristics;

[3] to relate species presence to simple habitat variables and consider the potential for developing species-level predictive models; and

[4] to provide plot-based vegetation structure descriptions to enable ground-truthing of remote sensing imagery.

Field work was done in 5 weeks in April–May 2001.

Site selection was designed to service two biotic groups — macroinvertebrates and riparian vegetation — but followed AUSRIVAS protocols; that is, site selection criteria were based on maximising the variation in stream order/type across the study area's catchments, and upstream catchment land use characteristics. The latter was based on three broad *a priori* categories: Reference, Agricultural and Urban. Sampling at the same sites was a deliberate compromise to maximise opportunity for integrating macroinvertebrate and riparian vegetation biodiversity. Within sites, vegetation sampling was determined by geomorphic forms and complexity. The result was 40 vegetation sites, comprising 72 plots across the five catchments of the Sydney Catchment Authority area of responsibility.

The data were analysed to identify patterns and correlates of various biodiversity measures. The measures included species composition, species richness and vegetation structure. Each of these was considered in terms of the relative occurrence of native versus alien species, plant life-forms (woody, herbaceous, ferns etc.) and the presence of threatened and noxious species. For some measures, there was the possibility to consider both the plot scale as well as site. The relationship of measures to the three site types used in site selection was also central to the analyses. Patterns and correlations were detected and summarised using descriptive techniques as well as numerical classification and statistical modelling.

Summary of results

Site Selection: Sites selected based on upstream catchment characteristics did not perfectly correspond with adjacent land use, a criterion important in determining vegetation condition. For riparian vegetation, sampling protocols need to accommodate both macro-scale and local characteristics.

Species Richness: The survey recorded 383 native species, with the number of species per site ranging from 2 to 67. Species of conservation significance were recorded, and these included three rated as 'Vulnerable' under Federal legislation, and twelve of regional significance.

Alien species: The presence of alien species is a threat to biodiversity. A total of 162 alien species were recorded, with the number per site ranging from 1 to 43. Weed species listed under the federal listing of Weeds of National Significance, and species listed as 'Noxious' under state legislation, were considered to be particularly threatening; the numbers involved were five and 22 respectively. Although many alien species were of low occurrence, a high proportion of sites surveyed (18/40) were dominated by alien shrubs and trees.

Macrophytes: In-channel plant diversity was not sampled, but the streamside plots showed a high level of macrophyte species diversity, including a large number of emergent macrophytes. The incidence of alien species was considerably lower than for the riparian vegetation as a whole, raising questions about relative biodiversity values for these two habitat groups.

Vegetation Structure: The vegetation in one-third of the sites was structurally dominated by alien plant species and these sites also had a high proportion (60%) of alien species in their understorey. Sites with native species as dominants were also highly invaded by alien species (33% alien), indicating the potential of the latter to dominate sites following disturbance.

Biodiversity correlates: Land alienation and increasing degree of disturbance were strong negative influences on riparian vegetation biodiversity at individual sites, affecting both structure and species composition.

Modelling species richness: Modelling the richness components of biodiversity demonstrated how different components of biodiversity are influenced by specific environmental characteristics at the plot and site level. This agreed with the weak differentiation of site and species groups shown in a classification analysis of the species composition for the commoner species. Community-level predictive models could be improved with additional environmental data collected for sites, such as climate, hydrology and lithology.

Single-species models: Models linking single species to the riparian environment will require substantially larger sample sizes and sampling effort, especially if the target species are native. Without this, the species likely to achieve suitably high frequencies are the widespread alien species such as willows and blackberry.

Summary of evaluation and recommendations

In the absence of standard protocols for identifying sites of scientific significance, an exercise was done using data from this survey. This addressed, albeit simplistically, the projected criteria of species richness, endemism and threatened plant species. Not surprisingly, the different criteria identified different sites. Special procedures will need to be developed if sites of scientific significance need to be identified.

All four project objectives were met. Measures of riparian plant diversity used in this survey were based on vegetation composition and structure, and used sub-sets of the data to target different characteristics of the riparian zone. Species-based measures are preferred for vegetation assessment, not only because the flora is diverse and well known but also because these link well with other monitoring requirements, such as legislation and social acceptability. Therefore these types of measures are recommended for future use.

Biodiversity was based on sites 1 km long, and rectangular plots 5 x 20 m. The enormous differences in scale between this sampling protocol and the mapping scale of 1:100,000 used in regional vegetation maps, makes it difficult to inter-relate these two sets of information. A special study will address this, if needed, but it is not seen as a high priority at present.

Generalised additive modelling (GAM) was used to link species richness to site variables at two spatial scales: site and plot. In general, site-based models had fewer predictive variables than plot-based models. Predictor variables that commonly featured in these models included upstream catchment land use and site canopy characteristics (dominant native or alien). This suggests there is good potential for developing links between remote sensing and biodiversity monitoring, and this is expected to give greater coverage and generate some cost-efficiences.

Inter-correlations between vegetation characteristics were not extensively analysed as part of this survey but there appears the likelihood of some cost-effective surrogate measures. It is recommended that the data, when increased, be further analysed and possibilities considered for surrogate measures.

Environmental correlations for individual species were not undertaken, because it was precluded by the characteristics of the data set (its low species frequency) obtained during the survey. These characteristics were attributed to the site selection process and the type of stratification used. Changes to these are expected to improve the opportunity for making robust species–environment correlations.

It was found that even sites in reference areas had alien species present. This highlights an issue currently engaging the research community, of incorporating reference condition in a quantitative form into monitoring designs. Development of a reference condition for riparian vegetation is required. It should be developed as part of comprehensive vegetation/habitat classifications and robust species distribution models to form the baseline for riparian vegetation biodiversity assessment.

Species records and site descriptors were entered in a readily accessible form in a Microsoft Access database. .

Plot and site summaries of some of the key data are provided as appendices in this report

Introduction

Background to study

The Cooperative Research Centre for Freshwater Ecology (CRCFE) was involved in the development of a long-term biodiversity-monitoring program with the Sydney Catchment Authority (SCA). An initial Biodiversity Synoptic Study was decided upon (CRCFE 2001) as a preliminary step to assess the distribution and variability of biodiversity across the SCA catchments and to identify "Sites of Scientific Significance" (defined in terms of species richness, endemism, rare and threatened biota). This synoptic study was to focus on in-stream biota (fish and macroinvertebrates) and riparian vegetation biodiversity.

The objectives of the Biodiversity Synoptic Study were to:

- form a preliminary assessment against which the results of future monitoring can be compared;
- test the sampling and evaluation methods and develop the objectives that will form the basis of a long-term biodiversity monitoring program;
- assist in the selection of sites for future monitoring;
- aid the selection/formulation of appropriate indicators of stream/riparian biodiversity that can be factored in to monitoring, evaluation and reporting mechanisms; and
- determine levels of variability within the biodiversity measures that will help to determine the site density required for future biodiversity monitoring.

This report presents results for riparian vegetation biodiversity, which is Task 2c of the Biodiversity Synoptic Study. It is based on sampling done in autumn/winter 2001 at 40 sites across the study area west and south of Sydney.

Riparian vegetation

Riparian vegetation is the woody and non-woody vegetation of the riparian zone. There is no standard single definition of 'riparian' zone, and definitions vary depending on purpose and the application. Broadly there are two types — process-based and legislative or jurisdictional definitions (Tubman and Price 1999).

Process-based definitions may be spatially narrow, referring to the bank of the active channel and the immediately adjacent depositional floodplain surfaces; or spatially broad, referring to the landscape surface affected by the adjacent body of water, whether wetland or river (e.g. Boulton and Brock 1999). Thus Naiman and Decamps (1997) defined riverine riparian zones as:

> the stream channel between the high and low water marks and that portion of the terrestrial landscape from the high water mark towards the uplands where vegetation may be influenced by elevated water tables of flooding and by the ability of the soils to hold water.

By implication, therefore, the riparian zone changes in width and extent with longitudinal (i.e. downstream) changes in river and flow characteristics.

The narrower definition is more common in geomorphological studies, whereas ecologists use the broader definition because of its emphasis on the transitional or ecotonal characteristics of the riparian zone.

In contrast to process-based definitions, legislative or jurisdictional definitions define the riparian zone in terms of a fixed distance from the river channel, such as 20 m.

Processes structuring riparian vegetation are physical and biological processes, such as flooding and competition, compounded by human-induced disturbances, such as clearing. Catchment-specific processes relevant to native riparian zones and rivers are not well known as there have been relatively few studies of riparian vegetation or riparian plant community ecology. In addition, riparian vegetation presents new challenges to sampling and monitoring because of its linear and mosaic nature. It is not surprising, then, that no standard protocol exists for sampling riparian vegetation for the purpose of monitoring specific attributes such as biodiversity. This survey, therefore, had the dual task of undertaking relevant work whilst working towards the development of sampling procedures.

Much effort and money have been expended on riparian management initiatives in recent years (e.g. Lovett and Price 1999) and simple measures of riparian condition have been incorporated into river health assessments (e.g. Ladson *et al.* 1999). In addition, there has also been a sustained research effort into the functional connections between riparian zones and the channel. Although these are important, they provide little information about plant biodiversity and the processes that maintain it.

Objectives and outputs

The specific objectives for Task 2c (Riparian Vegetation) were to:

- measure riparian plant biodiversity and its variation within and between the sites sampled;
- correlate species richness and vegetation structure measures with site physical characteristics;
- relate species presence to simple habitat variables and consider the potential for developing species-level predictive models; and
- provide plot-based vegetation structure descriptions to enable ground-truthing of remote sensing imagery.

The outputs expected were:

- a set of biodiversity measures for each plot, and aggregated measures for defined groups of sites;
- riparian biodiversity measures for sites indicating level of community diversity;
- simple habitat models for common species (correlation with stream power, substrate, valley form, elevation above channel);
- plot-based vegetation structure description for ground truthing of imagery in other projects, e.g. on riparian connectivity;
- primary data for correlation with fish and macroinvertebrate biodiversity scores.

Approach used

The definition of the riparian zone used here is a broad process-based definition, one that recognises the riparian zone as the landscape surface lateral to the river channel and under influence of river flow regime but excludes in-channel and riparian patches that are permanently inundated. In the field, the practical application was from the water's edge at base flow, up the bank and out to the highest level of floods. This definition recognises the riparian zone as a functional part of the stream ecosystem and is consistent with the ecotonal definition of riverine riparian ecosystems (Naiman and Decamps 1997).

The meaning and measures of biodiversity are fuzzy-edged but in practice nearly always focused at the level of species and its derivatives, and at a convenient scale. For this synoptic survey, riparian biodiversity is defined by the following attributes:

- species composition, including the number of species or 'species richness', their distribution patterns, lifeforms and origin (whether native or alien);

- vegetation structure, including vegetation height, canopy cover, number of dominants and proportions of lifeforms.

Accepted meanings of richness (e.g. Gould and Walker 1999) at different spatial scales are*: alpha diversity*, the number of species in a particular community or sampling unit; *beta diversity*, the variation in species composition among localities; *gamma diversity*, the total number of species in a region. Species richness is widely used to measure both alpha and gamma diversity. Care is needed when comparing species richness from different studies or habitats, as estimates can be strongly influenced by sampling effort and spatial scale. *Species pool* refers to the number of species actually within (or expected to be within) the study area. Some authors (e.g. Keddy 2000) consider species pool and biodiversity as equivalent terms.

In this survey, species richness at a site is defined in two ways, specific to the questions being asked.

- For general assessment of biodiversity, species richness is the total number of different species encountered; thus for site biodiversity, it is the sum of all species encountered in all plots at that site.
- For modelling, site richness is the mean of the richnesses of the plots in a site.

Vegetation structure is included in this study as a component of biodiversity because of its potential to influence the presence of riparian biota, both flora and fauna. In addition, structure is a basic descriptor of vegetation so is needed to meet the fourth study objective, of providing plot-based descriptions to enable ground-truthing of remote sensing and imagery.

Threatening processes

Physical and biological processes that threaten biodiversity include establishment of alien and invasive species, modifications to the physical environment, changes to life history cues and triggers, and changes in resource availability that affect community dynamics and competition. These can lead to loss of vigour, failure to reproduce, depletion of seed banks, or loss of animal vectors that are essential for a plant species to complete its reproductive cycle. The net result is population decline and species attrition, leading to general decrease in native biodiversity. Threatening processes that affect species or communities of special conservation significance are formally recognised under federal legislation (*Environment Protection and Biodiversity Conservation Act 1999*). Once threatening processes are recognised, this can be followed by the development of a Threat Abatement Plan that specifically targets the threatening process with the intent of minimisation.

In the *NSW Threatened Species Conservation Act 1995*, the general ecological phrase ‘threatening process’ has been given specific legislative meaning under Schedule 3, provided it meets one of two criteria of conservation impact. Ten threatening processes have so far been defined in this way under this legislation, and of these, the five relevant to plant species and vegetation are:

- clearing native vegetation;
- invasion by bitou bush;
- bushrock removal;
- bushfires that are too frequent; and
- climate change.

No threatening process specific to the riparian zone has yet been nominated under the NSW legislation. The most likely candidate is river regulation.

In the Sydney region, riparian biodiversity is particularly threatened (Benson and McDougall 1998, Benson 1999) by alien species, urban expansion and pollution. Human population expansion and urbanisation are probably the most serious of these, as they in turn contribute to the other two processes by introducing alien species and by affecting and disturbing adjacent areas for unknown distances downstream.

In terms of conservation of the natural environment, the three most important aspects of urbanisation are:

- changes in run-off patterns, resulting from extension of hard surfaces associated with urbanisation;
- propagule availability and dispersal of horticultural plants due to the proximity of gardens, the problem of rubbish dumping; and
- changes in downstream water quality, through spillages, road run-off, wastes and contaminants.

Riparian vegetation within the study area

The 28 sub-catchments managed for water supply by the Sydney Catchment Authority lie within a single bio-region[1], the Sydney Basin. This bio-region extends north to the Hunter Valley, south beyond Jervis Bay towards Nowra and includes parts of the Blue Mountains. The area considered for this survey comprises the Woronora, Nepean, Coxs, Wollondilly and Shoalhaven catchments. All of these catchments are within the SCA's area of responsibility.

The Sydney Basin bio-region has a broad climatic range, due in part to its topographic diversity and to the fact that it extends from sea level to mountain top. Most of the Sydney Basin bio-region lies on Tertiary sandstone, which is relatively low in nutrients, but there are also outcrops of richer lithology, such as Wianamatta shale, and limited basalts. There are over 2000 plant species within the region. Compared with most other bio-regions, the Sydney Basin is comparatively well-protected (Benson 1999) with some 39% of the Sydney area in conservation reserves.

Partly because of its floristic richness and consequent high level of endemism, and partly because of its proximity to major population centres, the Sydney Basin bio-region is much better known floristically than many other bio-regions in Australia. Parts of it have been mapped and described (e.g. Benson and Howell 1994, Keith 1994, Fisher *et al.* 1995) and one area, the Cumberland Plains west of Sydney, has been the focus of more intensive studies. Terrestrial plant communities within this bio-region are strongly influenced by underlying lithology, and by micro-climate effects due, for example to aspect and deep gullies. Although the area has been extensively mapped, the mapping scale most commonly used is 1:100,000, which is too coarse to represent the elongate patches of riparian plant communities. Paradoxically, then, riparian vegetation is not often described and mapped, as only the largest and most extensive patches can be defined in upland reaches at such coarse scales.

Three riparian vegetation types are described for different parts of the study area: (i) riparian scrub; (ii) closed forest; (iii) river oak forest. Factors determining the distribution of these riparian communities were not specifically examined. Keith's (1994) ordination of eleven non-swamp communities shows that soil moisture and soil depth were influential environmental factors for riparian scrub.

> **Riparian scrub** (2.3% of catchment area) occurs on 'moist sandy alluvium amongst rocks on major creeks' in the O'Hare's Creek catchment, a 9000 ha catchment south-west of Sydney (Keith 1994).
>
> Description: shrubs to 4 m tall, with 40% cover typically with no trees. Several shrubs — *Tristaniopsis laurina*, *Tristania nerifolia*, *Leptospermum morrisonii*, *Ceratopetalum apetalum*, *Pseudanthes pimelioides*, *Lomatia myricoides*, *Prostanthera lineraris*, *Phebalium dentatum*,

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[1] **Bio-region**: term applied to an area which is relatively homogenous although not uniform in terms of its terrain and soils, climate, and flora and fauna, and hence in terms of its ecology. A national system of bio-regions has been proposed through Environment Australia, and is now in its fifth version: IBRA (Interim Biogeographic Regionalisation for Australia) Version 4 was used for an Australia-wide approach for a national inventory of wetlands, the 3rd edition of the Directory of Wetlands of National Importance.

Phebalium squarrosum and *Micrantheum hexandrum* — and one sedge, *Lomandra fluviatilis*, were considered exclusive to this vegetation type.

Other typical species were: shrubs — *Acacia obtusifolia*, *Acacia irrorata*, *Monotoca scoparia*, *Bauera rubioides* and *Grevillea longifolia*; sedges; other groundcover — *Restio dimorphus*, *Sticherus flabellatus*, *Lomandra longifolia*, *Lepidosperma laterale*.

Riparian scrub included several ferns, such as: *Blechnum cartilagineum*, *Pteridium esculentum*, *Gleichenia microphylla*, *Adiantum hispidulum*.

When sampled, the condition of this riparian community was considered to be exceptionally good, as no alien species were recorded in quadrats from 6 sites.

Very similar to riparian scrub is the one of the sub-units of Sydney Sandstone Gully Forest described for the Sydney 1:100,000 mapsheet by Benson and Howell (1994), mainly from north of Sydney, so slightly outside the study area.

Closed-forest: *Ceratopetalum apetalum–Tristaniopsis laurina*, distinctive riparian flora on perennial creeks, varying from closed-forest to scrub amongst boulders, often as understorey to *Eucalyptus piperita* or *Angophora costata*.

Typical species are *Tristaniopsis laurina*, *Callicoma serratifolia*, *Lomatia myricoides*, *Leptospermum polygalifolium*, *Austromyrtus tenuifolia* and *Ceratopetalum apetalum*.

Occasional rainforest species found in sheltered gullies downstream of Wianamatta shales, and ferns in understorey.

River Oak Forest occurs on Quaternary alluvium, mobile sands and gravels of rivers such as the Wollondilly, the Nattai, the Kowmung and the Little, above 400 m asl (above sea level), within the Burragorang mapsheet (Fisher *et al.* 1995), also south-west of Sydney.

Open forest of *Casuarina cunninghamiana* subsp. *cunninghamiana* on channel and banks, with *Angophora floribunda* on higher ground. Shrub and ground cover are both sparse; the shrub layer comprising *Hymenanthera dentata*, *Acacia floribunda*, *Acacia longifolia*, *Acacia fimbriata* and *Bursaria spinosa*. Typical ground cover species are *Persicaria decipiens*, *Oplismenus aemulus* and *Cynodon dactylon* and also the alien herbs, *Conyza albida*, *Modiola caroliniana*, *Hypochaeris radicata* and *Rumex crispus*. One fern species was noted: the widespread *Pteridium esculentum*.

Plant species of conservation significance recorded in the riparian vegetation types in these studies were: *Lomandra fluviatilis*, along O'Hare's and Stokes Creeks, Colo River — Cataract Dam (Keith 1994).

