Aquatic Macrophytes of the Macquarie and South Esk Rivers, Tasmania

by

Kate Chappell, BSc.

Statement

This thesis contains no material that has been accepted for the award of any other degree or diploma in any university, and to the best of the author's knowledge and belief the thesis contains no copy or paraphrase of material previously published or written by other persons except when due reference is made in the text of the thesis.

Abstract

Aquatic macrophytes are the flowering plants and larger algae growing submerged in or emerging from water. Macrophytes are an essential component of riverine ecosystems: they produce oxygen, filter out sediments and pollutants and provide habitat and food sources for invertebrates, fish and mammals. The Macquarie and South Esk Rivers in Tasmania are the largest rivers of the northern central plain, and are unique in Tasmania in having long stretches of relatively stable and abundant macrophytic vegetation along their mid- to lower reaches.

The macrophyte communities of the mid- to lower reaches of the two rivers are described by classification into groups with similar species composition. Significant environmental variation between groups is determined. Depth, substrate type and distance upstream are the environmental factors most strongly associated with variation between the distribution of individual species/species assemblages. Distance upstream, percentage shading, river form, stream width, substrate type and bank height are the factors most strongly associated with variation between groups of sites.

Bank vegetation type, distance upstream, percentage shading, level of stock damage and stream width are found to be the environmental factors most strongly associated with differences in richness and diversity. Percentage shading and bank vegetation type are the factors most strongly associated with differences in cover. The two rivers are found to differ significantly in percentage cover and total species richness. The associated environmental factors that vary significantly between the rivers are percentage shading, bank height, bank vegetation type, level of stock damage and stream width.

The species rich and abundant macrophyte communities in the mid-reaches of the Macquarie River and in some parts of the South Esk are found to have high conservation value. A vulnerable marginal species, *Persicaria decipiens*, is also of high conservation value. Willow infestation and changes to flow regimes or water quality are seen as being the greatest threats to these communities. The importance of management of stock access to river edges and the potential value of buffer zones are discussed.

Acknowledgements

CONTENTS

Chapter 3

Characteristics and environmental relationships of the vegetation   34

Chapter 6

Overall Discussion and Conclusion   152

References   161

Tables

Figures

Plates

Chapter 1

Introduction

1.1 Introduction

The maintenance or restoration of the health of river systems is an issue of world-wide relevance and concern. Healthy rivers have been defined as those in which there remains a high proportion of the natural biological diversity, and in which the essential ecological processes have been maintained (see Bunn *et al.* 1999). Healthy rivers provide clean water for the use of humans and domestic animals, water for agriculture and industry, habitat for mammals, fish, insects, invertebrates and aquatic plants, and filter excess nutrients, sediments and heavy metals before these are released into the sea.

Many river systems around the world have been damaged by human activities. Land clearing, damming and other forms of flow regulation, straightening and hardening of river courses, aquatic plant removal, pollution from various sources and the introduction of exotic plants and animals have all had an impact on the overall health of river ecosystems.

In Australia, relatively few rivers remain in an unimpacted or pristine state. Schofield and Davies (1996:39) wrote that "most rivers are affected by a number of instream, riparian or catchment modifications or practices. This often results in them being less biologically functional and of lower ecological value than their original states". Recent recognition of the unsustainable nature of present river uses, and a deeper understanding of the values and benefits provided by healthy river systems, has led to an increasing interest in improving the health of river systems and managing human uses of rivers sustainably. Since river systems are connected longitudinally from the headwaters to the oceans, the most effective management is carried out at the catchment scale.

Once considered as nothing more than weeds that caused management problems such as flow retardation and obstruction of access for fishing, aquatic macrophytes (the larger, visible aquatic

plants) are now recognised as an integral part of the ecology of rivers. Davies and Humphries (1996:45) wrote that

> "*Macrophytes are plants that have an obligatory association with surface water. They form an essential element of river habitat structure (providing complex surfaces and shelter to algae and macroinvertebrates). They can be a dominant source of river ecosystem productivity and can act as major sinks or sources of nutrients, organic material and sediments, especially in lowland pool-dominated rivers*"

Some of the indispensable benefits of macrophytic vegetation in rivers are: photosynthetic production of oxygen; substratum for algae; habitat for invertebrates and fish eggs; nutrient cycling to and from sediments; and stabilisation of river beds and banks (Fox 1996). Macrophyte communities are functionally important for river systems as they provide critical refuge habitats for fauna. Massive production of invertebrates occurs in macrophyte beds. As a result, any environmental impact that adversely affects the aquatic macrophyte communities inevitably has an adverse effect on the whole river ecosystem. An understanding of the ecology of the aquatic vegetation is an essential component in sustainable catchment management. It is therefore important to describe the aquatic plant communities of rivers and their environmental relationships. The present study describes the macrophytic aquatic vegetation and its environmental relationships in two rivers in Tasmania, Australia. These two rivers are otherwise well known biologically, hydrologically and physico-chemically.

This chapter provides background information on aquatic macrophytes, describes the riverine aquatic macrophyte communities in Tasmania, then outlines the aims of this study and the structure of the thesis.

1.2 Definitions of aquatic plants and macrophytes

Cook (1974) defined 'aquatic plants' as those whose photosynthetically active parts are permanently or, at least, for several months each year submerged in, or floating on, fresh water.

This definition differentiates between truly aquatic species and those marginal species that only tolerate occasional inundation during flood events.

'Macrophytes' are macroscopic aquatic plants, a category that includes the flowering plants, bryophytes and larger algae (Butcher 1933, Fox 1996). With the exception of charophytes, this study focuses only on the flowering plants and does not include bryophytes and algae.

1.3 Macrophyte ecology

1.3.1 Relationships between aquatic macrophytes and the physical and hydrological characteristics of the river

Aquatic plant species differ in their adaptations to the lotic environment. For example, some species have well-developed root systems which wind around stones in rocky substrates, protecting the plant from being washed away by the force of the water. Others may not have a strong root-system, but reproduce rapidly from vegetative fragments after a flood disturbance. Some have developed thin, strap-like leaves which reduce their resistance to the water flow. These different adaptations mean that different species are suited to different flow velocities, substrate types, nutrient levels and other environmental variables within a river system. Dramatic changes in plant species/community composition can occur over a very short distance along a river, reflecting variability in the geomorphological, geological and hydrological factors.

It has been noted that lotic communities usually do not exist in a climax state, and that competition between species for available resources is rarely a determining factor in the distribution of or abundance of individual plant species (e.g. Riis *et al.* 2000). Rather, the composition of aquatic plant communities reflects the flow velocity, substrate type and frequency of disturbances such as floods. "Plants in natural streams are in dynamic equilibrium with the usual flow of the stream, both storm flows and normal flows, and the plants usually recover quickly from the peak and drought flows which may happen in the river" (Haslam 1978: 69).

Two of the most important factors governing the distribution of macrophytes in rivers are the variations in the velocity of the river current, and the frequency and severity of flood disturbances. As well as having a direct effect on the macrophytes themselves, these factors determine the nature of the river bed, which is both the rooting substratum of the macrophytes and the source of a large part of their nutrients (Butcher 1933, Haslam 1978). Current velocity varies continuously along the length of a river. The slope of the land and underlying geology create river forms known as runs, riffles and pools. The definitions of riffle, run and pool here are based on depth, visible current velocity and degree of surface disturbance, after Davies and Humphries (1996:24):

> *A riffle is a shallow section of river, exhibiting fast current and broken water; a run is a relatively shallow and narrow section of river, exhibiting moderate to slow current with smooth surface current velocity; a pool is a relatively deep and wide section of river, with slow or no detectable current and smooth surface current velocity.*

The current velocity is determined by the river profile and the volume of water flow. For a given rate of flow, wide and deep sites will have a lower velocity than narrow and shallow sites. As a result, pools have the slowest current velocity, often negligible, resulting in habitat more like that of a lake (Butcher, 1933). Runs, which are narrower than pools but may be deep, mostly have a slow to moderate velocity. Riffles, both shallow and narrow, generally have a fast current velocity.

The current velocity is the main determinant of the substrate type. Fast moving water scours fine particles from the riverbed, then carries them in suspension to slower moving or still stretches of the river, where they are deposited. As a result, riffles have mainly a rock or stone substrate, whereas runs can have a gravel, sand or mud substrate and pools generally have a mud substrate. Current velocity also has a direct effect on macrophyte growth, with species with a thick, leafy growth habit or shallow root system being unable to tolerate the drag effects of fast flowing water. Macrophyte growth also has an effect on both sediment deposition and current velocity. Dense macrophyte patches trap fine particles, causing an increase in fine

substrata (Butcher 1933, Haslam 1978, Sand-Jensen 1998), and also cause resistance to flow, resulting in deeper, slower moving water (Butcher 1933, Haslam 1978, Sand-Jensen *et al* 1989).

In a study of the macrophytic vegetation of British rivers, Haslam (1978) found that watercourses with similar flows had similar vegetation, other factors being equal, so that plant distribution was clearly correlated with flow. She found a similar relationship between vegetation distribution and substrate type, which of course is closely related to flow velocity. Obviously if the conditions are outside the range of tolerance for a particular species, that species will not be present. However Haslam (1978) pointed out that although a species will be best correlated with the flow and substrate type it actually prefers, individual plant species showed a wide and nearly continuous range of variation along the flow velocity gradient. Species were often frequently found in a particular habitat type because of the frequency of that habitat type along the river, rather than because of the species' preference for that habitat type.

The frequencies of high and low flows can be the determining factors of the survival of a species or community at a site. While emergent species can often tolerate brief dry periods in summer, submerged and floating plants usually die quickly if dried. Repeated dry periods have the effect of removing submerged and floating plants from a stream (Haslam 1978). Similarly some species cope better than others with flood events. Some species tend to break in the water under the stress of high flows, and this sort of loss is quickly replaced. Others tend to be uprooted and washed away. Large plants can shelter and protect smaller and less-securely rooted plants (Haslam 1978). Of course, the type of flood damage experienced by plant communities is dependent on the intensity of flood events and their duration. In the longterm these factors will determine the type of vegetation growing at a site. For example, Hughes (1987b; 1990) found that non-equilibrial or stochastic processes were important in regulating assemblages of aquatic plants along two rivers in eastern Tasmania. Discharge fluctuations occurred sufficiently frequently to maintain an individualistic community, where the species were assembled through converging accidents of space, time and similar environmental needs.

1.3.2 The effects of water quality on aquatic macrophytes

The ionic characterisation, pH, electrical conductivity and levels of various nutrients in the water column form the overall 'quality' of the water. The effects of changes to the water quality on aquatic macrophytes depends to a large degree on the species of macrophyte. There is natural variation in the tolerance of aquatic plants to various aspects of the water chemistry, which is one of the determining factors of variation in macrophyte species composition at a regional scale (see Hughes 1987b). Macrophytes vary in their mechanisms of nutrient uptake, in their tolerance of organic and inorganic pollution, and in their tolerance of changes in light levels caused by particles in the water column. For example, emergent species draw most of their nutrients from the substrate, while at the other end of the spectrum floating macrophytes obtain all of their nutrients from the water column.

There has been a lot of research into the effects of eutrophication-meaning nutrient enrichment, usually referring to increases of nitrogen and phosphorus-on aquatic vegetation in various parts of the world. Because of the variation in tolerance of increasing nutrient levels between species, certain macrophyte species can be used as indicators of nutrient enrichment (Jeffries and Mills 1990). Plants in the United Kingdom have been assigned to oligotrophic through to eutrophic categories, and preferred ranges of ion concentrations have been determined for some species (see Haslam 1978). In New South Wales, Australia, the CSIRO (1999) have undertaken recent experiments on the effects of nitrogen and phosphorus, both in the sediment and water, on different aquatic growth forms. As yet there has been no study undertaken on the preferred ranges of ion concentrations for aquatic species in Tasmania. However, the effects of severe eutrophication on aquatic vegetation are common to water bodies everywhere, and so affected parts of Tasmanian rivers could be identified if the aquatic vegetation characteristic to the river section were known.

Haslam (1990) described three effects of human-induced pollution on river vegetation: (1) a reduction in species diversity, (2) an increase in pollution-favoured species and (3) a reduction

in biomass and cover. The effects of eutrophication on submerged aquatic macrophyte communities has also been described by Jacobs (2000). With the initial input of nutrients there is often an increase in vegetative growth. Introduced species frequently have a competitive advantage, and increase at a proportionally higher rate under the new conditions. The extra nutrients allow epiphytes to grow more vigorously on the leaves, an increase in growth which does not seem to be correlated with a corresponding increase in the populations of grazers. The increase in plant biomass slows the water so that more sediment settles out. The extra weight causes the macrophyte leaves to sink lower, reducing the available light energy for photosynthesis, and eventually the populations of submerged macrophytes crash, releasing most of their accumulated nutrients into the water column. This can lead to an increase in the growth of algae, extensive communities of floating plants or an increase in the growth of emergent species if the water is shallow enough.

Pollution by heavy metals, suspended solids and biocides (pesticides and herbicides) also can have a dramatic impact on aquatic vegetation in rivers. These pollutants tend to decrease the species diversity, richness and abundance of aquatic vegetation. Again, some plant species are more sensitive, and so disappear faster than others. Acidification and increasing salinity also have a negative effect on the aquatic vegetation. The extent of the damage depends on the concentration of the pollutant and the length of time it is present (Haslam 1990). Jeffries and Mills (1990) describe how a frequent change in acid waters is for a smothering growth of algae to form a thick mat, often of just one species, on the substrate. These acid-tolerant algae are often unsuitable food and are poorly assimilated by surviving grazers.

Interactive effects of changes in land use, physical changes to the riverine environment and increasing concentrations of pollutants are described by Haslam (1990). Macrophytes react to the impact on their total habitat, not just to pollutants. Total damage depends on: the damage factors present, and the intensity of each; the species present; and the interactions between these. For example, increased nutrient concentrations may cause rapid growth of a weed species, which is exacerbated by the higher light levels caused by the removal of shade trees on the banks. Or, the effects of heavy metal pollution may be less apparent if the metal-sensitive species have already disappeared, perhaps because of increased turbidity caused by road-

building and forestry activities upstream. Thus the whole range of impacts on the river environment need to be taken into account when attempting to determining the effects of changes in water quality on aquatic plant communities.

1.4 Riverine macrophyte communities in Tasmania

1.4.1 Tasmanian Rivers

In a world-wide hydrological context, Australian streams have been shown to have a high variability in terms of annual flow volumes and large extreme flood events (McMahon 1982). Tasmania is an island state with a mountainous terrain, and its position in the path of westerly frontal systems creates a unique climate within the Australian continent. Hughes (1987a) used hydrological characteristics to classify Tasmanian rivers into four groups. The south-east region of the island exhibited hydrological regimes similar to those of the drier areas of mainland Australia, whereas the wettest areas, in the south and west, had regimes with no analogue elsewhere in Australia. The other two groups, which covered the northern and north-eastern parts of Tasmania, had more temperate regimes.

The South Esk River was classified into the groups of rivers with a temperate flow regime. Hughes' classification only included rivers with a natural flow, and altered rivers with available flow data for a substantial time period before impoundments or reservoirs were constructed. Thus the Macquarie River, which has had impoundments at the headwaters since the late 1800s, was not included in the classification. However the low rainfall in the Macquarie catchment would probably put the river into the dry south-east group, if it had a natural flow.

The Macquarie and South Esk are the two major rivers in the Midlands region of Tasmania. The Midlands region is important for agriculture and forestry, both of which involve land management practices that impact upon the river systems. These practices include damming, channel alteration, clearing of adjacent land and the input of nutrients from stock and fertilisers (Askey-Doran 1993). Askey-Doran (1993:3) explained that

"clearance of land up to the river edge and access by stock has reduced bank stability, causing erosion and ultimately changes in channel morphology. The deliberate planting of species such as willow and gorse has resulted in the infestation of riparian zones by these species at the expense of native species. Willow chokes river courses, forming dams, which further encourages erosion".

1.4.2 Macrophytes in Tasmanian Rivers

Hughes (1987b) surveyed distributions of aquatic macrophytes in 31 rivers at the regional scale in Tasmania, with the aim of determining which environmental parameters were the most important in influencing the presence or absence of species. She found that water chemistry and substrate were the most important influences determining the distributions of macrophyte communities in Tasmanian rivers. The acidic west coast rivers tended to support communities with a low species richness, whereas rivers in the east coast region had species rich communities along their midreaches- 18 species were found in two samples along the midreaches of one east coast river. Species-rich communities were also found in the north and north-west of the state where there were suitable substrates and chemical environments.

Sections of the South Esk and Macquarie rivers have extensive areas of stable, diverse and highly productive macrophyte beds, which are relatively rare in Tasmania. Davies and Humphries (1996:15) wrote that the "Macquarie and South Esk rivers are biologically highly significant. They represent the largest low gradient river systems of the northern coastal plain and as such contain several unique features. Most notable among these is the sequence of deep pools known locally as 'broadwaters' which frequently have features more akin to lakes: stratification, high plankton densities, relatively stable water levels and permanent fringing macrophyte communities with a high floristic and faunal diversity. These macrophyte communities, or 'riparian wetlands' have a high conservation value and are in need of some measure of formal protection."

In their <u>Environmental Flow Study of the Rivers of the South Esk Basin</u>, Davies and Humphries (1996:82) found that "most permanent 'riparian wetland' sites were floristically diverse, with between 13 and >22 species recorded. Plant species were recorded over a wide range of depths and velocities, within the constraints of being predominantly marginal to the main channel when in pools, and there was a lack of consistent preferences for depth or velocity for all species examined".

1.5 This Study

1.5.1 Context

There have been several recent studies on the biota of the Macquarie River. These have focused on macroinvertebrate (Humphries *et al.* 1996) and fish communities (Humphries 1995) or macroinvertebrate-macrophyte associations (Humphries 1996) rather than on macrophyte ecology *per se*. Askey-Doran (1993) described the riparian vegetation of the Tasmanian Midlands in general, which included the macrophyte communities at several points on the mid- to upper Macquarie. There has been no detailed study of the aquatic macrophyte communities along the lower section of the Macquarie or the South Esk rivers. The only major studies of macrophyte communities in Tasmanian rivers are those of Hughes (1987b, 1990), who studied the effect of disturbance on the riverine vegetation of two rivers on Tasmania's east coast, and also established a general classification of macrophyte communities in 31 rivers across the state. This separated the macrophyte communities in Tasmanian rivers into seven groups, illustrating the differences in water quality and substrate between different regions of the state.

The Macquarie and South Esk rivers have particularly well developed and stable macrophyte communities along much of their lower reaches, which are unusual in Tasmania and have a high conservation value (Davies and Humphries 1996).

This study addresses the need for a more thorough investigation of the species diversity and macrophyte community structures in the two rivers, with a view to providing baseline data for

future studies. It also provides a discussion of the conservation values and management requirements of the macrophytic vegetation.

1.5.2 Aims

The aims of this thesis are:

1. To collect baseline data on the distribution and composition of aquatic macrophyte communities along the mid- to lower reaches of the South Esk and Macquarie Rivers.
2. To compare the spatial distribution of the species richness, diversity and cover of aquatic macrophyte communities in the Macquarie and South Esk rivers, and relate this distribution to environmental characteristics of the two rivers.
3. To determine the environmental correlates of variation in aquatic macrophyte species composition, both within and between sites.
4. To identify conservation values and discuss some of the management issues relevant to the conservation of the aquatic macrophyte communities.

1.5.3 Scope and Limitations

The fieldwork for this study was carried out over the summer of 1998-1999. The intention was to undertake a 'snapshot' survey of the macrophyte communities along the two rivers, rather than to investigate any changes in communities over time. Time constraints meant that each site could only be visited once. As a result some of the sites were surveyed in early December while others were not visited until late March. Since the percentage cover and species richness of macrophyte communities can change over time, particularly during the summer growing season (Hughes 1990), there is possibly some inconsistency in the results between sites, especially in the abundance measurements. However this inconsistency would be ameliorated by the relative stability of the macrophyte communities on the two rivers, especially those found on the edges of pools (Davies and Humphries 1996).

Depth and current velocity measurements were dependent on the river flow, which varies from day to day depending on rainfall, abstraction of water for irrigation, and, on the Macquarie, the rate of release of water from impoundments. Water levels during summer are close to baseline flow levels, and there were no major flood events during the period of the fieldwork. Nonetheless there may well have been changes in water level during the period of the fieldwork, which would have slightly affected the between sites comparisons of depth and current velocity. A large volume of water was being released into the Macquarie via the Poatina power station and Brumby's Creek throughout the summer fieldwork season. This made the surveying of macrophyte communities on the lower part of the Macquarie difficult. It was possible to collect information to a depth of about 2 metres, below which there appeared to be very little vegetation, but it is possible that some plants that would be visible at times of lower flow were missed in this study.

1.5.4 Report Structure

Chapter 2 describes the climate, land use, hydrological and physical characteristics of the two rivers, then gives an overview of the changes in water quality along the rivers from the headwaters to the lower reaches. The classification of the macrophytic vegetation and the analysis of environmental variation between the classification groups are described in Chapter 3. Chapter 4 analyses the relationships of environmental variation, species richness, cover and diversity in the two rivers. In Chapter 5 the conservation values and health of the macrophyte communities are discussed, including an overview of management issues. Finally, there is a discussion of the overall findings and their relevance in terms of current literature in Chapter 6.

Plate 1

Mixed native and exotic bank vegetation on the South Esk River

Phragmites australis on the South Esk River

Riffle on the South Esk River, with mixed native/exotic bank vegetation

Plate 2

Exotic bank vegetation on the Macquarie and South Esk Rivers

Pasture on the lower reaches of the Macquarie River

Eleocharis sphacelata in the South Esk River, with gorse on the banks

Chapter 2

The Rivers

The South Esk Basin in north-eastern Tasmania is the largest water catchment in the state, with a catchment area of about 8 900 km^2 (DPIF 1996). There are three major sub-catchments in the basin, all draining into the South Esk River, which joins the Tamar Estuary at Launceston: the South Esk catchment is the eastern-most catchment, after which the basin is named; the Macquarie catchment is in the south, draining north; and the Meander catchment in the west, draining east (figure 2.1). Only the South Esk and Macquarie Rivers, both the major rivers in their respective catchments, were studied.

This chapter provides an overview of the hydrology, geophysical variation, climate and land use along the two rivers, then gives a brief comparison of the water quality in the two catchments.

Figure 2.1 The South Esk Basin, with the Macquarie, South Esk and Meander Rivers marked. Adapted from the DPIF (1996).
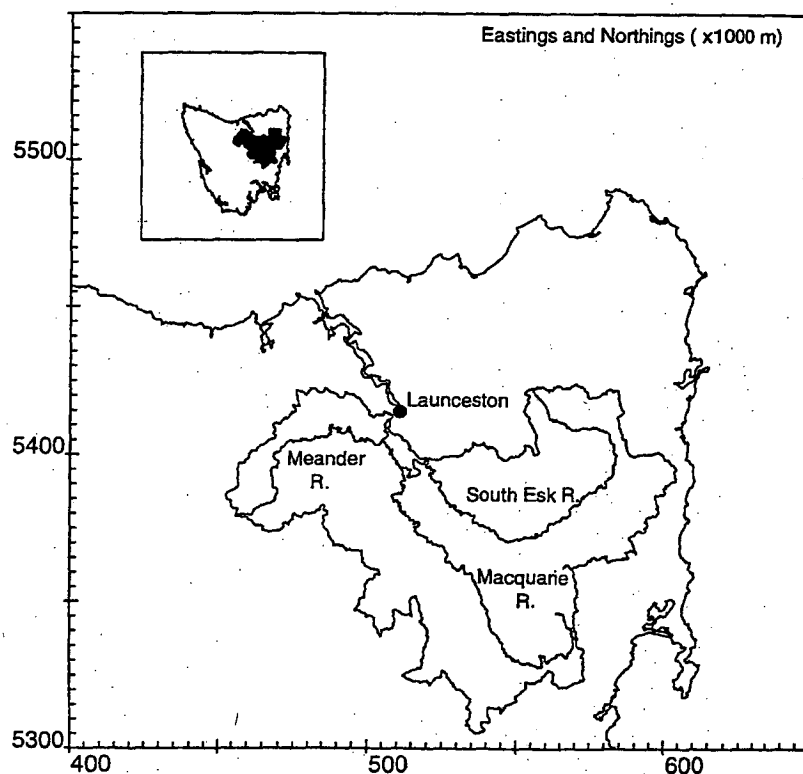
2.1 The South Esk River

2.1.1 Headwaters and Tributaries

The South Esk River rises in north-east Tasmania at an altitude of 800 m and drains an area of 3300 km^2, above its confluence with the Macquarie River (Davies and Humphries 1996). The South Esk has three major tributaries upstream of the confluences with the Macquarie and Meander rivers: the Break O'Day, St Pauls and Nile Rivers. Many smaller streams also flow into the South Esk, mainly from the north east highlands around Ben Lomond, e.g. Storys Creek and Buffalo Brook (figure 2.2).

Figure 2.2 The South Esk River and Tributaries. Adapted from the DPIF 1996.

Mathinna

Perth

Break O'Day River

Nile River

Fingal

Storys Ck

South Esk River

Buffalo Brook

Avoca

St Pauls River

10 km
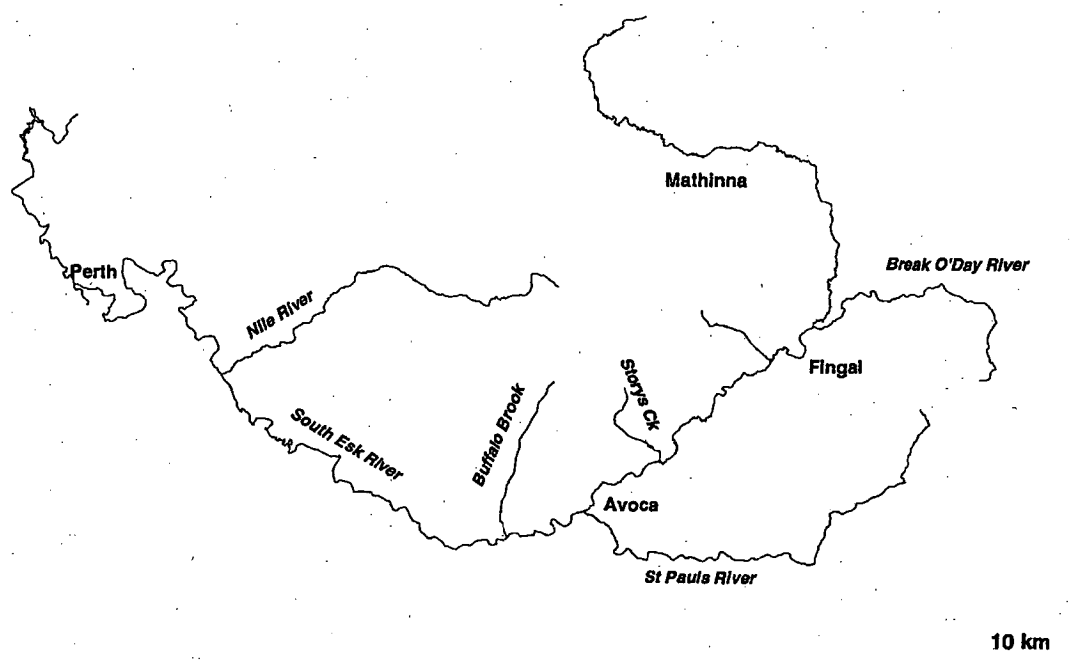
2.1.2 Flow

There is a high variability in average flow from year to year in the South Esk. The average annual flow at Perth ranged from 10 to 60 cumecs during the thirty-eight year period from 1957

to 1995 (DPIF 1996). There are no major storages in the catchment so that, apart from during the summer irrigation period, the flows monitored in the South Esk River catchment are essentially natural flows (DPIF 1996). At Perth, on the lower South Esk, the maximum daily extraction of water for irrigation is about one-sixth of the median daily discharge over the same months (Davies and Humphries 1996). Low flows in the upper South Esk are supplied from a single ground-water storage. See the DPIF State of Rivers Report (1996) for a more detailed analysis of long-term flow patterns.

The South Esk River, which has a high rainfall in the upper catchment, is well-known for flash-flooding in the upper reaches, and is a major source of floods affecting low lying agricultural areas and towns in the lower parts of the catchment (DPIF 1996).

2.1.3 River Form

The South Esk has a steep upper section until it reaches Mathinna, then follows a relatively low gradient for the 220 km to Trevallyn Dam near Launceston, descending only 330 m in that distance (figure 2.3). It has many riffle and pool sequences, with a relatively high frequency of large broadwater pools between Avoca and Perth (Davies and Humphries 1996).

Figure 2.3 Profile of the South Esk River.

Adapted from Davies and Humphries (1996)
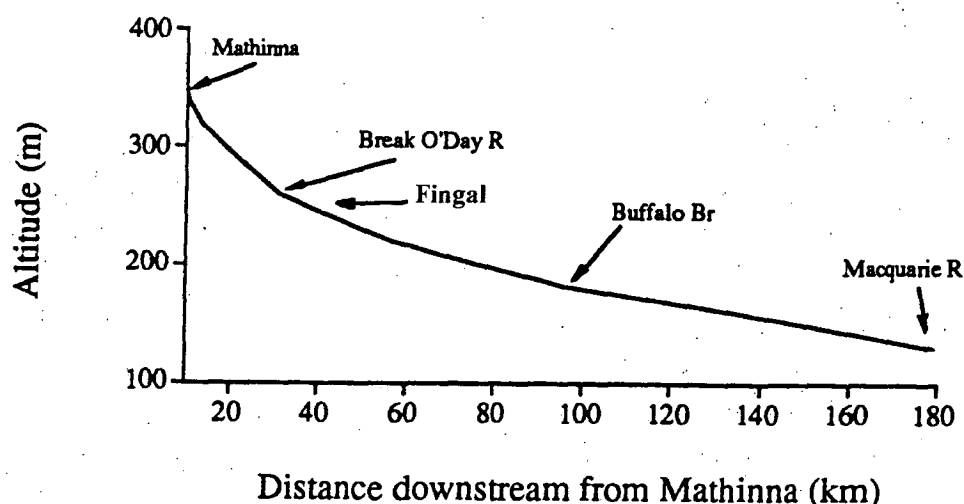
2.1.4 Geology

High in the catchment the South Esk flows through gentle slopes and rolling hills formed by Silurian mudstones and quartzwackes (Mathinna bed sequence). The River then crosses through a narrow belt of Jurassic dolerite and Carboniferous granite, which form the steeper slopes leading up to Ben Lomond and the North Eastern Highlands, before reaching the broadly undulating valleys of the Launceston Tertiary Basin (DPIF 1996).

2.1.5 Climate

Rainfall in the South Esk catchment is strongly influenced by topography, with the lowland areas to the west being driest (average 557 mm per year at Avoca) and the North East highlands being wettest (1238 mm at Gray). Rainfall is mainly due to westerly frontal systems and is highest in winter throughout much of the catchment. The exception is the area around St Marys and Gray where peak monthly falls can occur in autumn, due to low pressure systems off Tasmania's East Coast (DPIF 1996).

2.1.6 Landuse

Land use in the South Esk catchment is primarily agriculture and forestry, with limited mining for coal and metals in the upper catchment. Forestry activity occurs mainly in the upper reaches. Agricultural land is extensive in the lower areas, which creates a high demand for irrigation in the summer months (see figure 2.4).

Willow and gorse infestation is a problem in the lower South Esk, and the loss of native riparian vegetation is considered a significant cause of stream bank and gully erosion (Askey-Doran 1993).

Figure 2.4 Land Use in the Macquarie and South Esk Catchments

Legend
- Agricultural Land
- Plantation
- Native Vegetation
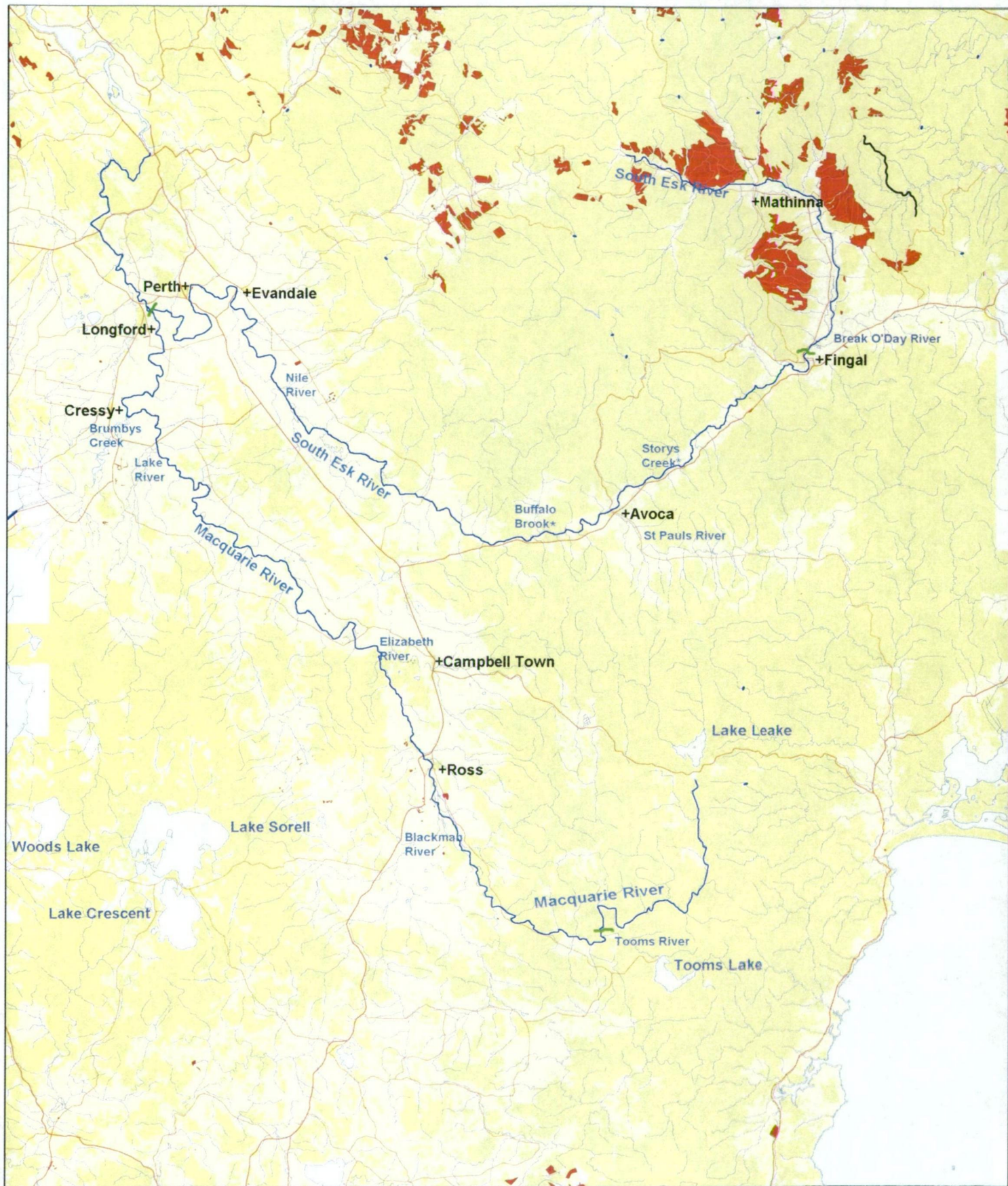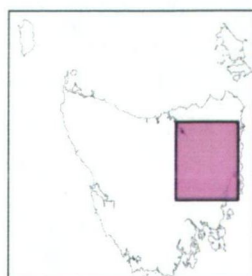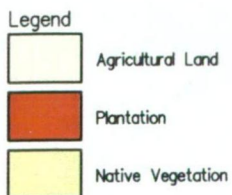
~ Upper and lower limits of study area

+ Towns that release treated sewage into rivers

* Heavy metal pollution enters river from tributary

Scale 1:570000

tted 24 Jan 01

2.2 The Macquarie River

2.2.1 Headwaters and Tributaries

The Macquarie River rises SW of Lake Leake at an elevation of 575 m, and has a total length of 155 km. Together with its tributaries it drains an area of 3765 km^2 (Davies and Humphries 1996). The Macquarie has four major tributaries: The Lake River, the Elizabeth River, Tooms River and the Blackman River. Brumbys Creek (with water from the Poatina power station) is also a major source of water during the summer months. The Macquarie River joins the South Esk at Longford (figure 2.5).

Figure 2.5 The Macquarie River and tributaries. Adapted from the DPIF (1996)
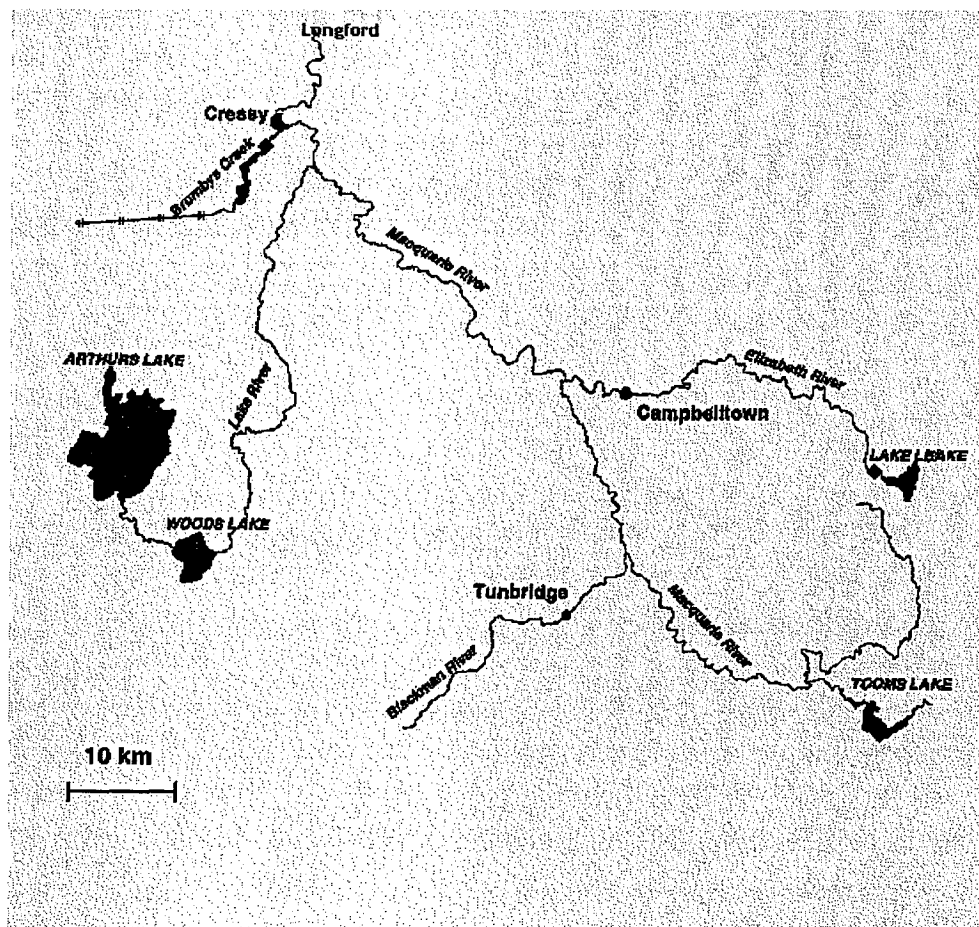
2.2.2 Flow

There is a high variability in average flows in the Macquarie from year to year. The Macquarie has a discharge range from a daily average of about 1.5 to 200 cumecs, with most of this flow occurring between June and October. Flows in the Upper Macquarie, the Elizabeth and Lake Rivers are regulated through releases of water from impoundments in the headwaters (DPIF 1996). This flow regulation has the greatest impact during the summer irrigation period. Irrigation demand is high, with the maximum daily take exceeding the median daily discharge over the same months (Davies and Humphries 1996). In the winter, flows in the Macquarie are essentially natural, and large floods are unaltered (Davies and Humphries 1996).

The upper Macquarie flows through one of the driest areas of Tasmania, with the township of Ross receiving a longterm average rainfall of only 510 mm per year (DPIF 1996). Streams in the area were historically ephemeral, often drying up completely during summer. The artificial storages of Lake Leake (in 1884) and Tooms Lake were constructed to provide irrigation water for the farming communities downstream. The Macquarie was further regulated by HEC activity over the last 40 years: Arthurs Lake (1962) was dammed at the head of the Lake River, then later the Lake River was dammed to form Woods Lake (1965). In 1966 Arthurs Lake was diverted into Great Lake, and water is no longer released into the Lake River from the Arthurs Lake dam unless absolutely necessary (DPIF 1996). Woods Lake provides a regulated flow in the Lake and lower Macquarie Rivers to provide riparian, stock and domestic requirements to prescriptive right holders (DPIF 1996).

A large volume of water from Great Lake is released into the lower Macquarie during summer, via Brumbys Creek, through the Poatina power station. As a result the section of the river between Brumbys Creek and the confluence with the South Esk is distinctly different to the river upstream. The water is colder and clearer, with a greater flow and reversed high flow season, and more active active streambank erosion (see Clerk 1994).

2.2.3 River Form

The Macquarie River drops 350 m between its confluences with Tooms River and the South Esk River. The greatest loss of altitude is over the first 50 km, with a drop of 150 m, after

which the gradient lessens and the river becomes a low gradient, sinuous channel, with the faster flowing runs and riffles interspersed with large deep pools (figure 2.6). The margins of the runs and pools of this lower 125 km section are extensively colonised by aquatic macrophytes.

Figure 2.6 Profile of the Macquarie River.

Adapted from Davies and Humphries (1996).
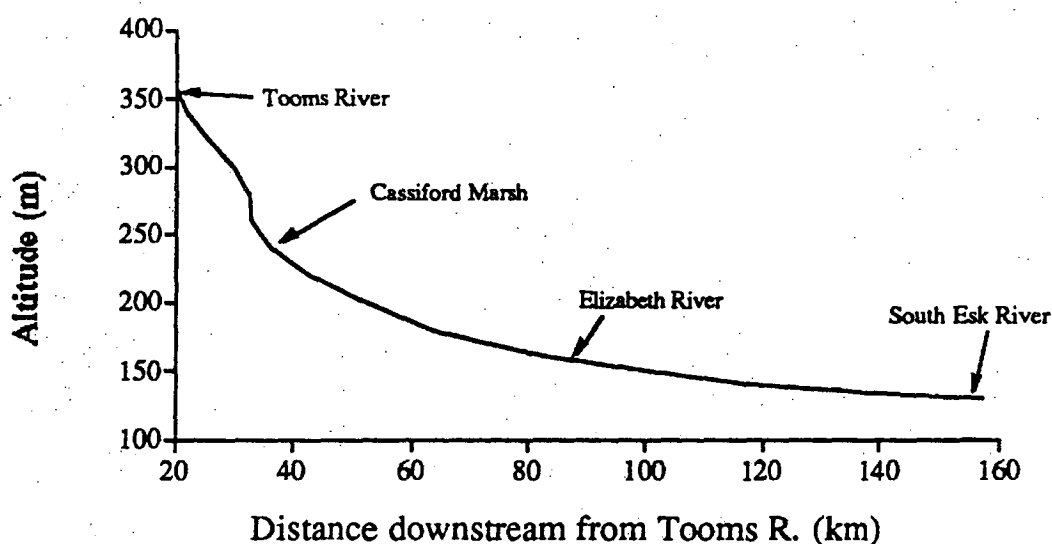
2.2.4 Geology

The underlying bedrock in the Upper Macquarie is Jurassic dolerite, which forms the cap of both the Central Plateau and the Eastern Tiers where the Macquarie rises. The lowland area, below about 250 m, is dominated by the weaker rocks of the Launceston Tertiary basin, mostly alluvial gravel, sands and till, with outcrops of older volcanic and igneous rocks. This geology has formed low relief hills with relict terraces and floodplains. The area is prone to streambank erosion and flooding (DPIF 1996).

2.2.5 Climate

The Macquarie catchment covers one of the driest areas of Tasmania, being in the rainshadow of both the Great Western Tiers and the Eastern Highlands. Large areas of the catchment have

22

a longterm average rainfall of less than 600 mm per year. Most of the rainfall is due to westerly frontal systems in the winter months (DPIF 1996).

Figure 2.7 Mean annual rainfall of Tasmania (mm). Reproduced from the Tasmanian Year Book (1985).
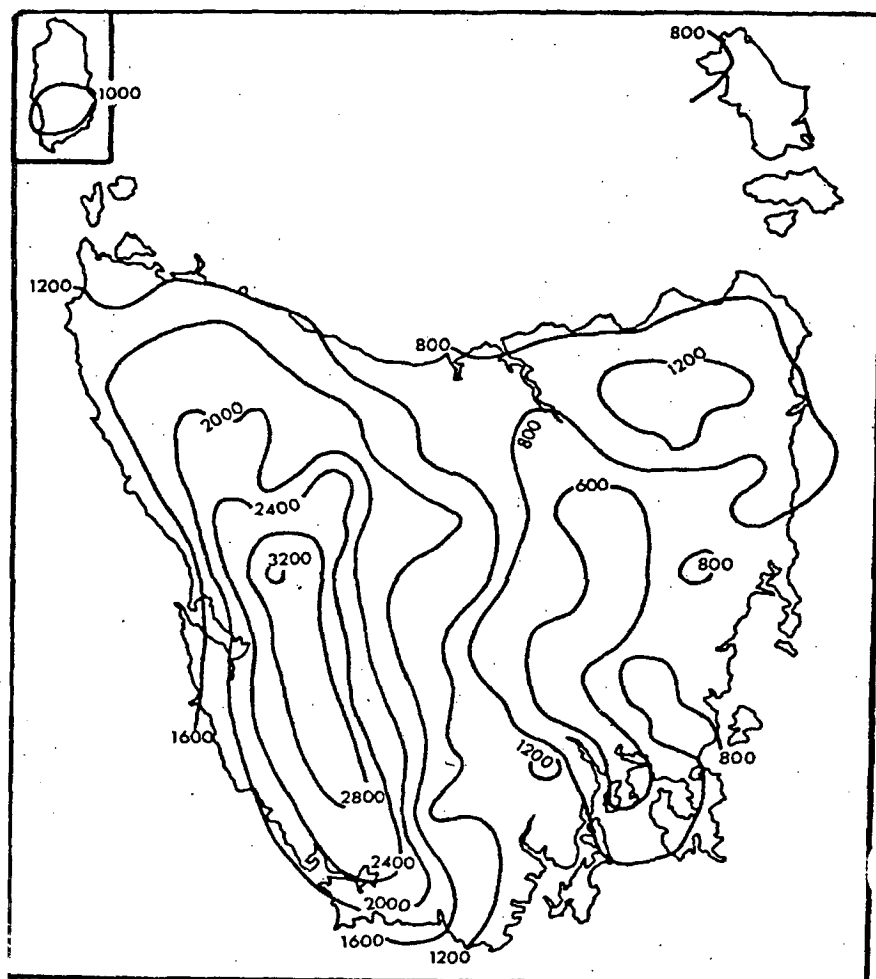
2.2.6 Landuse

The major agricultural activities in the Macquarie catchment are sheep and beef cattle farming. A growing number of farms are now also becoming involved in irrigation, especially of high yield crops such as potatoes (DPIF 1996). The Cressy-Longford area in the lower reaches of the catchment has its own irrigation scheme using water from Poatina Power Station, which has enabled intensive cultivation of vegetable crops. The DPIF (1996:5) noted that this area was

"now showing effects of salinity, mostly due to localised areas of poor drainage". Forestry activities are centred in the Lake Leake area in the upper catchment, and along the southern parts of the Great Western Tiers. Agricultural land is extensive in the lower parts of the catchment (see figure 2.4) and tree decline due to 'dieback' is of major concern to the community (DPIF 1996).

Willow and gorse infestation are serious problems in some areas, and the loss of native riparian vegetation is considered a significant cause of streambank and gully erosion (Askey-Doran 1993).

2.3 Water Chemistry

The Department of Primary Industries and Fisheries (DPIF) conducted water chemistry tests on the Macquarie and South Esk Rivers between May 1992 and October 1995, for their South Esk Basin State of Rivers Report (1996). Several sites on the Macquarie and South Esk were visited monthly during the study period. They also carried out longitudinal sampling along the length of the rivers in stable summer (March) and winter (August) flows in 1995 to give a snapshot view of the relative river conditions at these times, and to highlight any changes in water quality due to tributaries or point source inputs to the river and reveal any trends in water quality down the length of the river.

The results of these tests are used in the present study to illustrate basic differences in water chemistry between the two rivers and different reaches of each river. See Table 2.1 for a summary of these differences. No independent water chemistry tests were carried out in the present study.

2.3.1 Nutrients

The DPIF (1996:133) defined 'nutrients' as "the forms of nitrogen and phosphorus most commonly associated with plant growth and productivity". The relevant forms of nitrogen are ammonia-N, nitrite-N, nitrate-N, and Total Kjeldahl-N (TKN). Discussion in the DPIF (1996) report was limited to nitrate-N, which made up the largest portion of dissolved nitrogen, and Total Nitrogen (TN) which was derived by calculation (as TKN + nitrate-N + nitrite-N).

Total phosphorus (TP) is a measure of all phosphorus both bound to particulate matter and dissolved in the water. The dissolved phosphorus, measured as dissolved reactive phosphorus (DRP), is largely free and available to aquatic plants and algae (DPIF 1996). Since in natural waters DRP generally makes up only a very small fraction of TP, the DPIF (1996) discussion focussed on TP only, unless higher levels of DRP were detected.

2.3.1.1 The South Esk

The DPIF (1996) study of nutrient levels in the South Esk showed a distinct decrease in nitrate-N concentration with increasing distance from the headwaters of the river. Median nitrate-N concentrations were between 0.005 and 0.15 mgl^{-1} (Table 2.1), with the higher levels being at the top of the river. There was also a seasonal change in nitrate-N concentration at all sites, with higher concentrations generally occurring during the higher baseflow periods in winter. This is consistent with the theory that the groundwater discharge in the catchment has higher nitrate-N concentrations than surface waters (DPIF 1996). Total N concentrations were found to be reasonably uniform across all sites. This was because the TKN concentration (mainly composed of organic nitrogen) was higher in the lower parts of the catchment where nitrate-N levels were low. Median TN concentrations were between 0.17 and 0.33 mgl^{-1} (DPIF 1996:136). These levels fall in the lower end of the ANZECC (1992) guideline range (0.1 to 0.75 mgl^{-1}) for the protection of aquatic ecosystems in Australia, see Table 2.1.

Total phosphorus (TP) can be considered low for the entire catchment when compared to the ANZECC (1992) guidelines, which set a range of 0.01-0.1 mgl^{-1} for the protection of aquatic ecosystems. The highest median level in the catchment measured by the DPIF (1996) was 0.021 mgl^{-1} in the Break O'Day River. In general, the DPIF (1996) found that lower concentrations occurred in the upper parts of the catchment. The longitudinal transects showed that during summer TP concentrations above the junction with Storys Creek were fairly uniform, with a marked dilution occurring below this point. During winter baseflows there was a more gradual increase in TP concentrations towards the bottom of the catchment.

During flood events nutrient levels generally increase dramatically. The DPIF (1996:142-143) found that "nutrient concentrations during high flows can be an order of magnitude higher due to surface runoff...during flooding in rivers of the South Esk basin nutrient concentrations

increased by up to 15 times. This was especially so for parameters such as TP and TN which are linked to the resuspension of sediments and overland runoff".

2.3.1.2 The Macquarie

The DPIF (1996) found that most sites on the Macquarie had very low total phosphorus (TP) concentrations, i.e. below 0.02 mgl^{-1}, see Table 2.1, and there was no increase in TP levels towards the bottom of the catchment. However there was a much higher level of TP on the Elizabeth River below the sewage treatment plant at Campbell Town which may have locally influenced TP levels at a site on the Macquarie downstream of the Elizabeth junction- the DPIF study showed relatively high proportions of dissolved P at this site, accompanied by a prolific growth of attached algae. Higher than average levels of TP were also recorded just upstream of the entrance of the Blackman River, and at a site immediately downstream of the Ross sewage treatment plant. Catchment activities are suggested as the causes of the higher levels of phosphorus at these sites (DPIF 1996). During higher winter flows after significant rain, there was an increase in TP at all sites on the Macquarie, with a maximum concentration in the two upper sites.

The nitrate-N concentrations in the Macquarie were lower than in the South Esk at all sites, see Table 2.1, with median concentrations of below 0.04 mgl^{-1}. However the total N (TN) concentrations ranged between 0.3 and 0.6 mgl^{-1}, due to high levels of organic nitrogen. This was higher than in the South Esk, but within the the ANZECC (1992) guidelines for the protection of freshwaters in Australia (0.1-0.75 mgl^{-1}). The longitudinal transects showed that Total N concentrations were moderately uniform along the entire length of the river upstream of Brumbys Creek, with the exception of higher levels in the upper reaches during flood events (DPIF 1996). The TN concentration in the Macquarie decreased due to dilution downstream of the Lake River and Brumbys Creek, particularly during summer, when this lower section of the river is almost totally dominated by water from the Central Highlands (DPIF 1996). It is worth noting that measured loads of DIN (dissolved inorganic nitrogen) increased downstream (DPIF 1996:203).

The exception to the lower levels of nitrogen in the Macquarie was during flood events, when nutrient concentrations in the Macquarie catchment were up to 40 times their normal concentrations at some sites. The most notable increase was for nitrate-N which was normally

very low in the Macquarie. It appeared that rain events were mobilising nitrate-N which could not normally enter rivers due to lack of groundwater flows (DPIF 1996).

The DPIF Report (1996) suggests that given the high levels of total nitrogen, it appears that phosphorus is a limiting factor on algal growth in the Macquarie catchment. They did note that during prolonged low flows in the Macquarie during the summer of1994-95, there was considerable growth of filamentous algae at many sites.

2.3.2 Point Sources of Nutrients

2.3.2.1 The South Esk

There are six sewage treatment plants on the South Esk and tributaries, all of which discharge treated wastewater directly into the rivers. During limited sampling of the treatment plants, the DPIF (1996) measured concentration and flow to give estimates of nutrient loads. They found that even the minimum concentrations of nutrients in effluent were greater than concentrations measured during floods in the South Esk, when ambient nutrient concentration in rivers is highest. The DPIF (1996:144) write that "while during higher river flows the impact of this concentration of effluent may be minimal due to dilution, during low flows there may be localized nutrient enrichment of the receiving waters, resulting in nuisance algal blooms and prolific growth of aquatic weeds".

2.3.2.2 The Macquarie

The major point source inputs of nutrients on the Macquarie are the sewage treatment plants at Ross and Campbelltown. Both discharge treated wastewater directly to rivers; at Ross to the Macquarie River and at Campbelltown to the Elizabeth River. The DPIF (1996) undertook limited sampling of the treatment plants, measuring concentration and flow to give estimates of nutrient flows. They comment (DPIF 1996:197) that "the most notable figures... are those for nitrogen discharge. In a system where nitrate-N is low, a large percentage of the nitrogen discharged by both treatment plants is in the dissolved form". That is, in the form readily accessible to plants, which contributes to algal growth, at least in localised areas downstream from the sewage outfalls.

2.3.3 Temperature

2.3.3.1 The South Esk

The DPIF (1996:120) found that "temperature at all monitoring sites in the South Esk showed a distinctly seasonal pattern with temperatures ranging from a low in mid-winter of about 5°C...to a high in mid-summer of around 23 °C", see table 2.1. Diurnal fluctuations in winter were minimal, but in summer were as large as 10 °C. Apart from the uppermost site (which is above the stretch of river covered by the present study) being coolest, water temperature showed little gradation from the top of the catchment to the bottom.

2.3.3.2 The Macquarie

Similar temperatures ranges to the South Esk were found in the lower Macquarie River, while at sites higher in the river and in the main tributaries the temperature range was typically 4.5°C to18°C. The Lake River and Brumbys Creek, with water flowing from the highlands, were generally always colder than other sites in the catchment (DPIF 1996:181).

2.3.4 Electrical Conductivity (EC)

2.3.4.1 The South Esk

In the DPIF study (1996), EC throughout the South Esk catchment was found to be low, with medians ranging from 44 μScm^{-1} in the upper catchment at Mathinna to about 97 μScm^{-1} at Perth. A distinct seasonal pattern was shown at most sites on the South Esk, with EC rising during prolonged periods of stable flow. Rapid dilution occurred during high flow events. EC in the Break O'Day and St Paul's rivers upstream of their confluences with the South Esk were higher than in the South Esk (mean EC of 180 μScm^{-1} and 128 μScm^{-1} respectively), but still well within the normal ranges for freshwaters. The DPIF suggest that evaporation made be the cause of the greater concentration of ions in these two tributaries, as both can have very low summer flows.

The effects of these tributaries on the EC in the South Esk was shown clearly by the longitudinal transects, with an abrupt increase in EC appearing downstream of the confluences of the tributaries with the South Esk (DPIF 1996).

2.3.4.2 The Macquarie

EC in the Macquarie was higher than in the South Esk, see Table 2.1. There was a distinct increase in EC from sites high in the headwaters to sites low in the river. Tooms Lake had a median EC of 74 μScm^{-1} whereas Coburg (low on the Macquarie but above Brumbys Creek) had a median of 216 μScm^{-1}. The longitudinal transect of the river in summer showed three marked decreases in EC due to tributary inflows. These occurred downstream of the Elizabeth and Lake Rivers and downstream of Brumbys Creek, where very dilute water was being discharged from Poatina power station. In the winter transect the power station was not operating, and dilution was only evident from the Lake River inflow. Higher EC values tended to occur at most sites during winter (DPIF 1996).

2.3.5 Reaction (pH)

2.3.5.1 The South Esk

The DPIF (1996) found that the pH of the South Esk catchment water was typical of poorly buffered water with field pH ranging between 5 and 8.4. Median conditions at most sites was close to 6.5, see Table 2.1. The more acidic water of Storys Creek (due to mine effluents) appeared to have very little influence on pH levels in the South Esk downstream.

2.3.5.2 The Macquarie

The pH measurements in the Macquarie were of similar magnitudes to those in the South Esk.

2.3.6 Turbidity

2.3.6.1 The South Esk

The South Esk river has very low baseline turbidity, meaning that it is very clear for much of the time, as are most rivers in the catchment (DPIF 1996). In the 1992-1995 measuring period for the DPIF study, mean turbidities in NTU between Fingal and Perth ranged from 2.9 to 5.0 NTU, see table 2.1. The median turbidity in all cases was lower than the mean.

A twenty-year time series of data collected by the DPIF for the State of Rivers Report (1996; 116-117) showed a strong seasonal component to the turbidity readings, with highest turbidity occurring during the winter-spring period. Turbidity was affected by rainfall, with lower peak turbidity levels in years of below average rainfall. The seasonal variability of the readings made it difficult to assess real changes in turbidity in the longer term. Flood events caused a huge increase in turbidity, with recordings of up to 340 NTU measured at sites on the South Esk during flooding in 1995 (DPIF 1996).

Longitudinal transect data collected during stable winter flows clearly showed an increase in turbidity down the length of the South Esk. However in summer, during low baseflows, higher turbidity occurred further up in the catchment, where river velocities and associated erosional power is greater (DPIF 1996).

2.3.6.2 The Macquarie

The DPIF (1996) found that turbidity in the Macquarie was generally less than 5 NTU. Both the Elizabeth and Lake Rivers were more turbid due to very fine suspended clay particles. As a result the site on the Macquarie below the inflow of the Elizabeth River had high turbidity. The winter longitudinal transect of the Macquarie was taken after two days of rain, and showed the significant effect rain had on turbidity levels in the catchment, with a 5-10 fold increase in turbidity at sites in the lower part of the Macquarie, and a high peak of 80-100 NTU at two sites higher in the catchment (DPIF 1996).

2.3.7 Dissolved Oxygen

2.3.7.1 The South Esk

The DPIF (1996:129) found that "generally, dissolved oxygen throughout the South Esk catchment is typical of natural rivers, with levels at all stations showing a strong seasonal variation. The median dissolved oxygen concentration at most sites was within the range 9-10.5 mgl-1...which is indicative of a healthy environment", see table 2.1.

2.3.7.2 The Macquarie

Generally DO concentrations in the Macquarie were similar to those in the South Esk, with a similar broad seasonal variation. At two sites concentrations of below 6.5mgl-1 were recorded (Ross and Coburg), indicating that slight oxygen depletion was occurring in some areas during summer, but these concentrations are still above the ANZECC (1992) threshold of 6 mgl-1 for the protection of aquatic organisms (DPIF 1996).

2.3.8 Heavy metals

2.3.8.1 The South Esk

A significant stretch of the South Esk has been adversely affected by mining activity on Storys Creek and Aberfoyle Creek. These two small tributary streams converge before they enter the South Esk between Fingal and Avoca.

A report by Locher (1993) for the Department of Environment and Land Management investigated pollution from this area. The effects of heavy metal pollution on the riverine biota of the South Esk were also studied several times during the 1970s (see Tyler and Buckley 1973; Norris *et al* 1980; 1981;1982). These studies found that heavy metal pollution from the Storys Creek and Aberfoyle mines affected biotic communities as far downstream as Evandale, some 80 km from the source of the metals. Norris *et al* (1981) found that concentrations of cadmium, zinc, copper and lead in the sediment and solution were all well above the natural background levels up to 130 km below the source of contamination. It has also been suggested

that Buffalo Brook may be contaminated by metals from mining, which may contribute to the contamination of the South Esk (see DPIF 1996: 154).

There have been no studies into the effects of mining activity on the aquatic vegetation of the South Esk, however the DPIF (1996) pointed out that as well as the problems caused by heavy metal contamination, the instability of the substrate downstream from the confluence with Storys Creek (due to increased sedimentation) caused the elimination of algal and macrophytic growth.

2.3.8.2 The Macquarie

The DPIF (1996) sampled sites on the Macquarie for heavy metal analysis during March 1995. No significant levels were detected. This result was expected as no significant mining activity or chemical related processing occurs in the catchment.

2.3.9 Health Rating Using Macroinvertebrates

In the DPIF study (1996:156), analyses of the macroinvertebrate assemblages were used to assess the health of the river sites on the South Esk. All four sites that fall within the area of this present study were found to be degraded by human activities. The first, just upstream from the confluence with Storys Creek, was clearly stressed, with a great reduction in macroinvertebrate taxa sampled compared to sites further upstream. The DPIF (1996) suggest that extensive land clearing upstream, cleared land with pasture or introduced species such as willows or gorse growing right to the waters edge, and extensive erosion of river banks may be possible causes. There was a further degradation of the macroinvertebrate community at Avoca, downstream from Storys Creek. This was as expected, as the influence of heavy metal pollution from mining effluent flowing into Storys Creek has been well documented. Slightly higher numbers of taxa were sampled at Evandale and Perth, however both sites still had degraded macroinvertebrate communities.

The Macquarie was not rated using invertebrates in the DPIF (1996) study.

Table 2.1 Water Quality Parameters in selected upstream and downstream sites on the Macquarie and South Esk Rivers- adapted from the DPIF (1996)

	Macquarie		South Esk		Standard
	Median level upstream[a] (min-max)	Median level downstream[b] (min-max)	Median level upstream[c] (min-max)	Median level downstream[d] (min-max)	Australian Water Quality Guidelines[e]
Nitrate-N mgl^{-1}	0.012 (0.001-0.05)	0.016 (0.005-0.043)	0.13 (0.022-0.25)	0.02 (0.002-0.13)	*
Total N mgl^{-1}	*	0.412 (0.156-0.801)	0.345 (0.077-0.563)	0.23 (0.057-0.465)	0.1-0.75
Dissolved Reactive P mgl^{-1}	0.003 (0.001-0.009)	< 0.005 (< 0.005-0.022)	< 0.005 (< 0.005-0.012)	< 0.005 (< 0.005-0.062)	*
Total P mgl^{-1}	0.013 (0.009-0.021)	0.015 (0.005-0.031)	0.01 (0.002-0.7)	0.011 (0.003-0.14)	0.01-1
pH (field measurement)	6.9 (5.6-7.9)	6.6 (6.2-7.3)	6.4 (5.6-7.8)	6.4 (5.6-7.3)	6.5-9.0
Dissolved Oxygen mgl^{-1}	*	9.5 (6.4-11.8)	10.05 (6.8-11.8)	10 (7.34-12.2)	> 6
Conductivity @ 25^{0}C μScm^{-1}	130 (71-225)	233 (155-280)	66 (41-125)	93 (50-138)	< 1500
Turbidity NTU	< 5 *	< 5 *	4.98[m] (1.5-32.5)	4.45[m] (0.84-13.30)	*
Temperature Celsius	10.6 (4.2-19.1)	11.2 (6-22.5)	10.2 (5.1-22.5)	12.2 (4.3-24.2)	*

[a]Mt Morriston

[b]Coburg

[c]Fingal

[d]Perth

[e]Australian Water Quality Guidelines for Ecosystem Health (ANZECC 1992)

[m] Mean values rather than medians were given for turbidity. The medians were lower than the means (DPIF 1996)

*Not given in DPIF Site Monitoring Data (DPIF 1996: Appendix 1) or ANZECC Guidelines (1992)

Chapter 3

Characteristics and Environmental Relationships of the Vegetation

3.1 Introduction

Studies on the distribution of aquatic macrophyte communities (and the associated marginal and bank communities) along rivers in many parts of the world have become increasingly common during the last twenty years (see Holmes *et al.* 1998). Classification systems relating aquatic plants to physical variables such as substrate and water velocity were first developed in Britain during the 1920s (Butcher 1933). Later surveys confirmed many of these early species/habitat associations, and extended the range of physical and environmental factors under consideration (e.g. Haslam 1978; Holmes *et al.* 1998). Many authors have focussed on the distribution of species within a single river or river catchment, often describing the effects of human-induced changes in water quality between high and low parts of the catchment (e.g. Wiegleb 1984; Penuelas and Sabater 1987; Ferreira 1994). Others have described the environmental correlates of variation in macrophyte communities across a wider area, developing systems for assessing water quality and riverine health using macrophyte communities (e.g. Haslam 1987; Holmes *et al.* 1998; Small *et al.* 1996). The later developments have been largely due to progress in computer technology and statistical packages that can process large datasets, distinguishing groups of sites on the basis of similarity in their characteristics (Holmes *et al.* 1998). For example, TWINSPAN (Two-way Indicator Species Analysis: Hill, 1979) has been used to classify sites on the basis of similarity in their species characteristics in many studies of this type in the recent literature.

In Australia, classification systems relating aquatic macrophytes to environmental variables are still in the developmental stages (see Schofield and Davies 1996; CSIRO 1999; Jacobs 2000). While the well-known relationships between aquatic macrophytes and physical variables such as current velocity and substrate type seem to be applicable in almost every case, other associations are more specific to a particular plant species, for example the effects of the addition of nutrients into the water column on plant growth (see the CSIRO 1999). A high degree of environmental variation across Australia means that the development of classification systems at a regional level would be necessary to draw meaningful conclusions on the

relationships between environmental variables and aquatic plant species composition in any given river catchment.

In Tasmania there has been only one study (Hughes 1987b) that classifies aquatic macrophyte communities in rivers in relation to environmental variables. Hughes (1987b) classified the rivers in Tasmania on the basis of their macrophyte communities, and found that water chemistry (filterable residue, pH and salinity) and substrate were the most significant determining factors of species presence or absence at the regional (state-wide) scale. Obviously the scale of the classification is significant. As Westlake (1973) pointed out, on a world-wide scale temperature and dispersal ability are the two primary factors governing the distribution of riverine plant species. At a regional scale, the factors that determine the macrophyte community distribution (in this case water chemistry and substrate) will differ from those that determine the distribution of communities within a region (e.g. diffuse nutrient inputs, river slope and geology), a catchment (e.g. altitude, land-use, slope, hydrology and geology) or a reach (e.g. river form, bank slope, point source pollutants). At the finest scale, the distribution of individual plants within a plot will be determined by the distribution of different substrate types, local variations in water velocity, available light for photosynthesis, and in some cases the extent of competition between species for space and resources. This detailed distribution is often an unstable mosaic, but a regular pattern in time often develops from the interactions of the plants and flow (Westlake 1973).

In the present study, the macrophyte communties and associated marginal communities in the mid and lower reaches of the Macquarie and South Esk Rivers are classified in four ways: firstly, the individual species or assemblages of species at the plot level are classified into 'dominant species groups', and some of the environmental variables that are related to the distribution of these groups are determined. This provides information on the fine-level differences in the environmental preferences of species and species assemblages. Secondly, the presences or absences of both aquatic macrophyte and marginal species at each site are used to classify the sites into groups with similar species compositions. Again, some of the environmental relationships are determined at the site level. This provides information on the variation in aquatic and marginal communities between different sections of the rivers, in particular between upstream and downstream sections and between run, riffle and pool sections.

Finally, to avoid the potentially confusing effects of the marginal species on the aquatic macrophyte classification, the sites are classified into groups with similar compositions of aquatic species, and then into groups with similar compositions of marginal species, and environmental relationships are again determined for each of these classifications. Abundance data are used in these final two classifications.

This chapter describes the methods of site selection and data collection, and then classifies the vegetation in the four alternative ways described above. Significant differences between the groups in environmental variables and vegetation cover, species richness and diversity are then determined for all classifications. The data are ordinated, and the positions of the groups of sites/ species assemblages in the ordination space are related to the environmental variation between groups of sites or species assemblages.

Finally, all four classification groupings are integrated to describe the geographical variation in environmental factors and the related variation in aquatic and marginal vegetation along the two rivers. These results present baseline data on the distribution and composition of plant communities along the two rivers, and provide information on the environmental correlates of variation in aquatic macrophyte species composition, thus satisfying aims one and three from chapter 1.