The Burragorang study (Fisher *et al.* 1995) noted several rare species occurring beside or along rivers and creeks (e.g. *Acacia clunies-rossii*, *Bossiaea oligoserpma*, *Prostanthera rugosa*, *Ardisia bakeri*, *Eucalyptus aggregata*, *Eucalyptuis hypostomatica*, *Eucalyptus macarthuria*, *Eucalyptus oreades*, *Hakea* sp.B, *Asterolasia asteriophora*) which could include gully walls above the riparian zone. None of these was specifically linked to the riparian zone or the riparian plant community River Oak Forest. A survey of the Hawkesbury-Nepean River below the Nepean Dam has shown that most of the native riparian vegetation in that reach has been cleared and now exists as small patches with a high proportion of weed species. These weeds may in fact be able to respond better to environmental flows than the native species (Howell & Benson 2000).

Sampling methods

Site selection

Sites were selected using a hierarchical sequential procedure. The first step was to select reaches that would maximise the variation in stream order; the second step was to select sites to represent the upstream catchment character and pre-dominant land uses, whether cleared for agriculture, largely urbanised or relatively uncleared, named Agricultural, Urban and Reference respectively. This two-stage procedure follows the protocols proposed in the Research Proposal (CRCFE 2001) for defining sites for river health assessment, and is more fully described in the unpublished Task 2b report on aquatic macroinvertebrate biodiversity (Nichols *et al.* 2001). The need to develop a common approach and integrate across biota such as riparian vegetation and macroinvertebrates, and a degree of expediency, meant that this project used a pre-determined site selection protocol suitable for macro-invertebrates with no features specific to riparian vegetation.

Forty sites were selected, from all the major catchments of the Sydney Catchment Authority's region of responsibility. At all sites, sampling was restricted to within 0.5 km upstream and downstream of the location used for sampling aquatic macroinvertebrates, i.e. up to 1 km of river. Comments on the adequacy of site selection procedure for riparian vegetation biodiversity are included in the Evaluation section of this report.

Field protocol

All sites were sampled between 24 April and 1 June 2001.

Within sites, the sampling procedure was designed to obtain a representative sample of riparian vegetation for purposes of biodiversity assessment and for modelling species distributions across the study area. For logistical reasons such as access and time constraints, sampling was restricted to one bank at most sites, even when the opposite bank had significantly different vegetation structure and/or species composition. Although points of access are generally the most disturbed, this is unlikely to introduce a bias towards disturbed sites as each site was 1 km long, so points of obvious impact immediately adjacent to roads, bridges and stock watering points and gates, were avoided.

Within each site, geomorphology was sampled by visual inspection of substrate, topography and geomorphic units along wide transects at right-angles to the stream channel. Within each transect, rectangular plots, each 5 m x 20 m with long face parallel to the stream, were located so as to sample the range of vegetation types occurring within the transect (Figure 1).

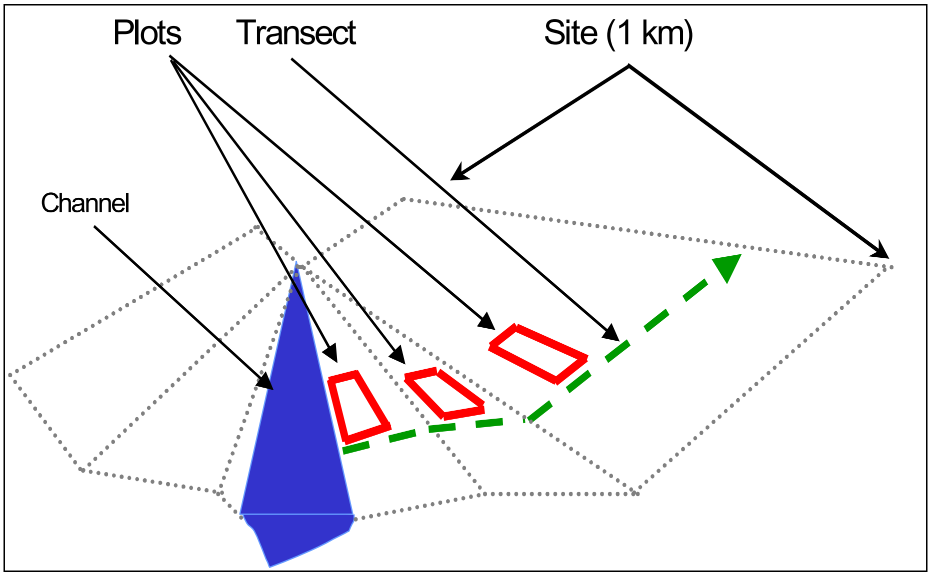

Figure 1. Diagram of the sampling layout in the riparian zone within a site

> Transects, at right-angles to the river channel, ran from the river channel (at base flow line) to the upper boundary of the riparian zone. Rectangular plots, each 5 m x 20 m with long face parallel to the river, were located on distinct geomorphic units along the transects.

The precise number and location of plots was thus determined by field appraisal of site geomorphic diversity (for transects) and within-transect diversity (for plots). It was not possible to define this degree of site–site and within-site variability beforehand without doing a dedicated study using remote sensing or recent appropriately-scaled (e.g. <1:20,000) colour aerial photography. The rationale for focusing on geomorphic units is that hydrology (flow regime as a disturbance and water as a resource) and geomorphology (substrate) exert a strong relationship on plant distribution in riverine systems, usually expressed as a correlation between fluvial landforms and vegetation types (e.g. Hupp and Osterkamp 1985).

Geomorphic units encountered and recorded during the study were island, littoral, bank, levee, terrace, runner, swamp and slope.

The topographic cross-section was measured along each transect using a laser survey instrument (Criterion 400, Laser Technology Inc., Colorado) to obtain relative elevations of plots and distances from the channel to an accuracy of 0.1 m. Plot positions were recorded using GPS and channel features were noted.

In each plot, the following variables were recorded (see datasheets in Appendix 1 and Appendix 2):

- vascular plant species present — all flowering plants and ferns were recorded;
- vegetation height, canopy outline cover and projective foliage cover (PFC) of the top stratum;
- contribution of three main species to the top stratum PFC;
- ground layer cover types (as % of mineral, litter, coarse woody debris, moss+lichen, vegetation < 0.5 m);
- mineral substrate cover (as % of clay+silt, sand, gravel, pebble, cobble, boulder, bedrock);
- category of geomorphic unit;
- plot elevation above and horizontal distance from river channel as well as total riparian width and maximum elevation (obtained from elevation profile);

- location (obtained from GPS or map);
- land use and vegetation type adjacent to the transect.

Sample processing and analysis

Plant specimens were collected at the time of sampling for nearly all species encountered. Most were pressed immediately for use as reference specimens during subsequent sampling. A set of voucher specimens has been lodged with the Australian National Herbarium in Canberra[2].

Species collection and identification were completed by consultant botanists working at the Australian National Herbarium in consultation with other taxonomists as necessary. Nomenclature follows the *Flora of NSW* (Harden 1993).

Terminology

Alien is used here for non-native species, in preference to other words such as introduced or exotic. This follows international usage, for example by the International Union for the Conservation of Nature (IUCN) in its Global Invasive Species Programme, and as recognised and promoted by scientists anxious to establish a standard terminology (Richardson *et al.* 2000).

Translocated refers to those species that are native to Australia and that have been introduced to a region where they did not formerly occur.

This report is concerned with native Australian and alien species only.

[2] **Voucher specimens**. A full list of specimen numbers and field collection data would be held by the Australian National Herbarium, Canberra. The botanists responsible for the collection were N. Taws and I. Crawford.

Results

Site categories

The location of the 40 sites in the study area is shown in Figure 2, with sites coded by up-stream land use category. These 40 sites comprised the sample. In total, 66 transects and 72 vegetation plots were surveyed in these 40 sites; the maximum number of transects per site was three, and the maximum number of plots per site was three (average 1.8), except for one site which had five plots (Site R4). Site locational features are summarised in Appendix 3.

The number of study sites across the three *a priori* site categories was 16 Agricultural (coded A), 13 Reference (coded R) and 11 Urban (coded U), for which the mean number of vegetation plots per site was 1.8, 2.2 and 1.4 respectively. It was not possible to achieve an even distribution of study sites by sub-catchment or by category, as shown by the cross-tabulation of sites by category and by five sub-catchments (Table 1). Two sub-catchments, the Woronora and the Nepean, are poorly covered.

Table 1. Number of sites in each catchment in each *a priori* site category

Catchment	Agricultural	Reference	Urban	Total
Woronora		2	1	3
Nepean		1		1
Coxs	2	2	2	6
Wollondilly	5	3	7	15
Shoalhaven	9	5	1	15
Total	16	13	11	40

Upstream catchment condition proved to be an inadequate predictor of land-use immediately adjacent to study sites. A comparison of the three *a priori* categories with three equivalent categories for adjacent land use, Alienated, Unalienated and Urbanised, found that 9 of the 40 sites did not agree (Table 2) giving a general correspondence of about 75% between the broad-scale *a priori* and local scale field-based site categories. Hence it is clear that site selection and *a priori* categorisation according to AUSRIVAS protocols does not fully align with riparian vegetation condition.

The nine sites that do not correspond were either adjacent to remnant urban or rural bushland (two A and two U sites) or adjacent to agricultural land but categorised as reference or urban based on upstream parameters (two R and three U sites). The largest contributor to mismatches was the Urban *a priori* category, with 5 out of a total of 11 sites mismatched.

Site categories are henceforward referred to as *a priori,* when based on broad-scale up-stream catchment characteristics, and *field-based*, when based on field observations of adjacent land use at local scale.

Analyses reported below concentrate on *a priori* site categories.

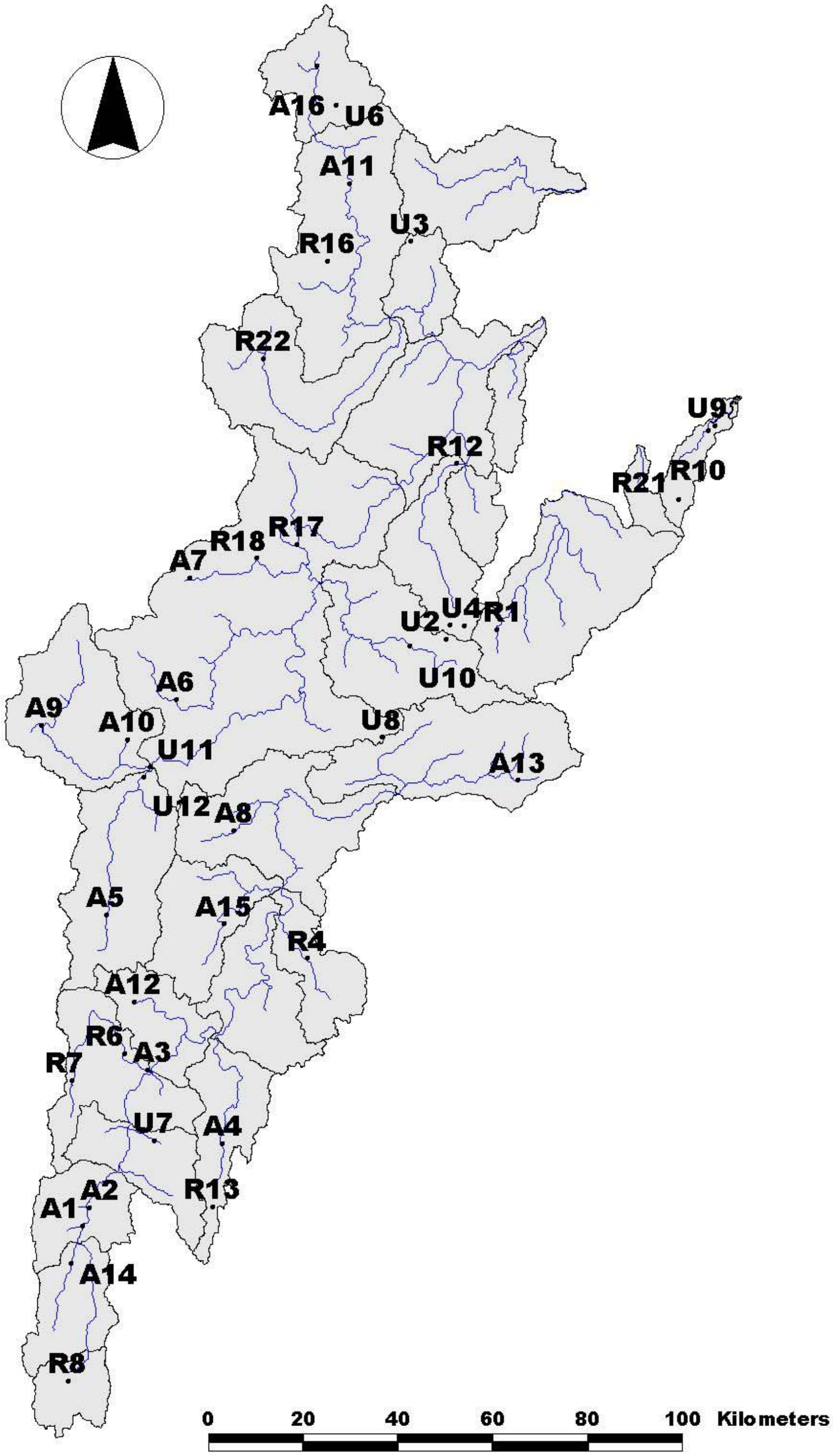

Figure 2. Location of sample sites across the sub-catchments of the study area

A, R or U, for Agricultural, Reference or Urban, indicate the *a priori* site category.

Table 2. Consistency between two site classifications

Sites were categorised *a priori* by AUSRIVAS procedures based on upstream catchment characteristics, and in the field, based on land use immediately adjacent to the riparian zone. The adjacent landuses were grouped into three broad categories, Alienated, Unalienated and Urbanised, approximating but not equivalent to Agricultural, Reference and Urbanised. Types of land use observed in the field and contributing to Alienated, Unalienated and Urbanised are retained below. Sites that are underlined are mismatches in the cross-classification.

Adjacent land use	***A priori* site category**			
	Agricultural	Reference	Urban	Totals
Agriculture/grazing	A1 A2 A3 A5 A6 A7 A8(part) A9 A10 A11 A12 A13 A14 A16	R7 R8	U7 U12	
Rural residential	A8(part)		U10	
Alienated totals	**14**	**2**	**3**	**19**
Rural bushland	A4 A15	R4 R6		
Protected catchment		R1 R21		
National Park		R10 R12 R13 R16 R17 R18 R22		
Urban bushland			U3 U8	
Unalienated totals	**2**	**11**	**2**	**15**
Recreation park			U11	
Urban residential			U2 U4 U5 U6 U9	
Urbanised totals	**0**	**0**	**6**	**6**
Totals	**16**	**13**	**11**	**40**

Site categories: Implications

The mismatch between broad-scale *a priori* and local scale field-based land use classifications raises the question as to which is the more appropriate for designing riparian vegetation survey.

- Defensible definition of a reference condition is needed to make sensible comparisons between impacted sites. Doing this for riparian vegetation will require resolution of the relative importance of driving variables at different scales.
- Although the sample of 40 sites gives a snapshot of the SCA area of responsibility, it does not provide representativeness at sub-catchment scale. Spatial extrapolation for riparian vegetation biodiversity mapping will require supplementary information such as catchment-wide longitudinal surveys or vegetation mapping by remote imagery.

Vegetation composition

Diversity overview

Out of a total of 552 plant species recorded in the study plots, 383 were native and 169 were alien. The total for native species is a slightly conservative estimate as at least four of the 46 plants able to be identified only to the level of genus would be additional species (*Clematis* sp; *Marsilea* sp; *Plectanthrus* sp; *Pterostylis* sp). These 383 native species occurred in 82 families and in 4 classes (Table 3), with strongest representation in the flowering plants (Angiospermae) and the ferns

(Filicopsida). A full plant species list is presented in Appendix 4. Alien species are discussed further below.

Table 3. Taxonomic diversity summary

Vascular plant diversity at three taxonomic levels of class, family and species, showing numbers of native and alien species.

	Native		Alien	
Class	**Family**	**Species**	**Family**	**Species**
Club mosses	2	2	0	0
Ferns	3	17	0	0
Conifers	1	1	0	0
Flowering plants				
Dicotyledons	62	260	42	124
Monocotyledons	20	103	7	45
Total	88	383	49	169

Within the native species, two groups can be identified, each making a different contribution to overall biodiversity. One comprises a few families that are species-rich; the other comprises a large number of families, each with relatively few species.

In the first group, the five species-rich families account for 144 species, equivalent to 6% of families and 38% of native plant biodiversity at this level. These five families also contribute distinctive growth-forms to the riparian flora:

- Poaceae — 37 grasses,
- Cyperaceae — 31 sedges,
- Myrtaceae — 30 species, mainly trees and shrubs,
- Asteraceae — 26 species, mainly non-woody herbs, and
- Proteaceae — 20 woody or shrub species.

The other 84 families account for the remaining 62% of species, and contribute growth-forms such as ferns, climbers, club-mosses.

Species recorded that are characteristic of riparian habitats include:

- trees such as Manna gum (*Eucalyptus viminalis*), River Oak (*Casuarina cunninghamiana*);
- shrubs such as *Bauera rubioides*, *Hakea salicifolia*, *Backhousia myrtifolia*, *Kunzea ericoides*;
- bottlebrushes (*Callistemon* spp.) and tea-tree species (*Leptospermum* spp.);
- emergent macrophytes and sedges such as *Bolboschoenus fluviatilis*, *Carex appressa*, *Eleocharis acuta* and *Phragmites australis*;
- small fast-growing or annual herbs such as *Centipeda cunninghamii*, *Alternanthera denticulata*, *Centella asiatica*.

Note that this definition of 'characteristic' riparian species is subjective, there being no definitive listing of native riparian plant communities or species to use as a reference[3]. Most of these species are also known to occur outside riparian zones; for instance, in wetlands and wet forests.

[3] **Riparian Studies**. Descriptions of riparian plant communities relevant to the study area include: Riparian Sandstone Scrub of the Western Sydney Cumberland Plain, and Creek side scrub in the Woronora Plateau in Benson *et al*. (1996).

Species of special conservation significance

Several species recorded during the survey have special conservation significance, at the national, state or regional level.

National: Three species are of national significance, according to the ROTAP classification (Rare or Threatened Australian Plants; Briggs and Leigh 1992). These are:

- *Bossiaea oligosperma* listed as 2V (total range less than 100 km (code 2) and vulnerable (code V)), meaning not officially Endangered but expected to be at risk over the next 25–50 years,
- *Pultenaea glabra* listed as 3VCa (total range greater than 100 km (code 3),vulnerable, with at least one population of at least 1000 plants within a reserve (codes C and a)),
- *Lomandra fluviatilis* listed as 3RCa (total range greater than 100 km, rare but not endangered or vulnerable (code R), with at least one population of at least 1000 plants in a reserve).

State: Two species are listed as Vulnerable according to the Wildlife Atlas for New South Wales (searched August 2001), and defined under the *Threatened Species Act 1995*. These are *Bossiaea oligosperma* and *Pultenaea glabra*, i.e. the same as described above.

- *Bossiaea oligosperma* (Fabaceae). An erect shrub, 1–2 m tall, with a very restricted distribution, being known only from near Yeranderra; generally occurs on stony slopes or ridges. This was recorded in two plots, from one site (A15) described as uncleared bush.
- *Pultenaea glabra* (Fabaceae). An erect shrub of dry sclerophyll forest on sandstone, occurring higher in the Blue Mountains. This was recorded from one plot at a site (R13) in a national park.