3.2 Definitions

3.2.1 Plant Growth Form

It is useful to classify macrophytes into groups with different growth forms, as growth form is often more useful than floristic composition when describing macrophyte communities in an ecological context (Sculthorpe 1967). A simple four- group system was adapted from that described by Sculthorpe (1967). Growth form 1- submerged plants were those with all of their vegetative tissue below the water surface; growth form 2- floating-leaved plants were those with leaves floating on the water surface; growth form 3- emergent plants were plants with most of their leaves and stem above the water surface; growth form 4, marginal plants, was added to this

list to describe non-woody species that were growing in the marginal zone between emergent aquatic species and terrestrial species. These species grew on the banks of the rivers, either underwater, on damp river margins or on the dry higher banks, depending on water levels at the time. Many marginal species were pasture species that had colonized the riverbanks from adjacent agricultural land.

Any attempt to apply rigid definitions when classifying aquatic macrophytes oversimplifies their plasticity of organism and diversity of habit (Sculthorpe 1967). As there were very few species in this study that fitted strictly into one growth form and never occurred in another, species with the first three growth forms were often grouped together and referred to as the 'aquatic vegetation', while plants with growth form 4 were referred to as the 'marginal vegetation'. This division of river plants into aquatic and marginal groups was similar to that described by Holmes *et al.*(1998) and Ferreira and Moreira (1999).

Bank vegetation was defined as terrestrial vegetation growing beyond the marginal vegetation on the riverbanks. The start of the bank vegetation was often marked by obviously terrestrial species such as *Poa* species. Woody species such as willows and *Leptospermum* species were included in the bank vegetation growth form rather than the emergent or marginal growth forms. These species grew substantially taller than the other marginal species, forming a separate canopy above the aquatic and marginal vegetation, and tended to overshadow the aquatic and marginal vegetation rather than competing with it for space.

3.2.2 Dominant species type

A dominant species type was defined as a distinct species assemblage that covered a total of more than five square metres in a site. These assemblages consisted of one or more species. They varied in size from 5 square metres upward.

3.3 Methods

3.3.1 Site Selection

Random sampling was used to select the site locations. Fifty-four sites were randomly selected on the Macquarie, and forty-eight on the South Esk. The sites were all situated between the confluence of the two rivers and the highest point of each river supporting substantial communities of macrophytes (the confluence with Tooms River on the Macquarie and the township of Fingal on the South Esk).

3.3.2 Data Collection

3.3.2.1 Vegetation cover and species richness

At each site a representative 25 m long section of the river was chosen. The percentage cover of each aquatic and marginal plant species, or assemblage of species if this was consistent in species composition, was measured. This was done by estimating the area (in square metres) covered by each species or species assemblage, calculating the site area (25 m by average stream width), then dividing the species/species assemblage area by the site area to give a percentage of the site covered by that species/species assemblage. The percentage cover of each species in each dominant species type was also estimated visually in the field. The dominant species in a dominant species type was defined as the species with the highest percentage cover.

Species/species assemblage and depth transects were conducted across the river at a point representative of that site. Transects started and ended one metre beyond the bank vegetation/ marginal vegetation boundaries. Depth was measured using water level as the zero point. Depths greater than 2 m did not generally support macrophyte growth and were simply recorded as >2 m.

Total species richness was defined as the total number of aquatic and marginal species found at the site. Exotic species richness was the total number of exotic species, aquatic species richness

the total number of aquatic species and marginal species richness the total number of marginal species found at the site.

Diversity was calculated using the Shannon-Weiner index, which combines species richness with relative abundance and is thus a measure of the evenness of cover (Kent and Coker 1992). Plants were identified to species level where possible. However, species in several genera could not be separated because of the absence of flowering parts at the time of the survey. For example, *Triglochin* species other than *T. procerum*, *Hydrocotyle* species and most *Isolepis* species. *Myriophyllum simulans* could not be distinguished from *M. variifolium*, and so both are recorded as *M. simulans/variifolium*. Similarly, *Isolepis fluitans* could not be distinguished from *Schoenus fluitans*. Both are recorded as *Isolepis fluitans*, which is the more common (Curtis and Morris 1994). Nomenclature follows Buchanan (1999).

3.3.2.2 Environmental data

The dominant substrate, minimum depth and maximum depth were recorded for each dominant species type. Four classes were used to record dominant substrate, based on the most common substrate combinations found in the field. These were mud, mud/rock, gravel (or, occasionally, sand) and rock. The definitions of mud, sand, gravel and rock were those of Riis *et al.* (2000), where mud referred to particles less than 0.1 mm in diameter, sand 0.1-3 mm, gravel 3-30 mm and rock > 30 mm in diameter. Depths of up to 2 m were measured using a pole marked at 20 cm intervals. The depths of the occasional dominant species types growing deeper than 2 m were estimated to the nearest metre. 'Above water' height was recorded as negative depth.

The single depth value used as a sample variable for each site was the deepest depth class found along the transect line, with depth in three classes: 1 = 0-1 m; 2 = 1-2 m; 3 = >2 m. Width was recorded as the distance along the transect line from the bank community/marginal community boundary on one side of the river to the bank community/marginal community boundary on the other side. The dominant substrate type was recorded as the substrate type that covered the greatest percentage of the site. The four classes used to record dominant substrate were the same as those described above. Sand was the dominant substrate type at only one site, and so was merged with the 'gravel' class. Organic matter was common and was included in the

'mud' class. The most common substrate type was mud/rock, with mud or organic matter dominating the macrophyte-lined banks and rock in the middle of the stream. In some parts of the analysis, 'rockiness of substrate' was used as an ordered variable, using the four classes of substrate in the order given above. Percentage shading was measured as the percentage of the site area shaded from directly above by overhanging bank vegetation. Bank height was defined as the vertical distance between water level and the first (usually obvious) substantial flattening of the bank. Where this differed between locations within the site, the maximum value was taken.

The bank vegetation was recorded in six classes: (1) willow; (2) pasture, or willow and pasture; (3) other exotic vegetation, or a mixture of willows and other exotics; (4) a mixture of natives and exotics, but more exotic than native; (5) more native than exotic; and (6) native. The extent of stock damage at each site was recorded in three classes: (1) no damage; (2) moderate damage and (3) severe damage. Sites with moderate damage had visible signs of trampling by stock (hoof prints, stock pathways, bank erosion, soil compaction, animal faeces and/or sediment in the water), but less than 10 percent of the vegetation along the river edges had been completely removed. Sites with severe stock damage were defined as those sites in which there were obvious signs of stock damage, and in which more than 10 percent of the river edges had been denuded of vegetation. The level of erosion was also recorded in three classes: (1) no active erosion; (2) moderate active erosion and (3) severe active erosion. In the first category the banks were well supported by vegetation and there were no visible signs of erosion; in the second category, there was some evidence of erosion, such as undercutting of the banks, on up to 20 percent of the river banks; and in the third category active erosion had affected more than 20 percent of the riverbanks.

Each site was defined as a riffle, run or pool, depending on depth, visible current velocity and degree of surface disturbance, after Davies and Humphries (1996:24, see page 4). For parts of the analysis in which it was useful to have current velocity as an ordered variable, the form of river site was ordered to provide three classes of 'slowness of current velocity': riffle = fast velocity; run = slow to moderate velocity; and pool = no discernible velocity. No separate current velocity measurements were recorded.

3.3.3 Data Analysis

3.3.3.1 The dominant species types

The dominant species types were distinct species or species assemblages covering an area greater than 5 m^2 in any one site. They were made up of various combinations of species, but were identified by their dominant species. Overall there were 28 different dominant species across all 295 dominant species types. Thus the dominant species types were aggregated into 28 groups by dominant species only. This grouping was independent of the sites in which the dominant species types were found. The intention of analysing the data on dominant species groups was to identify environmental correlates of variation in macrophyte species and species assemblages at the fine-scale 'plot' level, that is, taking into account environmental variation within sites as well as between sites. This detailed analysis of the environmental preferences of individual species/species assemblages was seen as necessary to fully satisfy aim three in chapter 1.

The percentage frequency of all taxa were calculated for each group (table 3.1). These data were ordinated using multidimensional scaling (MDS), following the default options in DECODA (Minchin 1990). The pattern of stress reduction suggested a four-dimensional solution to be the most useful.

Spearmans Rank Correlations and Kruskal-Wallis tests were used to determine the relationships between the position of dominant species types on the four axes from the multidimensional scaling and the environmental variables, vegetation cover and richness. Environmental, richness and cover vectors were fitted to the four dimensional MDS solution using the vector fitting option in DECODA (Minchin 1990). Correlations were tested using 1000 random permutations of the ordination axes (Minchin 1990). These were used to test the relationship between independent variables and the variation in species composition and abundance.

Statistical tests were used to test the strength of the relationships between the dominant species groups and the environmental variables. The environmental variables were not normally

distributed. All the environmental variables were measured on either continuous or ordinal scales, however some of the latter had as few as three ordered classes. Despite the low number of classes, Kruskal-Wallis tests were used in preference to chi-squared tests as the small number of samples in the groups created uncertainty about the validity of chi-squared tests.

3.3.3.2 The sites

TWINSPAN (Two-way Indicator Species Analysis, Hill 1979) was used to identify groups of sites with similar species composition. The sites were firstly grouped using presence/absence data for species of all four growth forms. They were then grouped using aquatic species only (growth forms 1,2 and 3), and then using marginal species only (growth form 4). Abundance data were used for the latter two analyses.

Since the cover, richness and environmental variables were either continuous (e.g. width) or ordered (e.g. depth), but were not normally distributed, Kruskal-Wallis tests were considered most appropriate to test the strength of the relationships between the TWINSPAN groups and the cover, richness and environmental variables. As mentioned above, some of the ordered data had as few as three ordered classes. However, despite the low number of classes, Kruskal-Wallis tests were used in preference to chi-squared tests as the small number of samples in the groups created uncertainty about the validity of chi-squared tests.

The species abundance data from the 102 sites were ordinated using multidimensional scaling (MDS), following the default options in DECODA (Minchin 1990). Species of all four growth forms were used for the initial ordination. The pattern of stress reduction suggested a three-dimensional solution to be the most useful. Species richness and cover vectors and vectors of the environmental variables were fitted to the three-dimensional MDS solution. Correlations were tested using 1000 random permutations of the ordination axes (Minchin 1990). This illustrated the strength and directionality of relationships between the cover, richness and environmental variables and the variation in vegetation. The above analysis was repeated twice, firstly grouping the sites using aquatic species only (growth forms 1, 2 and 3), and then using marginal species only (growth form 4).

This analysis was intended to provide baseline information on the distribution and composition of aquatic macrophyte communities along the two rivers, and to determine the environmental correlates of variation in aquatic macrophyte species composition (in conjunction with section 3.3.3.1) thus satisfying aims one and three from chapter 1.

3.4 Results

3.4.1 Results of the analysis of the dominant species types

3.4.1.1 Species composition and environmental characteristics of the dominant species groups

There were 295 dominant species types across the 102 sites. There were 28 dominant species groups. Table 3.1 shows the percentage frequency of species in each dominant species group.

Table 3.1 Percentage frequency of species in dominant species groups

(a) Groups 1-15

Species	GI	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15
Acaena novae-zelandiae	-	-	-	-	-	-	-	-	-	-	33.3	-	-	-	-
Agrostis aemula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Agrostis avenacea	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-
Agrostis stolonifera	-	-	5.26	-	-	-	-	-	-	40	-	-	-	11.11	-
Alisma plantago-aquatica	-	-	7.89	-	-	4.76	-	4.88	-	-	-	-	-	-	-
Alopecurus geniculatus	-	-	-	-	-	-	-	-	-	40	-	-	-	11.11	25
Azolla filiculoides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Batrachium tricophyllum	100	-	-	-	-	-	-	-	-	-	33.3	-	-	-	-
Baumea arthrophylla	-	100	-	-	-	-	-	2.44	-	-	-	-	-	11.11	-
Baumea articulata	-	9.09	-	-	-	-	-	-	-	-	-	-	-	-	-
Callitriche stagnalis	-	-	2.63	-	-	9.52	-	-	-	-	-	-	-	-	-
Carex appressa	-	-	2.63	-	-	4.76	-	-	-	40	-	-	-	-	12.5
Carex fascicularis	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Carex gaudichaudiana	-	-	100	-	-	4.76	-	2.44	-	-	33.3	5.56	50	11.11	62.5
Charophytes	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Centella cordifolia	-	9.09	-	100	-	4.76	-	-	16.67	-	-	5.56	-	-	-
Crassula helmsii	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Cyperus gunnii	-	-	26.32	-	100	-	-	-	-	10	-	-	-	-	12.5
Eleocharis acuta	-	9.09	39.47	-	100	100	66.67	12.2	-	40	-	-	-	44.44	62.5
Eleocharis pusilla	-	-	-	-	-	4.76	100	-	-	-	-	-	-	-	-
Eleocharis sphacelata	-	45.45	7.89	-	-	19.05	-	100	-	30	-	-	25	22.22	-
Elodea canadensis	-	-	2.63	-	-	-	-	9.76	100	-	-	-	-	11.11	-
Festuca spp.	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	12.5
Galium palustrium	-	-	2.63	-	-	-	-	2.44	-	40	-	-	-	-	-
Geranium spp.	-	-	-	-	-	4.76	-	-	-	-	-	-	-	-	-
Gratiola spp.	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-
Haloragis heterophylla	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Hemarthria uncinata	-	-	2.63	-	-	9.52	-	-	-	-	-	-	-	-	-
Hordeum marinum	-	-	-	-	-	-	-	-	-	30	-	-	-	-	-
Hydrocotyle pterocarpa	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Hydrocotyle spp.	-	9.09	44.74	-	100	42.86	66.67	4.88	-	100	-	-	-	22.22	25
Hypericum spp.	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Isolepis fluitans	-	-	2.63	-	-	4.76	-	4.88	16.67	20	-	100	-	11.11	-
Isolepis inundata	-	-	-	-	-	-	-	-	-	10	33.3	-	-	-	-
Isolepis spp.	-	-	-	-	-	-	-	-	-	-	100	-	25	-	-
Juncus articulatus	-	-	21.05	-	-	9.52	-	-	-	50	33.3	-	100	22.22	25
Juncus astreptus	-	-	2.63	-	-	-	-	-	-	-	-	-	-	44.44	-
Juncus australis	-	-	5.26	-	-	-	-	-	-	-	-	-	-	-	-
Juncus holoschoenus	-	-	-	-	-	-	-	-	-	-	-	-	-	11.11	-
Juncus procerus	-	-	7.89	-	-	-	-	-	-	-	-	-	-	33.33	-

Species														
Juncus spp.	-	-	36.84	-	-	9.52	-	-	-	50	33.3	-	100	100	25
Leontodon taraxacoides	-	-	28.95	-	100	-	-	-	-	30	-	-	25	11.11	12.5
Leptinella reptans	-	-	13.16	-	-	4.76	-	-	-	10	-	-	-	-	25
Lilaeopsis brownii	-	-	5.26	-	-	4.76	-	-	-	10	33.3	-	-	-	-
Lolium perenne	-	-	2.63	-	-	4.76	-	-	-	50	-	-	-	-	12.5
Lotus pedunculatus	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Lotus spp.	-	-	13.16	-	-	-	-	-	-	10	33.3	-	25	11.11	12.5
Lotus tenuis	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Lysimachia nummularia	-	9.09	47.37	-	100	23.81	-	-	-	50	-	-	25	22.22	100
Mentha pelugium	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-
Myosotis caespitosa	-	9.09	5.26	-	-	-	-	-	-	20	33.3	-	-	-	25
Myriophyllum amphibian	-	-	2.63	-	-	-	66.67	-	-	-	33.3	-	-	-	-
Myriophyllum salsugineum	-	18.18	-	-	-	9.52	-	7.32	-	-	-	11.1	-	-	-
Myriophyllum simulans/ variifolium	-	18.18	2.63	-	-	4.76	-	17.1	16.67	10	-	-	-	-	-
Neopaxia australasica	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Nymphoides spp.	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Persicaria decipiens	-	-	2.63	-	-	-	-	-	-	10	-	-	-	-	-
Persicaria hydropiper	-	-	5.26	-	-	-	-	-	-	10	-	-	-	-	12.5
Persicaria spp.	-	9.09	36.84	-	-	19.05	-	9.76	-	50	33.3	-	-	11.11	37.5
Phragmites australis	-	-	10.53	-	100	4.76	-	2.44	-	-	-	-	-	-	12.5
Plantago coronopus	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Poaceae spp.	-	-	5.26	-	100	9.52	-	7.32	-	10	-	-	-	11.11	12.5
Potamogeton australiensis	-	-	2.63	-	-	-	-	-	-	-	-	11.1	-	-	-
Potamogeton ochreatus	-	-	-	-	-	-	-	7.32	33.33	-	33.3	-	-	-	12.5
Potamogeton tricarinatus	-	9.09	-	-	-	-	-	-	-	-	-	-	-	-	-
Potentilla anglica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Pratia pedunculata	-	-	5.26	-	-	19.05	-	7.32	-	50	-	-	-	11.11	-
Prunella vulgaris	-	-	-	-	-	-	-	-	-	-	33.3	-	-	-	-
Pseudognaphalium luteo-album	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-
Ranunculus amphitrichous	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-
Ranunculus repens	-	-	2.63	-	-	-	-	-	-	-	-	-	-	11.11	12.5
Ranunculus rivularis	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Rumex crispus	-	-	2.63	-	-	-	-	-	-	-	-	-	-	-	12.5
Rumex spp.	-	-	5.26	-	100	-	-	-	-	30	-	-	-	11.11	25
Schoenoplectus validus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triglochin procerum	-	36.36	5.26	-	-	9.52	-	21.9	-	-	-	-	-	-	12.5
Triglochin spp.	-	45.45	5.26	-	-	33.33	-	29.3	16.67	20	-	-	-	11.11	12.5
Typha spp.	-	-	-	-	-	-	-	-	-	-	-	5.56	-	11.11	-
Vallisneria americana	-	-	-	-	-	4.76	-	17.1	-	-	-	-	-	-	-
Villarsia reniformis	-	27.27	5.26	-	-	4.76	-	7.32	-	10	-	-	-	-	-

(b) Groups 16-28

SPECIES	G16	G17	G18	G19	G20	G21	G22	G23	G24	G25	G26	G27	G28
Acaena novae-zelandiae	-	-	-	-	-	-	-	-	-	-	-	-	-
Agrostis aemula	-	-	-	-	-	-	-	-	-	-	-	-	-
Agrostis avenacea	-	-	-	-	-	-	-	-	-	-	-	-	-
Agrostis stolonifera	-	-	-	-	-	-	100	-	-	-	-	-	37.5
Alisma plantago-aquatica	-	-	-	-	-	-	-	-	-	-	-	-	-
Alopecurus geniculatus	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Azolla filiculoides	-	-	-	-	-	-	-	25	-	-	-	-	-
Batrachium tricophyllum	-	-	-	-	-	-	-	-	-	-	-	-	-
Baumea arthrophylla	-	6.25	6.25	-	-	-	-	-	-	-	-	-	-
Baumea articulata	-	-	-	-	-	-	-	-	-	-	-	-	-
Callitriche stagnalis	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex appressa	-	-	-	-	-	-	100	-	-	-	-	-	12.5
Carex fascicularis	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex gaudichaudiana	-	-	-	-	18.75	-	-	-	-	-	-	-	12.5
charophytes	-	-	-	-	-	-	-	-	-	-	-	-	-
Centella cordifolia	14.29	6.25	-	-	-	-	-	-	6.67	-	-	-	-
Crassula helmsii	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyperus gunnii	-	-	-	-	-	-	100	-	-	-	-	-	37.5

Species												
Eleocharis acuta	-	6.25	18.75	100	6.25	-	-	-	-	-	-	-	25
Eleocharis pusilla	-	-	-	-	-	-	-	-	-	-	-	-	-
Eleocharis sphacelata	-	12.5	12.5	-	-	-	-	50	-	-	-	-	-
Elodea canadensis	14.29	-	-	100	-	-	-	50	-	4	-	-	-
Festuca spp.	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Galium palustrium	-	-	-	-	-	-	100	-	-	-	-	-	12.5
Geranium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Gratiola spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Haloragis heterophylla	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemarthria uncinata	-	-	-	-	-	-	-	-	-	-	-	-	-
Hordeum marinum	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrocotyle pterocarpa	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrocotyle spp.	14.29	-	-	-	6.25	-	-	-	-	-	-	-	25
Hypericum spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Isolepis fluitans	57.14	12.5	37.5	-	12.5	-	-	25	6.67	4	-	-	-
Isolepis inundata	-	-	-	-	-	-	-	-	-	-	-	-	-
Isolepis spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Juncus articulatus	-	-	6.25	-	-	-	-	-	-	-	-	-	12.5
Juncus astreptus	-	-	-	-	-	-	-	-	-	-	-	-	37.5
Juncus australis	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Juncus holoschoenus	-	-	-	-	-	-	-	-	-	-	-	-	-
Juncus procerus	-	-	-	-	6.25	-	-	-	-	-	-	-	-
Juncus spp.	-	-	6.25	-	6.25	-	-	-	-	-	-	-	37.5
Leontodon taraxacoides	-	-	-	-	6.25	-	-	-	-	-	-	-	37.5
Leptinella reptans	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Lilaeopsis brownii	-	-	-	-	-	-	-	-	6.67	-	-	-	-
Lolium perenne	-	-	-	-	-	-	-	-	-	-	-	-	37.5
Lotus pedunculatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Lotus spp.	-	-	-	-	-	-	100	-	-	-	-	-	25
Lotus tenuis	-	-	-	-	-	-	-	-	-	-	-	-	-
Lysimachia nummularia	-	-	-	100	-	-	100	-	-	-	-	-	50
Mentha pelugium	-	-	-	-	-	-	-	-	-	-	-	-	-
Myosotis caespitosa	-	-	-	-	6.25	-	-	-	-	-	-	-	25
Myriophyllum amphibian	-	-	-	-	-	-	-	-	-	-	-	-	-
Myriophyllum salsugineum	28.57	100	12.5	-	-	-	-	-	-	-	-	100	12.5
Myriophyllum simulans/ variifolium	-	-	100	-	-	-	-	-	6.67	4	-	-	-
Neopaxia australasica	100	-	12.5	-	-	-	-	-	6.67	-	-	-	-
Nymphoides spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Persicaria decipiens	-	-	-	-	-	-	-	-	-	-	-	-	-
Persicaria hydropiper	-	-	-	-	-	-	-	-	-	-	-	-	-
Persicaria spp.	-	6.25	6.25	100	-	-	-	25	-	-	-	-	62.5
Phragmites australis	-	-	-	-	100	-	-	-	6.67	-	-	-	-
Plantago coronopus	-	-	-	-	-	-	-	-	-	-	-	-	-
Poaceae spp.	-	-	-	-	-	-	-	-	-	-	-	-	50
Potamogeton australiensis	14.29	6.25	-	-	-	-	-	-	-	-	-	-	-
Potamogeton ochreatus	14.29	-	12.5	-	-	100	-	-	-	32	-	-	-
Potamogeton tricarinatus	14.29	-	-	-	-	-	-	-	6.67	-	-	-	-
Potentilla anglica	-	-	-	-	-	-	-	-	-	-	-	-	12.5
Pratia pedunculata	-	6.25	-	-	-	-	-	-	-	-	-	-	-
Prunella vulgaris	-	-	-	-	-	-	-	-	-	-	-	-	-
Pseudognaphalium luteo-album	-	-	-	-	-	-	-	-	-	-	-	-	-
Ranunculus amphitrichous	-	-	-	-	-	-	-	-	-	-	-	-	-
Ranunculus repens	-	-	-	-	-	-	100	-	-	-	-	-	12.5
Ranunculus rivularis	-	-	-	-	-	-	-	-	-	-	-	-	-
Rumex crispus	-	-	-	-	-	-	-	-	-	-	-	-	-
Rumex spp.	-	-	-	-	-	-	100	-	-	-	-	-	25
Schoenoplectus validus	-	-	-	-	-	-	-	100	-	-	-	-	-
Triglochin procerum	28.57	6.25	12.5	-	-	-	-	50	60	8	-	100	-
Triglochin spp.	57.14	6.25	50	100	-	-	-	50	100	8	-	100	-
Typha spp.	-	-	-	-	-	-	-	-	-	-	-	100	-
Vallisneria americana	14.29	-	6.25	-	-	-	-	-	-	100	-	-	-
Villarsia reniformis	-	6.25	6.25	-	-	-	-	-	-	-	100	-	12.5

The following table summarises the distinguishing features of the 28 dominant species groups. The group means differed significantly in substrate type, minimum and maximum depth, distance upstream, site cover and species richness.

Table 3.2 Mean values for vegetation cover, species richness and environmental variables by dominant species group

Substr, substrate; Sitecover, percentage of site covered by dominant species type; Mindepth, minimum depth of dominant species type (m); Maxdepth, maximum depth of dominant species type (m); Kmsup, distance upstream from junction of the two rivers (kms); Stockd, stock damage at site; Rich, total number of species in dominant species type; Bankvg, nativeness of bank vegetation; Probability values from Kruskal-Wallis Tests are shown: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; n.s., $P > 0.05$. n = number of dominant species types in group.

Group	n	Dominant species	Substr[a]	Mindepth[d]	Maxdepth	Sitecover	Rich	Bankvg[b]	Stockd[c]	Kmsu
1	1	*Batrachium tricophyllum*	1	0.2	0.3	1.21	1	3	2	60
2	11	*Baumea arthrophylla*	1	0.16	0.65	6.39	3.64	2.45	2.64	99.73
3	38	*Carex gaudichaudiana*	1	-0.32	0.18	7.24	5.79	2.42	1.97	64.53
4	8	Charophytes	2.5	0.63	1.08	4.67	1	2.75	1.88	72.45
5	1	*Cyperus gunnii*	1	-0.6	0.1	13.33	8	2	3	29
6	21	*Eleocharis acuta*	1.24	-0.14	0.23	7.39	3.90	2.38	2.19	65
7	3	*Eleocharis pusilla*	1	-0.1	0.15	1.01	3	3	1.67	88.67
8	41	*Eleocharis sphacelata*	1.10	0.29	1.17	7.59	2.78	2.41	2.17	68.45
9	6	*Elodea canadensis*	1.17	0.57	1.56	20.18	2	2.33	2.17	55.48
10	10	*Hydrocotyle* spp.	1.2	-0.18	0.41	17.27	9.6	2.2	2.5	63.63
11	3	*Isolepis* spp.	1.67	-0.03	0.38	4.83	5.67	3	2.33	113.6
12	18	*Isolepis fluitans*	2.33	0.27	0.67	10.04	1.39	3.11	1.56	87.78
13	4	*Juncus articulatus*	1	-0.16	0.2	3.76	3.75	2.5	1.25	91.75
14	9	*Juncus* spp.	1	-0.01	0.2	4.23	5	2.56	2.11	90.44
15	8	*Lysimachia nummularia*	1	-0.31	0.23	11.05	6.38	2.5	2.25	74.5
16	7	*Neopaxia australasica*	2.14	0.3	0.74	18.66	3.71	2.57	2.14	101.14
17	16	*Myriophyllum salsugineum*	2.19	0.21	0.8	10.47	1.81	2.81	2.13	85.88
18	16	*Myriophyllum simulans/ variifolium*	1.88	0.24	0.87	21.38	3.06	2.44	2.13	64.48
19	1	*Persicaria* spp.	1	0.35	0.9	1.9	5	2	2	9.8
20	16	*Phragmites australis*	1	-0.13	0.51	4.74	1.69	3.25	1.44	81.17
21	2	*Potamogeton ochreatus*	1	2.5	3	5.78	1	2.5	2	73.5
22	1	*Ranunculus repens*	1	-0.4	0.35	7.7	8	2	2	9.8
23	4	*Schoenoplectus validus*	1	0.13	0.71	27.14	3.75	2	2	55
24	15	*Triglochin* spp.	1.53	0.60	0.97	3.17	2.07	2.8	2.2	89.89
25	25	*Vallisneria americana*	1.16	1.06	2.42	17.59	1.6	2.2	2.28	58.88
26	1	*Villarsia reniformis*	1	0	0.1	1.94	1	2	2	61
27	1	*Typha* spp.	1	0	0.5	9.23	4	2	2	108
28	8	Poaceae spp.	1	-0.21	0.28	15.85	6.75	2.38	2.25	41.98
		P	***	***	***	**	***	n.s.	n.s.	***

[a]Substrate, 1 = mud, 2 = mud/rock, 3 = gravel, 4 = rock
[b]Nativeness of bank vegetation, on a scale of 1-6 from least native to most native
[c]Stock damage, 1-3 from none to severe
[d]negative depth readings indicate height above water level

3.4.1.2 Relationships between environmental variables and cover and richness of dominant species types.

Table 3.3 shows the correlations between the percentage cover and species richness of the dominant species types and environmental variables. The environmental variables that were most strongly related to the richness and % site cover of the dominant species types were 'rockiness of substrate', distance upstream, maximum and minimum depth, river form and 'nativeness of bank vegetation'. Percentage cover was significantly related to form and species richness was significantly related to bank vegetation type. These variables were all inter-related, see Chapter 4, and varied from reach to reach along the two rivers.

A Kruskal-Wallis test ($P = 0.00$) showed that dominant species types found on mud were richer in species than those found on rocky substrates. Gravel dominant species types were particularly species poor. Note that the majority of dominant species types were found on mud, although more of the aquatic dominant species groups were found on gravel or rock than marginal dominant species groups.

Table 3.3 Correlations between the richness and cover of the dominant species types, and environmental variables. Spearmans rank correlation coefficients ($P < 0.05$) are used for continuous variables and Kruskal-Wallis probabilities for ordinal variables.

Substr, substrate; Sitecover, percentage of site covered by dominant species type; Mindepth, minimum depth of dominant species type; Maxdepth, maximum depth of dominant species type; Kmsup, distance upstream from junction of the two rivers; Stockd, stock damage at site; Rich, total number of species in dominant species type; Bankvg, nativeness of bank vegetation; Form, form of river site. Kruskal-Wallis Test Probabilities: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; -, $P > 0.05$.

	mindepth	maxdepth	sitecover	rich	bankvg[b]	stockd[c]	kmsup	form[d]
substr[a]	***	-	-	***	***	***	*	***
mindepth		0.80	-	-0.47	-	-	-	**
maxdepth			0.16	-0.35	-	-	-0.21	***
sitecover				0.32	-	-	-0.18	***
richness					**	-	-0.15	-
bankvg						***	***	*
stockd							***	***

[a]Substrate type, 1 = mud, 2 = mud/rock, 3 = gravel, 4 = rock
[b]Nativeness of bank vegetation, on a scale of 1-6 from least native to most native
[c]Stock damage, 1-3 from none to severe
[d] Form of river site; run, riffle or pool.

3.4.1.3 Multi-dimensional scaling of dominant species groups

The 28 dominant species groups formed distinct clusters (figure 3.1), and separated well along the minimum depth and maximum depth vectors (which were almost parallel). The positioning of the dominant species groups shows that species assemblages dominated by *Elodea canadensis, Vallisneria americana*, and *Neopaxia australasica* were found deepest, and those dominated by *Juncus* species, Poaceae species, *Carex gaudichaudiana* and *Lysimachia nummularia* were found in the shallowest water. Species assemblages dominated by *Carex gaudichaudiana, Lysimachia nummularia* and Poaceae species appeared in the top right of the first chart, which placed them high on the 'species richness' vector. Species assemblages dominated by *Elodea canadensis, Baumea arthrophylla, Neopaxia australasica* and *Triglochin* species appear in the bottom left corner, low on the richness vector. *Neopaxia australasica* and *Triglochin* dominated assemblages clustered highest on the 'rockiness of substrate' vector.

Table 3.4 shows the correlations between the dominant species group scores on the ordination axes and the environmental variables, species richness and cover. The maximum correlation coefficients (R) from the vector fitting are shown for continuous variables. Minimum and maximum depth were the environmental variables that correlated most strongly with the ordination space. Distance upstream was also significantly correlated. Species richness showed a stronger correlation than vegetation cover.

Figure 3.1a Dominant species groups

Legend:
- ◆ Baumea arthrophylla
- ■ Carex gaudichaudiana
- △ Charophytes
- ✕ Eleocharis acuta
- ✻ Eleocharis pusilla
- ● Eleocharis sphacelata
- + Elodea canadensis
- − Hydrocotyle
- − Isolepis
- ◆ Isolepis fluitans
- ■ Juncus articulatus
- ▲ Juncus
- ○ Lysimachia nummularia
- ✳ Neopaxia australasica
- ● Myriophyllum salsugineum
- + Myriophyllum simulans/variifolium
- ○ Phragmites australis
- − Potamogeton ochreatus
- ◆ Schoenoplectus validus
- ■ Triglochin
- ▲ Vallisneria americana
- ✕ Poaceae spp.

Figure 3.1b Dominant species groups

Legend:
- ◆ *Baumea arthrophylla*
- ● *Eleocharis sphacelata*
- ■ *Juncus articulatus*
- ✛ *Myriophyllum simulans/variifolium*
- ▲ *Vallisneria americana*
- ■ *Carex gaudichaudiana*
- ✛ *Elodea canadensis*
- △ *Juncus*
- – *Phragmites australis*
- ✕ Poaceae spp.
- △ Charophytes
- – *Hydrocotyle*
- ○ *Lysimachia nummularia*
- — *Potamogeton ochreatus*
- ✕ *Eleocharis acuta*
- – *Isolepis*
- □ *Neopaxia australasica*
- ◆ *Schoenoplectus validus*
- ✳ *Eleocharis pusilla*
- ◇ *Isolepis fluitans*
- ● *Myriophyllum salsugineum*
- ■ *Triglochin*

Figure 3.1c Dominant species groups

Legend:
- ◆ *Baumea arthrophylla*
- ■ *Carex gaudichaudiana*
- ▲ *Charophytes*
- ✕ *Eleocharis acuta*
- ✳ *Eleocharis pusilla*
- ● *Eleocharis sphacelata*
- ＋ *Elodea canadensis*
- – *Hydrocotyle*
- – *Isolepis*
- ◆ *Isolepis fluitans*
- ■ *Juncus articulatus*
- ▲ *Juncus*
- ✕ *Lysimachia nummularia*
- ✳ *Neopaxia australasica*
- ● *Myriophyllum salsugineum*
- ＋ *Myriophyllum simulans/variifolium*
- ＋ *Phragmites australis*
- – *Potamogeton ochreatus*
- ◆ *Schoenoplectus validus*
- ■ *Triglochin*
- ▲ *Vallisneria americana*
- ✕ Poaceae spp.

Table 3.4 Correlations between the dominant species type scores on the ordination axes and environmental variables. Spearmans rank correlation coefficients ($P < 0.05$) were used for continuous variables and Kruskal-Wallis test probabilities were used for categoric variables. Substr, substrate; Mindepth, minimum depth of dominant species type; Maxdepth, maximum depth of dominant species type; Sitecover, percentage of site covered by dominant species type; Richness, total number of species in dominant species type; Stockd, stock damage at site; Bankvg, nativeness of bank vegetation; Kmsup, distance upstream from junction of the two rivers; Kruskal-Wallis Test Probabilities: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; -, $P > 0.05$.

Variable	Axis 1	Axis 2	Axis 3	Axis 4	R[1]
Substr[a]	**	***	***	-	-
Mindepth	-0.73	-0.26	-	-	0.71
Maxdepth	-0.67	-0.18	-	-	0.71
Sitecover	-	-	0.17	-	0.21
Richness	0.28	0.25	0.13	0.18	0.46
Stockd[c]	**	-	-	-	-
Bankvg[b]	-	-	-	-	-
Kmsup	-	-0.16	-	-0.12	0.20
Form[d]	**	**	**	-	-

[a]Class of substrate, 1 = mud, 2 = mud/rock, 3 = gravel, 4 = rock
[b]Nativeness of bank vegetation, on a scale of 1-6 from least native to most native
[c]Stock damage, 1-3 from none to severe
[d]Form of river site; run, riffle or pool
[1]Maximum R correlation value from vector fitting in DECODA (Minchin 1990)

3.4.1.4 Geographical distribution of the dominant species groups

In the following description the terms 'upper reach', 'middle reach' and 'lower reach' refer to the position of these reaches on the sections of river included in this study. They do not refer to the river as a whole. Figures 3.2 (a)-(d) illustrate the geographical distribution of dominant species groups.

The most common vegetation assemblages on the upper reach of the Macquarie (between Tooms River and the Blackman River) were those dominated by *Myriophyllum salsugineum*, *Baumea arthrophylla*, *Juncus* species and *Triglochin* species.

The middle reach of the Macquarie (between the Blackman River and Brumbys Creek) consisted of dominant species groups *Myriophyllum salsugineum*, *Myriophyllum*

53

simulans/variifolium, Lysimachia nummularia, Neopaxia australasica, Elodea canadensis, Hydrocotyle species, *Baumea arthrophylla, Carex gaudichaudiana, Eleocharis acuta, Eleocharis sphacelata, Triglochin* species *and Vallisneria americana.*

The most common dominant species groups on the lower reach of the Macquarie (from Brumbys Creek to the junction with the South Esk) were those dominated by *Hydrocotyle* species, *Carex gaudichaudiana*, Poaceae species and charophytes.

The upper reach of the South Esk (between Fingal and Storys Creek) was dominated by *Triglochin* species, *Isolepis fluitans, Carex gaudichaudiana, Eleocharis sphacelata* and charophytes.

The middle reach of the South Esk (between Storys Creek and Buffalo Brook) was dominated by *Phragmites australis, Isolepis fluitans* and occasionally *Juncus* species, *Eleocharis acuta* and *Eleocharis sphacelata*.

The most common dominant species types along the lower reach of the South Esk (between Buffalo Brook and the junction with the South Esk) were *Phragmites australis, Myriophyllum salsugineum/variifolium,Isolepis fluitans, Carex gaudichaudiana, Eleocharis sphacelata, Eleocharis acuta, Vallisneria americana* and Poaceae species.

Figure 3.2(a) Geographical distribution of dominant species groups

Legend: ◆ *Baumea arthrophylla*　■ *Carex gaudichaudiana*　▲ Charophytes　✕ *Eleocharis acuta*　✳ *Eleocharis pusilla*　— *Eleocharis sphacelata*　+ Towns and tributaries

Labels on chart: South Esk River, Perth, Junction, Cressy, Brumbys Creek, Lake River, Nile River, Buffalo Brook, Storys Creek, Fingal, St Pauls River, Avoca, Elizabeth River, Ross, Blackman River, Tooms River, Macquarie River

Axis labels: northing, easting
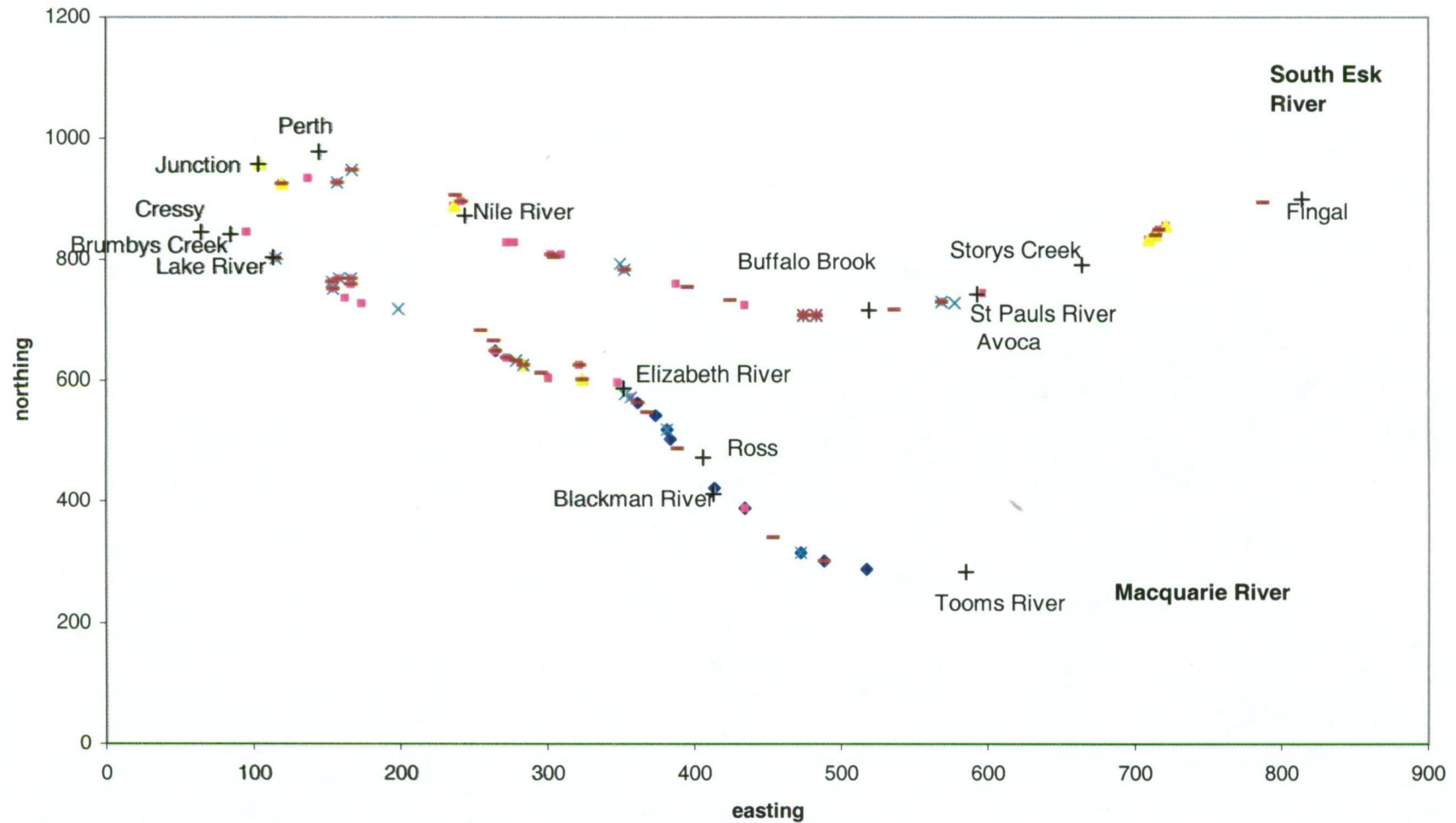
Figure 3.2(b) Geographical distribution of dominant species groups

Legend: ◆ Elodea canadensis   ■ Hydrocotyle   ▲ Isolepis   ✕ Isolepis fluitans   ✳ Juncus articulatus   ▬ Juncus   ✚ Towns and tributaries
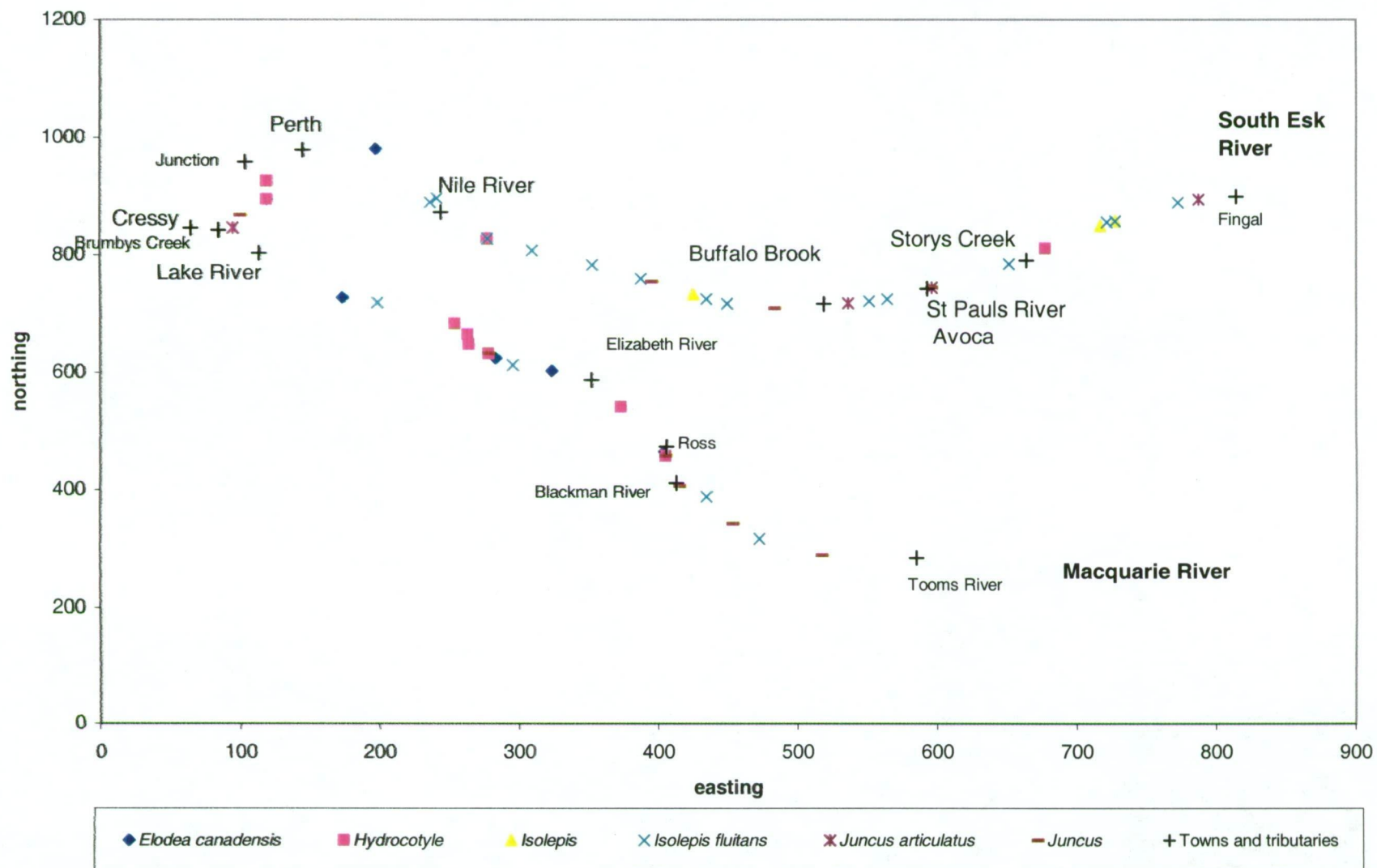
Figure 3.2(c) Geographical distribution of dominant species groups

Legend:
- ♦ Lysimachia nummularia
- ✳ Phragmites australis
- ■ Neopaxia australasica
- ● Potamogeton ochreatus
- ▲ Myriophyllum salsugineum
- + Towns and tributaries
- ☐ Myriophyllum simulans/variifolium
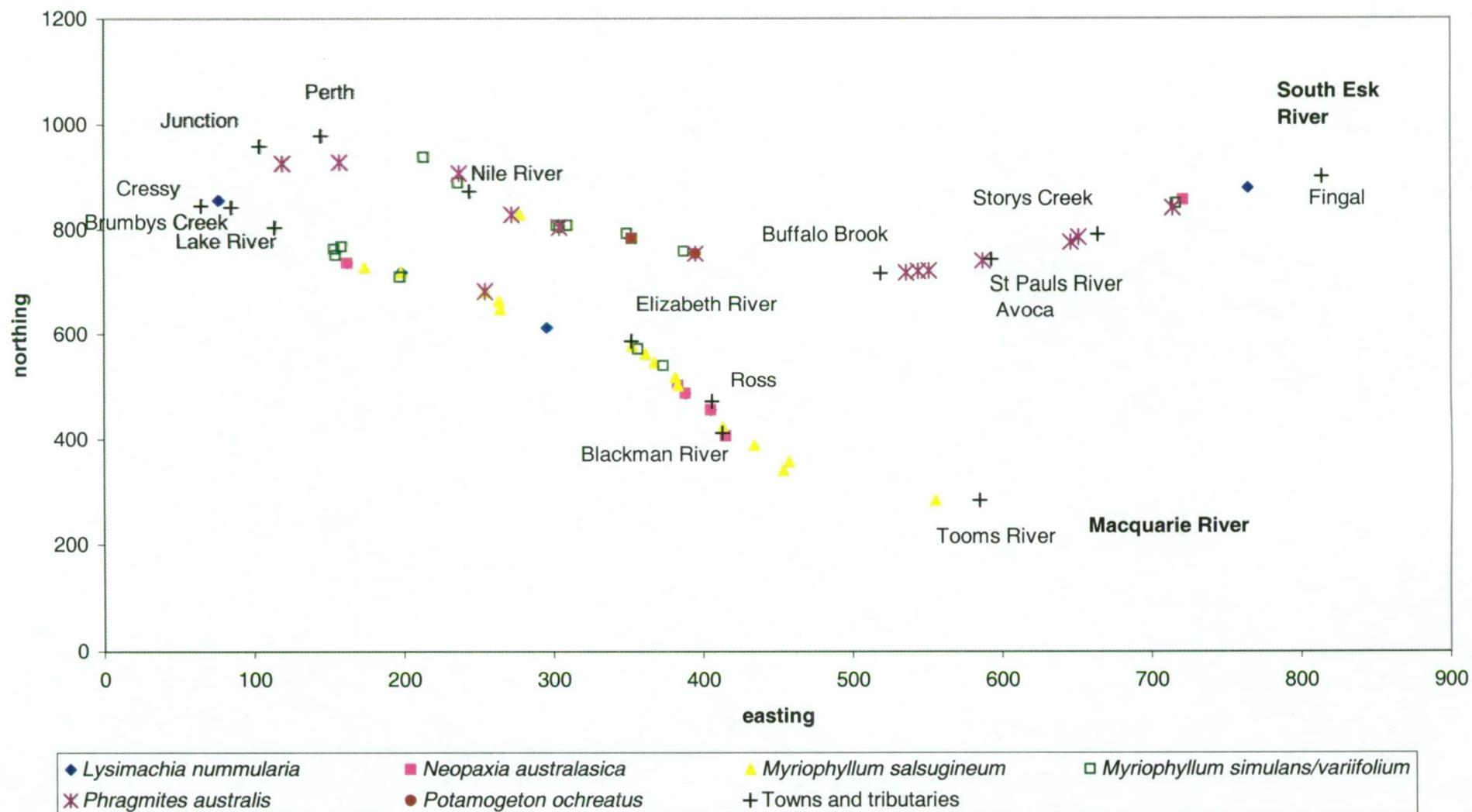
Figure 3.2(d) Geographical distribution of dominant species groups

South Esk River

Perth

Junction

Nile River

Cressy

Brumbys Creek

Lake River

Buffalo Brook

Storys Creek

St Pauls River

Avoca

Fingal

Elizabeth River

Ross

Blackman River

Tooms River

Macquarie River

northing

easting

◆ *Potamogeton ochreatus*   ■ *Schoenoplectus validus*   △ *Triglochin*   ✳ *Vallisneria americana*   ● Poaceae spp.   + Towns and tributaries
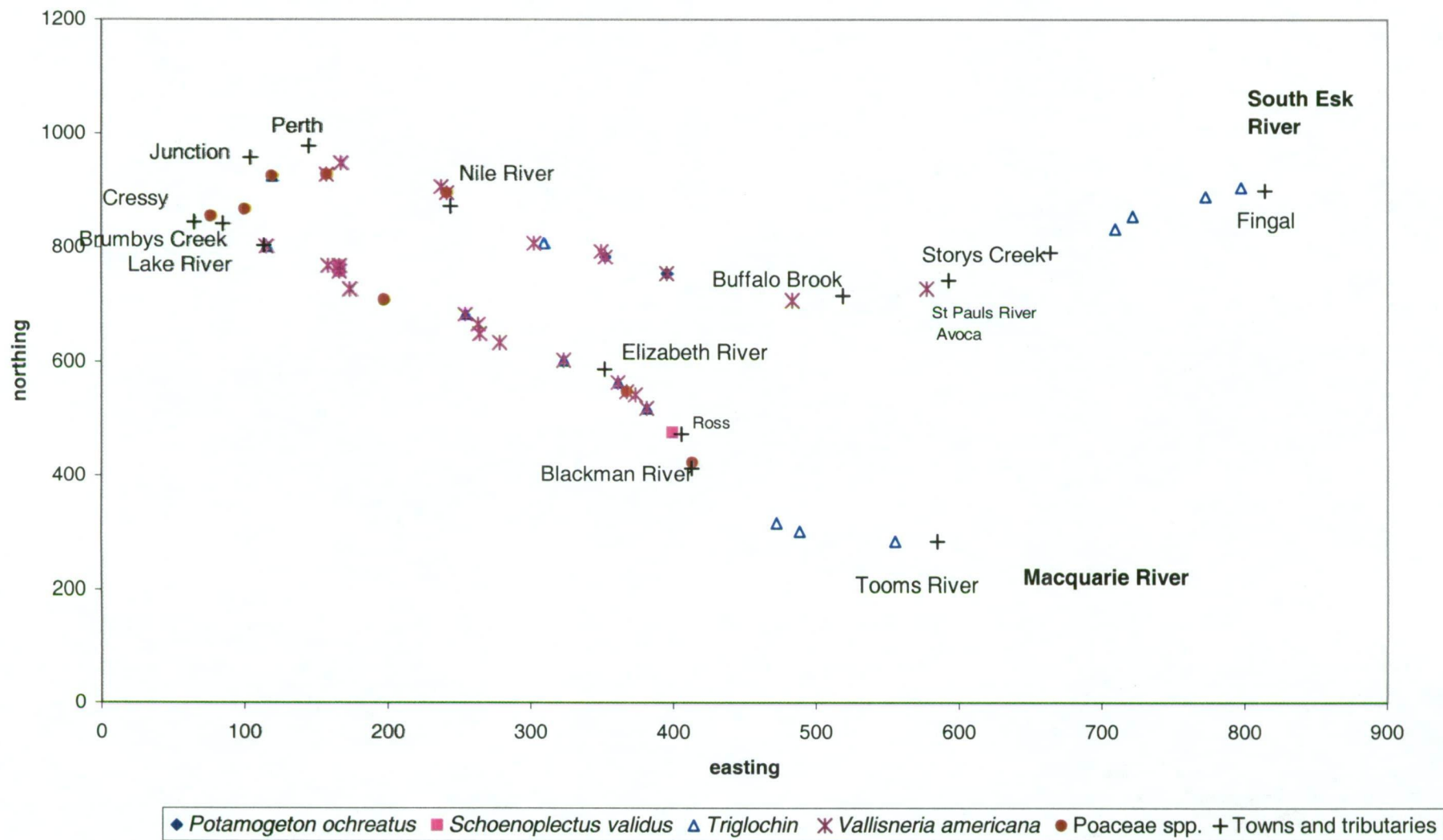
<u>3.4.2 Results of the analysis of the site vegetation using all species</u>

3.4.2.1 The species composition and geographical distribution of all-species groups

Eight groups were selected from the sorted table produced by TWINSPAN. Table 3.5 shows the percentage frequency of species in each group, figure 3.3 illustrates the geographical distribution of groups along the two rivers and figure 3.4 shows the indicator species for each TWINSPAN division:

1. Group 1 sites had very few species. All group 1 sites contained the submerged aquatic species *Isolepis fluitans,* more than three-quarters contained the marginal species *Carex gaudichaudiana* and two-thirds the emergent aquatic *Phragmites australis*. This group of nine sites was mostly found along a section of the upper half of the South Esk, starting just downstream of the confluence with Storys Creek.

2. The thirty group 2 sites all had *Juncus* species present, and most also had *Isolepis fluitans, Triglochin* species, *Eleocharis sphacelata, E. acuta* and *Carex gaudichaudiana.* Many had other aquatic and marginal species as well. That is, group 2 sites were species rich with a mixture of species of different growth forms. Group 2 was found along almost the entirety of the South Esk, but in only three points on the Macquarie - two upstream of Ross and one downstream of Brumbys Creek.

3. Group 3 sites were dominated by aquatic species, with very few marginal species. Almost all sites contained *Triglochin* species, most commonly associated with *Eleocharis sphacelata, Myriophyllum salsugineum, Isolepis fluitans* and/or *Juncus* species. The eighteen group 3 sites were found predominantly in the upper half of the Macquarie, higher than any major tributaries or sewage treatment plants.

4. Group 4 sites also almost all contained *Triglochin* species, *Eleocharis sphacelata* and *Eleocharis acuta,* along with a range of other species such as *Myriophyllum* species and/or *Vallisneria americana,* and/or the marginal species *Carex gaudichaudiana, Hydrocotyle*

59

species, *Lysimachia nummularia* and *Persicaria* species. More than a third of the sites contained *Elodea canadensis*. The twenty-five group 4 sites only occurred in the mid and lower reaches of the Macquarie, between the sewage treatment ponds at Ross and the confluence with Brumbys Creek.

5. The most common species in group 5 sites were *Juncus* species and *Eleocharis acuta*. These sites were conspicuously low in submerged or floating-leaved species, with only *Triglochin* species and *Isolepis fluitans* occurring frequently. The marginal species *Persicaria* species, *Lotus* species, *Leontodon taraxacoides, Myosotis caespitosa* and *Carex gaudichaudiana* were also frequent. The nine sites in group 5 occurred only in the very high reaches of the South Esk (upstream of Storys Creek) and the very low reaches of the Macquarie (downstream of Brumbys Creek).

6. Group 6 sites contained a mixture of marginal and aquatic species. *Triglochin* species, *Eleocharis sphacelata*, and *Potamogeton ochreatus* were found in each of these sites, as were the marginal species *Juncus* species, *Hydrocotyle* species, *Persicaria* species, *Lysimachia nummularia, Pratia* species and *Carex appressa*. There were only 5 sites in group 6, clustered together about a third of the way up the Macquarie, downstream of both the Ross and Campbelltown sewage outflows.

7. The three sites in group 7 were distinct in that they had almost no submerged or floating-leaved vegetation, apart from occasional *Potamogeton ochreatus* plants, but shared common emergent and marginal species such as *Juncus* species and *Eleocharis acuta, Lysimachia nummularia, Lotus* species, *Agrostis* species, *Alopecurus geniculatus* and *Lolium* species. These 3 sites all appeared just downstream of the confluence of Brumbys Creek with the Macquarie.

8. The banks of group 8 sites were so thickly infested with willows that there was no marginal or aquatic vegetation. All 3 of these sites were in the lower third of the South Esk.

Table 3.5 Percentage frequency of marginal and aquatic species in each TWINSPAN group.
Group 8 was not included as these sites had no aquatic or marginal vegetation.
n= number of sites, *signifies exotic species.

SPECIES	Group1 (*n*=9)	Group2 (*n*=30)	Group3 (*n*=18)	Group4 (*n*=25)	Group5 (*n*=9)	Group6 (*n*=5)	Group7 (*n*=3)
Acaena novae-zelandiae	–	–	–	–	11.11	–	–
Agrostis aemula	–	–	5.56	–	–	–	–
Agrostis avenacea	–	–	–	–	11.11	–	–
Agrostis stolonifera	–	3.33	–	–	33.33	80.00	100.00
Alisma plantago-aquatica	–	13.33	–	4.00	–	–	–
Alopecurus geniculatus	–	–	5.56	4.00	–	80.00	100.00
Azolla filiculoides	–	–	–	4.00	–	–	–
Batrachium tricophyllum	–	3.33	5.56	–	–	–	–
Baumea arthrophylla	11.11	6.67	33.33	28.00	–	40.00	–
Baumea articulata	–	–	11.11	–	–	–	–
Byophytes	–	–	–	–	22.22	–	–
Callitriche stagnalis	–	10.00	–	–	–	–	–
Carex appressa	–	–	11.11	4.00	11.11	100.00	66.67
Carex fascicularis	–	–	5.56	–	–	–	–
Carex gaudichaudiana	77.78	70.00	38.89	68.00	55.56	40.00	–
Charophytes	–	–	–	4.00	–	–	–
Centella cordifolia	–	13.33	22.22	8.00	33.33	20.00	–
Crassula helmsii	–	3.33	–	–	–	–	–
Cyperus gunnii	–	16.67	–	44.00	33.33	–	–
Cyperus lucidus	–	3.33	5.56	–	11.11	–	–
Eleocharis acuta	22.22	63.33	33.33	88.00	77.78	60.00	100.00
Eleocharis pusilla	–	6.67	5.56	–	–	–	–
Eleocharis sphacelata	–	63.33	50.00	80.00	44.44	100.00	–
Elodea canadensis	–	10.00	5.56	40.00	11.11	60.00	–
Festuca spp.	–	3.33	11.11	–	11.11	–	–
Galium palustrium	–	10.00	–	–	33.33	60.00	–
Geranium spp.	–	–	–	4.00	–	–	–
Gratiola spp.	–	–	–	–	11.11	–	–
Haloragis heterophylla	–	–	5.56	–	–	–	–
Hemarthria uncinata	–	10.00	–	–	–	–	–
Hordeum marinum ssp.gussoneanum	–	–	–	–	–	60.00	–
Hydrocotyle hirta	–	–	5.56	16.00	–	20.00	–
Hydrocotyle pterocarpa	–	–	5.56	–	–	–	–
Hydrocotyle spp.	11.11	50.00	11.11	44.00	44.44	100.00	–
Hypericum spp.	–	–	–	–	11.11	–	–
Isolepis fluitans	100.00	63.33	38.89	32.00	66.67	20.00	–
Isolepis inundata	–	–	5.56	–	22.22	–	–
Isolepis spp.	100.00	65.67	40.02	34.00	70.44	–	–
Juncus articulatus	–	36.67	16.67	4.00	88.89	100.00	100.00
Juncus astreptus	–	26.67	5.56	–	33.33	20.00	100.00
Juncus australis	–	6.67	–	–	–	–	66.67
Juncus holoschoenus	–	–	5.56	4.00	11.11	–	–
Juncus procerus	–	53.33	11.11	–	33.33	20.00	–
Juncus spp.	–	93.33	44.44	12.00	77.78	100.00	100.00
Leontodon taraxacoides	11.11	10.00	–	20.00	55.56	80.00	100.00
Leptinella reptans	–	–	–	28.00	11.11	20.00	–
Lilaeopsis brownii	–	3.33	11.11	12.00	11.11	–	–
Lolium perenne	–	–	–	12.00	22.22	80.00	100.00
Lotus pedunculatus	–	–	5.56	–	–	–	–
Lotus spp.	–	–	5.56	8.00	66.67	–	100.00
Lotus tenuis	–	–	5.56	–	–	–	–
Lysimachia nummularia	–	20.00	33.33	80.00	44.44	100.00	100.00
Mentha pelugium	–	–	–	–	–	80.00	–
Neopaxia australasica	–	6.67	16.67	24.00	22.22	–	–

61

*Myosotis caespitosa	11.11	6.67	5.56	8.00	55.56	–	–
Myriophyllum amphibian	–	23.33	5.56	8.00	–	–	–
Myriophyllum pedunculatum ssp. pedunculatum	–	–	5.56	–	–	–	–
Myriophyllum salsugineum	11.11	10.00	61.11	48.00	–	60.00	–
Myriophyllum simulans/ variifolium	–	40.00	5.56	40.00	33.33	40.00	–
Nymphoides spp.	–	–	–	4.00	–	–	–
Oxalis perennans	–	–	–	–	11.11	–	–
Persicaria decipiens	–	3.33	–	4.00	11.11	–	–
Persicaria hydropiper	–	3.33	–	–	33.33	–	–
Persicaria prostrata	–	–	–	–	11.11	–	–
Persicaria spp.	–	13.33	–	60.00	77.78	100.00	–
Phragmites australis	66.67	53.33	–	20.00	33.33	20.00	66.67
*Plantago coronopus	–	–	–	–	–	20.00	–
Potamogeton australiensis	–	20.00	16.67	4.00	–	–	–
Potamogeton ochreatus	–	16.67	16.67	16.00	–	100.00	100.00
Potamogeton perfoliatus	–	–	–	8.00	–	–	–
Potamogeton tricarinatus	–	3.33	16.67	–	22.22	–	–
*Potentilla anglica	–	–	–	–	22.22	–	–
Pratia pedunculata	11.11	6.67	–	12.00	–	100.00	–
*Prunella vulgaris	–	–	–	–	11.11	–	–
Pseudognaphalium luteo-album	–	–	–	–	11.11	–	–
Ranunculus amphitrichous	–	–	–	–	11.11	–	–
*Ranunculus repens	–	–	–	–	33.33	–	100.00
Ranunculus rivularis	–	–	–	–	11.11	–	–
*Rumex crispus	–	–	–	4.00	11.11	–	33.33
*Rumex spp.	–	3.33	–	12.00	11.11	80.00	66.67
Schoenoplectus validus	–	–	–	12.00	–	–	–
*Trifolium spp.	–	–	–	–	–	20.00	–
Triglochin procerum	–	33.33	77.78	76.00	–	80.00	–
Triglochin spp.	44.44	60.00	88.89	96.00	66.67	100.00	–
Triglochin striatum	11.11	6.67	–	–	33.33	–	–
*Typha spp.	–	–	16.67	–	–	20.00	–
Vallisneria americana	–	33.33	5.56	52.00	–	80.00	–
Villarsia reniformis	–	–	5.56	28.00	–	80.00	–

Figure 3.3 Geographical Distribution of TWINSPAN groups of sites using all species

Legend: ◆ Group1 ■ Group2 △ Group3 △ Group4 ○ Group5 ● Group6 □ Group7 ○ Group8 + Towns and Tributaries

Labels on plot: Junction, Perth, Cressy, Brumbys Creek, Lake River, Nile River, Buffalo Brook, Storys Creek, St Pauls River, Avoca, South Esk River, Fingal, Elizabeth River, Ross, Blackman River, Macquarie River, Tooms River
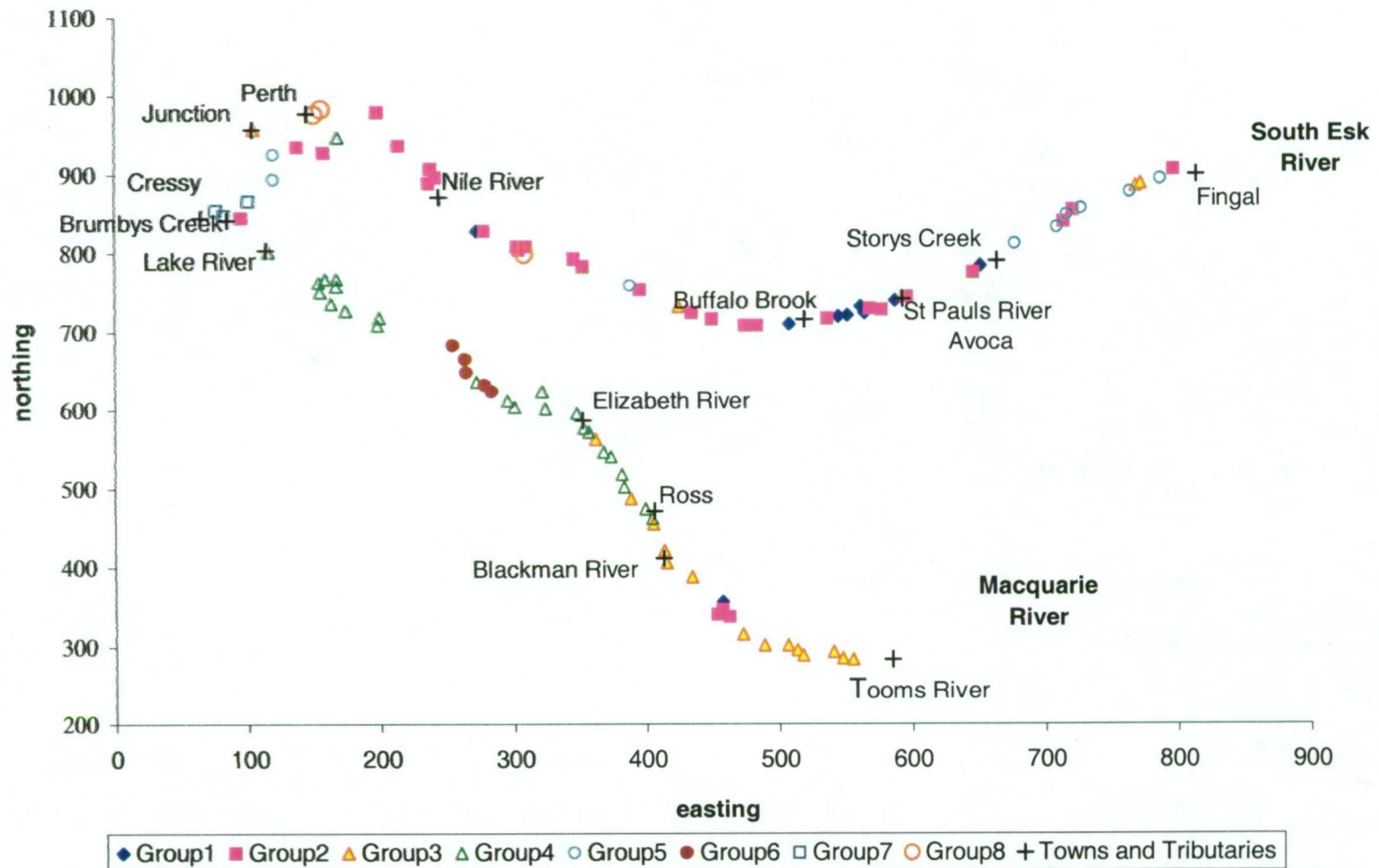
Figure 3.4 Dendrogram showing the preferential species for each TWINSPAN cluster, using presence/absence data for aquatic and marginal species in all sites on the Macquarie and South Esk Rivers. Groups with species names in brackets are defined by the absence rather than the presence of these species. Group numbers are given in bold.
n = number of sites.

```
                                                                    (Juncus spp.
                                                                    Eleocaris sphacelata)        1
                                                    Juncus spp.      (n = 9)
                                                    Phragmites australis
                                                      (n = 39)       Eleocharis sphacelata
                                                                     Juncus procera
                Triglochin procerum                                   (n = 30)                   2

                                                                     Juncus spp.
                  (n = 82)                                           Charophvtes
                                               Myriophyllum salsugineum.  (n = 18)               3
                                               Lysimachia nummularia
                                                                     Eleocharis acuta
                                                  (n = 43)           Persicaria spp.
                                               Myosotis caespitosa     (n = 25)                  4
                                               Isolepis spp.
                                                                                                 5
                Agrostis stolonifera              (n = 9)
                                                                     Eleocharis sphacelata
                  (n = 17)                                           Hydrocotyle spp.
                                               Potamogeton ochreatus   (n = 5)                   6
                                               Alopecurus geniculatus
                                                                     Ranunculus repens
                                                  (n = 8)            Lotus spp.
                                                                                                 7
                                                  (n = 3)
```

3.4.2.2 Variation in site cover, species richness and diversity between the TWINSPAN groups

There was a significant difference between the TWINSPAN groups in all richness, cover and diversity variables, see table 3.6. Group 6 had a significantly higher percentage cover of aquatic and marginal vegetation than groups 1, 3, 7 and 8. Group 6 also had a higher total species

64

richness than all other groups, a higher exotic species richness than groups 1, 3 and 8, and a higher aquatic species richness than groups 1, 7 and 8. Group 6 had a higher species diversity than groups 1 and 2.