The third species listed at the national level, *Lomandra fluviatilis*, is not listed as Vulnerable on the NSW Wildlife Atlas.

- *Lomandra fluviatilis* (Lomandraceae). A tufted perennial sedge, grows on sandy soils in creek beds. This was recorded from two plots at one site (R10) in a National Park.

In addition, there are 10 species specially listed for protection under Section 13 under the *National Parks and Wildlife Act 1974*, and coded P13 in the NSW Wildlife Atlas:

- Clubmoss *Lycopodium deuterodensum* (1 site);
- *Adiantum aethiopicum* (13 sites);
- *Cyathea australis* (1 site);
- *Dicksonia antarctica* (1 site);
- *Blandfordia nobilis* (1 site);
- *Caustis flexuosa* (1 site);
- *Doryanthes excelsa* (1 site);
- *Casuarina cunninghamiana* (11 sites);
- *Persoonia pinifolia* (2 sites); and
- *Xylomelum pyriformis* (1 site).

Region: At least 12 species recorded in the survey have some regional significance, having been given the rating '**rs**' by Benson *et al.* (1996). This list of 12 is indicative only, as the geographic area referred to in Benson *et al.* (1996) does not overlap perfectly with the study area for this project:

- a fern, *Blechnum ambiguum*;
- two trees, *Acacia binervata*, *Eucalyptus viminalis*;
- one shrub, *Grevillea juniperina*;
- two grasses. *Elymus scaber* and *Glyceria australis*;
- five small herbs, *Cynoglossum suaveolens*, *Haloragis heterophylla*, *Samolus valerandi*, *Phyllanthus similis* and *Persicaria prostrata*; and
- an amphibious plant *Lilaeopsis polyantha*.

Conservation significance: Implications

- Three species were recorded as being of conservation significance under federal and state legislation. These were all designated Vulnerable; none was classed as Endangered. Sampling was not appropriate for detecting other conservation categories of significance, namely threatened populations and threatened communities. At least 12 species are considered to have regional significance — a classification of botanical and conservation significance.
- The principal habitat for nearly all the species classed as Vulnerable (n = 3) or classed as P13 (n = 12) lies outside the riparian zone, with the obvious exception of River Oak (*Casuarina cunninghamiana*), which is a riparian-zone obligate. The occurrence of these species within the riparian zone suggests it could be an important refuge for species with restricted distribution.
- There is a strong possibility that an extensive survey of the riparian zone would detect more Vulnerable, more P13 species and more '**rs**' species. About 120 plant species are classed as Vulnerable in the Sydney region, and some of these are known to occur in riparian habitats.
- The Sydney Basin bio-region is extremely rich in species, but it is an area that is under considerable pressure from an expanding urban population and resource demands. These pressures will increase the importance of natural refuges, which could include the riparian zone, and will increase the number of species receiving '**rs**', P13 and Vulnerable classifications.

Macrophytes

The sampling program did not specifically target in-channel macrophytes, or aquatic plants. The rationale was that, based on field experience on other river systems, these plants were expected to have such a patchy distribution that it would not be possible to accommodate an appropriate sampling routine within the sampling protocol for riparian vegetation; therefore they would require additional sampling time. Moreover, even more than for riparian vegetation, sampling for aquatic macrophytes would very much require a preliminary survey to establish appropriate spatial scales.

However, macrophytes were sampled, because nearly all plots had a littoral zone that included some macrophytes. Therefore, this subsection on macrophytes has been included in order to highlight a specific aspect of riparian biodiversity, and one that is significant for in-channel micro and macro-fauna.

Data used are a sub-set of the riparian vegetation data, trimmed to exclude all species that are not macrophytes.

An objective definition of 'macrophyte' is just as elusive as a definition of 'riparian'. Here the word refers to those non-woody species known, either from literature or based on experience, to grow on, in or through water and that hence have a physiological adaptation to a water regime or water-logged conditions. Species expected to be flood-tolerant but lacking in physiological adaptation to flooding, such as tussock-forming *Juncus* spp., were not included here as 'macrophytes'.

In total, 46 species of macrophytes were recorded in plots. Of these, seven were alien and none was noxious (see below: Alien species). The 46 species covered four growth-forms: emergent macrophytes, submerged, mat-forming and amphibious.

Emergent macrophytes were the most common with 25 species (20 native), and also had the greatest size range, from diminutive *Eleocharis pusilla* to 2–3 m tall robust species such as *Typha* spp., *Phragmites australis* and *Schoenoplectus validus*. The family Cyperaceae was strongly represented in this group. The other growth-forms all had fewer species. Amphibious herbs (i.e. those herbs that grow and reproduce on moist muds and in shallow water) had six species (five native) including the regionally significant *Lilaeopsis polyanth.* Mat-forming species numbered only three and included a mix of grasses and herbs. Submerged macrophytes numbered eight (seven native) and included the slender *Neopaxia australasica* and the carnivorous *Utricularia uliginosa*.

Overall, the five most frequently-encountered macrophytes were the alien emergent *Cyperus eragrostis* at 19 sites, *Isolepis inundatus* and the alien rush *Juncus articulatus* at 17 sites, and *Carex gaudichaudiana* and *Crassula helmsii* at 15 sites each.

Species richness per site ranged from 1 to 15. Sites with highest macrophyte species richness were predominantly disturbed, rather than undisturbed. Thus although R6 (classed as Reference and as Unalienated, see Table 2) had 12 macrophyte species, Site A2 had 15 species, and sites A6, A7, U10 and U8 each had 11 species. There were 9 sites with only 1 or 2 macrophytes, and these were mainly R and U-type sites.

If incidental observations from outside the plots are also included, then total species richness is increased by a further five taxa, all native, and the number of growth-forms by two: the floating-leafed *Nymphoides montana* and free-floating *Azolla*, a fern. The other species were submerged macrophytes (Characeae and *Vallisneria* sp.) and an amphibious fern, *Marsilea*. Although not identified to species level, the *Marsilea* may also prove to be of regional significance, as three *Marsilea* species are already recognised as '**rs**'.

Macrophytes: Implications

- Based on limited sampling, macrophyte diversity appears to be high, as evidenced by number of species recorded, number per site, and the range of growth-forms. This diversity is evident despite using a sampling protocol that was not structured to target macrophytes occurring in the channel, and a less than optimal sampling season.
- Emergent macrophytes dominated the species list and were the most frequently recorded species and growth-form. However, it is unlikely that this emphasis on emergent macrophytes is truly representative of species richness and growth-forms for the macrophytes due to plot locations. Plots were aligned parallel with but above the margin of the river channel, so they sampled the littoral zone and did not specifically target the in-channel or benthic habitats.
- No vulnerable or endangered species were identified. This is not surprising as the distribution of macrophytes, especially in riparian habitats, is not well understood. Moreover, as most species are inadequately collected compared with terrestrial species, and their temporal dynamics not formally known, their conservation status is difficult to assess. The two species, *Lilaeopsis polyantha* and *Marsilea* sp., recognised as regionally significant are both small non-robust amphibious species.
- Alien species were significant overall in that, although the incidence of alien macrophytes was not exceptionally high (17%), the most frequently-encountered species was an alien emergent, *Cyperus eragrostis*. The fact that no noxious macrophytes were recorded should not be considered evidence that such species are not present.
- Native species richness appears to be low in both least disturbed and most disturbed sites, a trend that is consistent with ecological theory (the Intermediate Disturbance Hypothesis or IDH). If this could be established more rigorously, then it would be a valuable insight that could be incorporated into the sampling design for any future macrophyte surveys.

Alien species

In total, 169 alien species in 48 families were recorded in this survey (Table 3), i.e. 31% of all species. Although the incidence of alien species is higher than for most lowland floodplains (e.g. Young 2000, Table 5.5), high (>20%) incidence of alien species is not unusual for riparian floras (e.g. Roberts 2002). All were flowering plants (i.e. Angiospermae) and most were dicots; no alien ferns or conifers were recorded. Alien species that are, or have the potential to be, significant weeds are considered in the following section.

The most significant families, in terms of the number of alien species contributed, were Poaceae (34 species), Asteraceae (25 species), Faboideae (13 species) and Rosaceae (10 species). These four families contributed 82 species (48.5%) of alien species. The remaining 51.5% of species came from 44 families, which thus have mostly one or two species per family; most of these families were dicots. As with native species, most of the richness in alien species comes from dicots, whether expressed at species or family level.

The character of the alien species is quite diverse and includes:

- agricultural escapees such as *Medicago* spp. (4 species) and *Trifolium* spp. (3 species);
- agricultural weeds such as skeleton weed *Chondrilla juncea*, St John's wort *Hypericum perforatum*, soursob *Oxalis pes-caprae*, Bathurst burr *Xanthium spinosum* and a range of thistles such as spear thistle *Cirsium vulgare*, variegated thistle *Silybum marianum* and Scotch thistle *Onopordum acanthium* subsp. *acanthium*;
- self-established fruit trees such as apple *Malus domestica* and plum *Prunus domestica*;
- ornamental trees and shrubs such as *Populus nigra cv. 'Italica'*, several *Salix* spp., hawthorn *Cratageus monogyna*, cotoneaster *Cotoneaster francheti*, gorse *Ulex europeaus*, broom *Genista monspessulana*, *Rhododendron* sp., Japanese honeysuckle *Lonicera japonica*, broad-leafed and narrow-leafed privet *Ligustrum lucidum* and *Ligustrum sinense*;
- traditional garden herbs such as yarrow *Achillea millefolium*, and salad burnet *Sanguisorba minor* ssp*. muricata*;
- garden flowers such as *Watsonia meriana* cv. *Bulbillifera*, *Arum italicum* and *Zantedeschia aethiopica*.

Most of these are terrestrial in habitat and of temperate climate origin. Several have fruits or seeds that are dispersed by animals. Only a few are truly 'riparian', in sense of being flood disturbance tolerant or obligates. The riparian zone offers favourable habitats to many alien plant species because of additional moisture and nutrients relative to the adjacent landscape and because of its habitat value for diverse fauna (refuge, protection, breeding or nesting habitat, perching) that may serve as animal vectors.

In addition, the seven alien macrophytes (See above: Macrophytes) were: *Isolepis prolifer*, *Scirpus polystacha*, *Aster subulatus*, *Rorippa nasturtium-aquaticum*, *Callitriche stagnalis*, *Mentha X piperita* and *Ludwigia peruviana*. Nutrient enrichment is a habitat correlate for most of these herbs (Sainty and Jacobs 1994). One macrophyte, *Ludwigia peruviana*, is potentially a serious threat to biodiversity. Prior to an extensive control program, this species covered nearly 30% of the Botany wetlands, Sydney, replacing much of the native wetland vegetation (Jacobs *et al.* 1994). Four species are widespread and rarely become dominant. The incidence of alien macrophytes, 17% (7 out of 46 records), was considerably lower than the incidence of aliens across the riparian zone sites as a whole.

At the site level, there is some evidence of an inverse relationship between native and alien species. Sites with highest number of native species (e.g. more than the mean of 31 per site) tend to have fewer alien species (e.g. less than the mean of 20 per site) and fall mostly in the bottom-right quadrant of **Figure 3**: these are largely Reference sites. Conversely, sites with most alien species (e.g. more than 20 per site) tend to have fewer native species (e.g. less than 31) and fall in top-left quadrant; this quadrant does not include any of the sampled Reference sites.

Thus, land use is implicated, not just in terms of total species richness but in the relative importance of native vs. alien species richness. Whereas values for Reference sites form a distinct group with relatively high numbers and proportions of native species, values for Agricultural and Urbanised sites overlap, indicating no clear distinction between them in terms of species richness and origin.

Alien species: Implications

- The alien plants demonstrate two important characteristics that make it a challenge to predict their distribution and abundance: (i) the non-riparian temperate-zone species are growing in habitats beyond their original habitat; (ii) the types of weeds are very diverse, including agricultural pests, garden escapes, ornamental, food and utilitarian species, implying the existence of multiple pathways for species entry to the riparain zone.
- There is evidence of an inverse relationship at the site level between the number of native species and the number of alien species. Land use is implicated in the loss of native plant species. Sites classified *a priori* as Reference sites have the combined attribute of higher numbers of native species and lower numbers of alien species than do sites classed as Agricultural or Urbanised. Limitations on site selection and sample size mean these are indicative findings only.

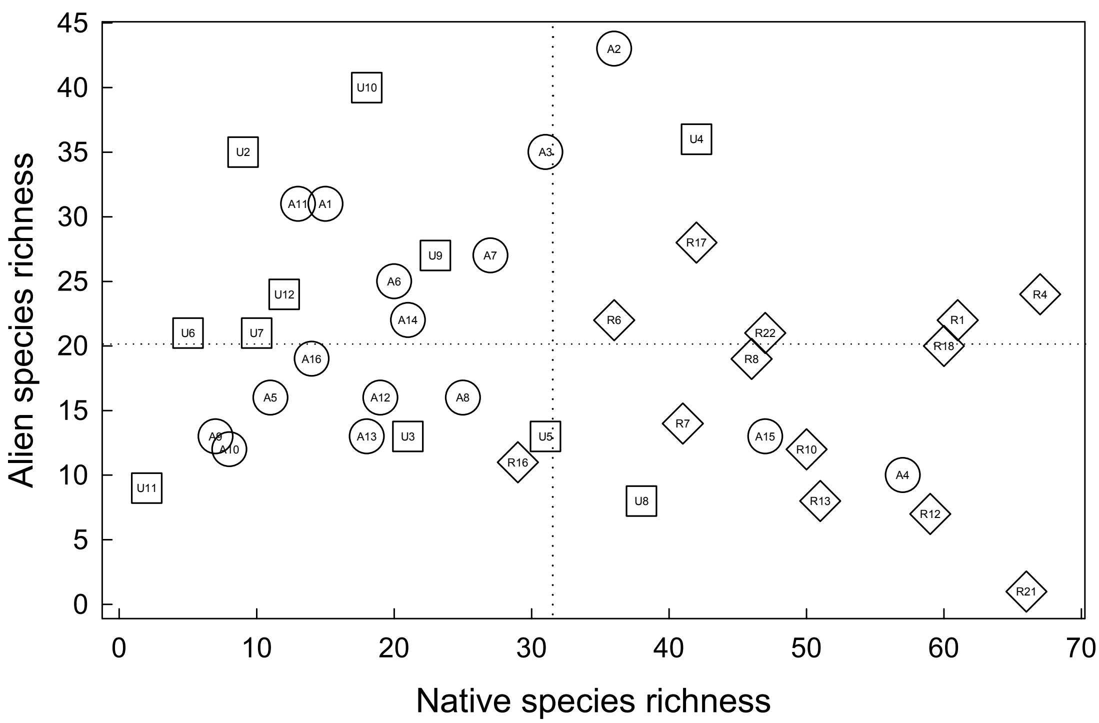

Figure 3. Native and alien species richness for each site categorised by the *a priori* site types. Reference lines show the mean richnesses.

◇= Reference, ○= Agricultural ☐ Urban sites

Most Reference sites had more than the mean richness for native species; the highest counts for alien species were in some of the Agricultural and Urban sites, which had less than the mean native richness.

- Whether upstream land use can be an indicator of the presence of more (or fewer) native species and fewer (or more) alien species, as suggested in **Figure 3**, is worth examining further, with a view to establishing generality and its predictive value and to understanding the processes that cause it. Although processes threatening native biodiversity are known in general, the specific processes relevant to these study sites and to these sub-catchments will need to be better identified before effective management approaches can be developed that protect existing riparian and in-channel (macrophyte) biodiversity.

- The incidence of alien aquatic plants in streamside habitats at the edge of the riparian zone is lower than for alien species in the riparian zone overall, 17% compared with 30%, but is still relatively high. Reasons for this are not understood.

Noxious and undesirable species

National: Collaboration between states and federal organisations has resulted in a listing of the nation's most serious production and environmental weeds, Weeds of National Significance (WONS). The initial list launched in 1999 lists 20 weed species. It is a measure of significance and carries no legislative requirements. Five WONS species were recorded in this survey:

blackberry ─ Rubus fruticosus

Chilean needle grass ─ *Nassella neesiana*

gorse ─ Ulex europaeus

serrated tussock ─ *Nassella trichotoma*

willows ─ all *Salix* spp. except *S. babylonica*.

State: Each state has its own listing of weed species that are noxious and its own list of weed categories. A total of 22 plant species (Table 4) recorded in this survey are listed as noxious under New South Wales legislation (*Noxious Weeds Act 1993*, *Noxious Weeds Regulations 1993*). Eleven of these were recorded at only 1 or 2 sites. Two, crofton weed *Ageratina adenophora*, and blackberry *Rubus fruticosus,* occurred fairly frequently, at 10 and 21 sites respectively. The abundance of individual species was not specifically recorded but a qualitative measure of their importance can be obtained from their occurrence as dominant species. Based on this, and allowing for the stratified process for selecting sites, there are indications that *Salix* spp. is the most abundant, for it was noted as a dominant species in at least seven sites in the analysis of vegetation structure (see below: Table 6) whereas *Ligustrum lucidum*, *Cytisus scoparius* and *Conium maculatum* each dominated once.

Management obligations are indicated by the status code (Table 4) and are set out under the *Noxious Weed Act 1993*. W2 species need to be fully and continuously suppressed and destroyed and W3 species must be prevented from spreading, and their numbers and distribution must be reduced. General requirements for W4 species, willows (W4g), moth plant (W4c p) and Easter cassia (W4b p), are that the plant is not to be sold, propagated, or knowingly distributed and that existing weeds must be prevented from flowering or fruiting ('b' species) or from spreading to adjoining property ('c' species).

This state-level information needs to be cross-checked with local control area categories for the relevant sites for individual noxious weeds, as they can differ. For example, crofton weed is declared noxious in the Shoalhaven control area but not in Camden.

Noxious weeds: implications

- At least 22 species recorded in this riparian survey are listed as Noxious, for various reasons, under state legislation. Riparian habitats can be particularly demanding in terms of weed management, either for reasons of accessibility or because the number of control options is limited, and may require special attention in the SCA's weed management program. Future management of these weeds rests with the SCA and will be influenced by species abundance and by the requirements of individual local control areas.
- Being listed under WONS and classified as noxious are both clear signals that a species is invasive, and hence potentially (if not already) a threat to biodiversity. The presence of these listed

species defines points in the riparian landscape where biodiversity is currently threatened. These would therefore be candidate sites for a control program.

Table 4. Noxious weeds recorded in survey plots.

The status code for weeds, as taken from NSW legislation, is: W2 species to be fully and continuously suppressed and destroyed; W3 species to be prevented from spreading, and to have their numbers and distribution reduced; W4 species not to be sold, nor propagated nor knowingly distributed.

Common Name	Species	Family	Status (NSW)
Crofton weed	*Ageratina adenophora*	Asteraceae	W 2/3 p
Mist flower	*Ageratina riparia*	Asteraceae	W 2/3 p
Moth plant	*Arauji sericiflora*	Asclepiadaceae	W 4c p
Hemlock	*Conium maculatum*	Apiaceae	W 2/3 p
Broom	*Cytisus scoparius* spp. *scoparius*	Fabaceae - Faboideae	W 2 p
Patterson's curse	*Echium plantagineum*	Boraginaceae	W 2/3 p
Viper's bugloss	*Echium vulgare*	Boraginaceae	W 2/3 p
African lovegrass	*Eragrostis curvula*	Poaceae	W 2/3 p
Montpellier brood	*Genista monspessulana*	Fabaceae – Faboideae	W 2/4 p
St John's wort	*Hypericum perforatum*	Clusiaceae	W 2/3 m
Broad-leafed privet	*Ligustrum lucidum*	Oleaceae	W 2/4 p
Narrow-leafed privet	*Ligustrum sinense*	Oleaceae	W 2/4 p
Ludwigia	*Ludwigia peruviana*	Onagraceae	W 2 p
Chilean needle grass	*Nassella neesiana*	Poaceae	W 2/3 p
Serrated tussock	*Nassella trichotoma*	Poaceae	W 2/3 p
Scotch thistle	*Onopordum acanthium ssp. Acanthium*	Asteraceae	W 2/3 p
Blackberry	*Rubus fructicosus* spp. *aggregate*	Rosaceae	W 2/3 m
Easter cassia	*Senna pendula*	Fabaceae – Caesalpinoideae	W 4 b p
Willows	*Salix* spp.	Salicaceae	W 4 g
Black willow	*Salix nigra*	Salicaceae	W 2 p
Gorse	*Ulex europaeus*	Fabaceae – Faboideae	W 2 p
Bathurst burr	*Xanthium spinosum*	Asteraceae	W 2/3 m

Vegetation structure

The vegetation structure in plots was summarised using :

- canopy height and canopy outline cover;
- projective foliage cover and species of the three largest contributors to the canopy;
- growth form of the tallest stratum;
- species richness in lifeform classes of herb, woody, climber and fern; and
- origin (native or alien) of the dominant species (>10% cover in the top stratum).

Structural classes were based on the growth form of the tallest stratum following the Specht scheme (AUSLIG 1990), except that the height boundary between forest and shrubland was set to 8 m rather than 10 m.

In general, riparian vegetation does not have a characteristic structure, since it naturally varies with stream size, climate and geomorphic development. Thus, in headwater streams, the riparian vegetation may be hardly distinguishable from adjacent non-flooding areas, whereas further downstream it becomes distinct from the adjacent upland vegetation. Site heterogeneity (which contributes to beta diversity) is influenced by larger geomorphic units such as gorges, benches, bars and unconfined floodplains.

In this survey the structural class of the riparian vegetation varied from sedgelands, grasslands and shrublands through to open forest. This is not surprising given the range in climate and stream conditions across the study area. Approximately one-third of plots and sites were structurally dominated by alien plant species, i.e. where the top stratum of the vegetation was predominantly composed of aliens.

The structural classes of forest, shrubland and herbland showed no overall differences in the height and cover measures between plots dominated by native and alien vegetation compared within the same structural class (Table 5). However native-dominated vegetation classes are highly invaded by alien species. Conversely, alien-dominated vegetation tends to have fewer native species and more alien species in total and as a proportion. In other words, there is an inverse relationship between the number of alien vs. native species when similar vegetation structural classes are compared. This indicates a close linkage between structure of the vegetation and the overall species composition in relation to aliens.

Table 5. Mean structural properties of the vegetation in the plots characterised by origin of dominant species and structural class

Origin of dominant species	Structural class	Percent-age of plots (*n* = 72)	Canopy height (m)	Canopy cover (%)	Native species richness	Alien species richness	Alien species as % of total
Native	Open Forest	32	15	49	29	12	29
Alien	Open Forest	21	11	46	12	16	57
Native	Shrubland	25	5	21	28	10	26
Alien	Shrubland	7	3	5	9	21	70
Native	Heathland	1	1	10	35	1	-
Native	Herbland	1	0.5	5	8	4	33
Alien	Herbland	4	1.4	30	16	28	64
Native	Sedgeland	6	1	43	16	15	50
Alien	Grassland	2	0.3	74	20	20	50

There was not an even distribution of sites across the vegetation types in relation to *a priori* site types (**Table 6**). While such a distribution was not a goal of the site selection process, it may need to be considered in the future in order to adequately sample biodiversity. All but two reference sites were native-dominated, whilst Agricultural and Urbanised sites were approximately evenly divided between native- and alien-dominated.

Plots with native species as dominants had a wide range of species forming their upper layer, with many *Acacia* and *Eucalyptus* spp. contributing. The range of species was slightly lower at plots with alien species dominating, with mainly willow (*Salix* spp.) and noxious shrubs such as hawthorn *Cratageus monogyna*, privet *Ligustrum lucidum* and broom *Cytisus scoparius* (**Table 7**). Although the alien blackberry was among the most frequently occurring species, occurring in more than half the sites, no plots had them as dominants in the top stratum. This may be an occasion of sampling bias.

Table 6. Sites categorised by vegetation structural classes and origin of the dominants

Sites occurring in more than one cell showed differences between plots for these category variables.

Vegetation structural class	Sites with vegetation dominated by native species	Sites with vegetation dominated by alien species
Open Forest	A4 A11 A13	A1 A2 A3 A6 A8 A9 A10 A11
	R1 R4 R8 R10 R12 R13 R16 R17 R18 R22	R7
	U3 U4 U5 U8 U9	U2 U7 U11
Shrubland	A3 A4 A8 A15	A2 A14
	R1 R4 R6 R10 R13 R18 R21 R22	
		U2 U7 U12
Heathland	R21	
Grassland	A2	A7
Herbland	A5 A7 A12 A16	
		R17
	U12	U6 U10
Sedgeland	A5 A7 A12 A16	

Vegetation structure: Implications

- Twenty-one sites were dominated by alien plant species or contained at least one plot that was alien-dominated. As these dominants are usually willows, they are likely to be affecting site properties such as channel stability, litter inputs and stream shading.
- Sites with native species as dominants were significantly invaded by alien species (average of 30% alien species), though not as much as sites where aliens were dominant (average of 65% alien species). This has implications for the potential of the former sites to become alien dominated in future.
- Sites with alien species as dominants had more aliens than native species. This indicates a potential difficulty in managing their biodiversity since so many species are alien. Once sites have been disturbed so much that alien species are dominant, the overall species composition is also mainly alien, indicating that there have been gross changes in habitat conditions that species such as willow, gorse and privet utilise and in turn affect. Management of these changes in environmental conditions will be necessary if some of the native species are to be restored.

Table 7. Structurally-dominant species in sites

Number in brackets is number of plots in which the species was recorded as contributing most to the cover of the top stratum; otherwise the species occurred once.

Vegetation	Native species dominant	Alien species dominant
Open Forest	*Casuarina cunninghamiana* (7)	*Salix alba var. vitellina* (7)
	Acacia mearnsii (2)	*Salix alba*
	Eucalyptus ovata (2)	*Salix nigra*
	Eucalyptus radiata (2)	*Populus nigra*
	Eucalyptus viminalis (2)	
	Eucalyptus ovata, *Eucalyptus viminalis*,	
	Eucalyptus pauciflora, *Angophora costata*,	
	Pittosporum undulatum, *Tristaniopsis laurina*,	
	Acacia trachyphloia, *Acacia dealbata*,	
	Acacia floribunda	
	TOTAL = 25 plots, 15 dominant species	**TOTAL = 10 plots, 4 dominant species**
Shrubland	*Acacia mearnsii* (5)	*Salix nigra*
	Acacia floribunda (2)	*Populus nigra*
	Acacia trachyphloia (2)	*Cratageus monogyna*
	Leptospermum lanigerum (2)	*Ligustrum lucidum*
	Lomatia myricoides (2)	*Cytisus scoparius*
	Acacia parramattensis, *Acacia dealbata*,	
	Allocasuarina distyla, *Bursaria spinosa*	
	Leptospermum morrisonii, *Melaleuca parvistaminea*	
	TOTAL = 19 plots, 11 dominant species	**TOTAL = 5 plots, 5 dominant species**
Heathland	*Darwinia fascicularis*	
	TOTAL = 1 plot, 1 dominant species	
Grassland		*Eragrostis curvula*, *Bromus mollis*
		TOTAL = 2 plots, 2 dominant species
Herbland	*Persicaria prostrata*	*Veronica anagallis-arvensis*
		Conium maculatum
	TOTAL = 1 plot, 1 dominant species	**TOTAL = 2 plots, 2 dominant species**
Sedgeland	*Typha orientalis* (2)	
	Juncus gregiflorus, *Eleocharis acuta*	
	TOTAL = 4 plots, 3 dominant species	

Environmental relationships

Species and site classification

Species presence data: Species presence data for sites were analysed to identify whether there were distinctive associations between species groups and sites. Classification using only those species with a relatively high site occurrence (i.e. found at 20% or more sites, total of 63 species) was done to form groups for both sites and species using the Czekanowski coefficient of similarity for sites and the two-step measure of Austin and Belbin (1982) for species, both combined with the flexible UPGMA fusion strategy (with beta = -0.1). The groups were cross-tabulated to show eight species groups (A to H), and 6 site groups (1 to 6). There are 11 species-by-site-group combinations (noda) of interest because they contain a high proportion of the species' occurrences. These noda are shown shaded in **Table 8**.

Table 8. Joint classification of 63 most common (>20% frequency) species in the 40 sites

Asterisks indicate species presence. Shaded blocks indicate noda where species occurrences total more than 40% within each nodum. Lifeform codes for species indicate native (N) or alien (E), woody (W) or herbaceous (H).

		Sites and Site groups																																							
		Group 1												Group 2										Group 3					Group 4									Gp 5		Gp 6	
Species Group	Species and lifeform	A1	A2	U10	A11	U6	U7	A10	A16	U2	A6	U12	U11	A12	A14	A5	A7	A9	A15	A3	A8	R6	U3	A13	R17	U9	U4	U5	A4	R13	R1	U8	R18	R7	R22	R4	R8	R12	R16	R10	R21
Group A	Acacia mearnsii NW																		*	*	*	*					*	*			*		*	*		*					
	Sonchus oleraceus EH														*	*			*	*	*				*	*	*				*		*								
	Acaena novae-zelandiae NH	*						*											*	*		*	*						*	*		*	*	*	*	*	*				
	Euchiton gymnocephalus NH									*				*			*		*	*		*							*				*	*	*		*				
	Acetosella vulgaris EH	*	*							*					*	*	*	*	*	*		*	*						*							*	*				
	Carex gaudichaudiana NH														*	*	*		*			*	*	*					*			*		*	*	*	*	*	*		
	Anagallis arvensis EH		*	*	*				*					*	*				*	*	*	*			*		*						*	*	*	*	*				
	Prunella vulgaris EH	*	*	*	*		*								*		*			*	*	*			*				*	*	*	*	*	*	*	*	*				
	Senecio diaschides NH		*												*					*		*			*				*			*	*		*	*	*				
	Epilobium billardierianum subsp NH	*	*				*							*	*					*		*					*			*				*	*		*				
	Holcus lanatus EH	*	*		*	*								*	*	*	*		*	*		*	*				*	*	*	*	*			*	*	*	*				
	Hypochaeris radicata EH		*	*	*				*	*	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
	Plantago lanceolata EH	*	*	*	*	*	*			*	*			*	*	*	*		*	*	*		*		*	*	*	*					*			*	*				
	Poa labillardieri NH	*	*				*	*			*			*	*	*	*	*		*	*	*					*		*		*		*	*	*	*	*				
	Trifolium repens EH	*	*	*			*				*			*	*	*	*	*		*		*	*			*				*	*				*	*	*				
	Juncus articulatus NH	*	*	*			*	*			*			*	*		*			*	*	*	*		*	*							*							*	
	Cirsium vulgare EH	*	*	*				*	*	*	*	*			*	*	*		*								*		*		*		*	*	*	*		*	*		
	Isolepis inundata NH	*	*	*	*					*	*									*		*		*	*			*	*		*	*	*	*				*			
	Conyza albida EH	*	*		*	*													*	*		*			*	*		*			*		*	*	*	*	*		*		
	Oxalis sp. NH		*						*	*									*	*	*				*	*	*	*	*	*	*		*	*	*	*	*	*			
	Rubus parvifolius NW		*																*						*				*	*	*		*	*	*	*	*	*			
	Lomandra longifolia NH									*									*	*		*		*	*	*	*		*	*	*	*	*	*	*	*		*		*	
	Rubus fruticosus spp. agg. EW	*		*		*		*	*	*					*				*	*	*	*			*	*	*		*	*	*	*	*		*	*					
	Microlaena stipoides NH					*		*	*	*				*			*		*	*	*	*	*	*		*	*	*			*	*	*	*	*	*	*	*	*	*	
Group B	Gratiola peruviana NH		*	*															*	*		*			*				*	*	*	*									
	Isolepis fluitans NH		*	*												*			*	*									*	*		*		*							
	Isolepis cernua NH		*				*	*											*	*	*	*							*	*							*				
	Hydrocotyle peduncularis NH			*					*	*							*		*	*	*								*	*		*						*	*		
Group C	Adiantum aethiopicum NF																										*		*		*	*	*	*	*	*	*	*			
	Dichondra repens NH																		*												*	*	*	*	*	*	*	*			
	Geranium solanderi var NH	*			*																						*				*	*	*	*	*		*				
	Blechnum nudum NF																						*			*	*	*	*	*		*		*		*	*				
	Echinopogon ovatus NH																											*	*	*			*	*	*	*	*	*	*		
	Pteridium esculentum NF				*																					*		*		*	*	*			*	*	*	*	*		
	Cyperus lucidus NH	*	*												*															*	*	*	*			*	*				
	Gnaphalium americanum EH		*						*					*					*											*	*	*	*			*	*	*		*	
	Entolasia stricta NH																					*	*					*	*	*	*		*			*				*	*
	Galium propinquum NH			*																		*							*	*	*	*			*	*		*			
	Lomatia myricoides NW																												*	*	*	*			*	*	*			*	*
Group D	Blechnum minus NF		*																*			*	*	*				*			*			*			*				
	Juncus sp. UH			*					*								*					*	*	*	*	*				*	*	*		*		*			*		
	Euphorbia lathyrus EH	*	*	*	*	*		*																*	*						*					*					
Group E	Euphorbia peplus EH			*	*																			*	*	*	*						*					*	*		
	Persicaria decipiens NH									*		*												*	*	*	*	*			*							*			
Group F	Austrodanthonia racemosa var NH								*		*	*		*			*	*	*	*	*				*								*		*	*					
	Trifolium subterraneum EH										*	*		*	*	*	*	*		*																*					
	Taraxacum officinale EH				*		*				*			*	*		*			*	*						*								*	*					
Group G	Eleocharis acuta NH		*								*	*		*	*	*	*				*	*																			
	Lythrum hyssopifolia NH	*	*	*							*			*	*	*			*			*																			
	Persicaria hydropiper NH	*	*	*							*			*	*																*	*							*		
Group H	Bromus catharticus EH	*	*	*	*	*	*	*		*	*	*				*								*			*						*								
	Conium maculatum EH	*	*	*	*	*	*					*	*							*							*														
	Rumex crispus EH	*	*			*	*			*	*	*	*			*	*	*		*							*												*		
	Cyperus eragrostis EH	*	*	*	*	*	*	*	*	*	*	*				*	*					*			*	*					*	*								*	
	Paspalum dilatatum EH			*	*		*		*	*	*	*				*	*			*	*				*																
	Dactylis glomerata EH	*		*	*	*	*	*	*	*	*							*		*	*	*	*				*	*						*	*						
	Phalaris aquatica EH	*	*		*	*	*	*	*	*	*	*	*	*		*				*	*	*													*						
	Ranunculus repens NH			*	*	*	*		*	*	*				*		*						*			*	*	*			*										
	Salix sp. EW		*		*	*	*	*		*	*											*											*	*							
	Crassula helmsii NH	*	*	*					*		*	*		*			*		*	*					*				*												
	Hirschfeldia incana EH	*	*	*					*	*	*	*	*							*		*			*																
	Sonchus asper subsp. glaucescens EH	*	*	*	*			*	*	*	*	*		*						*		*							*							*					
	Paspalum distichum NH	*			*				*		*	*				*				*					*		*														*

Site groups: Site groupings (Groups 1 to 6, columns in **Table 8**) are largely characterised by land use attributes, so may reflect also other environmental factors such as altitude, soils and topography. These are summarised below, and site groups are compared with the two site classifications.

Groups 1 and 3 are most disturbed, being a mix of cleared, agricultural and urban sites. Group 1 sites are more consistent with the field categorisation than the *a priori* categorisation (9 matches with alienated vs. 6 matches with A-sites); there is no such distinction with Group 3 sites.

Group 2 is less disturbed, being a mix of agricultural and grazed sites. Sites in this group correspond almost equally to the two site categorisations (7 matches with alienated and 8 matches with A-sites).

Groups 4, 5 and 6 are relatively undisturbed, being mostly uncleared bush, protected catchment or in a national park. Group 4 sites matched the *a priori* site categories better than the field categories (7 matches with R-sites compared with 5).

Species groups: Species groups (Groups A to H, rows in Table 8) are characterised by habitat factors, whether associated with streambanks and moist habitats, and species origin, whether alien or native. Note that the smallest groups are not described.

Group H (*n* = 12), a weedy group, is characterised by alien grasses, sedge and herbs, and includes two WONS (weeds of national significance) *Conium maculatum* and willow *Salix* spp. (Refer to Alien species). The alien species in this group are either found in moist/edge habitat, or are opportunistic invaders, responding to moist conditions. The group includes two aquatic macrophytes, both shallow water Australian species, *Ranunculus repens* and *Crassula helmsii*.

Group A (*n* = 24) is a suite of alien and native stream bank grasses and sedges, and several alien annual herbs. It is structurally-diverse, for it includes most of the non-woody growth-forms, a native tree *Acacia mearnsii* and the dominating tangled shrub blackberry *Rubus fruticosus*, a widespread and significant weed. Species composition appears to be influenced by land use. The group is described as a modified streambank group, on account of its mix of native and alien species.

Group C (*n* = 11) is characterised by native streambank species, with the shrub *Lomatia myricoides* as an overstorey and a short understorey of perennial herbs such as *Dichondra repens* and ferns, *Adiantum aethiopicum*, *Blechnum nudum* and *Pteridium esculentum*.

Group B (*n* = 4) and **Group G** (*n* = 3) are both small groups of lentic and moist habitat native species. Group B comprises shallow-water herbs and sedges; Group G comprises medium-tall emergents, typical of channel edge habitats.

Group F (*n* = 3) is a small group, suggesting modified terrestrial grassland; it comprises the perennial native grass *Austrodanthonia racemosa* var. *racemosa* and two common alien species, subclover *Trifolium subterraneum* and dandelion *Taraxacum officinale*.

Site x species groups: The distribution of Site x Species Groups (Table 8) suggested correlations between land use disturbance and species composition. For example:

Site Group 1, the most disturbed sites, was characterised by Species Group H, the alien and weedy group. No other species groups were strongly associated with this group of disturbed sites. Species Group A was represented at these sites.

Site Group 2, a group of sites with less disturbance, was characterised by three species groups: Species Group A, the modified and structurally diverse streambank assemblage with blackberry; Species Group G, with medium-tall native channel edge species; Species Group F modified grassland.

Site Group 4, which were sites expected to have least disturbance, was characterised by three species groups; the modified streambank group (Group A); the native riparian assemblage with *Lomatia* overstorey and fern understorey (Group C); and the shallow-water edge sedge-herbs group (Group B).

Similarly, with the species groups:

Species Group H, the alien and weedy group, was strongly associated with the most disturbed group of sites (Group 1).

Species Group B, the shallow-water edge sedge-herbs, and **Group C**, the riparian assemblage with fern understorey, are both native-dominated groups and are both strongly associated with the least disturbed sites (Group 4).

Species Group A, the modified and structurally diverse streambank assemblage, is not specific to a site group, but occurs across a range of sites from most disturbed (Group 3) to sites expected to be least disturbed (Groups 4) and including intermediate sites (Group 2). This was the only species group to show wide ecological amplitude.