Groups 5, 6 and 7 had a significantly higher exotic species richness and proportion of exotic species than all other groups. Groups 5 and 7 also had a lower proportion of aquatic species than the other groups. Group 1 had a lower total species richness and a lower exotic species richness than all groups except group 8. Group 1 also had a lower diversity than groups 4, 5, 6 and 7.

It is important to note that as there was only one exotic aquatic species found in this study (*Elodea canadensis*), a high exotic species richness implies a large number of exotic marginal species, that is, pasture species. This explains the low proportion of aquatic species in sites with a high proportion of exotic species.

Table 3.6 Mean values of species richness and cover for the TWINSPAN groups.
%cover, percentage of site covered by aquatic and marginal vegetation; Totrich, total number of species; Exrich, number of exotic species; Exr/totr, proportion of exotic species; Aqrich, number of aquatic species; Aqr/tr, proportion of aquatic species; Diversity, Shannon diversity. Probability values from Kruskal-Wallis tests are shown: ***, $P < 0.001$; n = number of sites.

	Group1 $n=9$	Group2 $n=30$	Group3 $n=18$	Group4 $n=25$	Group5 $n=9$	Group6 $n=5$	Group7 $n=3$	Group8 $n=3$	P
%cover	12.14 [ac]	25.00 [abc]	14.25 [ac]	44.83 [ab]	23.06 [abc]	79.28 [b]	4.74 [ac]	0 [c]	***
Totrich	4.11 [b]	10.6 [ae]	8.39 [e]	12.16 [a]	16.44 [c]	23.8 [d]	15.33 [ac]	0 [b]	***
Exrich	0.22 [b]	1.17 [ab]	0.94 [b]	1.96 [ab]	5.11 [a]	9 [a]	9.33 [a]	0 [b]	***
Exr/totr	0.03 [b]	0.11 [b]	0.11 [b]	0.16 [ab]	0.32 [a]	0.38 [a]	0.61 [a]	-	***
Aqrich	2.78 [ac]	5.7 [abc]	5.78 [abc]	7.2 [ab]	5.22 [abc]	8.8 [b]	2.67 [ac]	0 [c]	***
Aqr/tr	0.71 [a]	0.52 [abc]	0.71 [a]	0.61 [ab]	0.32 [c]	0.37 [bc]	0.17 [c]	-	***
Diversity	0.37 [b]	0.67 [ab]	0.69 [abc]	0.75 [ac]	0.87 [ac]	1.02 [c]	0.94 [ac]	-	***

[a,b,c,d,e] If any letter is the same then figures are not significantly different- from Dunn's Method of Pairwise comparisons

3.4.2.3 Environmental variation between TWINSPAN groups using all species

There were significant differences between the TWINSPAN groups in many of the environmental variables, see table 3.7. Although the groups were found to vary significantly in velocity, substrate, bank height, depth and stock damage, significant pairwise differences between groups at $P<0.05$ could not be determined using Dunn's method of pairwise comparisons.

Group 1 sites had the lowest mean values for 'slowness of current velocity' and depth, and the highest mean value for 'rockiness of substrate'. This indicates that group 1 sites were rockier, faster flowing and shallower, suggesting that they occurred on a higher proportion of riffles than the other groups. Group 1 sites were also significantly narrower than groups 2 and 6.

Groups 1, 5 and 8 were significantly different to group 6 in the percentage of shading from the bank vegetation. Groups 1,5 and 8 had a high percentage of shading whereas group 6 had a low percentage of shading. Groups 1 and 8 had a significantly lower level of stock damage than group 6.

Group 8 had much higher banks than the other groups. Groups 2 and 4 also appeared to have relatively high banks. The mean bank height for group 6 sites was lowest.
Group 3 was found further upstream than groups 4, 7 and 8.

Table 3.7 Mean values of environmental variables by TWINSPAN group. Vel, slowness of current velocity; %shade, percentage of site overshadowed by bank vegetation; Substr, dominant substrate; Bankht, height of bank on highest side; Width, maximum width at site; Depth, maximum depth at site; Bankvg, nativeness of bank vegetation; Kmsup, distance upstream from junction of the two rivers; Erosion, visible erosion of banks; Stockd, obvious trampling by stock; Probability values from Kruskal-Wallis tests are shown: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; n.s., $P > 0.05$. n = number of sites.

	Group1 $n=9$	Group2 $n=30$	Group3 $n=18$	Group4 $n=25$	Group5 $n=9$	Group6 $n=5$	Group7 $n=3$	Group8 $n=3$	P
Vel[1]	1.67*	2.37	2.78	2	1.89	2.6	2.33	2.67	*
%shade	37.03^a	8.25^{ab}	8.15^{ab}	5.00^{ab}	19.73^a	0^b	12.87^{ab}	46.67^a	***
Substr[2]	3.11*	2.27	2.17	1.72	2.67	1	1.33	1	**
Bankht	1.84*	2.89	1.08	2.53	1.67	0.98	1.37	5.5	**
Width	15^a	37.1^b	22.17^{ab}	18.98^{ac}	27.44^{ab}	36.4^{bc}	45.67^{ab}	56.67^{ab}	***
Depth[3]	1.67*	2.37	2.06	2.2	1.89	3	3	2.33	*
Bankvg[4]	3.33^a	2.9^{ab}	3.5^a	2.6^{ab}	2.67^{ab}	2^{ab}	2^{ab}	1^b	*
Kmsup	97.19^{ac}	76.16^{ac}	112.02^c	65.08^{ab}	97.81^{ac}	65.6^{abc}	17.33^b	33.33^{ab}	***
Erosion[5]	1.56	1.63	1.72	1.88	1.89	2	1.67	2.33	n.s.
Stockd[6]	1.22*	1.67	1.78	2.16	1.89	2.6	2	1	**

[1]Slowness of current velocity, 1=fast (riffle) 2=slow (run) 3=no discernible current velocity (pool)

[2] 'Rockiness' of substrate, 1=mud, 2=mud/rock, 3=gravel, 4=rock

[2]Depth, 1 = < 1 m, 2= 1-2 m, 3= >2 m

[3]Nativeness of bank vegetation, on a scale of 1 to 6 from least native to most native

[4]Erosion, 1-3 from none to severe

[5]Stock damage, 1-3 from none to severe

[a,b,c]If any letters are the same the figures are not significantly different, from Dunn's Method of Pairwise comparisons.

*Although a Kruskal-Wallis test found that the groups were significantly different at $P<0.05$, the pairwise test was not able to determine which pairs differed.

3.4.2.4 Multidimensional scaling (MDS) of sites using all species

A three-dimensional solution to the ordination was found to be most useful.

The eight TWINSPAN groups were plotted onto two scattercharts using the MDS ordination axes (figure3.5). Groups 1, 3, 4, 6 and 7 clustered together separately to the other groups on at least one of the charts. Groups 2 and 5 were not easily distinguishable. Group 8 did not appear at all because group 8 sites had no aquatic or marginal vegetation. The scattercharts illustrate the correlations between the environmental variable vectors and the TWINSPAN groups. They also illustrate relationships between the environmental and vegetation cover/richness variables themselves, for example, on both charts percentage cover and aquatic species richness are almost parallel, showing the correlation between aquatic richness and percentage vegetation cover.

Figure 3.5a TWINSPAN groups of sites using all species
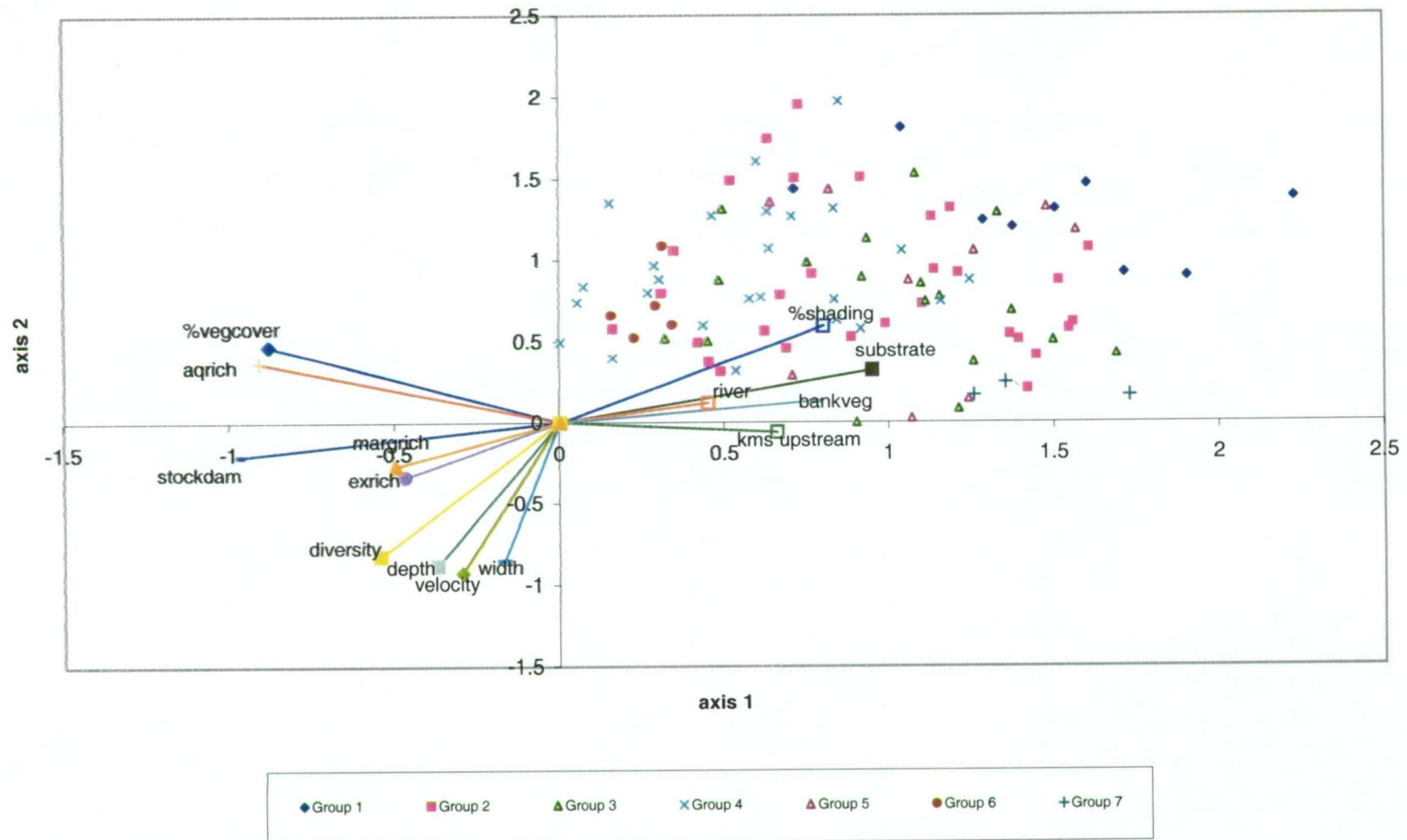
Figure 3.5b TWINSPAN groups of sites using all species
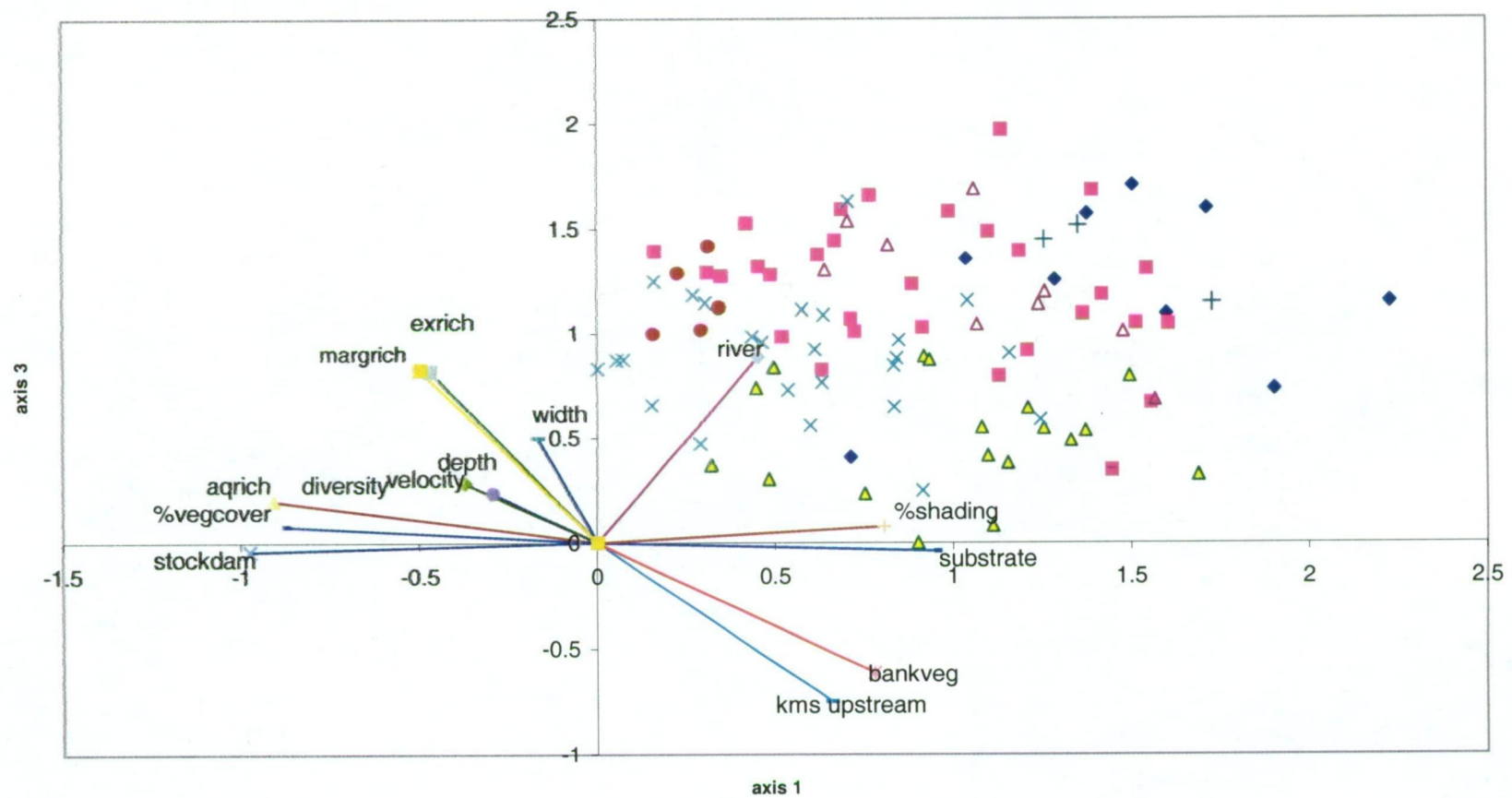
Table 3.8 shows that percentage cover and aquatic species richness were the variables most highly correlated with the positioning of sites along the first axis. Stream width, depth and current velocity were the (inter-related) variables most strongly correlated with the second axis, whereas proportion of aquatic species and marginal species richness were most strongly correlated with the third axis. Correlation coefficients (maximum R values) from the vector fitting are also shown in table 3.8. Percentage shading, stream width, distance upstream, percentage vegetation cover, aquatic and marginal species richness and diversity were all significantly correlated with the ordination values from MDS.

Table 3.8 Correlations between the site scores on the MDS axes and the maximum R values from vector fitting, and environmental variables, species richness and cover.
Spearmans rank correlation coefficients (*P* < 0.05) are shown for continuous variables and Kruskal-Wallis probabilities are shown for categoric variables.

Velocity, slowness of current velocity; %shade, percentage of site overshadowed by bank vegetation; Substr, dominant substrate; Bankht, height of bank on highest side; Width, maximum width at site; Depth, maximum depth at site; Bankvg, nativeness of bank vegetation; Kmsup, distance upstream from junction of the two rivers; Erosion, visible erosion of banks; Stockd, obvious trampling by stock; %cover, percentage of site covered by aquatic and marginal vegetation; Diversity species diversity using ?Shannon index; Totrich, total number of species; Exrich, number of exotic species; Exr/totr, proportion of exotic species; Aqrich, number of aquatic species; Aqr/tr, proportion of aquatic species. Probability values from Kruskal-Wallis Tests are shown: ***, *P* < 0.001; **, *P* < 0.01; *, *P* < 0.05; -, *P* > 0.05.

	Axis 1	Axis 2	Axis 3	Max R[1]
Velocity[a]	-	***	-	-
%shade	0.38	0.22	-	0.42
Substr[b]	***	-	-	-
Bankht	-	-	-	-
Width	-	-0.49	0.31	0.51
Depth[c]	-	***	-	-
Bankvg[d]	*	-	*	-
Kmsup	0.33	-	-0.29	0.37
Erosion[e]	-	-	-	-
Stockd[f]	***	-	-	-
%cover	-0.86	0.37	-	0.86
Diversity	-	-0.23	-	0.35
Totrich	-0.45	-	-	0.52
Exrich	-0.21	-	0.27	0.30
Exr/totr	-	-	0.24	-
Aqrich	-0.63	-	-	0.65
Mrich	-0.25	-	0.36	0.40
Aqr/tr	-	-	-0.42	-

[a]Slowness of current velocity, 1=fast 2=slow 3=no discernable current velocity
[b] 'Rockiness' of substrate, 1=mud, 2=mud/rock, 3=gravel, 4=rock
[c]Depth, 1 = < 1 m, 2= 1-2 m, 3= >2 m
[d]Nativeness of bank vegetation, on a scale of 1-6 from least native to most native
[e]Erosion, 1-3 from none to severe
[f]Stock damage, 1-3 from none to severe
[1]Maximum R-value from Vector Fitting in DECODA (Minchin 1990)

3.4.3 Results of the analysis of the site vegetation using aquatic species only

3.4.3.1 The species composition and environmental characteristics of the Aquatic
Groups

Nine groups were apparent from the TWINSPAN sorted table. Table 3.9 shows the percentage frequency of species in each aquatic group, figure 3.6 illustrates the geographical distribution of aquatic groups, and figure 3.7 shows the indicator species for each TWINSPAN division:

1. Aquatic group 1 consisted of four sites containing *Eleocharis acuta* and very little else. Three of the sites contained *Potamogeton ochreatus* and two *Phragmites australis*. Three of these sites were grouped together on the Macquarie just below the junction with Brumbys Creek, and one was on the South Esk just upstream of Avoca.

2. The fifteen aquatic group 2 sites all contained *Eleocharis sphacelata*, most also contained *Eleocharis acuta,* and more than half contained *Vallisneria americana, Phragmites australis* and/or *Triglochin* species. *Potamogeton ochreatus, Myriophyllum simulans* and *Isolepis fluitans* were also common. These sites were fairly evenly spaced along the South Esk, with only one occurring on the Macquarie.

3. The eighteen aquatic group 3 sites all contained *Triglochin* species (mostly *Triglochin procerum*), *Eleocharis sphacelata,* and *Vallisneria americana* (in all but one). Several other species were common, including *Eleocharis acuta* (in all but 3) *Potamogeton ochreatus, Myriophyllum simulans, Myriophyllum salsugineum, Villarsia reniformis* and *Elodea canadensis*. Most of this group were found on the Macquarie between Ross and the confluences with the Lake River and Brumbys Creek. Two were on the South Esk between Buffalo Brook and the confluence with the Nile River.

4. Aquatic group 4 sites all contained *Triglochin procerum*. *Myriophyllum salsugineum, Eleocharis sphacelata* and *Baumea arthrophylla* each occurred in about half of the 14 sites,

Eleocharis acuta in a third and several other species only in one or two sites. Ten of these sites were found in the top section of the Macquarie, above any towns or major tributaries. Three were found lower in the Macquarie, below the confluence with the Elizabeth River, and one was in the South Esk at Fingal.

5. Aquatic group 5 sites almost all contained *Isolepis fluitans, Triglochin* species and *Myriophyllum salsugineum* or *Myriophyllum simulans. Eleocharis sphacelata* and *Eleocharis acuta* were also very common, and *Neopaxia australis* and *Elodea canadensis* each occurred in about a third of the 24 sites in this group. These sites were found scattered along much of the Macquarie upstream of Brumbys Creek, with a particularly dense cluster around Ross. They were also found in the lower half of the South Esk.

6. The twelve aquatic group 6 sites were characterised by the presence of *Triglochin* species, *Isolepis fluitans,* charophytes and/or *Eleocharis acuta.* Each of these species was found in at least seven of the twelve sites. Other species were not common in this group. The lowest three sites on the Macquarie and the bottom South Esk site were in aquatic group 6. The other sites in this group were mostly found in the upper half of the South Esk.

7. The eight aquatic group 7 sites were species poor. All contained *Phragmites australis* and *Isolepis fluitans.* Four also contained *Eleocharis acuta* and three contained *Triglochin* species. These sites were all on the South Esk. Six were found between Storys Creek and Buffalo Brook, with only one found upstream of Storys Creek and one in the lower third of the river.

8. The four aquatic group 8 sites all contained *Isolepis fluitans* and almost nothing else. They all were found on the South Esk, three in the river section just downstream of Avoca (and so downstream of Storys Creek), and one upstream of Storys Creek.

9. The bank vegetation at the three aquatic group 9 sites was so willow choked that there was no aquatic vegetation. These sites were all on the lower section of the South Esk, two on pools at Perth and one on a run upstream of the confluence with the Nile River.

Table 3.9 Percentage frequency of species in Aquatic Groups

SPECIES	GRP1 (n=4)	GRP2 (n=15)	GRP3 (n=18)	GRP4 (n=14)	GRP5 (n=24)	GRP6 (n=12)	GRP7 (n=8)	GRP8 (n=4)
Alisma plantago-aquatica	–	13.33	5.56	–	8.33	–	–	–
Azolla filiculoides	–	–	–	–	4.17	–	–	–
Batrachium tricophyllum	–	6.67	–	–	4.17	–	–	–
Baumea arthrophylla	–	–	33.33	57.14	8.33	8.33	12.50	–
Baumea articulata	–	–	–	14.29	–	–	–	–
Callitriche stagnalis	–	–	5.56	–	8.33	–	–	–
Charophytes	–	6.67	11.11	14.29	8.33	58.33	–	–
Eleocharis acuta	100.00	86.67	83.33	35.71	58.33	58.33	50.00	–
Eleocharis pusilla	–	13.33	–	7.14	–	–	–	–
Eleocharis sphacelata	–	100.00	100.00	42.86	58.33	16.67	25.00	–
Elodea canadensis	–	13.33	38.89	–	29.17	16.67	–	–
Isolepis/Shoenus fluitans	–	33.33	16.67	14.29	83.33	66.67	100.00	100.00
Isolepis inundata	–	–	–	–	–	16.67	–	25.00
Isolepis spp.	–	40.33	16.67	14.29	83.33	72.00	100.00	100.00
Lilaeopsis brownii	–	20.00	–	–	12.50	8.33	–	–
Neopaxia australasica	–	6.67	–	–	37.50	25.00	–	–
Myriophyllum amphibian	–	33.33	5.56	–	12.50	8.33	–	–
Myriophyllum pedunculatum ssp. pedunculatum	–	–	–	7.14	–	–	–	–
Myriophyllum salsugineum	–	6.67	44.44	50.00	54.17	8.33	–	–
Myriophyllum simulans/ variifolium	–	46.67	50.00	–	41.67	16.67	–	–
Phragmites australis	50.00	53.33	27.78	14.29	25.00	16.67	100.00	–
Potamogeton australiensis	–	6.67	–	21.43	20.83	8.33	–	–
Potamogeton ochreatus	75.00	40.00	50.00	7.14	–	8.33	–	–
Potamogeton perfoliatus	–	–	11.11	–	–	–	–	–
Potamogeton tricarinatus	–	–	–	14.29	4.17	25.00	–	–
Triglochin procerum	–	33.33	77.78	100.00	54.17	8.33	–	–
Triglochin spp.	–	53.33	100.00	100.00	79.17	83.33	37.50	25.00
Triglochin striatum	–	6.67	–	–	–	25.00	12.50	25.00
Typha spp.	–	–	5.56	14.29	4.17	–	–	–
Vallisneria americana	–	66.67	94.44	–	4.17	–	–	–
Villarsia reniformis	–	–	38.89	14.29	12.50	–	–	–

Figure 3.6 Geographical distribution of TWINSPAN groups of sites using aquatic species only
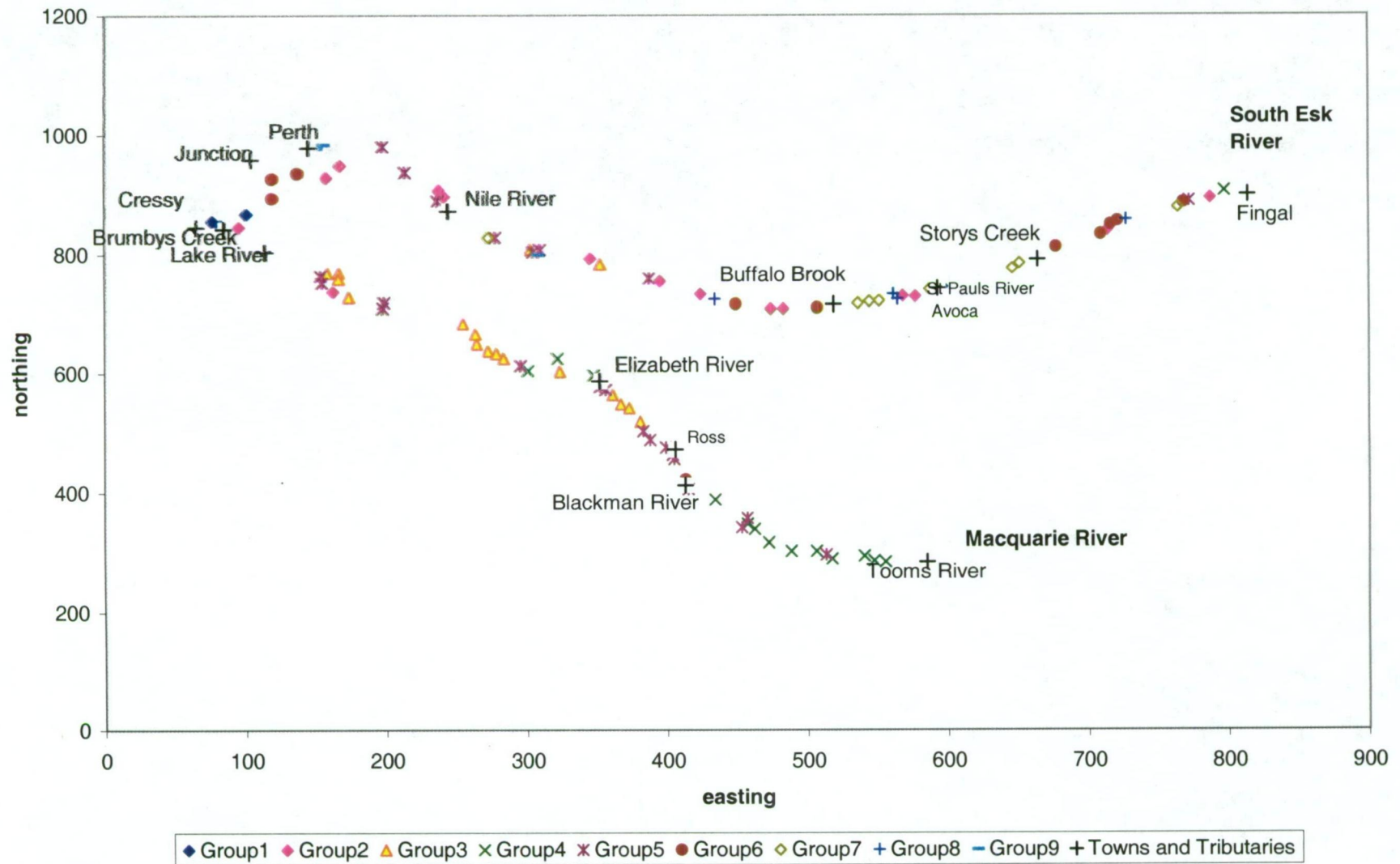
Figure 3.7 Dendrogram showing the preferential species for each TWINSPAN cluster, using abundance data for aquatic species in all sites on the Macquarie and South Esk Rivers. Groups with species in brackets are defined by the absence of these speciess rather than the presence. Group numbers are given in bold type. n = number of sites.

(Vallisneria americana
Eleocharis sphacelata)

1

Myriophyllum amphibian
Phragmites australis

(n=4)

Vallisneria americana
Eleocharis acuta
Eleocharis sphacelata

(n=19)

Vallisneria americana
Eleocharis sphacelata

2

Vallisneria americana
Eleocharis sphacelata
Potamogeton ochreatus

(n=37)

(n=15)

(n=51)

Triglochin spp.
Vallisneria americana

3

(n= 18)

Triglochin procerum
Baumea arthrophylla

4

(n= 14)

Isolepis fluitans
Myriophyllum salsugineum

5

Myriophyllum salsugineum
Triglochin procerum
Neopaxia australasica

(n=24)

(n= 36)

Charophytes
Triglochin striata

6

(n=12)

Isolepis fluitans
Neopaxia australasica

(n=48)

Phragmites australis
Eleocharis acuta

7

Phragmites australis

(n=8)

(n=12)

Isolepis inundata.

8

(n=4)

3.4.3.2 Variation in percentage cover and species richness between the TWINSPAN Aquatic Groups

Table 3.10 shows the variation in percentage cover and species richness between the TWINSPAN Aquatic Groups. Aquatic group 3 was significantly richer in species than aquatic groups 7, 8 and 9. Aquatic group 3 also had the greatest percentage site cover, significantly more than aquatic groups 1,4, 6, 8 and 9. Aquatic group 5 had a significantly higher site cover than aquatic groups 1 and 9.

Table 3.10 Mean values for cover and richness by aquatic group
Aqrich, number of aquatic species; Aqcover, percentage site cover of aquatic species. Probability values from Kruskal-Wallis tests are shown: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; n.s., $P > 0.05$. n=number of sites.

	Group1 $n = 4$	Group2 $n = 15$	Group3 $n = 18$	Group4 $n = 14$	Group5 $n = 24$	Group6 $n = 12$	Group7 $n = 8$	Group8 $n = 4$	Group9 $n = 3$	P
Aqrich	2.25[ab]	6.6[ab]	8[b]	5.43[ab]	6.42[ab]	5.08[ab]	3.38[a]	2.25[a]	0[a]	***
Aqcover	0.33[c]	16.44[abc]	43.02[b]	7.35[ac]	37.00[ab]	6.52[ac]	10.49[abc]	2.92[ac]	0[c]	***

[a,b,c] If any letter is the same then the figures are not significantly different

3.4.3.3 Differences in environmental variables between aquatic groups

Table 3.11 shows the environmental variation between aquatic groups. Aquatic group 3 had a significantly higher level of stock damage than aquatic groups 7 and 9. Aquatic group 3 occupied sites with significantly less shade than aquatic groups 7, 8 and 9.

Aquatic group 2 was found in sites with a significantly faster current velocity than aquatic groups 5 and 6. Although the groups were found to vary significantly in substrate, depth and bank vegetation, significant pairwise differences between groups at $P < 0.05$ could not be determined using Dunn's method of pairwise comparisons.

The largest difference in mean values of substrate 'rockiness' between the aquatic groups was between group 8 and groups 3 and 9. Group 8 was higher on this scale than groups 3 and 9. Aquatic groups 1 and 3 had the highest 'mean depth' values, substantially higher than group 8. Aquatic group 4 had the highest mean score on the 'nativeness of bank vegetation' scale, substantially higher than groups 3 and 9.

Table 3.11 Mean Values for Environmental Variables by Aquatic Group

Vel, slowness of current velocity; %shade, percentage of site overshadowed by bank vegetation; Substr, dominant substrate; Bankht, height of bank on highest side; Width, maximum width at site; Depth, maximum depth at site; Bankvg, nativeness of bank vegetation; Kmsup, distance upstream from junction of the two rivers; Erosion, visible erosion of banks; Stockd, obvious trampling by stock; Probability values from Kruskal-Wallis tests are shown: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; n.s., $P > 0.05$. n=number of sites.

	Group1 n =4	Group2 n =15	Group3 n =18	Group4 n =14	Group5 n =24	Group6 n =12	Group7 n =8	Group8 n =4	Group9 n =3	P
Vel[1]	2.25 ab	2.67 b	2.44 ab	2.5 ab	1.71 a	1.83 a	1.88 ab	2 ab	2.67 ab	***
%shade	10.21 ab	7.44 ab	1.93 b	3.57 ab	12.02 ab	9.9 ab	27.93 a	50.21 a	46.67 a	*
Substr[2]	1.75 *	2.2	1.67	2.21	2.17	2.67	2.88	3	1	**
Bankht	1.53	3.93	2.01	2.12	1.37	2.04	1.64	2.13	5.5	n.s.
Width	41.75 ac	46 abc	34.61 b	24 ac	13.60 ab	27.08 ac	19.25 abc	16.5 ac	56.67 c	**
Depth[3]	2.75 *	2.67	2.72	2.29	1.79	1.92	1.75	1.75	2.33	**
Bankvg[4]	2.25 *	2.6	2.11	4	2.88	2.83	3.63	2.75	1	**
Kmsup	39.5 a	70.09 ab	64.32 a	117.07 b	78.30 ab	79.12 ab	101.65 ab	103.88 ab	33.33 a	**
Erosion[5]	1.5	1.67	2	1.5	1.71	2.08	1.38	2	2.33	n.s.
Stockd[6]	2 ab	1.67 ab	2.56 b	1.57 ab	1.88 ab	1.83 ab	1.13 a	1.5 ab	1 a	***

[ab] If any letter is the same, the figures are not significantly different.
* Although a Kruskal-Wallis test found that the groups were significantly different at $P<0.05$, the pairwise test was not able to determine which pairs differed.
[1] 'Slowness' of current velocity, 1=fast 2=slow 3=no discernable current velocity
[2] 'Rockiness' of substrate, 1=mud, 2=mud/rock, 3=gravel, 4=rock
[3] Depth, 1 = < 1 m, 2= 1-2 m, 3= >2 m
[4] Erosion, 1-3 from none to severe
[5] Stock damage, 1-3 from none to severe
[6] Nativeness of bank vegetation, on a scale of 1-6 from least native to most native

3.4.3.4 Multidimensional Scaling (MDS) of sites using Aquatic Species only

A three-dimensional solution to the ordination was found to be most useful. When the nine aquatic groups were plotted on two 2-dimensional scattercharts using the MDS axes (figure 3.8), each aquatic group did form a distinct cluster on both graphs, although there was a high degree of overlap in some cases. Group 9 did not appear at all because group 9 sites had no aquatic vegetation.