Site x species groups: Implications

- The strong correspondence between site disturbance and species groups confirms the expectation that land use is an important variable for riparian and channel-edge species, with the degree of disturbance being directly correlated with the extent of modification.
- Site disturbance is not a perfect predictor, however. Species groups are not completely specific to a group of sites but may occur, in part, at other sites, or may even occur across a range of land use types, as with the modified streambank assemblage. This indicates that broad land use groupings are probably too coarse to be used alone as a predictive variable for species composition for riparian and in-channel plant groups, for example if extending survey elsewhere.
- Categorising sites based on upstream catchment characteristics was more successful in identifying undisturbed or reference sites, but less successful in indicating degrees of disturbance. Although the evidence for this is slight, there are implications for the development of sampling protocols in the future; hence a review of existing data and/or a small pilot study to establish this could greatly improve riparian sampling in the future.

Modelling species richness

The scope of this proposal included the examination of predictive models for riparian biodiversity. These may be at the species or community level. Such models would also be useful for understanding biodiversity and for guiding condition assessment, monitoring and rehabilitation.

The purpose of the modelling completed was to examine which variables most influenced the levels of species richness found in the sample. Whilst richness is only one facet of biodiversity, it is one on which we had suitable data. The results help to inform us about why species richness might be varying across the catchments and also help to refine sampling methods for the future.

The modelling of vegetation using statistical techniques combined with GIS capabilities is now a major approach for vegetation mapping and prediction. It has a major advantage over conventional mapping techniques, those using aerial photography or other remote sensing, in that there is an explicit model for extending the mapping to areas cleared of much or even all of their native vegetation. Moreover, since the approach can be applied at the species and vegetation level, it is finding many applications in the management of biodiversity.

Model development here has proceeded based on a conceptual model of riparian vegetation processes (see Malanson 1993 for overview). Geomorphic and hydrologic factors are key physical driving variables in the riparian zone, since they form the substrate and impose characteristic water and nutrient regimes. Other physical and biotic factors which influence the distribution and abundance of terrestrial plants are solar radiation, rainfall, temperature, herbivory and competition. In modelling species richness, predictor variables have been deliberately selected to reflect these processes, based on the limited set of variables available for this analysis.

Predictor Variables: Based on the conceptual model and the classification of species and sites, a candidate set of predictor variables was generated from the survey data (**Table 9**). These candidate predictor variables were selected for modelling at either the plot level or the site level. The list differs between these two levels, as some variables are not available or relevant at both levels.

As this modelling study was a preliminary exercise, no attempt was made to develop a set of definitive predictor variables. Predictor variables are not well-tested for riparian species, but are presumably based on the land–water characteristics of the riparian zone, i.e. on lithology, climate and flow hydrology. Stream power data were not available but are also strong candidate variables. Land use is also a strong correlate of native biodiversity (**Figure 3**) so was included in this analysis.

Geographic position (latitude/longitude) was not used as a predictor variable, as the purpose in modelling using direct environmental factors is to create models that are geographically robust, meaning they can better predict distributions within the study area, when applied to new sites within it.

Table 9. Predictor variables used for modelling various measures of species richness

Variables are stratified by scale (Plot or Site).

Scale	Variable	Definition
Plot	Aspect	Azimuth of the fall line of maximum slope
	Ground covers	Percent cover in categories (refer datasheet Appendix 2)
	Substrate cover	Percent cover of mineral substrate in categories as per datasheet
	Canopy height	Average height
	Canopy cover	Crown outline cover for the top stratum
	Canopy PFC	Projective foliage cover for the top stratum
	Dominants	Whether the dominant species are Australian or Alien
	Plot distance	Horizontal distance from channel
	Plot elevation	Vertical distance above channel
	Geounit type	Category of geomorphic unit
	Channel habitats	P=pools, R= riffles & runs PR = all present
	Channel width	Bankfull width
	Riparian width	Maximum horizontal distance along transect
	Riparian elevation	Maximum vertical distance on transect
	Distance from source	Calculated from map
	Site type	Based on upstream catchment. A=agriculture, U=urban R=reference
	Altitude	From map
Site	Channel width	Bankfull width
	Channel habitats	P=pools, R= riffles & runs PR = all present
	Riparian width	Mean maximum horizontal distance along transect
	Riparian elevation	Mean maximum vertical distance along transect
	Distance from source	From map
	No. of geounits	Number of geomorphic units recorded in the site
	No. transects	Number of transects placed in site
	Site type	Based on upstream catchment. Agriculture, Urban or Reference
	Adjacent landuse	The field-based site category, refer Table 2.
	Altitude	From map

Response variables

The major response variables modelled were species richness and selected components such as richness of particular lifeform groups (**Table 10**). Selected single species models have not been developed at this stage. This is because species site occurrences are generally too low, as a consequence of small sample size, spatial heterogeneity and wide habitat diversity across the study area. Thirty occurrences is a desirable minimum for developing a robust species model (Austin *et al.* 2000). With a sample of 40 sites, only species occurring in at least 75% sites would be suitable for modelling, but even with this number of occurrences, the robustness of the model will be restricted by the low number of site absences. Only one species met this criterion for presences in the sample, and most of the ones that occurred in more than 50% of sites are of low interest in terms of their ecology or management (**Table 11**). Possibly several hundred sites are needed for modelling species presence data, as it is also important to have absence sites in the modelling process model (Austin *et al.* 2000). In addition, the stratification used in this study to locate the sample sites was not optimal for plant species, and hence would compromise model success.

Table 10. List of response variables used in modelling

Plot level	Native species richness Native woody plant richness Alien species richness Alien herbaceous species richness Native macrophyte richness Alien macrophyte richness
Site level	Native species richness Alien species richness

Table 11. Species which occurred in more than 50% of sites

Species	Lifeform	Site frequency/40
Hypochaeris radicata — Flatweed	EH	30
Microlaena stipoides — Weeping grass	NH	25
Plantago lanceoloata — Plantain	EH	23
Rubus fruticosus — Blackberry	EW	21
Holcus lanatus — Yorkshire fog grass	EH	21
Poa labillardieri — Tussock	NH	21
Cirsium vulgare — Scotch thistle	EH	21
Prunella vulgaris — Self-heal	EH	20

Species richness is definable as total species found for individual plots and for sites with a single plot. (The sampling protocol did not permit any estimation of 'true' species richness based e.g. on jackknife estimates from numerous small plots.) However, for sites with more than one plot there was found to be an effect of sample area (no. of plots) on species richness (**Figure 4**). It would be possible to examine this effect more closely to establish whether this is a true species-area effect, or a real property of those sites which displayed greater geomorphic complexity and therefore were allocated more sampling plots. However, for the present modelling, the effect of sampling intensity has been removed by averaging the number of species across plots within a site. This has the effect of making the mean, variability and range of richness of multi-plot sites very close to that of single plot sites. Further work needs to be done to establish optimal plot sizes in the riparian zone.

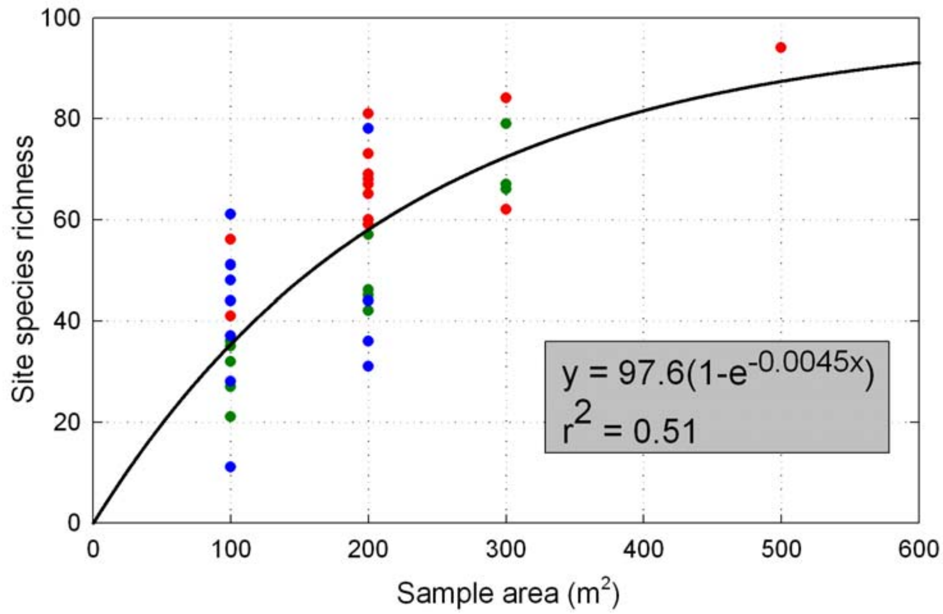

Figure 4. Site species richness as an exponential function of the area sampled

Area sampled was dependent on the number of 100 m^2 plots.

Modelling approach

Generalised linear models (GLM) emphasise estimation and inference for the model parameters; generalised additive models (GAM), on the other hand, focus on exploring the data set non-parametrically and visualising relationships between response and predictor variables. The latter were used as they better suited our objectives. Generalised additive models were fitted by an iterative procedure to establish the most parsimonious models (Crawley 1993) using procedure GENMOD in SAS v.8.01[4]. This procedure enables both continuous and categorical variables to be used. Since species richness is a count variable, we assumed Poisson error distributions and log links between the response variable and the linear predictor (Crawley 1993).

Fitted models

The results are summarised in tables below which show the most parsimonious model fitted to each response variable. The parameter estimate and the magnitude of chi square for the Wald statistic indicate the relative contribution of parameters to the fit. The fit is measured by the rank correlation between observed and predicted values and reported with the Pearson rank correlation value in the tables. However, since statistical tests of significance for GAM are unreliable (Austin *et al.* 1995) the fit of these models is indicative only.

For each categorical variable, one level of the variable has to be arbitrarily assigned as the base level and it has zero degrees of freedom. A point summary of each model is provided below the tables.

[4] Now available as procedure GAM in SAS version 8.2.

Table 12. Model for native species richness in sites

Parameter	DF	Estimate	St. Error	Wald 95% Confidence Limits		Chi-squared	Pr>chisq
Intercept	1	3.2324	0.1159	3.0054	3.4595	778.4	<0.0001
Riparian width	1	-0.0094	0.0035	-0.0163	-0.0025	7.03	0.008
Riparian elevation	1	-0.101	0.0310	-0.1617	-0.0404	10.65	0.0011
Site type A	1	0.0083	0.1028	-0.1932	0.2098	0.01	0.9356
Site type R	1	0.6893	0.0892	0.5145	0.8642	59.69	<0.0001
Site type U	0	0	0	0	0	.	.
Wald statistics							
Riparian width	1					7.03	0.008
Riparian elevation	1					10.65	0.0011
Site type	2					89.53	<0.0001
Rank correlation = 0.7276							

- This model for native species shows a strong effect of one site type, Reference, compared with Urban and Agricultural sites, which are not very different. The spatial dimensions of the riparian zone explain a further small component of variation in species richness.

Table 13. Model for alien species richness in sites

Parameter	DF	Estimate	St. Error	Wald 95% Confidence Limits		Chi-squared	Pr>chisq
Intercept	1	3.3376	0.1427	3.058	3.6172	547.22	<0.0001
Distance from source	1	0.0036	0.0015	0.0006	0.0066	5.62	0.0178
No of transects	1	-0.2227	0.0863	-0.3919	-0.0535	6.65	0.0099
Channel habitats P	1	-0.3267	0.0934	-0.5097	-0.1437	12.24	0.0005
Channel habitats R	1	-0.5383	0.2153	-0.9604	-0.1162	6.25	0.0124
Channel habitats PR	0	0	0	0	0	.	.
Site type A	1	-0.2335	0.0991	-0.4278	-0.0392	5.55	0.0185
Site type R	1	-0.5923	0.1307	-0.8486	-0.3361	20.52	<0.0001
Site type U	0	0	0	0	0	.	.
Wald Statistics							
Distance from source	1					5.62	0.0178
No of transects	1					6.65	0.0099
Channel habitats	2					17.03	0.0002
Site Type	2					20.62	<0.0001
Rank correlation = 0.6395							

- Site category and in particular the Reference category, the presence of channel pools vs. riffles and runs, distance from source and number of transects (an indicator of within-site geomorphic heterogeneity) all contribute to this model of alien species richness.
- This model indicates a longitudinal contrast with changing alien species richness on larger streams with more plant habitats.

Table 14. Model for native species richness in plots

Parameter	DF	Estimate	St. Error	Wald 95% Confidence Limits		Chi-squared	Pr>chisq
Intercept	1	2.595	0.0996	2.3998	2.7902	678.84	<0.0001
Aspect	1	0.002	0.0004	0.0013	0.0027	32.2	<0.0001
Sand cover	1	0.0056	0.0009	0.0038	0.0074	37.04	<0.0001
Bedrock cover	1	0.0083	0.0019	0.0046	0.012	19.2	<0.0001
Plot distance	1	-0.0012	0.0039	-0.0088	0.0065	0.09	0.7654
Dominants alien	1	-0.4039	0.0756	-0.552	-0.2557	28.55	<0.0001
Dominants native	0	0	0	0	0	.	.
Litter cover	1	0.0106	0.0047	0.0014	0.0197	5.12	0.0237
Sand*Plot distance	1	-0.0005	0.0001	-0.0007	-0.0003	21.66	<0.0001
Aspect*Bedrock	1	0	0	-0.0001	0	17.43	<0.0001
Aspect*Litter	1	-0.0002	0	-0.0003	-0.0001	28.13	<0.0001
Site type A	1	0.1736	0.0882	0.0007	0.3465	3.87	0.0491
Site type R	1	0.5464	0.0805	0.3886	0.7042	46.05	<0.0001
Site type U	0	0	0	0	0	.	.
Wald Statistics							
Aspect	1					32.2	<0.0001
Sand cover	1					37.04	<0.0001
Bedrock cover	1					19.2	<0.0001
Plot distance	1					0.09	0.7654
Dominants	1					28.55	<0.0001
Litter	1					5.12	0.0237
Sand*Plot distance	1					21.66	<0.0001
Aspect*Bedrock	1					17.43	<0.0001
Aspect*Litter	1					28.13	<0.0001
Site type	2					56.11	<0.0001
Rank correlation = 0.7927							

- Many factors contribute to a model with one of the highest fits ($r^2 = 0.63$) for native species richness in plots. The major factors are substrate composition, aspect, origin of dominants, site type and the interactions of some of these factors. However, the large number of predictor variables may indicate the model is over-fitted, i.e. it may have poor generality.

Table 15. Model for alien species richness in plots

Parameter	DF	Estimate	St Error	Wald 95% Confidence Limits		Chi-squared	Pr>chisq
Low vegetation cover	1	0.0048	0.0014	0.0019	0.0076	10.92	0.001
Boulder cover	1	-0.0084	0.0022	-0.0127	-0.0041	14.88	0.0001
Canopy height	1	-0.0163	0.0056	-0.0273	-0.0052	8.36	0.0038
Channel habitats P	1	-0.398	0.0757	-0.5464	-0.2497	27.65	<0.0001
Channel habitats R	1	0.8008	0.1733	0.4612	1.1404	21.36	<0.0001
Channel habitats PR	0	0	0	0	0	.	.
Site type A	1	-0.1571	0.083	-0.3197	0.0055	3.58	0.0583
Site type R	1	-0.634	0.0906	-0.8115	-0.4564	48.99	<0.0001
Site type U	0	0	0	0	0	.	.
Wald Statistics							
Aspect	1					2.61	0.106
Low vegetation cover	1					10.92	0.001
Boulder cover	1					14.88	0.0001
Canopy height	1					8.36	0.0038
Channel habitats	2					51.43	<0.0001
Site type	2					55.53	<0.0001
Rank correlation = 0.6366							

- At the plot level, site type, specifically whether Reference site or not, and channel habitats are major contributors to the model of alien species richness; also contributing to the model are structural features of the vegetation, namely canopy height, and type and extent of ground cover, boulder and low vegetation cover.
- This model emphasises protected catchments, channel habitats and some structural features.

Table 16. Model for native woody species richness in plots

Parameter	DF	Estimate	St Error	Wald 95% Confidence Limits		Chi-squared	Pr>chisq
Intercept	1	2.1223	0.2448	1.6426	2.602	75.18	<0.0001
Altitude	1	-0.0009	0.0002	-0.0014	-0.0005	17.7	<0.0001
Aspect	1	0.0006	0.0005	-0.0003	0.0016	1.78	0.1826
Channel habitats: P	1	-0.0491	0.1185	-0.2813	0.183	0.17	0.6782
Channel habitats: R	1	1.535	0.6342	0.292	2.7779	5.86	0.0155
Channel habitats: PR	0	0	0	0	0	.	.
Distance from source	1	-0.0122	0.0039	-0.0198	-0.0046	10	0.0016
Dominants alien	1	-1.4646	0.2365	-1.9281	-1.001	38.35	<0.0001
Dominants native	0	0	0	0	0	.	.
Site type: A	1	0.0916	0.2278	-0.3548	0.5381	0.16	0.6875
Site type: R	1	0.8427	0.189	0.4722	1.2132	19.87	<0.0001
Site type: U	0	0	0	0	0	.	.
Wald Statistics							
Altitude	1					17.7	<0.0001
Aspect	1					1.78	0.1826
Channel habitats	2					6.27	0.0436
Distance from source	1					10	0.0016
Dominants	1					38.35	<0.0001
Site type	2					34.53	<0.0001
Rank correlation = 0.7938							

- Site type and origin of dominants are the major contributors to this well-fitted model.
- This model emphasises catchment protection and domination by aliens in affecting woody natives.

Table 17. Model for alien herb species richness in plots

Parameter	DF	Estimate	St Error	Wald 95% Confidence Limits		Chi-squared	Pr>chisq
Intercept	1	0.9937	0.3042	0.3974	1.59	10.67	0.0011
Altitude	1	0.0004	0.0002	-0.0001	0.0009	2.76	0.0969
Mineral cover	1	0.0134	0.0034	0.0067	0.02	15.44	<0.0001
Low vegetation cover	1	0.0137	0.003	0.0079	0.0195	21.17	<0.0001
Gravel cover	1	0.0127	0.0045	0.0039	0.0216	7.95	0.0048
Aspect	1	0.0006	0.0004	-0.0001	0.0013	2.84	0.0918
Channel habitats P	1	-0.3005	0.087	-0.471	-0.1299	11.93	0.0006
Channel habitats R	1	0.68	0.1907	0.3062	1.0538	12.71	0.0004
Channel habitats PR	0	0	0	0	0	.	.
Dominants alien	1	0.3469	0.0853	0.1797	0.514	16.54	<0.0001
Dominants native	0	0	0	0	0	.	.
Site type A	1	-0.1583	0.0955	-0.3455	0.029	2.74	0.0976
Site type R	1	-0.4093	0.1102	-0.6253	-0.1933	13.79	0.0002
Site type U	0	0	0	0	0	.	.
Wald Statistics							
Altitude	1					2.76	0.0969
Mineral cover	1					15.44	<0.0001
Low vegetation cover	1					21.17	<0.0001
Gravel cover	1					7.95	0.0048
Aspect	1					2.84	0.0918
Rank correlation = 0.6211							

- Factors include cover of low vegetation, bare ground and gravel in plots, with aspect and altitude as minor contributors.
- This model emphasises the effects of substrate and vegetation cover on alien species richness.