The 'distance upstream' and 'nativeness of bank vegetation' vectors were almost parallel on both charts (implying closely related variables) and 'rockiness of substrate' was parallel to but in the opposite direction to the 'level of stock damage' vector, implying an inverse relationship between these two variables.

Figure 3.8a TWINSPAN groups of sites using aquatic species only

◆Group1 ■Group2 △Group3 ✕Group4 ✳Group5 ●Group6 +Group7 −Group8
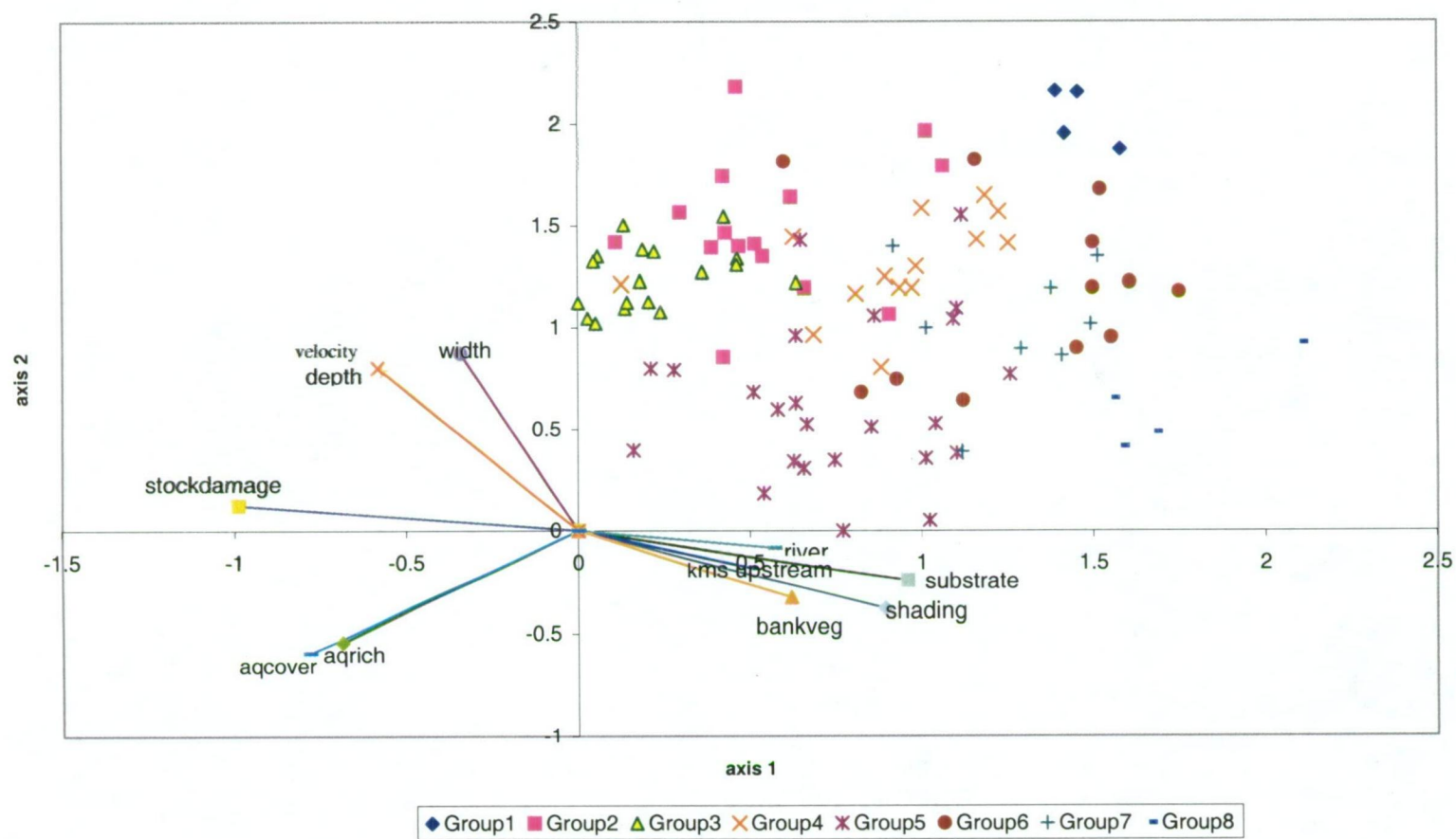
Figure 3.8b TWINSPAN groups of sites using aquatic species only

Group1 ◆ Group2 ■ Group3 △ Group4 ✕ Group5 ✳ Group6 ● Group7 + Group8 −
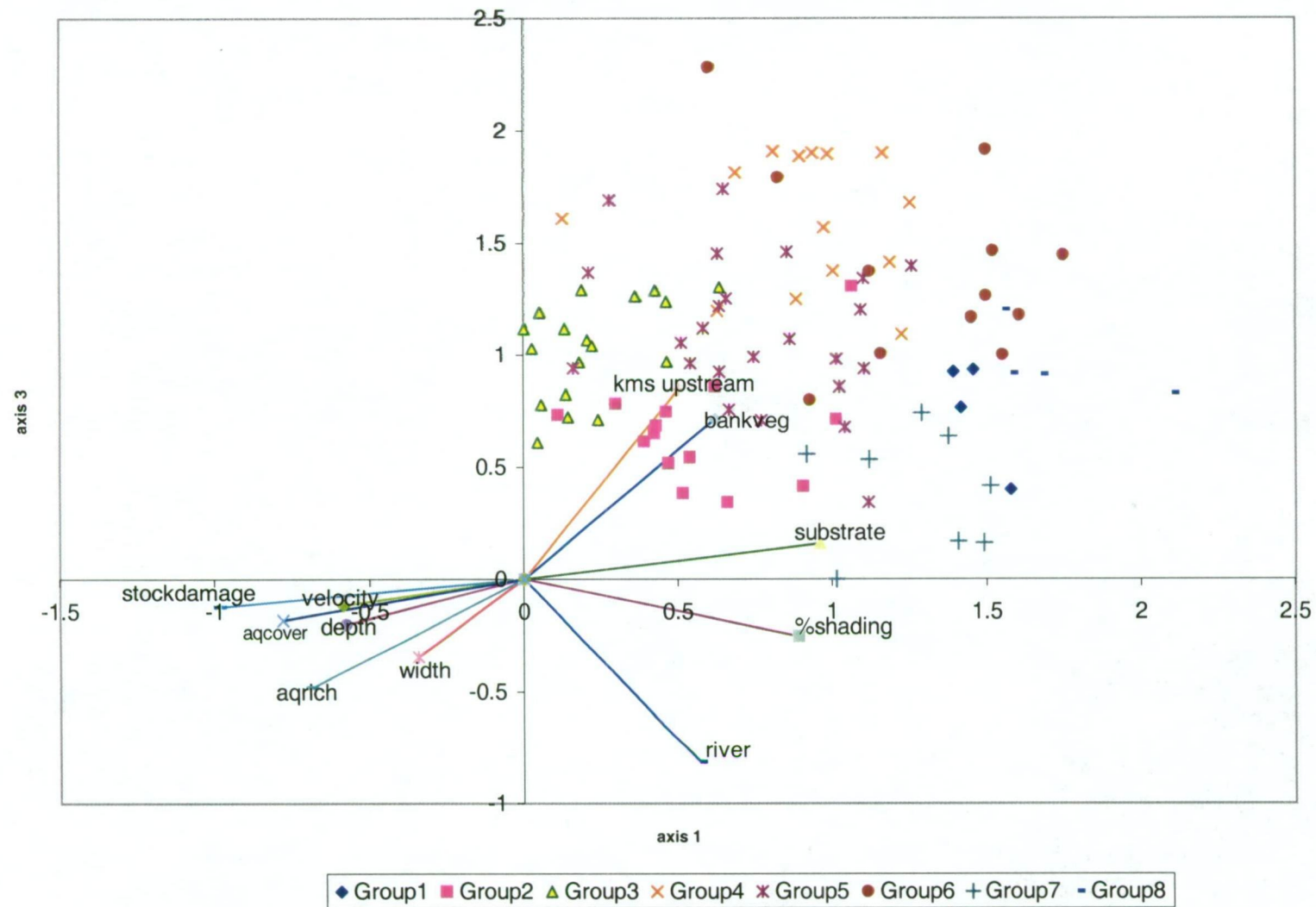
Aquatic vegetation cover, aquatic species richness, rockiness of substrate and percentage shading were the variables most highly correlated with axis1 (table 3.12). Aquatic vegetation cover, stream width and current velocity were highly correlated with axis 2, and distance upstream and stream width were correlated with axis 3. Significant R-values from the vector fitting show the correlations between the environmental and cover/richness vectors and the ordination space. Width and depth were the independent (environmental) variables with the strongest correlation, followed by percentage shading and distance upstream. Aquatic vegetation cover and aquatic species richness were the dependent variables with the strongest correlations.

Table 3.12 Correlations between the site scores on the (aquatic) MDS axes and environmental variables. Spearmans rank correlation coefficients ($P < 0.05$) were used for continuous variables, and Kruskal-Wallis test probabilities were used for categoric variables. R-values are the significant (P<0.05) correlation coefficients from vector fitting.
Velocity, slowness of current velocity; %shade, percentage of site overshadowed by bank vegetation; Substr, dominant substrate; Bankht, height of bank on highest side; Width, maximum width at site; Depth, maximum depth at site; Bankvg, nativeness of bank vegetation; Kmsup, distance upstream from junction of the two rivers; Erosion, visible erosion of banks; Stockd, obvious trampling by stock; Aqcover, % of site covered by aquatic species; Aqrich, number of aquatic species; Probability values from Kruskal-Wallis Tests are shown: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; -, $P > 0.05$.

Variable	Axis1	Axis2	Axis3	R^1
Velocity[a]	*	***	-	-
%shade	0.38	-	-	0.41
Substr	***	-	-	-
Bankht	-	-	-	-
Width	-	0.49	-0.24	0.52
Depth[b]	**	***	-	0.57
Bankvg[c]	*	-	-	-
Kmsup	0.28	-	0.38	0.40
Erosion[d]	-	-	-	-
Stockd[e]	**	-	*	-
Aqcover	-0.76	-0.51	-	0.85
Aqrich	-0.59	-	-	0.61

[a]Slowness of current velocity, 1=fast 2=slow 3=no current velocity
[b]Depth, 1 = < 1 m, 2= 1-2 m, 3= >2 m
[c]Nativeness of bank vegetation, on a scale of 1-6 from least native to most native
[d]Erosion, 1-3 from none to severe
[e]Stock damage, 1-3 from none to severe
[1]Maximum R-value from Vector Fitting in DECODA (Minchin 1990)

3.4.4 Results of the analysis of the site vegetation using marginal species only

3.4.4.1 Species composition and geographical distribution of the Marginal Groups

Nine different groups were apparent from the TWINSPAN sorted table. Table 3.13 gives the percentage frequency of species in each marginal group, figure 3.9 illustrates the geographical distribution of the marginal groups and figure 3.10 shows the indicator species for each TWINSPAN division:

1. Marginal Group 1 consisted of five sites, all with Poaceae species, all but one with *Juncus* species, and three with *Hydrocotyle* species and *Persicaria* species, and/or *Galium palustrium*. Four of these sites were spread along the South Esk, and one was on the Macquarie between Ross and Campbelltown.

2. The 37 sites in Marginal Group 2 were characterized by *Juncus* species and *Carex gaudichaudiana*. *Hydrocotyle* species and *Lysimachia nummularia* were the next most common species, each occurring in about a quarter of the sites in this group. These sites were spread along the entire South Esk, and the upper section of the Macquarie above any towns or major tributaries.

3. The five Marginal Group 3 sites contained a large range of species. All sites had *Persicaria* species, and most also had *Myosotis caespitosa* and *Juncus articulatus* with *Hydrocotyle* species, *Cyperus gunnii*, *Ranunculus repens* and *Lotus* species each appearing in three sites. Three of these sites were on the South Esk upstream of Storys Creek, and two were on the lower Macquarie, downstream of Brumbys Creek.

4. All Marginal Group 4 sites had *Juncus articulatus, Lysimachia nummularia,* and *Alopecurus geniculatus,* and all but one had *Agrostis stolonifera* and *Lolium perenne. Carex appressa* and *Leontodon taraxacoides* were also in most sites. A wide range of

other species were found in several of the sites. There were eight sites in the group, all on the Macquarie downstream of Ross.

5. Marginal Group 5 sites all had a high percentage of *Hydrocotyle* species, and all but two sites also had *Carex gaudichaudiana, Lysimachia nummularia* and/or *Persicaria* species. There were seven sites in this group, all but one on the Macquarie downstream of the Blackman River.

6. Marginal Group 6 was made up of 13 sites, with all but one containing *Carex gaudichaudiana*. Each Group 6 site also had one or more of *Hydrocotyle* species, *Lysimachia nummularia, Cyperus gunnii, Persicaria* species and *Leontodon taraxacoides*. All but one of the Group 6 sites were found along the Macquarie between the Elizabeth and Lake Rivers.

7. This group of eleven sites all contained *Carex gaudichaudiana*. There was almost no other marginal vegetation in these sites, with only four sites containing one other species. Five of these sites were on the South Esk just downstream of Avoca, and the remaining six were at various points on the Macquarie between Brumbys Creek and the top of the study area.

8. Marginal Group 8 was made up of 5 sites which all had only *Lysimachia nummularia* and one other marginal species (a different one in each site). Two of the sites were on the South Esk just downstream of Fingal, and the other three were near Ross on the Macquarie.

9. Marginal Group 9 consisted of ten sites that had no marginal species. These occurred at various points on both the South Esk and Macquarie, and included the three willow-choked sites on the South Esk that had no marginal or aquatic vegetation.

Table 3.13 Percentage frequency of species in marginal groups
Marginal group 9 is not shown as it had no marginal vegetation.

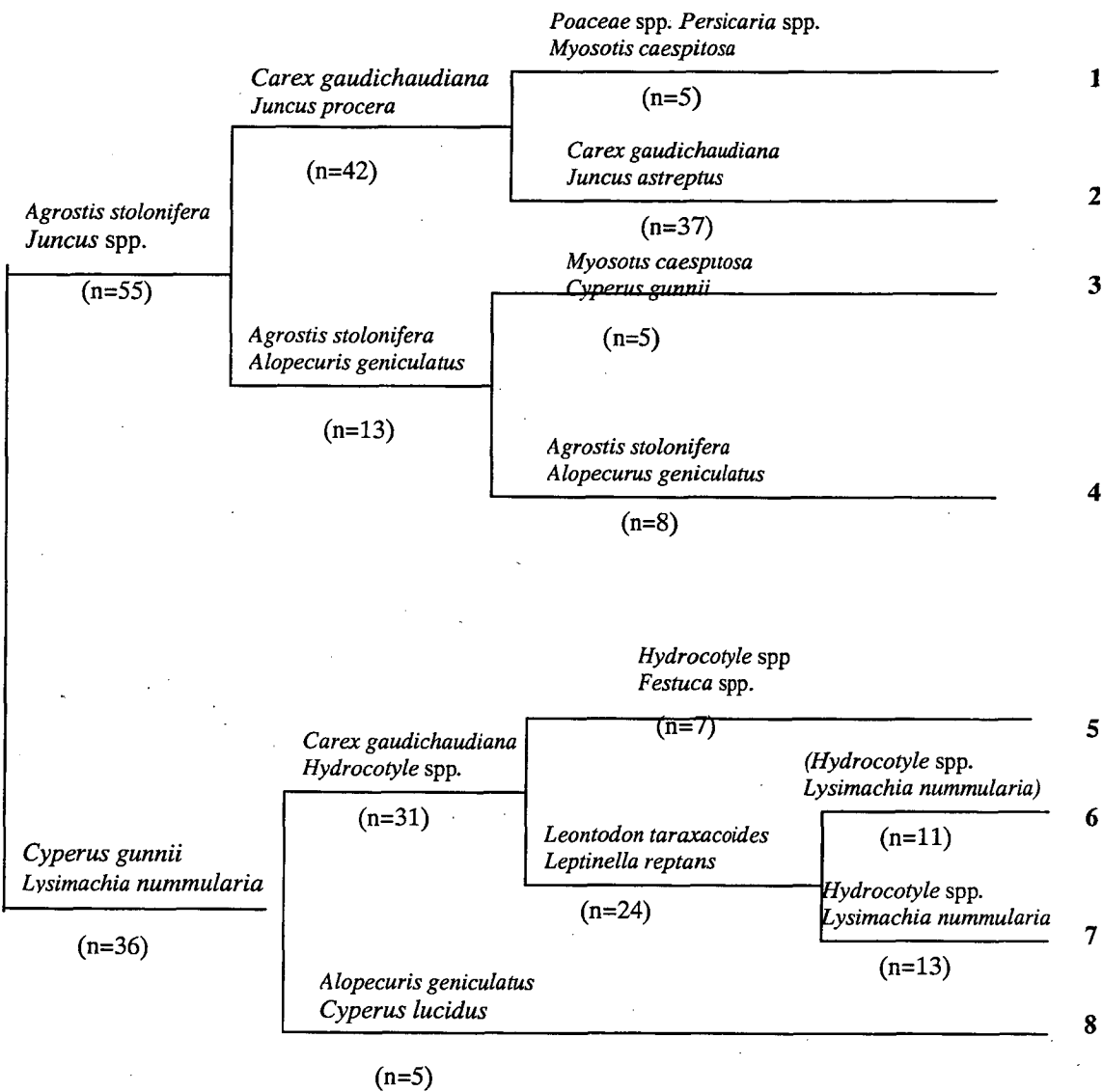| SPECIES	Group1 (n=5)	Group2 (n=37)	Group3 (n=5)	Group4 (n=8)	Group5 (n=7)	Group6 (n=13)	Group7 (n=11)	Group8 (n=5)
Acaena novae-zelandiae	–	–	20.00	–	–	–	–	–
Agrostis aemula	–	–	–	–	14.29	–	–	–
Agrostis avenacea	–	–	20.00	–	–	–	–	–
Agrostis stolonifera	–	5.41	40.00	87.50	–	–	–	–
Alopecurus geniculatus	–	–	–	100.00	–	–	–	20.00
Carex appressa	–	5.41	20.00	75.00	–	15.38	–	–
Carex fascicularis	–	2.70	–	–	–	–	–	–
Carex gaudichaudiana	–	75.68	40.00	12.50	71.43	92.31	100.00	–
Centella cordifolia	–	–	–	–	–	7.69	–	–
Crassula helmsii	–	2.70	–	–	–	–	–	–
Cyperus gunnii	20.00	8.11	60.00	–	57.14	61.54	–	–
Cyperus lucidus	–	5.41	–	–	–	–	–	20.00
Festuca spp.	–	2.70	20.00	–	28.57	–	–	–
Galium palustrium	60.00	2.70	40.00	37.50	–	–	–	–
Geranium spp.	–	–	–	–	14.29	–	–	–
Gratiola spp.	–	–	20.00	–	–	–	–	–
Haloragis heterophylla	–	2.70	–	–	–	–	–	–
Hemarthria uncinata	–	8.11	–	–	–	–	–	–
Hordeum marinum ssp. *gussoneanum*	–	–	–	37.50	–	–	–	–
Hydrocotyle hirta	–	–	–	12.50	42.86	15.38	–	–
Hydrocotyle pterocarpa	–	2.70	–	–	–	–	–	–
Hydrocotyle spp.	60.00	35.14	60.00	50.00	100.00	53.85	9.09	–
Hypericum spp.	20.00	–	–	–	–	–	–	–
Juncus articulatus	40.00	40.54	80.00	100.00	14.29	7.69	–	–
Juncus astreptus	–	27.03	40.00	50.00	–	–	–	–
Juncus australis	–	5.41	–	25.00	–	–	–	–
Juncus holoschoenus	20.00	2.70	–	–	14.29	–	–	–
Juncus procerus	60.00	43.24	20.00	12.50	14.29	–	–	–
Juncus spp.	80.00	94.59	60.00	100.00	28.57	15.38	–	–
Leontodon taraxacoides	40.00	10.81	40.00	75.00	–	53.85	–	–
Leptinella reptans	40.00	2.70	–	–	14.29	38.46	–	–
Lolium perenne	–	2.70	20.00	87.50	14.29	7.69	9.09	–
Lotus pedunculatus	–	2.70	–	–	–	–	–	–
Lotus spp.	20.00	8.11	60.00	37.50	–	15.38	–	–
Lotus tenuis	–	2.70	–	–	–	–	–	–
Lysimachia nummularia	–	24.32	60.00	100.00	71.43	92.31	18.18	100.00
Mentha pelugium	–	–	–	50.00	–	–	–	–
Myosotis caespitosa	40.00	2.70	80.00	–	28.57	7.69	9.09	–
Nymphoides spp.	–	–	–	–	–	7.69	–	–
Oxalis perennans	–	–	20.00	–	–	–	–	–
Persicaria decipiens	20.00	2.70	20.00	–	–	–	–	–
Persicaria hydropiper	20.00	2.70	40.00	–	–	–	–	–
Persicaria prostrata	–	2.70	–	–	–	–	–	–
Persicaria spp.	60.00	13.51	100.00	50.00	71.43	53.85	18.18	–
Plantago coronopus	–	–	–	–	–	7.69	–	–
Poaceae spp.	100.00	16.22	40.00	12.50	14.29	23.08	–	20.00
Potentilla anglica	–	–	40.00	–	–	–	–	–
Pratia pedunculata	–	8.11	–	50.00	28.57	15.38	–	–
Prunella vulgaris	–	–	20.00	–	–	–	–	–
Pseudognaphalium luteo-album	–	–	20.00	–	–	–	–	–
Ranunculus amphitrichous	–	–	20.00	–	–	–	–	–
Ranunculus repens	–	–	60.00	37.50	–	–	–	–
Ranunculus rivularis	–	2.70	–	–	–	–	–	–
Rumex crispus	–	–	20.00	12.50	–	7.69	–	–
Rumex spp.	–	–	20.00	62.50	14.29	30.77	–	–
Schoenoplectus validus	–	–	–	–	–	15.38	–	20.00
Trifolium spp.	–	–	–	–	–	7.69	–	–

Figure 3.9 Geographical distribution of TWINSPAN groups of sites using marginal species only
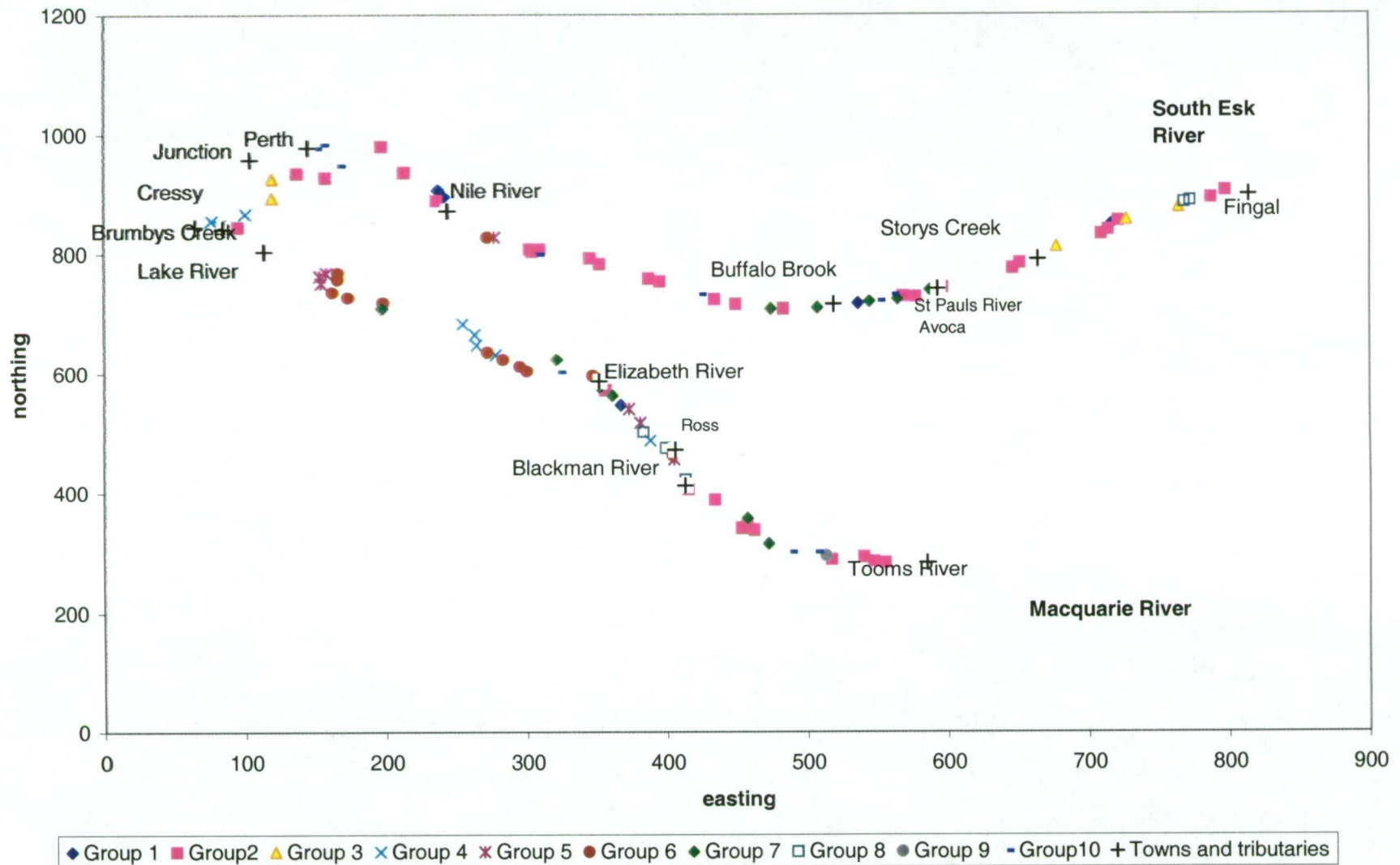
Figure 3.10 Dendrogram showing the preferential species for each TWINSPAN cluster, using abundance data for marginal species in all sites on the Macquarie and South Esk Rivers. Groups with species in brackets are defined by the absence of those species, rather than the presence. Marginal group numbers are given in bold type.

Poaceae spp. *Persicaria* spp.
Myosotis caespitosa

Carex gaudichaudiana
Juncus procera

(n=5)   **1**

Carex gaudichaudiana
Juncus astreptus

(n=42)

(n=37)   **2**

Agrostis stolonifera
Juncus spp.

Myosotis caespitosa
Cyperus gunnii   **3**

(n=55)

(n=5)

Agrostis stolonifera
Alopecuris geniculatus

(n=13)

Agrostis stolonifera
Alopecurus geniculatus

(n=8)   **4**

Hydrocotyle spp
Festuca spp.

(n=7)   **5**

Carex gaudichaudiana
Hydrocotyle spp.

(Hydrocotyle spp.
Lysimachia nummularia)

(n=31)

(n=11)   **6**

Leontodon taraxacoides
Leptinella reptans

Hydrocotyle spp.
Lysimachia nummularia

Cyperus gunnii
Lysimachia nummularia

(n=24)   **7**

(n=36)

(n=13)

Alopecuris geniculatus
Cyperus lucidus

(n=5)   **8**

86

3.4.4.2 Variation in richness and cover between marginal groups

There were significant differences in cover, species richness and exotic species richness between marginal groups (table 3.14). Marginal groups 1, 3, 4, 5 and 6 had a high percentage cover of marginal species, although this was only significantly higher than group 9, which had no marginal vegetation. Marginal groups 3 and 4 had a significantly higher richness than groups 7, 8 and 9. Groups 5 and 6 had a significantly higher richness than groups 7 and 9, and groups 1 and 2 had a significantly higher richness than group 9. Groups 3 and 4 had a significantly higher exotic species richness than groups 2, 7 and 9. Group 6 had a significantly higher exotic species richness than groups 7 and 9.

Table 3.14 Mean values for richness variables by marginal group
Mcover, percentage of site covered by marginal species; Exrich, number of exotic species; Mrich, number of marginal species;
Probability values from Kruskal-Wallis Tests are shown: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; n.s., $P > 0.05$. n = number of sites.

	Group1 $n=5$	Group2 $n=37$	Group3 $n=5$	Group4 $n=8$	Group5 $n=7$	Group6 $n=13$	Group7 $n=11$	Group8 $n=5$	Group9 $n=10$	P
Mcover	13.1 [a]	3.9 [ab]	16.3 [a]	14.5 [a]	29.3 [a]	13.4 [a]	1.0 [ab]	7.0 [ab]	0 [b]	***
Exrich	2.2 [ab]	1.24 [ac]	6.2 [b]	8.75 [b]	1.71 [ab]	2.85 [bc]	0.45 [a]	1.6 [ab]	0 [a]	***
Mrich	7.2 [ab]	4.84 [ab]	12.8 [b]	12.88 [b]	6.57 [bc]	6.77 [bc]	1.64 [ad]	1.8 [acd]	0 [d]	***

[abcd]If any letter is the same then figures are not significantly different

3.4.4.3 Environmental variation between marginal groups

Table 3.15 summarises the environmental variation between the Marginal Groups. The marginal groups differed significantly in 'rockiness of substrate', width, 'nativeness of bank vegetation, distance upstream and level of stock damage. Significant pairwise differences at $P<0.05$ could only be determined for width, using Dunn's method of pairwise comparisons. Groups 3 and 7 had substantially higher mean values of 'rockiness of substrate' than group 4. Group 8 was significantly narrower than group 4. Group 7 had a much higher mean value on the 'nativeness of bank vegetation' scale and had a lower mean value of 'level of stock damage' than groups 4 and 5.

Table 3.15 Mean Values for Environmental Variables by Marginal Group

Vel, slowness of current velocity; %shade, percentage of site overshadowed by bank vegetation; Substr, dominant substrate; Bankht, height of bank on highest side; Width, maximum width at site; Depth, maximum depth at site; Bankvg, nativeness of bank vegetation; Kmsup, distance upstream from junction of the two rivers; Erosion, visible erosion of banks; Stockd, obvious trampling by stock; Probability values from Kruskal-Wallis Tests are shown: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; n.s., $P > 0.05$. n = number of sites.

	Group1 n =5	Group2 n =37	Group3 n =5	Group4 n =8	Group5 n =7	Group6 n =13	Group7 n =11	Group8 n =5	Group9 n =10	P
Vel[1]	2.4	2.27	1.6	2.5	1.86	2.08	1.91	2	2.6	n.s.
%shade	1.658	7.61	27.61	4.83	6.05	13.12	17.71	11.83	25.03	n.s.
Substr[2]	2.4*	2.27	3	1.13	1.57	1.62	2.82	1.4	2	*
Bankht	1.98	2.22	1.7	1.13	1.27	1.63	1.96	1.32	5.75	n.s.
Width	27.2[ab]	33.51[ab]	28.8[ab]	37.38[a]	12.86[ab]	24.5[ab]	19.91[ab]	9.2[b]	35.9[ab]	**
Depth[3]	2.4	2.23	1.8	2.75	2.14	2.46	2	1.8	2.2	n.s.
Bankvg[4]	2.4*	3.05	2.8	2	2	2.31	3.91	2.4	2.82	*
Kmsup	78.66*	88.48	80.86	50.88	64.86	59.28	92.91	116.06	72.81	*
Erosion[5]	1.6	1.62	2.2	1.88	1.71	2	1.36	2.4	2	n.s.
Stockd[6]	2*	1.59	2	2.38	2.43	2.08	1.55	2	1.6	*

[a,b]If any letter is the same, the figures are not significantly different.

*Although a Kruskal-Wallis test found that the groups were significantly different at $P<0.05$, the pairwise test was not able to determine which pairs differed.

[1]Slowness of current velocity, 1=fast 2=slow 3=no discernable current velocity

[2]'Rockiness' of substrate, 1=mud, 2=mud/rock, 3=gravel, 4=rock

[3]Depth, 1 = < 1 m, 2= 1-2 m, 3= >2 m

[4]Nativeness of bank vegetation, on a scale of 1-6 from least native to most native

[5]Erosion, 1-3 from none to severe

[6]Stock damage, 1-3 from none to severe

3.4.4.4 Multidimensional Scaling (MDS) of sites by Marginal Species

A four-dimensional solution to the ordination was found to be most useful. When the sites were plotted onto three scattercharts using pairs of the ordination axes (figure 3.11), some of the marginal groups did form distinct clusters on some of the graphs.

The vectors on these three charts could be described as two groups of vectors with opposite directions, that is inversely related variables. One group consisted of 'richness of exotics' and 'stock damage', the other 'distance upstream, 'nativeness of bank vegetation' and 'rockiness of substrate'.

Several variables were significantly related to the site scores on the ordination axes (table 3.16). Distance upstream was the only environmental continuous variable that was significantly correlated with the ordination space. Marginal vegetation cover, marginal

species richness and exotic species richness were the vegetation variables that were significantly correlated with the ordination space.

Table 3.16 Correlations between the site scores on the MDS axes and environmental variables. The significant correlation coefficients (P< 0.05)from Vector Fitting are also shown. Spearmans rank correlation coefficients ($P < 0.05$) were used for continuous variables and Kruskal-Wallis test probabilities for categoric variables. Velocity, slowness of current velocity; %shade, percentage of site overshadowed by bank vegetation; Substr, dominant substrate; Bankht, height of bank on highest side; Width, maximum width at site; Depth, maximum depth at site; Bankvg, nativeness of bank vegetation; Kmsup, distance upstream from junction of the two rivers; Erosion, visible erosion of banks; Stockd, obvious trampling by stock; Margcover, % of site covered by marginal species; Exrich, number of exotic species; Mrich, number of marginal species; Probability values from Kruskal-Wallis Tests are shown: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; -, $P > 0.05$.