Table 18. Model for native macrophyte species richness, in stream edge plots

Parameter	DF	Estimate	St Error	Wald 95% Confidence Limits		Chi-squared	Pr > chisq
Intercept	1	1.6854	0.1839	1.3249	2.0459	83.96	<0.0001
Aspect	1	-0.0021	0.0005	-0.0031	-0.0011	16.12	<0.0001
Plot elevation	1	-0.5088	0.2467	-0.9923	-0.0254	4.26	0.0391
Type A	1	0.6048	0.2430	0.1285	1.0811	6.19	0.0128
Type R	1	-0.2707	0.2296	-0.7207	0.1793	1.39	0.2383
Type U	0	0	0	0	0		
Substrate: Sand	1	0.0029	0.0017	-0.0005	0.0063	2.75	0.0972
Adjacent Landuse: A	1	0.1946	0.2878	-0.3694	0.7586	0.46	0.4989
Adjacent Landuse: R	1	0.5794	0.2815	0.0278	1.1311	4.24	0.0395
Adjacent Landuse: U	0	0	0	0	0		
Wald Statistics							
Aspect	1					16.12	<0.0001
Plot elevation	1					4.26	0.0391
Site type	2					18.28	0.0001
Substrate: sand	1					2.75	0.0972
Adjacent landuse	2					5.87	0.0532
Rank correlation = 0.5844							

- Aspect and catchment land use (site type) are the dominant factors influencing native macrophyte species richness in edge plots; also influential but less important is plot elevation.
- Univariate plot of significant variables shows that native macrophyte species richness varies with catchment land use (type), being higher in A than in either R or U; increases towards north and east-facing transects; increases with proximity to river channel.

Table 19. Model for: Alien macrophyte species richness, in edge plots

Parameter	DF	Estimate	St Error	Wald 95% Confidence Limits		Chi-squared	Pr > chisq
Intercept	1	-2.2401	0.9984	-4.1968	-0.2833	5.03	0.0249
Ground: mineral	1	0.0250	0.0115	0.0024	0.0477	4.70	0.0320
Ground: low veg	1	0.0240	0.0106	0.0032	0.0448	5.13	0.0236
Dominants E	1	0.9379	0.2452	0.4572	1.4185	14.63	0.0001
Dominants: N	0	0	0		0		
Wald Statistics							
Ground: mineral	1					4.70	0.0302
Ground: low veg	1					5.13	0.0236
Dominants	1					14.63	0.0001
Rank correlation = 0.4624							

- The significant factors in this model are the type of canopy, whether alien or native (Dominants), in the adjacent riparian community. Also important but less influential factors are extent of ground cover in the lowest stratum (ground: low veg) and the substrate cover itself, how much is bare of vegetation and litter (ground: mineral).
- Species richness of alien species increases when adjacent riparian canopy is dominated by alien species and also with increasing area of rock and increasing cover of low vegetation.

Table 20. Model for: Native macrophyte species richness per site

Parameter	DF	Estimate	St Error	Wald 95% Confidence Limits		Chi-squared	Pr > chisq
Intercept	1	1.2081	0.2554	0.7075	1.7086	22.38	<0.0001
Type A	1	0.7086	0.2322	0.2535	1.1638	9.31	0.0023
Type R	1	0.1371	0.2356	- 0.3246	0.5988	0.34	0.5606
Type U	0	0	0	0	0		
Adjacent landuse: A	1	- 0.1663	0.2868	- 0.7284	0.3959	0.34	0.5622
Adjacent landuse: R	1	0.3817	0.2688	- 0.1452	0.9086	2.02	0.1557
Adjacent landuse: U	0	0	0	0	0		
Altitude	1	0.0007	0.0003	0.0001	0.0013	4.59	0.0321
Wald Statistics							
Type	2					15.02	0.0005
Adjacent landuse	2					12.04	0.0024
Altitude	1					4.59	0.0321
Rank correlation = 0.418							

- Land use is the dominant factor relating to native macrophyte species richness at the site level, and is effective at both catchment-scale and adjacent. Altitude is also significant, but of secondary importance.
- Univariate plots (not shown) show that macrophyte species richness is consistently higher at A and R sites than at U sites, for both catchment type and adjacent land use, and also increases with increasing altitude.

Modelling: Implications

- Overall, models of species richness fitted at the site level were most influenced by site type, especially the contrast between Reference vs. Agricultural and Urban sites. Models for native species and alien species differed in the other significant variables in their respective models.
- Site type was also significant in plot-level models, but local environmental features were additionally important. These included substrate texture, dominants, aspect and altitude.
- Modelling the richness component of biodiversity has been successful in demonstrating the importance of site and plot environmental characteristics on this component of biodiversity. This supports the relatively weak differentiation of site and species groups shown in the classification analysis.
- It is likely that these community-level models could be improved with additional environmental data collected for sites, such as climate, hydrology and lithology. Rather than increasing the total number of predictor variables, these would replace some of those included in the present study; such as altitude, site type, distance from source and aspect, because they are more direct plant resource variables. Clearly such data would also benefit species level models.
- Single species models will require a significantly larger sample size. Unfortunately the species most likely to achieve suitably high frequencies are the widespread alien species such as willows *Salix* spp. and blackberry *Rubus* aggregate; many native species with lower frequency will require even greater sampling effort. Biodiversity criteria will be needed to select species for modelling.
- Larger sample size will also make multivariate techniques more useful in exploring biodiversity patterns. For example, delineation of riparian vegetation types and determination of their habitat correlates is an important part of biodiversity planning. Comprehensive vegetation-in-habitat definitions and robust species distribution models based on extensive site records can together form the basis for much biodiversity assessment and management.

Evaluation

Sites of scientific significance

One of the broader goals of the overall biodiversity project was to identify sites of scientific significance. Identification of these 'on the ground' will possibly require a combination of riparian mapping and predictive modelling of biodiversity measures. In addition, some criteria as to what constitutes a 'site' and 'scientific significance' will need to be developed, as well as the operational value of identifying them. Mapping, modelling and development of criteria are all outside the scope of this study. In anticipation, however, the challenge in developing such criteria can be demonstrated in a simple exercise applying univariate and aggregated criteria based on biodiversity such as the presence of federally listed species; and site species richness and integrity.

(1) Listed species: presence of a species with special distribution attributes:

- Occurrence of a species recognised as Vulnerable (ROTAP).

(2) Richness and Integrity criteria:

- Macrophyte species richness (native) is high (top 4 values for richness)
- Macrophyte species richness is mainly native (native/Total > 75%)
- Riparian SR is high (native species > 40 per site)
- Riparian SR not much influenced by exotics (aliens = < 15 per site)
- Structural diversity intact (only native spp. dominate structure).

This analysis shows that application of these two criteria returns different results. For example, based on the presence of listed species, sites of scientific significance are A10, R10 and R13. However, based on criteria of site species richness and simple measures of integrity, the sites of scientific significance are A15 and A4 (both misclassified in the *a priori* site-classification scheme as Agricultural).

Even though this exercise did not include biodiversity criteria such as representativeness, rare species, patch size and connectivity, presence of threatening processes, or community attributes, nor consider riparian vegetation in terms of its habitat value, it does show that a clear working definition of biodiversity 'site of scientific significance' will be needed, and that multivariate approaches will need to be applied to define such sites. However defined, they must be placed in a broader context of biodiversity characterisation and monitoring, and hence a site could in fact refer to a reach, tributary or most of a sub-catchment.

Project objectives

The four specific objectives of this survey of riparian vegetation biodiversity have all been addressed through field sampling and analysis. The advances made for each of these four objectives are set out below.

Measure riparian plant biodiversity and its variability

Prior to this survey, riparian vegetation and its variability were known through surveys and vegetation mapping that have been done within the relevant areas of the Sydney Basin, a species-rich bio-region high in endemic species, as described above (Section 2.6). Despite using a coarse scale of 1:100,000 for mapping, these projects recognised three riparian plant communities (Riparian Scrub, Closed Forest and River Oak Forest), of which two were expected within the study area. In this survey, sites were defined as 1 km long river reaches but data were collected from rectangular plots, each 5 x 20 m, thus data obtained in this study were at a much finer spatial resolution than that used in the prior vegetation mapping projects.

As expected, plots with vegetation characteristics consistent with two of the three mapped riparian plant communities were found . Nineteen plots were classed as native shrubland (Table 7), and three of these were dominated by shrub species considered to be exclusive to the Riparian scrub vegetation type (Keith 1994). Similarly, of the 25 plots classed as open forest (Table 7), seven were dominated by River Oak (*Casuarina cunninghamiana)*, and thus are consistent with the River Oak Forest recognised by Fisher *et al.* (1995). Differences in scale at which information is recorded and difficulties in comparing studies with different objectives and working at very different scales means it is not possible to determine whether the other 16 open forest plots and 18 shrubland plots from this survey are variations within the two previously-mapped plant communities, or whether there are other riparian plant communities that need to be formally described.

Thus, whilst it is clear that riparian plant communities are diverse in terms of dominant species at the scale of plots within sites, it is not clear how this plot-based diversity relates to regional descriptions of riparian communities. This can only be clarified with more intensive sampling.

The several measures of biodiversity used in this survey were found to give interesting and relevant insights into species-level aspects of biodiversity. Some of these are suitable for applications requiring summaries of biodiversity at site and higher scales.

Correlates of species richness and vegetation structure

Environmental correlates of species richness were established through the GAM modelling using ~17 plot-based variables, and ~9 site-based variables. The outcomes are summarised below (**Table 21**).

Two characteristics emerged from this modelling. The first was the importance of land use as a primary correlate for a range of species richness measures at both site and plot scale, and for different groups of species, suggesting that disturbance is a pervasive and key determinant of biodiversity measured as species richness. The second was the relationship between the number and type of variables contributing to the model and the scale of the model. Site-based models generally contain fewer variables than plot-based models. Plot-based models generally incorporate a number of substrate descriptors.

The data were not systematically interrogated with the intention of establishing correlates between the different biodiversity measures used in modelling, but this approach was explored graphically by noting trends in bivariate plots of , for example, native woody plant species richness and native and alien herb species richness (**Figure 5**). Note here the difference in trend of the relationship for the two graphs. One question such data raise is the extent to which a subset of the flora might be used as indicators. For example, woody species are easier to find and identify compared with herbs. Whilst it will be possible to explore such correlates at both plot and site level, more work will be needed to refine these relationships and test their utility as surrogate measures which might reduce monitoring costs.

Table 21. Summary of models for species richness showing main predictors (with less influential variables, where tested)

Note that for macrophytes, plot-scale refers to littoral edge plots only.

Species richness	Predictor variables in site-scale models	Predictor variables in plot-scale models	Source table
native	site type, dominants (riparian width)		Table 12
Alien	site type (channel habitats)		Table 13
native		site type (aspect, ground cover)	Table 14
Alien		site type (channel habitats, ground cover)	Table 15
native woody		site type (dominants, altitude)	Table 16
Alien herbs		ground cover	Table 17
native macrophytes		site type, aspect (plot elevation, adjacent landuse, substrate cover)	Table 18
Alien macrophytes		dominants (ground cover, substrate cover)	Table 19
native macrophytes	site type, adjacent landuse (altitude)		Table 20

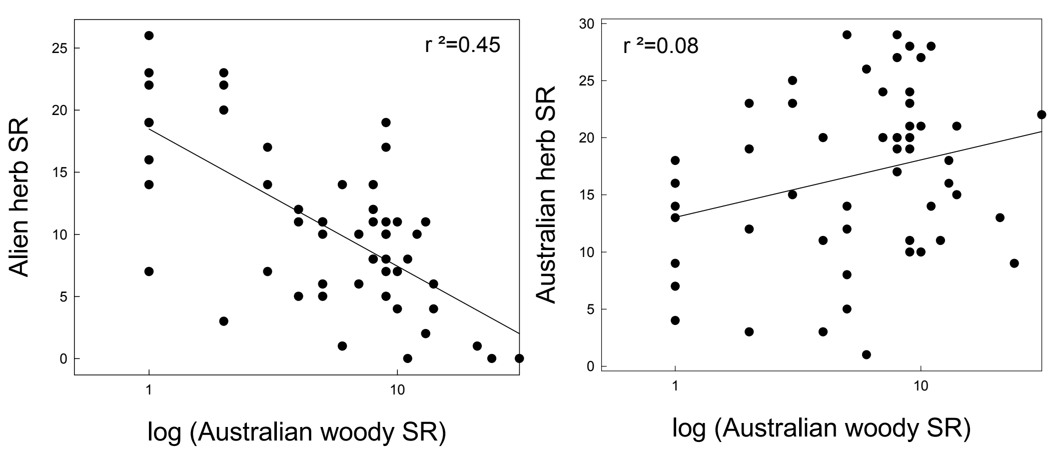

Figure 5. Scatterplot for several species richness (SR) measures in plots

Relate species presence to habitat variables and consider the potential for species predictive models

The study area's level of beta diversity (the variation in species composition from place to place), as measured by the pilot sample of sites, was high. The number of species that were recorded as being in the top three contributors to dominance in plots was 70 in the 72 plots, but of these, only seven occurred in more than three plots (Figure 6). These species were *Acacia mearnsii*, *Salix alba*, *Casuarina cunninghamiana*, *Eucalyptus viminalis*, *Salix* sp., *Acacia dealbata* and *Allocasuarina littoralis,* in decreasing order of frequency.

These low species frequencies mean there is little statistical power for correlation with habitat variables. This is why species richness was the main response variable for modelling; it is a continuous measure with every plot having a known value.

However, with an appropriate stratification of the study area leading to a representative and larger sample of sites, it will be possible to develop species-based models. Stratification is based on identifying the environmental range of species using variables which are directly related to plant requirements for growth and survival A well-documented strategy for achieving this design was formalised by Austin and Heyligers (1989, 1991) and is known as the SR^3 strategy. SR^3 refers to a geographical Stratification, environmental Representation, sampling Replication and site Randomisation. The method is fully illustrated in Austin *et al.* (2000), available by searching at URL http://csiro.cse.au/. This work also details an approach to species distribution modelling using GAM.

In addition, the prevalence of non-native species, even at sites categorised as Reference sites, shows the difficulty in locating pristine or even mildly disturbed plant communities in the riparian zone. This is not unique to the Sydney bio-region, as riparian vegetation, world-wide, is known to have a relatively high incidence of non-native species (Hood and Naiman 2000). The implications of this for monitoring biodiversity are, as suggested by Chapman and Underwood (2000), that using a monitoring program designed around a reference system concept will require special effort to generate conceptual but quantitative descriptions of reference states.

Given that species are the fundamental unit of biodiversity (Gaston 1996) and that vegetation types (communities) are largely descriptive conveniences, species-based models should be much more heuristic for biodiversity than community-based ones. Species-specific models, such as are used in BIORAP and the CSIRO study on predicting pre-European vegetation in the Lachlan valley (Austin *et al.* 2000), have demonstrated their power to consider large numbers of species in highly degraded environments. These techniques provide a consistent and explicit method for modelling vegetation composition in cleared and degraded areas by predicting the probability of presence of each species at a site independently. Their development for riparian vegetation would improve prediction accuracy and geographic robustness of the models, since emphasis is placed on the variables that directly affect plant growth. Two other potentially useful outputs that could be gained from the development and application of riparian species-level predictive models are site-specific species lists for rehabilitation of riparian zones and, habitat indicators for species planting within the riparian zone at a site.

Plot-based vegetation structure descriptions

The main plot-based vegetation structure data have been summarised in Appendix 5 . They comprise canopy heights, canopy outline cover estimates, the three top species contributing to canopy projective foliage cover and their percentage PFC. The 72 plots from which these data were collected were rectangular, each 5 m x 20 m, aligned with long face parallel to the river channel. The summary includes location information that is necessary for ground-truthing remote sensing imagery as well as several other plot features that can be extracted from the data, including ground slope and geomorphic unit.

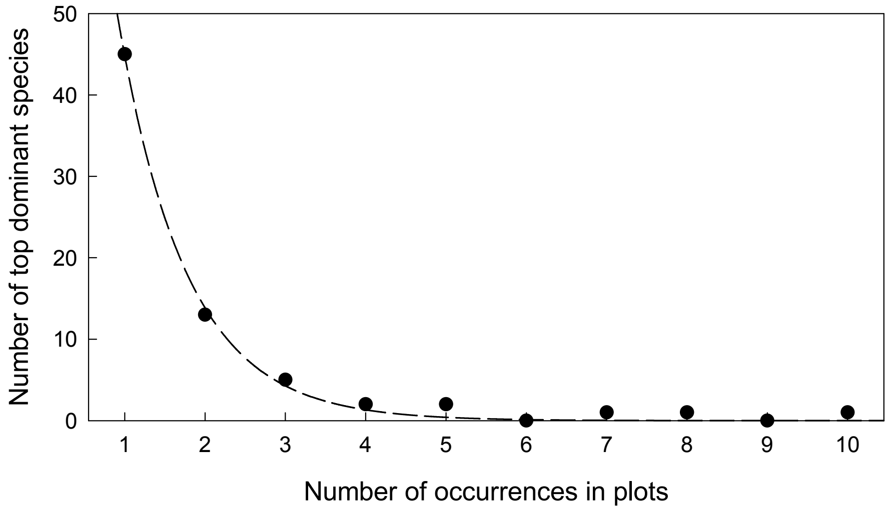

Figure 6. Frequency of occurrence of the 70 dominant species recorded in the 72 riparian plots

Dominant here refers to a maximum of three species in each plot which contributed most to the foliage cover in that plot. Some plots had only one or two species in the upper stratum.

These data could provide the initial training set for interpreting aerial photography at scales of 1:20,000 down to 1:5,000. Such scales provide the high spatial resolution required for riparian vegetation studies apart from the lowland floodplain context (Muller 1997).

Riparian vegetation, as well as being of intrinsic importance, partially determines the physical conditions in the riparian zone and river channel, by defining physical space and by shading and light interception, and by influencing local hydrological patterns. The plot-based information incorporates the basic information on vegetation structure and composition that is necessary to service studies on fish and macroinvertebrates. However, the integration of riparian and macrophyte information with other biota in an integrated survey is outside this study.

General comment on using the same sites for sampling different taxa

As discussed earlier in this report, the riparian zone is subject to modification through a variety of factors which act both through changes in the flow and sedimentary regime and through terrestrial processes such as land clearance, grazing and weed invasion. For this reason, vegetation condition and biodiversity status are not readily derived from a broad-scale examination of upstream catchment characteristics such as used here for defining site categories.

The use of a common site for sampling biodiversity of different taxonomic groups may have advantages in terms of logistics, cost-savings, economy of resources and working on contextual data. However, it is evident that this aspect of biodiversity sampling will need to be specifically developed, as taxa are likely to be differentially affected by various environmental factors and disturbance regimes. This is particularly true for organism groups distinguished by contrasting habitats (in-stream vs. riparian), autotrophy vs. heterotrophy, size ranges (cm vs. m), and life spans (months vs. decades). A similar conclusion was reached by Mensing *et al*. (1998) after they investigated bird, amphibian, fish and riparian vegetation diversity in northern parts of Unites States, including parts of the Upper Mississippi River basin and tributaries.

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Appendices

Appendix 1. Vegetation Transect Datasheet

CRCFE/SCA Riparian Vegetation Biodiversity Pilot Survey 2001 TRANSECT Datasheet

Contact (02) 62012544

Team		Date	/ /200	Site
Site valley type				*Each site on new page*
Transect#				
Bankfull width				
Channel habitat/s				

Comments on each unit. Bank erosion, stock, fire, macrophytes, vegetation. Always note adjacent land use and veg at end of transect

	Transect#	Unit# and name	Est. length	Plot#	Easting (plot)	Northing	LMK#

Name lists		Profile sketch (indicate approx. distances and veg type/height)
Valley type	gorge upland confinedFP unconf.FP	
Channel habit	riffle pool run inbend(point) outbend(cut)	
Riparian unit	island littoral bank levee terrace runner swamp slope	
Mineral Subst	fines sand gravel pebble cobble boulder bedrock	

Appendix 2. Vegetation Plot Datasheet

CRCFE/SCA Riparian Vegetation Biodiversity Pilot Survey 2001 PLOT Datasheet

Contact: (02) 62012544

COOPERATIVE RESEARCH CENTRE FOR FRESHWATER ECOLOGY

Team		Date	/ / 2001	Site	

Transect#	1	2	3	4
Plot #	1	2	3	4
	5	6	7	8

Placement	Aspect
U/s	(deg. mag.)
Mid	
D/s	

GROUND LAYER	*total is 100%*	Mineral	Litter	CWD	Moss Lichen	Veg <0.5m L & D
	Projective Cover %					

MINERAL SUBSTRATE	*total is 100%*	clay/silt	sand	gravel	pebble	cobble	boulder	bedrock	*GUIDE below*
	Cover %	<0.25mm	<2mm	<16mm	<64mm	<256mm	<2048mm		

TOP STRATUM	Height (m)	Canopy cover %	PFC%		PFC% & species	PFC% & species	PFC% & species	CONTRIBUTION to PFC
				→				*total <= top stratum PFC*

PLOT FLORA

4 X 4	# CODE	4 X 4	# CODE	4 X 4	# CODE	4 X 4	# CODE	4 X 4	# CODE

COMMENTS / NOTES relevant to veg condition:

Changes in PLOT size (if not 5 x 20 m)

PLOT position on transect: U/s = Upstream Mid = Middle (ie straddles transect) D/s = Downstream of transect

Condition notes *Fire *Macrophyte *Weediness *Disturbance *Stock *Grazing *Flood

CANOPY AND P.F.C. canopy cover = crown outline cover projective foliage cover = vertical projection of leaves and stems
CWD coarse woody debris all dead and down > 5 mm smallest diameter

SIZE GUIDE Wentworth scale (diameter) sand = 0.25 to 2 mm gravel = 2 to 16 mm pebbles = 16 to 64 mm cobble = 64 to 256 mm boulder = 256 to 2048 mm

Appendix 3. Site locations within the catchments

Site	River	Sub-Catchment	Catchment	Altitude m	Dist. from source km	Latitude °S	Longitude °E
A1	Witts Ck.	Back & Round Mountain Ck.	Shoalhaven	672	16.0	-35.61	149.62
A10	Sooly Ck.	Upper Wollondilly R.	Wollondilly	663	17.2	-34.68	149.69
A11	Coxs R.	Mid Coxs R.	Coxs	571	49.2	-33.62	150.16
A12	Kings Ck.	Boro Ck.	Shoalhaven	618	7.1	-35.18	149.72
A13	Brogers Creek	Kangaroo R.	Shoalhaven	86	193.3	-34.74	150.59
A14	Jerrabattagulla Ck.	Jerrabattagulla Ck.	Shoalhaven	691	30.6	-35.68	149.59
A15	Nadgigomar Ck.	Nerrimunga R.	Shoalhaven	555	17.2	-35.03	149.93
A16	Coxs R.	Upper Coxs R.	Coxs	878	17.8	-33.40	150.08
A2	Upper Shoalhaven R.	Back & Round Mountain Ck.	Shoalhaven	667	57.3	-35.57	149.63
A3	Reedy Ck.	Reedy Ck.	Shoalhaven	573	66.1	-35.31	149.76
A4	Upper Mongarlowe R.	Mongarlowe R.	Shoalhaven	627	30.5	-35.45	149.94
A5	Mulwarree R.	Mulwarree R.	Wollondilly	667	20.8	-35.02	149.65
A6	Upper Tarlo R.	Wollondilly R.	Wollondilly	707	33.5	-34.61	149.80
A7	Woolshed Ck.	Wollondilly R.	Wollondilly	789	12.4	-34.37	149.82
A8	Bungonia Ck.	Bungonia Ck.	Shoalhaven	565	23.6	-34.85	149.94
A9	Heffernans Ck.	Upper Wollondilly R.	Wollondilly	671	14.7	-34.66	149.49
R1	Nepean R.	Upper Nepean R.	Nepean	518	24.0	-34.46	150.53
R10	Heathcote Ck.	Woronora R.	Woronora	22	13.2	-34.06	151.00
R12	Nattai R.	Nattai R.	Wollondilly	124	49.9	-34.14	150.42
R13	Upper Mongarlowe R.	Mongarlowe R.	Shoalhaven	679	13.3	-35.57	149.92
R16	Little R.	Mid Coxs R.	Coxs	676	9.9	-33.77	150.12
R17	Wollondilly R.	Wollondilly R.	Wollondilly	222	166.1	-34.31	150.07
R18	Guineacor Ck.	Wollondilly R.	Wollondilly	471	30.4	-34.33	149.98
R21	Waratah Rivulet	Woronora R.	Woronora	214	5.7	-34.20	150.93
R22	Kowmung R.	Kowmung R.	Coxs	888	37.3	-33.96	149.98
R4	Endrick R.	Endrick R.	Shoalhaven	535	24.9	-35.09	150.12
R6	Reedy Ck.	Reedy Ck.	Shoalhaven	607	57.8	-35.28	149.70
R7	Mulloon Ck.	Reedy Ck.	Shoalhaven	756	24.8	-35.33	149.59
R8	Currumbene Ck.	Upper Shoalhaven Ck.	Shoalhaven	787	13.2	-35.90	149.59
U10	Wingecarribee R.	Wingecarribee R.	Wollondilly	639	37.1	-34.49	150.33
U11	Wollondilly R.	Wollondilly R.	Wollondilly	625	68.1	-34.74	149.75
U12	Mulwaree R.	Mulwaree R.	Wollondilly	626	30.3	-34.75	149.73
U2	Mittagong Ck.	Wingecarribee R.	Wollondilly	670	8.8	-34.48	150.42
U3	Katoomba Ck.	Lower Coxs R.	Coxs	934	1.9	-33.72	150.30
U4	Gibbergunyah Ck.	Nattai R.	Wollondilly	620	1.6	-34.45	150.42
U5	Nattai R.	Nattai R.	Wollondilly	632	3.5	-34.45	150.46
U6	Farmers Ck.	Upper Coxs R.	Coxs	890	14.3	-33.47	150.13
U7	Gillamatong Ck.	Braidwood Ck.	Shoalhaven	632	10.2	-35.44	149.78
U8	Paddys R.	Wollondilly R.	Wollondilly	632	14.8	-34.67	150.28
U9	Forbs Ck.	Woronora R.	Woronora	118	1.7	-34.05	151.01

Appendix 4. List of plant species recorded in plots

Class Lycopsida

"Club Mosses & Quill Worts"

Lycopsidaceae

Lycopodium deuterodensum

Selaginellaceae

Selaginella uliginosa

Class Filicopsida

"Ferns"

Adiantaceae

Adiantum aethiopicum

Aspleniaceae

Asplenium flabellifolium

Blechnaceae

Blechnum ambiguum
Blechnum camfeldii
Blechnum minus
Blechnum nudum
Doodia caudata var. *caudata*

Cyathaceae

Cyathea australis
Cyathea cooperi

Dennstaedtaceae

Pteridium esculentum

Dicksoniaceae

Dicksonia antarctica

Dryopteridaceae

Lastreopsis decomposita

Gleicheniaceae

Gleichenia dicarpa

Sinopteridaceae

Cheilanthes austrotenuifolia
Pellaea falcata var. *falcata*

Lindsaeaceae

Lindsaea linearis
Lindsaea microphylla

Class Coniferopsida

Conifers

Cupressaceae

Callitris rhomboidea

Class Angiospermae

"Flowering Plants"

Dicotyledons

Amaranthaceae

Alternanthera denticulata

Apiaceae

Actinotus minor
Centella asiatica
* *Ciclospermum leptophyllum*
* *Conium maculatum*
Daucus glochidiatus
* *Foeniculum vulgare*
Hydrocotyle geraniifolia
Hydrocotyle laxiflora
Hydrocotyle peduncularis
Hydrocotyle tripartita
Platysace lanceolata
Platysace linearifolia
Xanthosia pilosa
Xanthosia tridentata

Aquifoliaceae

* *Ilex aquifolium*

Araliaceae

Astrotricha latifolia
* *Hedera helix*
Polyscias sambucifolia

Asclepediaceae

* *Arauji sericiflora*
Marsdenia rostrata

Asteraceae

* *Achillea millefolium*
* *Ageratina adenophora*
* *Ageratina riparia*
* *Arctotheca calendula*
* *Aster subulatus*
* *Bidens pilosa*

** Bidens tripartita*
Cassinia aculeata
Cassinia longifolia
Cassinia quinquefaria
Centipeda cunninghamii
Centipeda minima
** Chondrilla juncea*
** Cirsium vulgare*
** Conyza albida*
** Conyza bonariensis*
** Conyza parva*
** Crepis capillaris*
** Erigeron karvinskianus*
Euchiton gymnocephalus
Euchiton involucratus
Euchiton sphaericus
** Gnaphalium americanum*
Helichrysum scorpioides spp. *complex*
** Hypochaeris radicata*
Lagenifera stipitata
** Leontodon taraxacoides*
** Leucanthemum vulgare*
Olearia stellulata
Olearia viscidula
** Onopordum acanthium* ssp. *acanthium*
Pseudognaphalium luteoalbum
Rhodanthe anthemoides
Senecio diaschides
Senecio hispidulus ssp. *dissectus*
Senecio hispidulus var. *hispidulus*
** Senecio madagascarensis*
Senecio quadridentatus
Senecio sp. aff. glomerata
Senecio sp. aff. minimus
Senecio sp. E.
Sigesbeckia australiensis
Sigesbeckia orientalis ssp. *orientalis*
** Silybum marianum*
Solenogyne dominii
Solenogyne gunnii
** Sonchus asper* ssp. *glaucescens*
** Sonchus oleraceus*
** Taraxacum officinale*
Vittadinia cuneata var. *cuneata forma minor*
** Xanthium spinosum*

Baueraceae

Bauera rubioides

Bignoniaceae

Pandorea pandorana

Boraginaceae

Austrocynoglossum latifolium
Cynoglossum suaveolens
** Echium plantagineum*
** Echium vulgare*
** Myosotis caespitosa*
** Myosotis sylvatica*

Brassicaceae

** Cardamine hirsuta*
Cardamine paucijuga
** Hirschfeldia incana*
** Rorippa nasturtium-aquaticum*
** Rorippa palustris*

Callitrichaceae

** Callitriche stagnalis*

Campanulaceae

Wahlenbergia graniticola
Wahlenbergia multicaulis

Caprifoliaceae

** Lonicera japonica*

Caryophyllaceae

** Cerastium glomeratum*
** Paronychia brasiliana*
** Petrorhagia nanteuillii*
** Polycarpon tetraphyllum*
** Saponaria officinalis*
Silene gracilis
Stellaria flaccida
** Stellaria media*
Stellaria pungens

Casuarinaceae

Allocasuarina distyla
Allocasuarina littoralis
Casuarina cunninghamiana

Chenopodiaceae

Atriplex semibaccata
** Chenopodium ambrosioides*
** Chenopodium detestans*
Chenopodium pumilio
Einadia nutans ssp. *nutans*

Clusiaceae

** Hypericum androsaemum*
Hypericum gramineum
Hypericum japonicum
** Hypericum perforatum*

Convolvulaceae

Calystegia marginata
Dichondra repens

Crassulaceae

Crassula helmsii
Crassula sieberiana

Cucurbitaceae

** Citrillus lanatus* var. *lanatus*

Cunoniaceae

Aphanopetalum resinosum
Callicoma apetalum
Ceratopetalum gummiferum

Dilleniaceae

Hibbertia acicularis
Hibbertia bracteata

Droseraceae

Drosera auriculata
Drosera spatulata

Elatinaceae

Elatine gratioloides

Epacridaceae

Epacris breviflora
Epacris impressa
Epacris microphylla var. *microphylla*
Epacris obtusifolia
Epacris paludosa
Epacris pulchella
Leucopogon ericoides
Leucopogon juniperinus
Leucopogon lanceolatus
Styphelia triflora

Euphorbiaceae

Bertya rosmarinifolia
* *Euphorbia lathyrus*
* *Euphorbia peplus*
Omalanthus populifolius
Phyllanthus gunnii
Phyllanthus similis
Poranthera microphylla

Fabaceae – Caesalpinioideae

* *Senna pendula*

Fabaceae – Faboidoideae

Bossiaea oligosperma
* *Cytisus scoparius* ssp. *scoparius*
Daviesia corymbosa
Daviesia mimosoides
Dillwynia floribunda var. *floribunda*
* *Genista monspessulana*
Glycine clandestina
Glycine tabacina
Gompholobium minus
Indigofera australis
* *Lotus suaveolens*
* *Lotus uliginosus*
* *Medicago arabica*
* *Medicago laciniata*
* *Medicago lupulina*
* *Medicago polymorpha*
Phyllota phylicoides
Pultenaea daphnoides
Pultenaea glabra
Pultenaea stipularis
* *Trifolium repens*
* *Trifolium striatum*
* *Trifolium subterraneum*
* *Ulex europaeus*
* *Vicia sativa* ssp. *angustifolia*
* *Vicia villosa* ssp. *villosa*
Viminaria juncea

Fabaceae – Mimosoideae

Acacia binervata
Acacia dealbata
Acacia elongata var. *elongata*
Acacia falcata
Acacia floribunda
Acacia linifolia
Acacia longifolia
Acacia mearnsii
Acacia melanoxylon
Acacia obtusifolia
Acacia parramattensis
Acacia rubida
Acacia trachyphloia

Fumariaceae

* *Fumaria muralis* ssp. *muralis*

Gentianaceae

* *Centaurium erythraea*
* *Erodium cicutarium*

Geraniaceae

Geranium retrorsum
Geranium solanderi var. *solanderi*

Goodeniaceae

Dampiera stricta
Goodenia ovata
Goodenia paniculata
Gonocarpus humilis
Gonocarpus micranthus
Gonocarpus tetragynus
Gonocarpus teucrioides

Haloragaceae

Haloragis heterophylla
Myriophyllum variifolium
Myriophyllum verrucosum

Lamiaceae

* *Mentha X piperita*
Prostanthera lasianthos
Prostanthera linearis
Prostanthera rotundifolia
* *Prunella vulgaris*

Lauraceae

Cassytha glabella

Lentibulariaceae

Utricularia uliginosa

Lobeliaceae

Lobelia alata
Pratia purpurascens

Luzuriagaceae

Eustrephus latifolius
Geitonoplesium cymosum

Lythraceae

Lythrum hyssopifolia
Lythrum salicaria

Malvaceae

* *Malva parviflora*
* *Modiola caroliniana*
* *Sida rhombifolia*

Menispermaceae

Stephania japonica var. *discolor*

Monimiaceae

Hedycarya angustifolia

Moraceae

Ficus coronata

Myrsinaceae

Rapanea howittiana

Myrtaceae

Acmena smithii
Angophora costata
Backhousia myrtifolia
Baeckea imbricata
Baeckea linifolia
Callistemon citrinus
Callistemon pallidus
Callistemon sieberi
Calytrix tetragona
Corymbia gummifera
Darwinia fascicularis ssp. *fascicularis*
Eucalyptus bridgesiana
Eucalyptus cinerea
Eucalyptus elata
Eucalyptus fastigata
Eucalyptus ovata
Eucalyptus pauciflora ssp. *pauciflora*
Eucalyptus radiata ssp. *radiata*
Eucalyptus radiata ssp. *robertsonii*
Eucalyptus sieberi
Eucalyptus viminalis
Kunzea ericoides
Leptospermum brevipes
Leptospermum continentale
Leptospermum emarginatum
Leptospermum lanigerum
Leptospermum morrisonii
Leptospermum myrtifolium
Leptospermum obovatum
Leptospermum polygalifolium
Leptospermum polygalifolium var. *polygalifolium*
Leptospermum squarrosum
Melaleuca capitata
Melaleuca linariifolia
Melaleuca parvistaminea
Tristaniopsis laurina

Oleaceae

* *Ligustrum lucidum*
* *Ligustrum sinense*
Notelaea neglecta

Onagraceae

Epilobium billardierianum ssp. *cinereum*
Epilobium billardierianum ssp. *hydrophilum*
* *Epilobium ciliatum*
Epilobium gunnianum
Ludwigia peploides ssp. *montevidensis*
* *Ludwigia peruviana*

Oxalidaceae

Oxalis perennans
* *Oxalis pes-caprae*

Passifloraceae

* *Argemone ochroleuca* ssp. *ochroleuca*
Passiflora herbertiana ssp. *herbertiana*

Phytolaccaceae

* *Phytolacca octandra*

Pittosporaceae

Billardiera scandens var. *scandens*
Bursaria spinosa ssp. *lasiophylla*
Bursaria spinosa ssp. *spinosa*
Pittosporum revolutum
Pittosporum undulatum

Plantaginaceae

* *Plantago coronopus* ssp. *coronopus*
Plantago debilis
* *Plantago lanceolata*
* *Plantago major*

Platanaceae

* *Platanus x acerifolia*

Polygonaceae

* *Acetosella vulgaris*
Persicaria praetermissa
Persicaria decipiens
Persicaria hydropiper
Persicaria lapathifolia

Persicaria prostata
Persicaria strigosa
* *Polygonum aviculare*
Rumex brownii
* *Rumex conglomeratus*
* *Rumex crispus*
* *Rumex obtusifolius* ssp. *obtusifolius*

Primulaceae

* *Anagallis arvensis*
Samolus valerandi

Proteaceae

Banksia ericifolia
Banksia integrifolia
Grevillea arenaria ssp. *arenaria*
Grevillea juniperina
Gervillea juniperina ssp. *amphitricha*
Grevillea linearifolia
Grevillea mucronulata
Grevillea rosmarinifolia
Hakea dactyloides
Hakea eriantha
Hakea microcarpa
Hakea salicifolia
Hakea sericea
Hakea teretifolia
Lomatia myricoides
Persoonia linearis
Persoonia mollis ssp. *ledifolia*
Persoonia pinifolia
Petrophile pedunculata
Telopea mongaensis
Xylomelum pyriforme

Ranunculaceae

Ranunculus inundatus
Ranunculus plebeius
Ranunculus repens
Ranunculus rivularis

Rhamnaceae

Pomaderris aspera
Pomaderris eriocephala
Pomaderris phylicifolia ssp. *ericoides*
Pomaderris phylicifolia ssp. *phylicifolia*
Pomaderris prunifolia

Rosaceae

Acaena echinata
Acaena novae-zelandiae
* *Cotoneaster franchetii*
* *Crataegus monogyna*
* *Duchesnea indica*
* *Geum urbanum*
* *Malus x domestica*
* *Prunus domestica*
* *Rosa rubiginosa*
* *Rubus discolor*
* *Rubus fructicosus* ssp. *agg*
Rubus parvifolius
* *Sanguisorba minor* ssp. *muricata*

Rubiaceae

Asperula conferta
Coprosma quadrifida
* *Galium aparine*
Galium migrans
Galium propinquum
Morinda jasminoides
Opercularia aspera
Opercularia hispida