Variable	Axis1	Axis2	Axis3	Axis4	R[1]
Velocity[a]	**	**	**	-	-
%shade	-	-	-	-	-
Substr	-	-	**	-	-
Bankht	-	-	-	-	-
Width	-	-	-0.32	-	-
Depth[b]	-	-	-	-	-
Bankvg[e]	**	*	-	-	-
Kmsup	0.42	-	-	-	0.40
Erosion[c]	-	-	-	-	-
Stockd[d]	*	-	-	-	-
Margcover	-0.70	0.34	0.42	0.47	0.78
Exrich	-0.36	0.54	-	-	0.54
Mrich	-0.47	0.30	-	0.35	0.59

[a]Slowness of current velocity, 1=fast 2=slow 3=no current velocity
[b]Depth, 1 = < 1 m, 2= 1-2 m, 3= >2 m
[c]Erosion, 1-3 from none to severe
[d]Stock damage, 1-3 from none to severe
[e]Nativeness of bank vegetation, on a scale of 1-6 from least native to most native
[1]Maximum R-value from Vector Fitting in DECODA (Minchin 1990)

Figure 3.11a TWINSPAN groups of sites using marginal species only

Legend: ◆ Group 1 ■ Group 2 △ Group 3 □ Group 4 △ Group 5 ● Group 6 ✳ Group 7 ○ Group 8
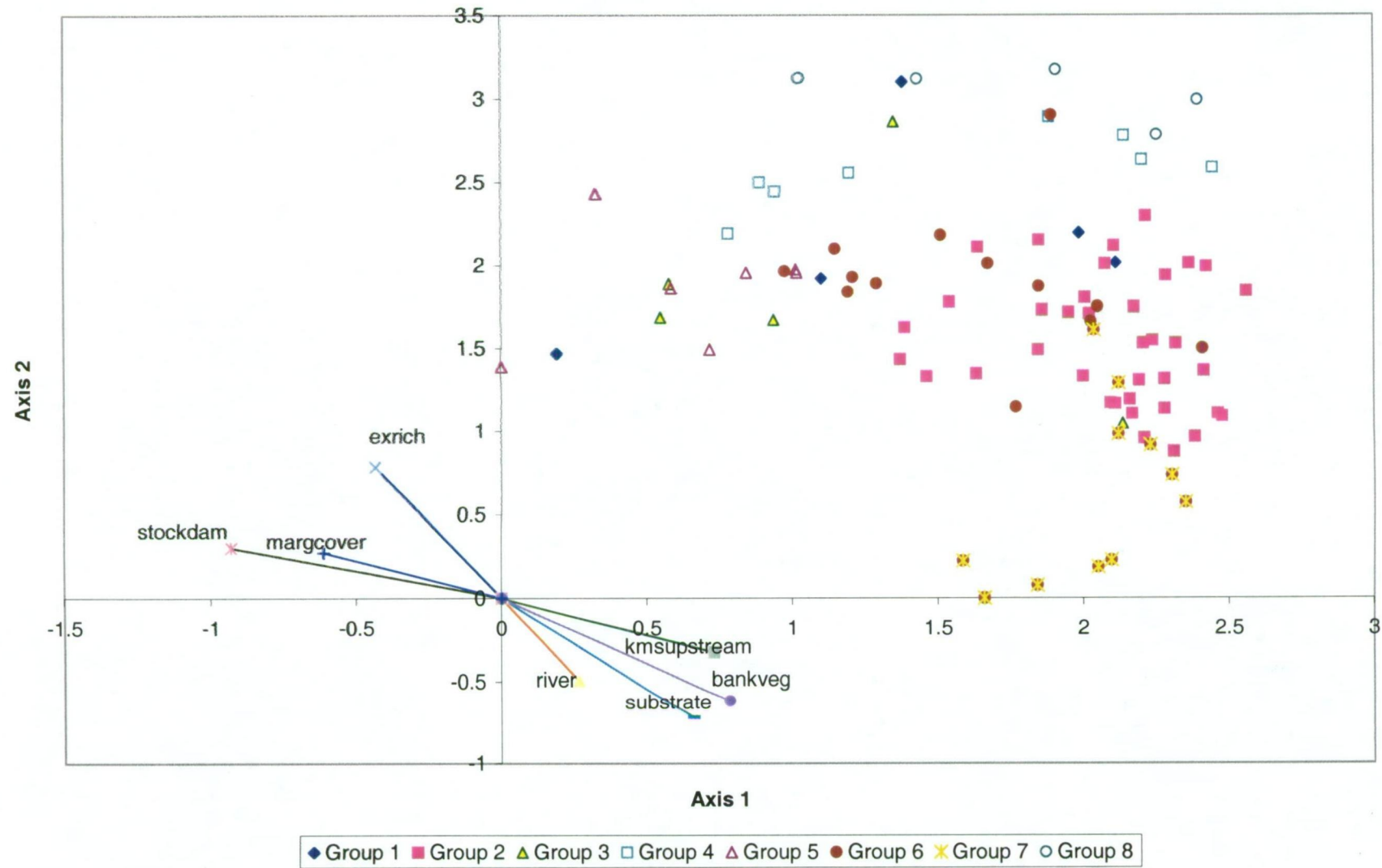
Figure 3.11b TWINSPAN groups of sites using marginal species only

Legend: ◆ Group 1 ■ Group 2 △ Group 3 ☐ Group 4 △ Group 5 ● Group 6 ✳ Group 7 ○ Group 8
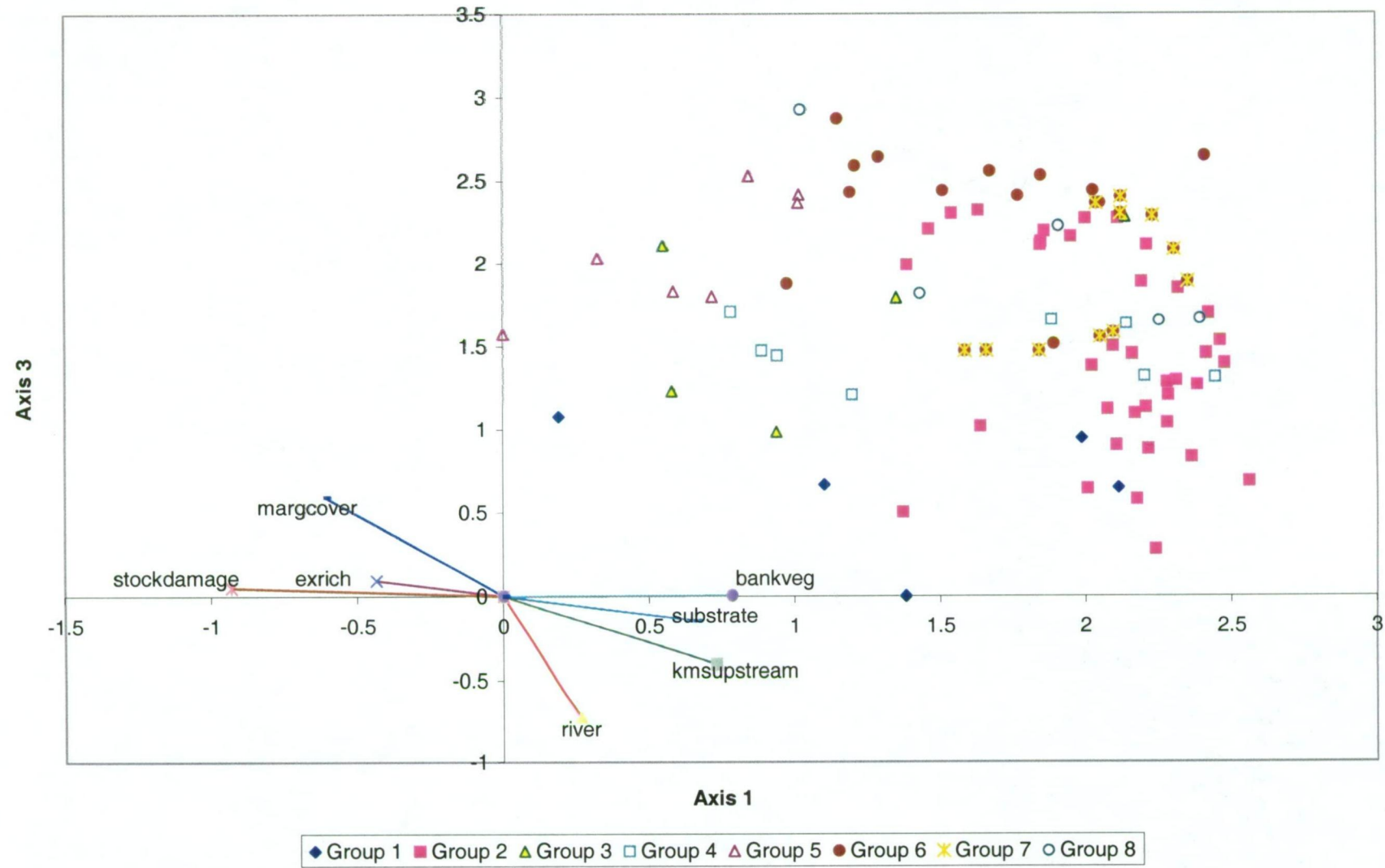
Figure 3.11c TWINSPAN groups of sites using marginal species only

Group 1 ◆ Group 2 ■ Group 3 △ Group 4 □ Group 5 △ Group 6 ● Group 7 ✕ Group 8 ○
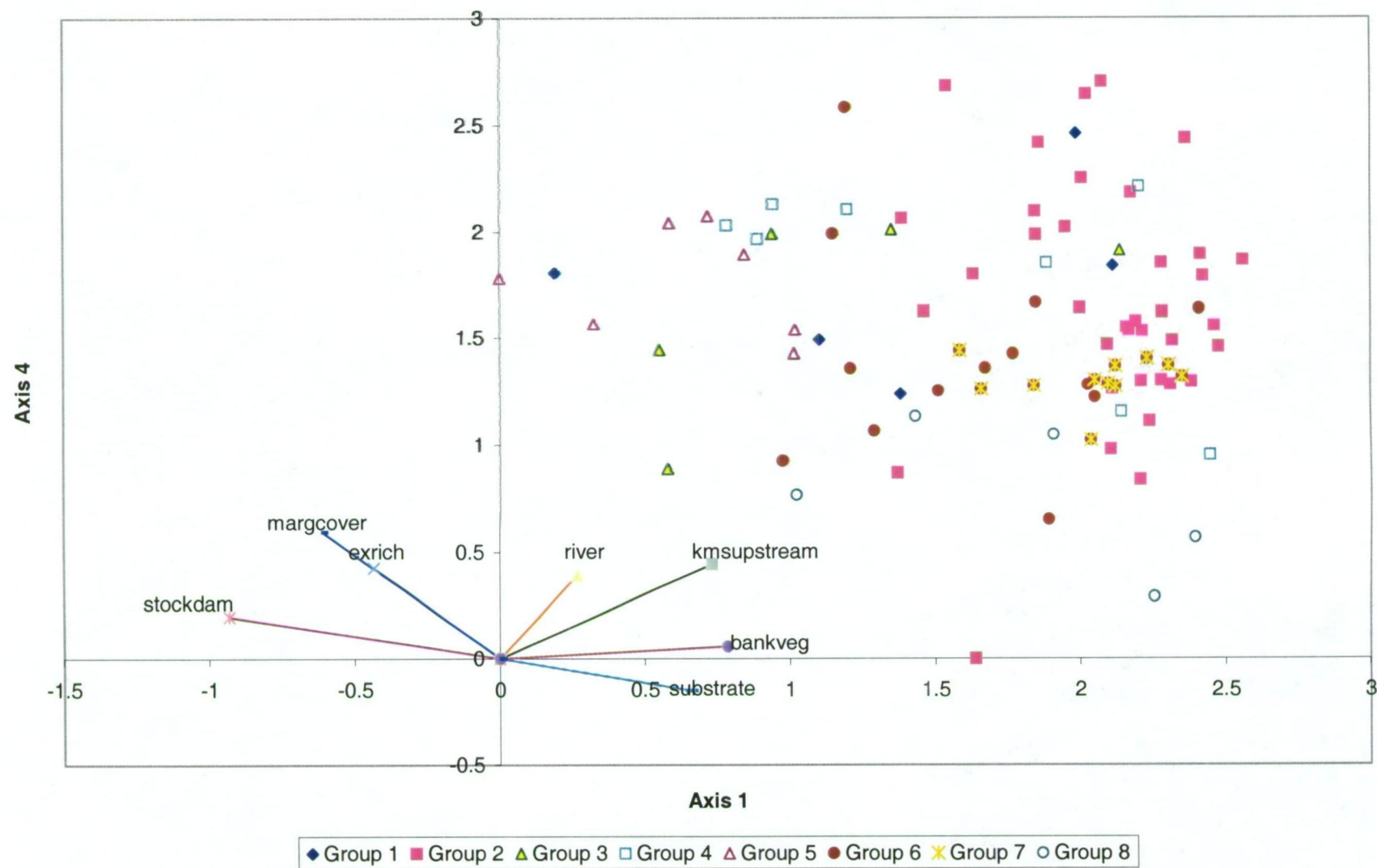
3.5 Relationships between classification groupings

Most of the dominant species groups are not evenly distributed between all-species groups, aquatic groups or marginal groups. Similarly, the sites in each all-species groups do not strictly fall into the same aquatic and marginal groups, as the environmental factors have differing effects on the different growth forms. For many sites the aquatic vegetation appears to be largely independent of the marginal vegetation.

The six tables below show the relationships between the different classification groupings.

Table 3.17 Cross-tabulation of dominant species types by all-species groups

Dominant species	All-spp1	2	3	4	5	6	7	All
Batrachium tricophyllum	0	1	0	0	0	0	0	1
Baumea arthrophylla	0	0	6	3	0	2	0	11
Carex gaudichaudiana	1	15	2	13	5	2	0	38
Charophytes	0	3	1	1	2	1	0	8
Cyperus gunnii	0	0	0	1	0	0	0	1
Eleocharis acuta	0	7	1	11	0	2	0	21
Eleocharis pusilla	0	3	0	0	0	0	0	3
Eleocharis sphacelata	0	15	4	13	3	6	0	41
Elodea canadensis	0	1	0	3	1	1	0	6
Hydrocotyle spp.	0	1	1	1	3	4	0	10
Isolepis spp.	0	0	1	0	2	0	0	3
Isolepis fluitans	3	8	3	2	2	0	0	18
Juncus articulatus	0	3	0	0	1	0	0	4
Juncus spp.	0	4	3	0	0	1	1	9
Lysimachia nummularia	0	0	2	4	1	0	1	8
Neopaxia australasica	0	2	3	2	0	0	0	7
Myriophyllum salsugineum	1	2	4	6	0	3	0	16
Myriophyllum simulans/ variifolium	0	7	0	7	2	0	0	16
Persicaria spp.	0	0	0	0	1	0	0	1
Phragmites australis	6	8	0	0	1	1	0	16
Potamogeton ochreatus	0	2	0	0	0	0	0	2
Ranunculus repens	0	0	0	0	1	0	0	1
Schoenoplectus validus	0	0	0	4	0	0	0	4
Triglochin spp.	0	3	5	3	3	1	0	15
Vallisneria americana	0	10	1	10	0	4	0	25
Villarsia reniformis	0	0	0	0	0	1	0	1
Typha spp.	0	0	1	0	0	0	0	1
Poaceae spp.	0	2	1	2	1	0	2	8
All	11	97	39	86	29	29	4	295

Table 3.18 Cross-tabulation of dominant species types by aquatic groups

Dominant species	Aqgr1	2	3	4	5	6	7	8	All
Batrachium tricophyllum	0	0	0	0	1	0	0	0	1
Baumea arthrophylla	0	0	5	4	1	1	0	0	11
Carex gaudichaudiana	1	7	10	5	7	6	1	1	38
Charophytes	0	1	2	0	1	4	0	0	8
Cyperus gunnii	0	0	1	0	0	0	0	0	1
Eleocharis acuta	0	7	7	1	6	0	0	0	21
Eleocharis pusilla	0	3	0	0	0	0	0	0	3
Eleocharis sphacelata	0	13	17	2	6	2	1	0	41
Elodea canadensis	0	0	3	0	2	1	0	0	6
Hydrocotyle spp.	0	0	5	0	2	3	0	0	10
Isolepis spp.	0	1	0	0	0	1	0	1	3
Isolepis fluitans	0	1	1	2	7	2	2	3	18
Juncus articulatus	1	2	0	0	0	0	1	0	4
Juncus spp.	2	2	1	1	3	0	0	0	9
Lysimachia nummularia	1	1	0	0	5	0	1	0	8
Neopaxia australasica	0	1	0	0	4	2	0	0	7
Myriophyllum salsugineum	0	0	7	2	6	1	0	0	16
Myriophyllum simulans/ variifolium	0	1	5	0	9	1	0	0	16
Persicaria spp.	0	0	0	0	0	1	0	0	1
Phragmites australis	0	5	1	0	1	1	8	0	16
Potamogeton ochreatus	0	1	1	0	0	0	0	0	2
Ranunculus repens	0	0	0	0	0	1	0	0	1
Schoenoplectus validus	0	0	3	0	1	0	0	0	4
Triglochin spp.	0	0	5	4	2	4	0	0	15
Vallisneria americana	0	9	16	0	0	0	0	0	25
Villarsia reniformis	0	0	1	0	0	0	0	0	1
Typha spp.	0	0	0	0	1	0	0	0	1
Poaceae spp.	2	2	1	0	1	2	0	0	8
All	7	57	92	21	66	33	14	5	295

Table 3.19 Cross-tabulation of dominant species types by marginal groups

Dominant species	Mg1	2	3	4	5	6	7	8	9	All
Batrachium tricophyllum	0	1	0	0	0	0	0	0	0	1
Baumea arthrophylla	0	2	0	1	2	1	2	2	1	11
Carex gaudichaudiana	2	17	2	1	4	10	2	0	0	38
Charophytes	0	5	1	0	0	1	0	0	1	8
Cyperus gunnii	0	0	0	0	0	1	0	0	0	1
Eleocharis acuta	0	8	0	1	5	4	2	0	1	21
Eleocharis pusilla	0	2	0	0	0	0	1	0	0	3
Eleocharis sphacelata	7	10	1	6	3	7	3	0	4	41
Elodea canadensis	0	1	1	0	0	3	0	0	1	6
Hydrocotyle spp.	0	0	3	4	3	0	0	0	0	10
Isolepis spp.	1	0	1	0	0	0	0	0	1	3
Isolepis fluitans	1	9	1	0	1	2	2	1	1	18
Juncus articulatus	1	3	0	0	0	0	0	0	0	4

Juncus spp.	0	6	0	2	1	0	0	0	0	9
Lysimachia nummularia	0	0	1	2	1	4	0	0	0	8
Neopaxia australasica	0	3	0	1	1	1	0	1	0	7
Myriophyllum salsugineum	1	3	0	3	2	2	3	2	0	16
Myriophyllum simulans/ variifolium	1	9	0	0	5	0	1	0	0	16
Persicaria spp.	0	0	1	0	0	0	0	0	0	1
Phragmites australis	2	8	1	1	0	1	2	0	1	16
Potamogeton ochreatus	0	2	0	0	0	0	0	0	0	2
Ranunculus repens	0	0	1	0	0	0	0	0	0	1
Schoenoplectus validus	0	0	0	0	0	3	0	1	0	4
Triglochin spp.	0	5	2	1	1	1	2	1	2	15
Vallisneria americana	3	8	0	4	3	4	1	0	2	25
Villarsia reniformis	0	0	0	1	0	0	0	0	0	1
Typha spp.	0	1	0	0	0	0	0	0	0	1
Poaceae spp.	2	1	1	2	0	0	1	1	0	8
All	21	104	17	30	32	45	22	9	15	295

Table 3.20 Cross-tabulation of all-species groups by aquatic groups

	All-spp1	2	3	4	5	6	7	8 All
Aqgr1	0	1	0	0	0	0	3	0	4
2	0	11	1	2	1	0	0	0	15
3	0	2	1	10	0	5	0	0	18
4	0	3	8	3	0	0	0	0	14
5	1	7	5	10	1	0	0	0	24
6	1	3	3	0	5	0	0	0	12
7	5	2	0	0	1	0	0	0	8
8	2	1	0	0	1	0	0	0	4
9	0	0	0	0	0	0	0	3	3
All	9	30	18	25	9	5	3	3	102

Table 3.21 Cross-tabulation of all-species groups by marginal groups

	All-spp1	2	3	4	5	6	7	8 All
Mg1	0	3	0	1	1	0	0	0	5
2	1	25	7	1	3	0	0	0	37
3	0	0	0	0	5	0	0	0	5
4	0	0	1	0	0	4	3	0	8
5	0	1	1	5	0	0	0	0	7
6	1	0	0	11	0	1	0	0	13
7	5	1	2	3	0	0	0	0	11
8	0	0	3	2	0	0	0	0	5
9	2	0	3	2	0	0	0	3	10
All	9	30	18	25	9	5	3	3	101

Table 3.22 Cross-tabulation of aquatic groups by marginal groups

	Aqgr1	2	3	4	5	6	7	8	9 All	
Mg1	0	2	1	0	0	1	1	0	0	5
2	1	9	2	8	9	5	2	1	0	37
3	0	0	0	0	0	3	1	1	0	5
4	3	0	4	0	1	0	0	0	0	8
5	0	0	3	0	4	0	0	0	0	7
6	0	1	6	2	3	0	1	0	0	13
7	0	1	1	2	3	1	2	1	0	11
8	0	0	0	0	3	2	0	0	0	5
9	0	2	1	2	0	0	1	1	3	10
All	4	15	18	14	24	12	8	4	3	101

3.6 Discussion: variation in macrophytic vegetation and environmental factors along the two rivers

The differences in geographical distribution of the different species and species assemblages can be at least partly explained by individual species adaptations to environmental variation between different reaches of the two rivers. Fox (1996) identified three major factors that determine the presence or absence of species at a particular site: dispersal, tolerance of the abiotic environment, and interactions with the biota. If a species has had the opportunity to reach a site through dispersal- which would apply to all species except recent introductions in the small area of this study- then its absence from a site is due to either intolerance of the abiotic environment or unfavourable interactions with the biota. Fox (1996:30) explained that "the absence of a species will be determined by intolerance of extremes of abiotic conditions. The abundance of a species will be related to how near the conditions are to those optimal for maximum growth rates".

Combining the dominant species groups with all three sets of TWINSPAN groups of the sites: all-species groups, aquatic groups and marginal groups- gives the clearest picture of the variation in vegetation along the different reaches of the two rivers. When this is added to the distribution of environmental variables along the rivers, a picture is developed of the relationships between the species composition of the macrophytic

vegetation and the environmental variation along the two rivers. This satisfies aim three in chapter 1: to determine the environmental correlates of variation in aquatic macrophyte species composition.

From the geographical distribution of the all-species groups and the aquatic groups (figures 3.3 and 3.6) six distinct reaches could be defined, three on the Macquarie and three on the South Esk. The marginal groups did not divide so clearly along the reaches, but still contribute valuable information to the overall picture (figure 3.9). Note that the terms 'upper', 'middle' and 'lower' in the following discussion refer to the sections of the rivers covered in this study. They do not refer to the upper and lower reaches of the whole rivers.

The highest reach on the Macquarie was between the confluence with Tooms River and the confluence with the Blackman River. This reach was above any towns or major tributaries, and had the most intact native bank vegetation of all reaches (figure 3.12). Erosion and stock damage were both very low (figures 3.13 and 3.14). Sites mostly had a rock or mud/rock substrate (figure 3.15). The river vegetation was dominated by all-species group 3 and aquatic group 4. That is, by native aquatic communities with a low species richness and low vegetation cover, and very few marginal species. *Triglochin procerum, Myriophyllum salsugineum* and *Isolepis fluitans* were common submerged and floating-leaved species along this reach, along with the emergent species *Eleocharis sphacelata, Baumea arthrophylla* and marginal species *Juncus* species. This reach was the steepest reach on the Macquarie, with a drop of 150 m over a distance of 50 km (see Chapter 2). Aquatic vegetation growth along this reach was probably limited by abiotic factors such as low nutrient levels, a high water velocity and resultant lack of fine substrate.

The middle reach on the Macquarie was between the confluence with the Blackman River and the confluence with Brumbys Creek. This reach included the confluences with the Elizabeth River and the Lake River, and received primary treated sewage from the towns of Ross and Campbell Town. A large part of the landuse was agricultural, and the bank vegetation was predominantly pasture, often right to the river edge. Willow

infestation occurred in some areas. The river gradient was low (see Chapter 2), and the substrate was mostly mud. The river vegetation was dominated by all-species groups 4 and 6 and aquatic groups 3 and 5. That is, this reach of the Macquarie had a high aquatic vegetation cover, a high total aquatic and marginal species richness and a high exotic species richness in parts. Since there was only one exotic aquatic species found in this study (*Elodea canadensis*), high exotic species richness at a site implies a high exotic species richness in the marginal vegetation. This was mostly due to the invasion of the river margins by pasture species. The one exotic aquatic species, *Elodea canadensis*, was found in more than a third of the sites along this reach. Other common aquatic species were *Triglochin* species, *Isolepis fluitans*, *Neopaxia australasica*, *Eleocharis acuta*, *E. sphacelata*, *Myriophyllum* species, *Vallisneria americana* and *Potamogeton ochreatus*. Common marginal species were *Carex* species, *Juncus* species, *Hydrocotyle* species, *Lysimachia nummularia* and *Persicaria* species. Vegetation growth at these sites was probably only limited by competition between species for space and light, as there was plentiful suitable habitat for macrophytic growth at most of these sites.

It is probable that fertilizers used on adjacent agricultural land are washed into the river during rainfall events, increasing the nutrient levels along this reach. This may be one of the causes of the high vegetation richness and abundance along this section of the river. The DPIF (1996) found that nitrogen and phosphorus levels increased dramatically during times of flood (see chapter 2). A more detailed study of the correlation between water nutrient levels and rainfall is necessary to determine the effects of agricultural fertilizers on macrophyte growth in these two rivers.

The lower reach of the Macquarie was a short stretch of river between the confluence with Brumbys Creek and the confluence with the South Esk. Because of the large volume of water entering the Macquarie from the highlands via Poatina power station at the Brumbys Creek junction, this reach was distinctly different in character to the reaches upstream. The river was wider and the larger volume of water was clearer and colder with a faster current velocity. All-species groups 7 and 5 corresponded with aquatic groups 1 and 6 and marginal groups 3 and 4 for the five sites surveyed along this reach. That is, these sites were conspicuously low in aquatic species but had a high marginal
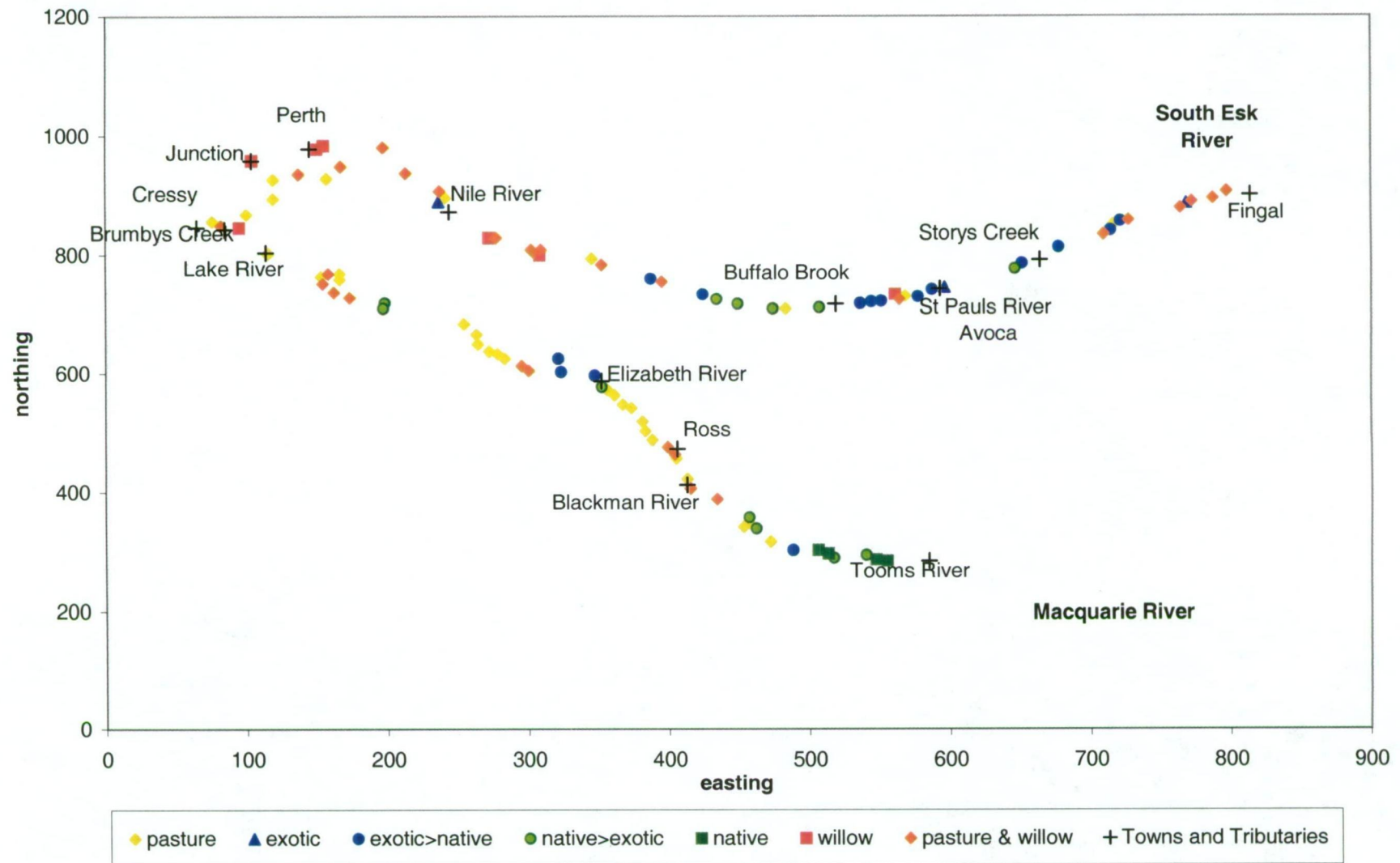
species richness and a high exotic species richness. Percentage vegetation cover was low, as vegetation only occurred on the river margins. Bank vegetation was entirely pasture and willows. Common species were *Juncus* species, *Eleocharis acuta, Lysimachia nummularia, Agrostis* species, *Alopecurus geniculatus, Carex gaudichaudiana, Myosotis caespitosa* and *Persicaria* species. The occasional aquatic species were mainly *Isolepis fluitans*, charophytes and *Triglochin* species. Vegetation cover and richness were most likely limited by the water velocity and low nutrient levels.

The highest reach on the South Esk was between Fingal and the confluence with Storys Creek. This reach was dominated by all-species group 5, aquatic group 6 and a mixture of marginal groups. That is, the aquatic vegetation was low in both richness and cover, mostly consisting of only two or three native species, while the marginal vegetation was richer and contained a mixture of native and exotic species. The bank vegetation was predominantly a mixture of pasture and willows, with some infestation by gorse, hawthorn and blackberry. Common aquatic species were *Juncus* species, *Triglochin* species, *Isolepis fluitans* and *Eleocharis acuta*. Common marginal species were *Persicaria* species, *Lotus* species, *Leontodon taraxacoides*, *Myosotis caespitosa* and *Carex gaudichaudiana*.
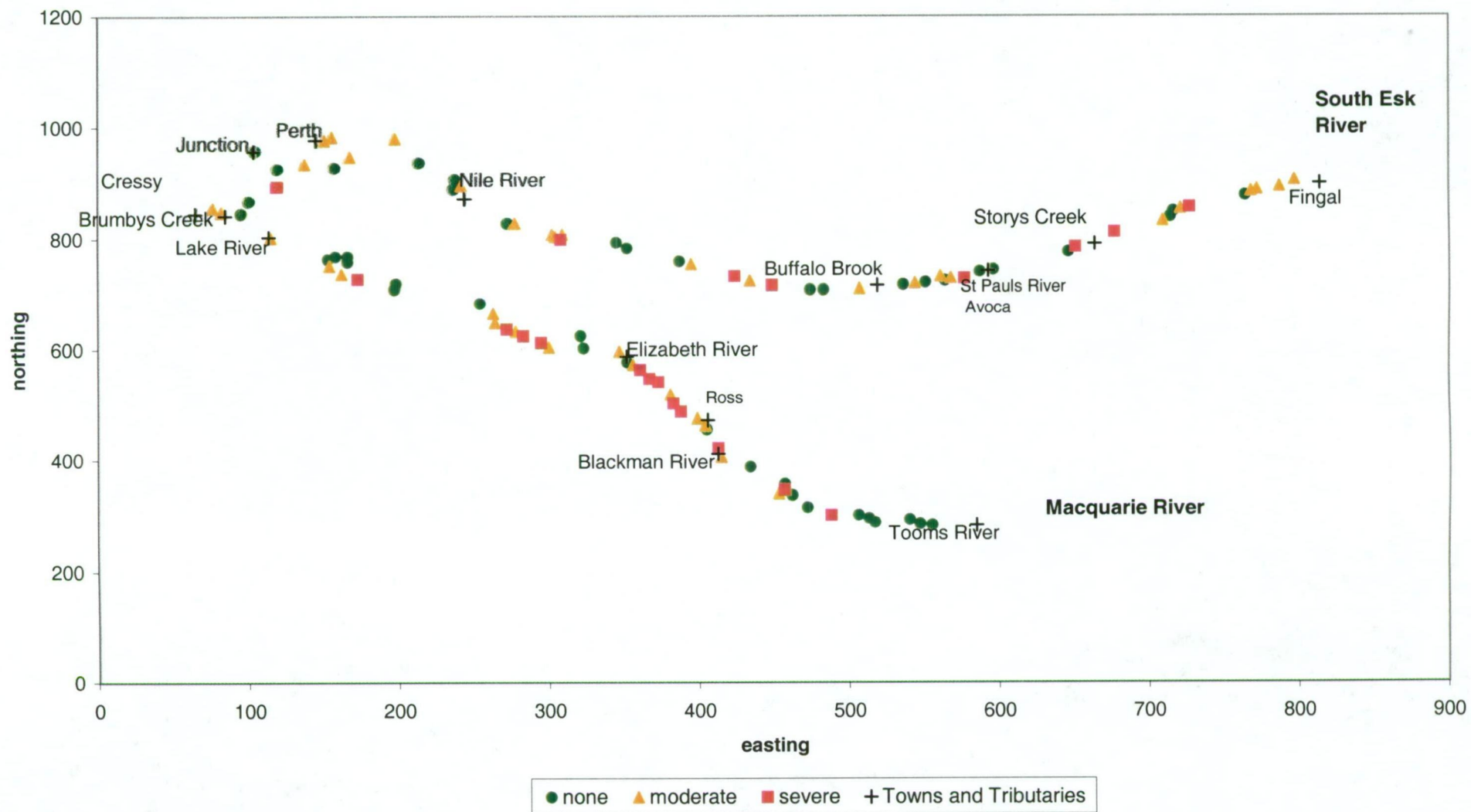
The middle reach of the South Esk was between the confluences with Storys Creek and with Buffalo Brook. This section had a low total species richness and a low diversity of species. The bank vegetation was a mixture of exotic (gorse, hawthorn, blackberries) and native species. There was a high proportion of gravel substrates along this reach. All-species groups 1 and 2, aquatic group 7 and marginal group 7 were the dominant river vegetation groups. *Carex gaudichaudiana* and *Juncus* species dominated the marginal vegetation, while *Isolepis fluitans,Eleocharis acuta, Triglochin* species and *Phragmites australis* were the most common aquatic species. This section of the river is known to be biologically impoverished due to heavy metal contamination from mining activity on Storys Creek (Norris *et al*. 1982; Locher 1993). However determining the cause of the low aquatic plant species richness and diversity was complicated by the high percentage shading along this reach, which is correlated with low aquatic species richness (see Ch.4).