Rutaceae

Phebalium dentatum
Philotheca scabra var. *scabra*

Salicaceae

* *Populus nigra* cv. *'Italica"*
* *Salix alba* var. *vitellina*
* *Salix babylonica*
* *Salix nigra*

Sambucaceae

Sambucus gaudichaudiana

Sapindaceae

Dodonaea triquetra

Scrophulariaceae

Glossostigma elatinoides
Gratiola peruviana
Lilaeopsis polyantha
Limosella australis
Neopaxia australasica
* *Verbascum thapsus*
* *Verbascum virgatum*
* *Veronica anagallis-arvensis*
Veronica calycina
* *Veronica persica*
Veronica plebeia

Solanaceae

Duboisia myoporoides
* *Solanum chenopodioides*
* *Solanum nigrum*
* *Solanum pseudocapsicum*

Sterculiaceae

Brachychiton populneus
Lasiopetalum ferrugineum var. *ferrugineum*

Stylidiaceae

Stylidium graminifolium

Tropaeolaceae

* *Tropaeolum majus*

Ulmaceae

** Trema aspera*

Urticaceae

Australina pusilla
Urtica incisa
** Urtica urens*

Verbenaceae

** Verbena bonariensis*

Violaceae

Hymenanthera dentata
Viola betoncifolia
** Viola caleyana*
Viola hederacea
** Viola odorata*

Vitaceae

Cayratia clematidea
Cissus hypoglauca

Monocots

Anthericaceae

Arthropodium milleflorum

Araceae

Alocasia brisbanensis
** Arum italicum*
** Zantesdechia aethiopica*

Asparagaceae

** Protosparagus aethiopicus*

Asphodelaceae

Bulbine glauca

Blandfordiaceae

Blandfordia nobilis

Centrolepidaceae

Centrolepis strigosa var. *strigosa*

Commelinaceae

Commelina cyanea
** Tradescantia albiflora*

Cyperaceae

Baumea teretifolia
Bolboschoneus fluviatilis
Carex appressa
Carex bichenoviana
Carex breviculmis
Carex gaudichaudiana
Carex inyx
Caustis flexuosa
Chorizandra cymbaria
** Cyperus brevifolius*
** Cyperus congestus*
** Cyperus eragrostis*
Cyperus lucidus
Cyperus sanguinolentus
Cyperus sphaeroideus
Eleocharis acuta
Eleocharis gracilis
Eleocharis pusilla
Eleocharis sphacelata
Gahnia radula
Gahnia sieberana
Isolepis cernua
Isolepis fluitans
Isolepis gaudichaudiana
Isolepis inundata
Isolepis platycarpa
** Isolepis prolifer*
Lepidosperma filiforme
Lepidosperma gunnii
Lepidosperma laterale
Schoenoplectus validus
Schoenus apogon
Schoenus maschalinus
Schoenus melanostachys
Schoenus paludosus
** Scirpus polystachus*

Doryanthaceae

Doryanthes excelsa

Iridaceae

Libertia paniculate
** Watsonia meriana* cv. *Bulbillifera*

Juncaceae

Juncus articulatus
** Juncus bufonius*
Juncus flavidus
Juncus gregiflorus
Juncus laeviusculus ssp. *laeviusculus*
Juncus prismatocarpus
Juncus sarophorus
Juncus usitatus

Juncaginaceae

Triglochin procerum

Lomandraceae

Lomandra filiformis ssp. *coriacea*
Lomandra fluviatilis
Lomandra longifolia

Phormiaceae

Dianella caerulea
Dianella revoluta

Poaceae

Agrostis avenacea var. *avenacea*
* *Agrostis capillaris*
* *Agrostis stolonifera*
* *Agrostis viridis*
* *Aira elegantissima*
* *Andropogon virginicus*
* *Anthoxanthum odoratum*
* *Arrhenatherum elatius* var. *bulbosum*
Austrodanthonia penicillata
Austrodanthonia racemosa var. *racemosa*
Austrodanthonia tenuior
Austrofestuca eriopoda
Austrostipa ramosissima
Austrostipa rudis ssp. *nervosa*
Austrostipa scabra var. *falcata*
* *Axonopus affinis*
Bothriochloa macra
* *Briza maxima*
* *Bromus catharticus*
* *Bromus mollis*
Cynodon dactylon
* *Dactylis glomerata*
Deyeuxia parviseta var. *boormanii*
Deyeuxia quadriseta
Dichelachne crinita
Diechelachne inaequiglumis
Dichelachne rara
Dichelachne sp. aff. *rara*
* *Digitaria sanguinalis*
* *Echinochloa crus-galli*
Echinopogon ovatus
* *Ehrharta erecta*
* *Eleusine tristachya*
Elymus scaber
Entolasia marginata
Entolasia stricta
Eragrostis brownii
* *Eragrostis curvula*
* *Eragrostis tenuifolia*
* *Festuca elatior*
Glyceria australis
Hemarthria uncinata var. *uncinata*
* *Holcus lanatus*
Isachne globosa
* *Lolium perenne*
* *Lolium temulentum*
Microlaena stipoides
* *Nassella neesiana*
* *Nassella trichotoma*
Oplismenus aemulus
Oplismenus imbecillis
Panicum effusum
Panicum maximum var. *maximum*
* *Paspalum dilatatum*
Paspalum distichum
* *Paspalum urveillei*
Paspalidium criniforme
* *Pennisetum clandestinum*
* *Phalaris aquatica*
Phragmites australis
* *Poa annua*
Poa labillardieri
* *Poa pratensis*
Poa tenella
Pseudoraphis paradoxa
Sacciolepis indica
* *Setaria gracilis*
* *Setaria pumila*
* *Setaria viridis*
* *Stenopetalum secundatum*
Themeda australis

Restionaceae

Empodisma minus
Guringalia dimorpha
Leptocarpus tenax
Lepyrodia scariosa
Restio complanatus
Saropsis fastigata
Sporadanthus gracilis

Smilaceae

Smilax glyciphylla

Typhaceae

Typha domingensis
Typha orientalis

Uvulariaceae

Schelhammera undulata

Xanthorrhoeaceae

Xanthorrhoea resinifera

Xyridaceae

Xyris gracilis var. *gacilis*

Appendix 5. Vegetation structure description and location of plots

Plot code indicates transect number and plot number. Species1, PFC1 etc. refer to the top three contributors to the projective foliage cover (PFC) of the canopy. Species codes refer to initial four letters of the species scientific name as in the project database.

Site/Plot Code	Origin of Dominants	Structure	Canopy Height (m)	Canopy Outline Cover %	Species1	PFC1	Species2	PFC2	Species3	PFC3	Easting	Northing
A10-t2p1	E	forest	12	70	SALI SP	100	.	.	.	.	746501	6158324
A11-t1p1	E	forest	9	70	SALI SP	100	.	.	.	.	236449	6276322
A11-t1p2	A	forest	10	85	CASU CUNN	100	.	.	.	.	236407	6276318
A12-t1p1	A	sedgeland	1.5	5	TYPH ORIE	50	JUNC ARTI	40	JUNC SARO	10	747869	6103203
A13-t1p1	A	forest	30	100	CASU CUNN	100	.	.	.	.	273019	6184420
A14-t1p1	E	shrubland	1.5	2	SALI NIGR	100	.	.	.	.	734558	6048074
A15-t1p1	A	shrubland	6	10	ACAC MEAR	100	.	.	.	.	767043	6119836
A15-t1p2	A	shrubland	5	50	ACAC MEAR	100	.	.	.	.	767050	6119847
A16-t1p1	A	sedgeland	1	50	TYPH ORIE	40	DACT GLOM	30	PHAL AQUA	20	228360	6300651
A1-t1p1	E	forest	15	100	SALI ALBV	100	.	.	.	.	737026	6056059
A1-t1p2	E	forest	9	1	SALI ALBV	100	.	.	.	.	737007	6056073
A2-t1p1	A	grassland	0.5	50	ERAG CURV	30	CYPE ERAG	30	CYPE LUCI	20	738430	6059811
A2-t1p2	E	shrubland	4	1	POPU NIGR	30	.	.	.	.	738407	6059813
A2-t1p3	E	forest	12	50	SALI ALBV	100	.	.	.	.	738443	6059803
A3-t1p1	E	forest	8	50	SALI ALBV	80	ACAC MEAR	20	.	.	750815	6088960
A3-t1p2	A	shrubland	3	5	MELA PARV	90	LEPT OBOV	10	.	.	750818	6088964
A3-t1p3	E	forest	16	50	SALI ALBV	100	.	.	.	.	750810	6088980
A4-t1p1	A	shrubland	1.5	1	LEPT LANI	100	.	.	.	.	766500	6073343
A4-t1p2	A	shrubland	5	20	ACAC TRAC	100	.	.	.	.	766489	6073344
A4-t2p1	A	forest	10	50	ACAC TRAC	80	EUCA VIMI	20	.	.	766489	6073343
A5-t1p1	A	sedgeland	1	35	JUNC GREG	50	CARE APPR	30	PHAL AQUA	20	741967	6121602
A6-t1p1	E	forest	10	5	SALI SP	100	.	.	.	.	756773	6166950
A6-t1p2	E	forest	11	4	SALI SP	100	.	.	.	.	756781	6166967
A7-t1p1	A	sedgeland	0.6	80	ELEO ACUT	40	CYPE SPHA	30	RORI NAST	30	759419	6192330
A7-t1p2	E	grassland	0.05	98	BROM MOLL	35	TRIF SUBT	25	ADAN RACR	10	759409	6192338
A8-t2p1	A	shrubland	8	25	ACAC PARR	70	EUCA VIMI	30	.	.	768969	6138954
A8-t2p2	E	forest	10	25	SALI ALBV	100	.	.	.	.	768966	6138961
A9-t1p1	E	forest	12	5	POPU NIGR	100	.	.	.	.	727819	6162034
R10-t1p1	A	forest	10	95	TRIS LAUR	70	CERA APET	30	.	.	314917	6228751
R10-t2p1	A	shrubland	3	10	LEPT MORR	60	ALLO LITT	20	ACAC OBTU	20	314960	6228760
R10-t2p2	A	forest	8	30	ANGO COST	30	CORY GUMM	25	ALLO LITT	25	314962	6228759
R12-t1p1	A	forest	20	90	CASU CUNN	100	.	.	.	.	250091	6265005
R12-t1p2	A	forest	25	60	CASU CUNN	100	.	.	.	.	262858	6218439
R13-t1p1	A	forest	22	15	EUCA RADR	100	.	.	.	.	764531	6060125
R13-t2p1	A	shrubland	4	5	ACAC TRAC	100	.	.	.	.	764517	6060135
R16-t1p1	A	forest	9	5	CASU CUNN	100	.	.	.	.	235214	6258828
R17-t1p2	E	herbland	0.3	20	VERO ANAG	40	RORI PALU	40	PERS DECI	10	230024	6200009
R17-t1p3	A	forest	12	90	CASU CUNN	100	.	.	.	.	230020	6200012
R18-t2p1	A	forest	18	80	CASU CUNN	100	.	.	.	.	773860	6196577
R18-t2p2	A	shrubland	4	5	BURS SPIS	60	GREV AREA	20	ACAC MEAR	20	773865	6196585

Appendix 5. continued

Site & Plot Code	Origin of Dominants	Structure	Canopy Height (m)	Canopy Outline Cover %	Species 1	PFC1	Species 2	PFC2	Species 3	PFC3	Easting	Northing
R1-t1p1	A	shrubland	4	10	ACAC FLOR	100	.	.	.	.	273105	6184337
R1-t1p2	A	forest	10	40	ACAC FLOR	100	.	.	.	.	273314	6184033
R1-t2p1	A	shrubland	8	60	ACAC FLOR	60	ACAC BINE	30	ACAC MEAR	10	273019	6184420
R21-t1p1	A	shrubland	4	8	ALLO DIST	50	ACAC OBTU	40	EUCA SIEB	10	309548	6213945
R21-t2p1	A	heath	1	10	DARW FASF	40	EPAC MICR	40	LEPT SQUA	10	309557	6213958
R22-t2p1	A	shrubland	3	30	ACAC DEAL	-9	HYME DENT	-9	LOMA MYRI	-9	775002	6238557
R22-t2p2	A	forest	8	25	ACAC DEAL	70	EUCA VIMI	30	.	.	775011	6238580
R4-t1p1	A	forest	11	15	EUCA VIMI	100	.	.	.	.	237337	6113020
R4-t2p1	A	shrubland	4	5	ACAC MEAR	65	ACAC RUBI	35	.	.	237309	6112987
R4-t2p2	A	shrubland	4	10	LOMA MYRI	65	LEPT BREV	35	.	.	237301	6112983
R4-t2p3	A	forest	13	25	ACAC MEAR	100	.	.	.	.	237278	6112979
R4-t3p1	A	shrubland	4.5	70	LOMA MYRI	90	MELA PARV	10	.	.	237274	6113032
R6-t1p1	A	shrubland	4	12	ACAC MEAR	95	SALI ALIX	5	.	.	745818	6093173
R6-t2p1	A	shrubland	6	50	ACAC MEAR	95	SALI ALBV	5	.	.	745825	6093167
R7-t1p1	E	forest	12	90	SALI SP	100	.	.	.	.	734917	6086573
R8-t1p1	A	forest	9	25	EUCA VIMI	80	EUCA PAUP	10	ACAC DEAL	10	733996	6023429
R8-t2p1	A	forest	10	8	EUCA PAUP	75	ACAC DEAL	25	.	.	735980	6023445
U10-t1p1	E	herbland	2	50	PERS LAPA	-9	SALI NIGR	-9	.	.	254883	6179951
U11-t1p1	E	forest	10	25	SALI BABY	95	LIGU SINE	5	.	.	751542	6152844
U12-t1p1	E	shrubland	5	3	CRAT MONO	50	MALU DOME	50	.	.	750162	6150823
U12-t1p2	A	sedgeland	0.5	5	PERS PROS	60	CYPE ERAG	20	RUME CRIS	20	750152	6150824
U2-t1p1	E	forest	12	50	SALI ALBV	100	.	.	.	.	262561	6181867
U2-t2p1	E	shrubland	1.5	10	LIGU LUCI	50	LIGU SINE	30	VERB BONA	20	262566	6181867
U3-t1p1	A	forest	18	40	EUCA LYPT	100	.	.	.	.	250091	6265005
U4-t1p1	A	forest	20	35	EUCA OVAT	100	.	.	.	.	263185	6184881
U4-t2p1	A	forest	10	75	ACAC MEAR	70	ALLO LITT	30	.	.	263176	6184878
U5-t1p1	A	forest	20	50	EUCA OVAT	40	EUCA ELAT	60	.	.	266093	6184710
U6-t1p1	E	herbland	2	20	CONI MACU	50	RUME CRIS	40	SALI ALIX	10	232814	6292686
U7-t1p1	E	forest	15	100	SALI NIGR	90	SALI BABY	10	.	.	752165	6074257
U7-t1p2	E	shrubland	1.5	5	CYTI SCOS	70	SALI ALIX	20	CRAT MONO	10	752174	6074277
U8-t1p1	A	forest	25	80	EUCA RADR	100	.	.	.	.	250354	6160667
U9-t1p1	A	forest	8	15	PITT UNDU	90	ALLO LITT	10	.	.	316332	6229991

Appendix 6. Summary of site richness variables

Macrophyte totals are included in columns headed 'Herb'. Structural type in each plot is summarised as N or E for native vs. alien dominants, and f = forest, s = shrubland, g = grassland, e = sedgeland, h = herbland.

	Native lifeforms				Alien lifeforms							
Site	Herb	Woody	Climber	Fern	Herb	Woody	Fern	All Macrophyte	Overall richness	Plot mean richness	% Australian species	Plot structural types
A1	14	1	0	0	25	4	2	6	46	29	0.33	Ef Ef
A10	8	0	0	0	8	4	0	2	21	21	0.40	Ef
A11	10	2	0	1	28	2	1	4	45	30	0.30	Ef Nf
A12	18	1	0	0	16	0	0	7	36	36	0.54	Ne
A13	8	5	3	2	11	2	0	2	32	32	0.58	Nf
A14	19	2	0	0	20	2	0	5	44	44	0.49	Es
A15	35	10	1	1	10	3	0	8	60	39	0.78	Ns Ns
A16	14	0	0	0	16	2	1	5	35	35	0.42	Ne
A2	34	1	0	1	37	4	2	14	79	37	0.46	Ef Es Ng
A3	26	5	0	0	31	4	0	8	66	32	0.47	Ef Ef
A4	40	13	1	3	9	1	0	10	67	37	0.85	Nf Ns Ns
A5	11	0	0	0	16	0	0	7	27	27	0.41	Ne
A6	20	0	0	0	22	1	2	11	45	29	0.44	Ef Ef
A7	27	0	0	0	26	1	0	10	57	34	0.50	Eg Ne
A8	20	5	0	0	11	5	0	6	42	25	0.61	Ef Ns
A9	7	0	0	0	12	1	0	2	21	21	0.35	Ef
Mean A	**19.4**	**2.8**	**0.3**	**0.5**	**18.6**	**2.3**	**0.5**	**6.7**	**45.2**	**31.8**	**0.5**	
R1	39	14	2	6	19	2	1	5	84	42	0.73	Nf Ns Ns
R10	18	29	1	2	10	2	0	2	62	26	0.81	Nf Ns Nf
R12	27	19	11	2	7	0	0	3	68	48	0.89	Nf Nf
R13	32	16	0	3	7	1	0	3	60	39	0.86	Nf Ns
R16	14	5	4	6	10	0	1	2	41	41	0.73	Nf
R17	27	10	5	0	25	2	1	7	73	46	0.60	Eh Nf
R18	41	13	2	4	15	5	0	1	81	52	0.75	Nf Ns
R21	26	37	1	2	1	0	0	0	67	47	0.99	Nh Ns
R22	29	14	1	3	19	1	1	4	69	51	0.69	Nf Ns
R4	39	23	1	4	22	2	0	2	94	36	0.74	Nf Nf Ns
R6	32	3	0	1	18	4	0	10	59	38	0.62	Ns Ns
R7	28	9	1	3	10	3	1	4	56	56	0.75	Ef
R8	32	9	1	4	17	1	1	2	65	46	0.71	Nf Nf
Mean R	**29.5**	**15.5**	**2.3**	**3.1**	**13.8**	**1.8**	**0.5**	**3.5**	**67.6**	**43.7**	**0.8**	
U10	18	0	0	0	33	4	3	9	61	61	0.31	Eh
U11	2	0	0	0	5	3	1	1	11	11	0.18	Ef
U12	10	1	0	1	20	2	2	5	36	21	0.33	Es Ne
U2	9	0	0	0	25	6	4	4	44	27	0.20	Ef Es
U3	12	5	0	4	11	2	0	1	37	37	0.62	Nf
U4	25	13	2	2	28	5	3	3	78	48	0.54	Nf Nf
U5	20	7	1	3	10	2	1	3	44	44	0.70	Nf
U6	5	0	0	0	18	2	1	3	28	28	0.19	Eh
U7	10	0	0	0	15	5	1	3	31	18	0.32	Ef Es
U8	29	5	1	3	6	2	0	10	48	48	0.83	Nf
U9	10	9	1	3	19	6	2	2	51	51	0.46	Nf
Mean U	**13.6**	**3.6**	**0.5**	**1.5**	**17.3**	**3.5**	**1.6**	**4.0**	**42.6**	**35.8**	**0.4**	