The lower reach of the South Esk stretched from Buffalo Brook all the way to the confluence with the Macquarie. This section of river was dominated by all-species group 2, aquatic groups 2 and 5 and marginal group 2. That is, these sites contained a mixture of species of different growth forms. They tended to have a high percentage vegetation cover and a high aquatic species richness, but only a moderate marginal species richness and a moderately low proportion of exotic species. The bank vegetation was entirely pasture and willows. Common species were *Juncus* species, *Isolepis fluitans, Triglochin* species, *Eleocharis sphacelata, E. acuta, Carex gaudichaudiana, Phragmites australis* and *Myriophyllum* species.
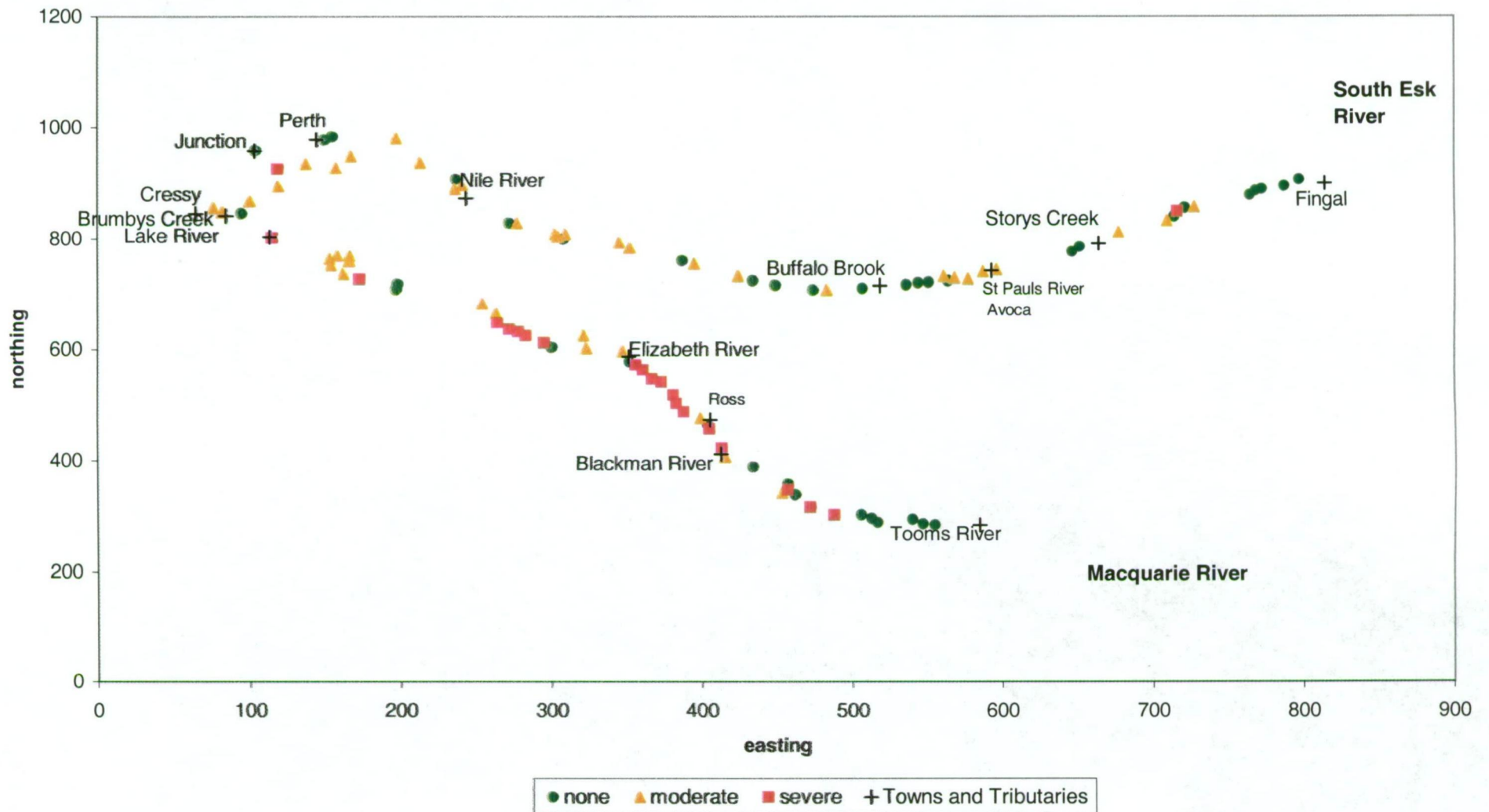
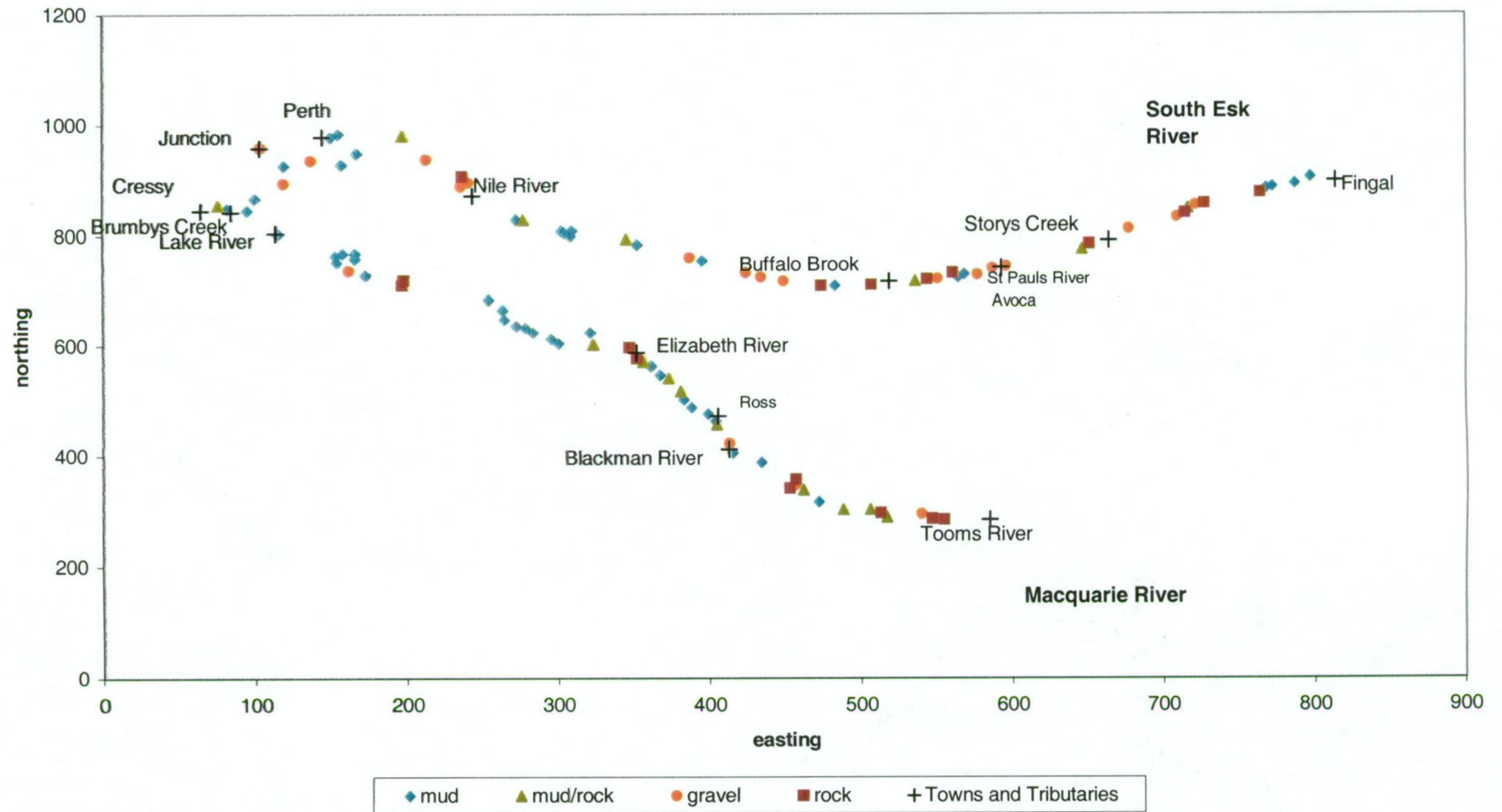**Figure 3.12 Geographical Distribution of Bank Vegetation**

Legend: pasture, exotic, exotic>native, native>exotic, native, willow, pasture & willow, Towns and Tributaries

Labels visible on chart: Perth, Junction, Cressy, Brumbys Creek, Lake River, Nile River, Storys Creek, South Esk River, Fingal, Buffalo Brook, St Pauls River, Avoca, Elizabeth River, Ross, Blackman River, Tooms River, Macquarie River

Figure 3.13 Geographical distribution of erosion of riverbanks

Figure 3.13 Geographical distribution of erosion of riverbanks

Axis labels: northing (y-axis), easting (x-axis)

Labels: South Esk River, Perth, Junction, Cressy, Brumbys Creek, Lake River, Nile River, Fingal, Storys Creek, Buffalo Brook, St Pauls River, Avoca, Elizabeth River, Ross, Blackman River, Macquarie River, Tooms River

Legend: ● none   ▲ moderate   ■ severe   + Towns and Tributaries

102

Figure 3.14   Geographical Distribution of Stock Damage

Figure 3.15 Geographical Distribution of Dominant Substrate Types

Legend: mud, mud/rock, gravel, rock, Towns and Tributaries

Labels visible on chart: Perth, Junction, Cressy, Brumbys Creek, Lake River, Nile River, Buffalo Brook, Storys Creek, St Pauls River, Avoca, Elizabeth River, Ross, Blackman River, Tooms River, South Esk River, Fingal, Macquarie River

Axis labels: northing (y-axis), easting (x-axis)

Plate 3

Native vegetation on the Upper Macquarie River

Triglochin procerum

Native bank vegetation

Plate 4

Abundant marginal and aquatic vegetation on the Macquarie River

A floodplain on the lower Macquarie River

A run on the mid-lower Macquarie River, with abundant cover of the aquatic species *Vallisneria americana*.

Chapter Four

Relationships between environmental variation and variation in macrophyte diversity, richness and cover- a comparison of the two rivers.

4.1 Introduction

The second aim of this study was to compare the spatial distribution of the species richness, abundance and diversity of aquatic macrophyte communities in the Macquarie and South Esk rivers, and to relate this distribution to environmental characteristics of the two rivers. In this chapter, between-site variation in the species diversity, richness and percentage cover of the macrophytic vegetation are related to environmental variation between sites. These relationships are analysed for each river, providing an overview of the differences in environmental relationships between the two rivers.

4.2 Methods

Statistical tests were used to determine the relationships between the species richness, diversity and percentage cover and the environmental variables (described in Chapter 3), and between the environmental variables themselves. The tests used were Spearmans Rank Correlation Coefficients for non-parametric continuous by continuous data and Kruskal-Wallis tests for non-parametric continuous or ordinal data. Some of the ordinal data were measured in as few as three classes. However, despite the low number of classes, Kruskal-Wallis tests were used in preference to chi-squared tests as the small number of samples in the groups created uncertainty about the validity of chi-squared tests. Mann-Whitney U-tests were used to compare the environmental variables in the two rivers.

4.3 Results

### 4.3.1 Upstream-downstream relationships

The most obvious environmental gradient in this study was that of distance upstream from the confluence of the two rivers. Table 4.1 shows that type of bank vegetation and level of stock damage were significantly related to distance upstream in both rivers, substrate type was significantly related to distance upstream in the Macquarie, and river width and depth decreased with distance upstream in the Macquarie. Native bank vegetation and rock substrates were more often found at upstream sites, and modified bank vegetation and mud substrates were more often found at downstream sites (see Tables 4.4 and 4.5). Sites with no stock damage were more often found upstream on the Macquarie. Figures 3.12, 3.14 and 3.15 provide an illustration of the distribution of bank vegetation, stock damage and substrate types along the two rivers.

Upstream-downstream differences were not as dramatic on the South Esk, as the study area did not extend up into the steeper rockier parts of the catchment. There was, however, a relationship between the type of bank vegetation and distance upstream on the South Esk, with the most modified bank vegetation types (pasture and willows) occurring furthest downstream (see Table 4.4).
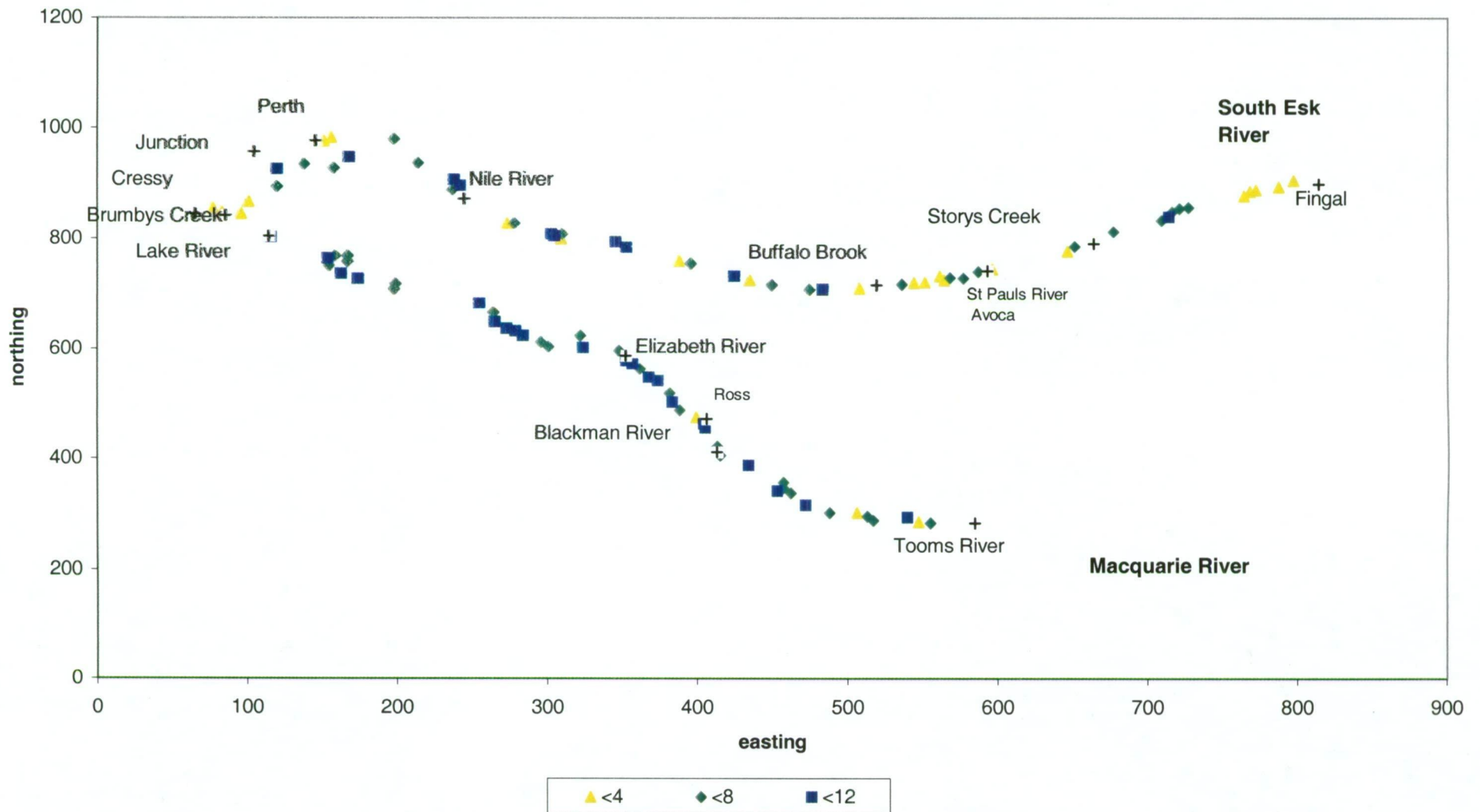
Table 4.2 summarises the relationship between the richness variables at each site and the distance upstream. Figures 4.1, 4.2, 4.3 and 4.4 illustrate the distribution of macrophyte species richness and cover along the two rivers. The total species richness, the marginal species richness, the exotic species richness and the proportion of exotic species lessened with distance upstream on the Macquarie. These variables were all inter-related, see Table 4.3. The proportion of aquatic species increased with distance upstream. This was due to the decline in marginal species richness with distance upstream, rather than any increase in aquatic species richness. Aquatic species richness (which consisted almost entirely of native species) did not vary significantly with distance upstream. The chart
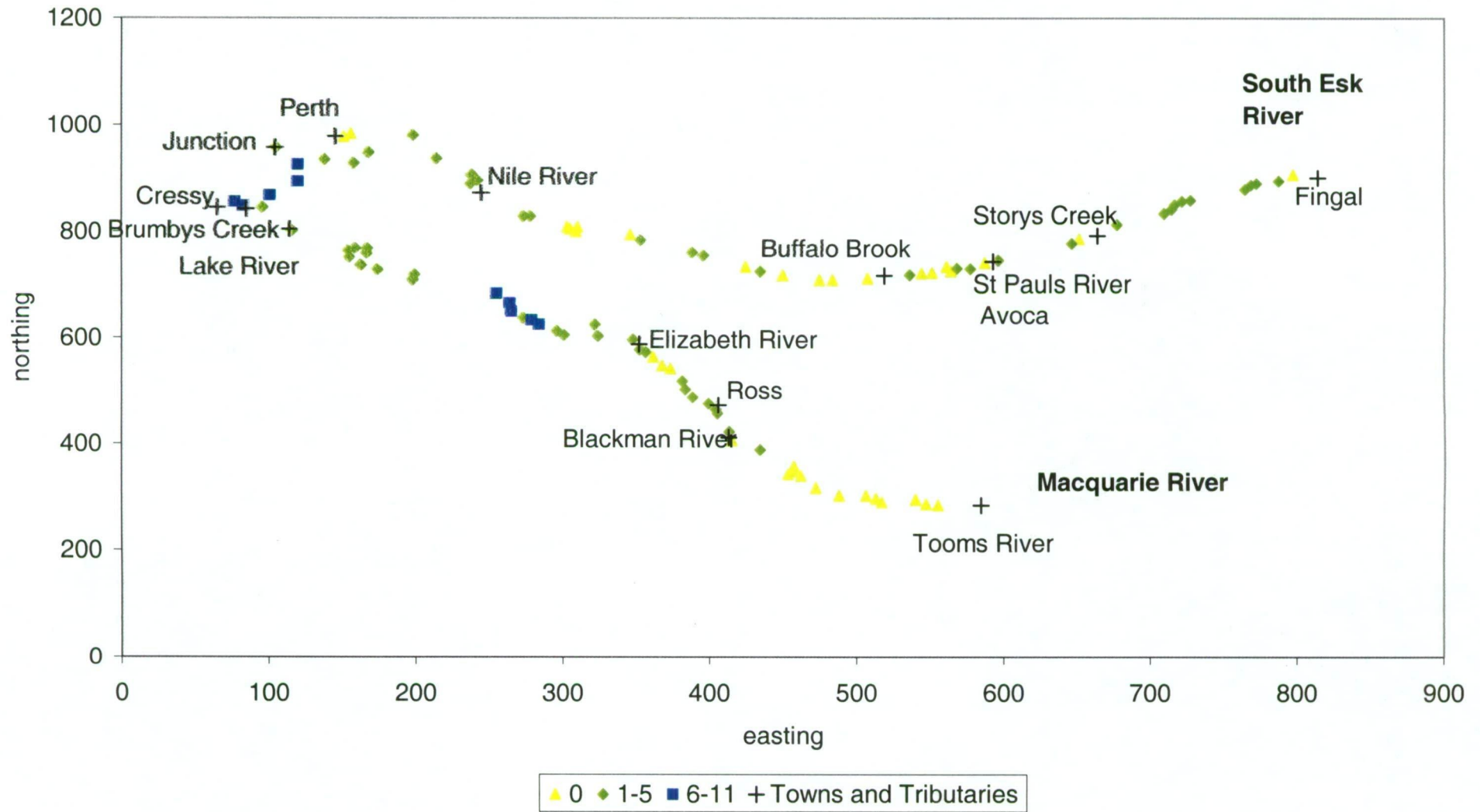
Figure 4.1 Geographical Distribution of Classes of Percentage Cover
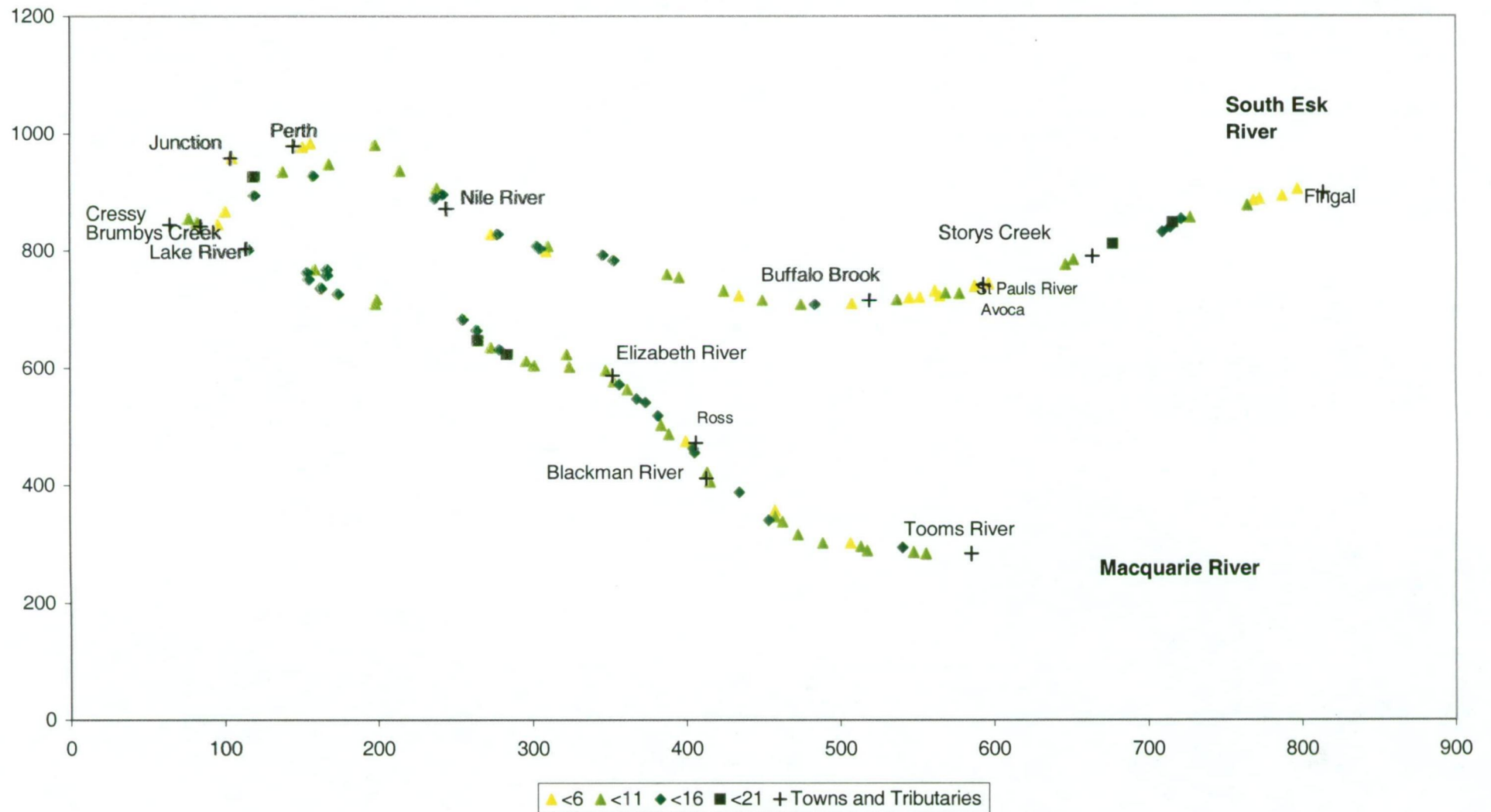
Legend: — <1 ▲ 0-4 ▲ 5-9 ♦ 10-24 ♦ 25-49 ■ 50-100 + Towns and Tributaries
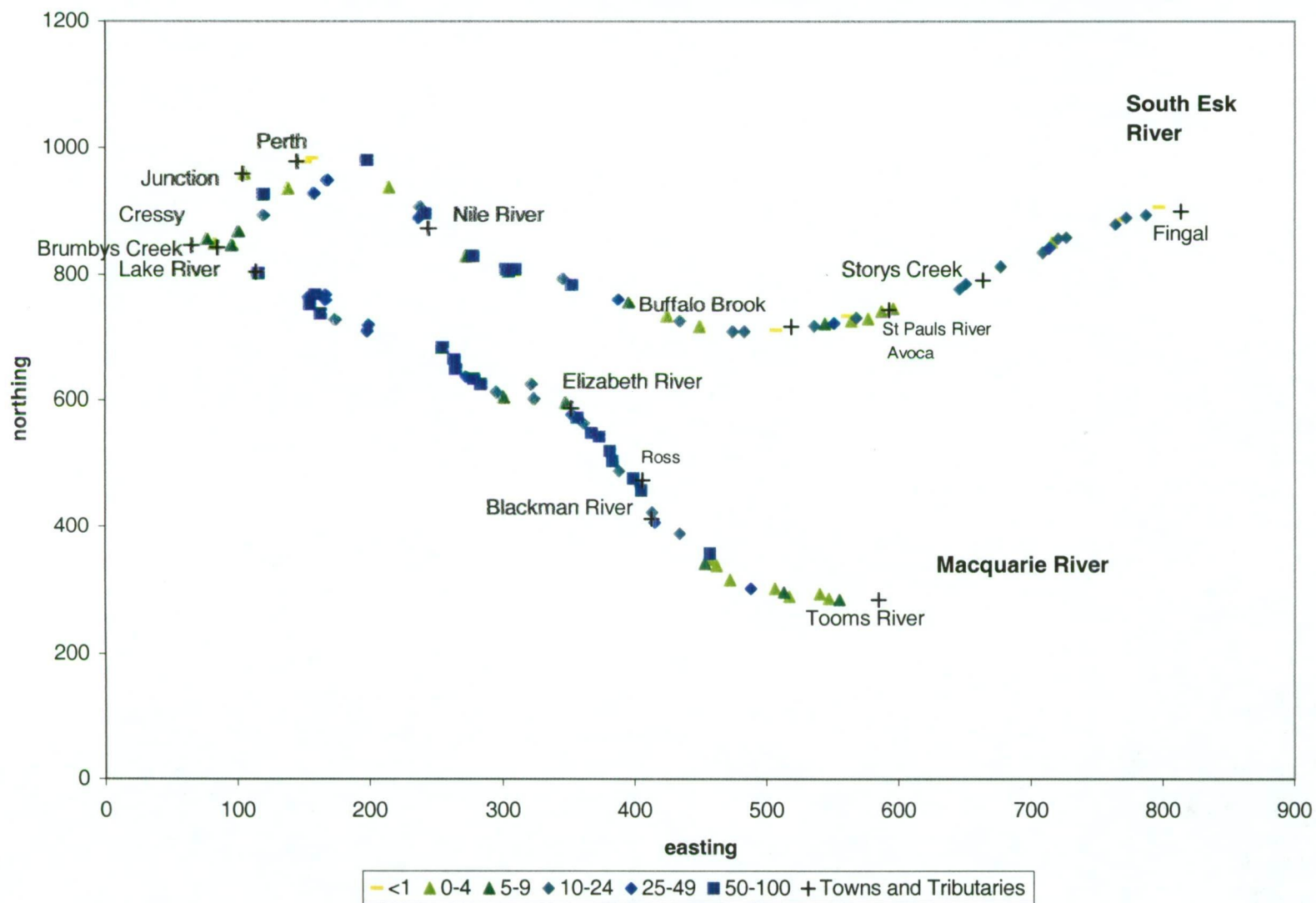
Figure 4.2 Geographical Distribution of Classes of Aquatic Species Richness

Legend: ▲ <4   ◆ <8   ■ <12

Figure 4.3 Geographical Distribution of Classes of Exotic Species Richness

Legend: 0 (yellow triangle) · 1-5 (green diamond) · 6-11 (blue square) · + Towns and Tributaries

Figure 4.4 Geographical Distribution of Classes of Native Species Richness

Legend: ▲ <6 ▲ <11 ◆ <16 ■ <21 + Towns and Tributaries

showing the geographical distribution of aquatic species richness (figure 4.2) shows that the highest species richness appears to occur in the mid-reaches.

It is important to note that the lower part of the Macquarie, below Brumbys Creek, was of a completely different character to the other parts of the lower reaches of either river, as it was diluted by large amounts of cold, clear water from the Central Highlands. This uncharacteristic stretch of river lessened the statistical significance of upstream-downstream variation in some variables. When the 7 sites downstream of the confluence with Brumbys Creek were excluded from the dataset, percentage total vegetation cover (figure 4.5), percentage aquatic vegetation cover and diversity (figure 4.6) were all significantly negatively correlated with distance upstream.

There was not a significant upstream-downstream difference in richness variables on the South Esk.

4.3.2 Relationships with shading

Tables 4.1 and 4.4 show that percentage shading by bank vegetation is significantly inversely related to 'nativeness' of bank vegetation on the South Esk, with willow dominated sites having a significantly higher level of shading than sites dominated by native species on the banks. Percentage shading is negatively correlated with river width on the South Esk, and is significantly related to lower levels of stock damage on the Macquarie (table 4.1). A high percentage of shading by bank vegetation is also significantly associated with a low percentage cover of aquatic and marginal vegetation on the Macquarie, a low total species richness on both rivers and a low aquatic species richness on both rivers (table 4.2).

4.3.3 Relationships with bank vegetation type

Substrate type and river depth were significantly related to bank vegetation type on both rivers. Mud sites had the least native bank vegetation and gravel and rock sites the most native bank vegetation (see table 4.5). On the South Esk, sites with more native bank vegetation were

shallower than sites with willows or pasture as bank vegetation (table 4.4). As mentioned in the section on upstream-downstream differences above, bank vegetation was also significantly related to distance upstream- willow and pasture sites were furthest downstream, native sites were furthest upstream (see table 4.4).

Table 4.2 shows that on both rivers there was a significant relationship between type of bank vegetation and percentage cover of aquatic and marginal vegetation, diversity of aquatic and marginal vegetation, total aquatic and marginal vegetation richness and total native species richness. On the Macquarie there was also a significant relationship between bank vegetation type and the proportion of exotic species. Sites with more exotic bank vegetation (pasture sites) had a greater diversity, cover and species richness in the (combined) marginal and aquatic vegetation, and a greater proportion of exotic species in the marginal vegetation than sites with native bank vegetation or willow-choked sites (Table 4.4). On the Macquarie, sites with mixed exotic/native bank vegetation had a higher proportion of aquatic species (growth forms 1,2 and 3), due to the lower number of marginal species (growth form 4), than pasture sites.

Correlations between percentage shading by willows and percentage macrophyte cover and macrophyte species richness and diversity were investigated using 62 sites with only willows and pasture as bank vegetation (that is, with no shading from native vegetation or exotic species other than willows). Percentage shading was significantly negatively correlated with aquatic and marginal vegetation cover, diversity, total species richness, aquatic species richness, marginal species richness and native species richness. Observations in the field suggested that there was almost never any vegetation growing under willows.

4.3.4 Relationships with stock damage

Tables 4.1 and 4.7 show that the level of stock damage at sites on the Macquarie was significantly related to percentage shading, substrate type, distance upstream and bank vegetation type. It was also significantly positively related to percentage aquatic and marginal vegetation cover, total aquatic and marginal species richness and exotic species richness. Sites

with moderate levels of stock damage had the highest diversity. Many of these variables were inter-related. Distance upstream was related to substrate and bank vegetation, and decreasing species richness (Table4.2). Total species richness was positively related to exotic species richness (Table 4.3).

On the South Esk, level of stock damage was significantly related to type of bank vegetation (see Table 4.4), and total species richness.

4.3.5 Relationships with erosion

Table 4.1 shows that on the Macquarie the level of erosion was significantly related to the bank vegetation type. That is, sites with bushy vegetation on the banks were not as eroded as pasture sites, which had been cleared right to the river margins (see table 4.4). On the Macquarie, level of erosion was also significantly related to level of stock damage (see table 4.7) which is higher in pasture-dominated areas.

4.3.6 Relationships with substrate

On the Macquarie there was a significant relationship between substrate type and total species richness, exotic species richness and proportion of exotic species (table 4.5). That is, on the Macquarie, sites with muddy substrates had a higher species richness and higher degree of invasion by exotics than sites with a gravel or rock substrate. On both rivers substrate type was significantly related to both river form and depth, illustrating the difference in current velocity between riffles, runs and pools. Substrate type was also associated with bank vegetation type on both rivers. See the relationship (below) between form of river site and bank vegetation.

4.3.7 Relationships with river form

As would be expected from the criteria used to define riffles, runs and pools, riffles were shallow, runs were variable in depth, and pools were deep (table 4.6). Similarly riffles were narrow, runs wider and pools wider again. On both rivers there was also a positive correlation between site width and site depth (table 4.1).

Riffles had mostly a bedrock or gravel substrate, runs mostly a mud or gravel substrate, and pools mostly a mud substrate (table 4.6). Note that substrate was also significantly correlated with depth- muddy sites were medium or deep, gravel and bedrock sites were shallow (table 4.5).

On the Macquarie, deep sites (>2 m) had a higher species diversity than shallow sites (1-2 m). That is, pools had a higher species diversity than riffles (table 4.6). However on the South Esk, shallow sites had a significantly higher diversity than medium-depth sites, but there was not a significant relationship between form and diversity.

4.3.8 Comparison of the two rivers

Table 4.9 gives a comparison of the median values for environmental variables, species cover and richness between the two rivers. The species composition of both the marginal and aquatic vegetation varied between different reaches of the two rivers, see Chapter 3.

The most notable differences between the rivers were that the middle section of the Macquarie, after the rocky, fast flowing higher reaches, tended to be flatter and slower flowing than the South Esk, with long deep runs and pools through pasture land, generally with stock access right into the river, little shading, and a high aquatic vegetation cover and total species richness. The South Esk had long stretches of shallower fast flowing water over a pebbly riverbed, mainly runs and riffles, with little aquatic vegetation cover. The bank vegetation tended to be a mixture of pasture, gorse, blackberries, wattles, tea-tree, and willow, with only a few sites of pure pasture. Percentage shading was higher than on the Macquarie, the river was wider and the banks tended to be higher.

Table 4.1 Correlations between environmental variables, divided by river.

Spearmans Correlation Coefficients ($P < 0.05$) were used for continuous variables, and Kruskal-Wallis probabilities for categoric variables. Form, form of river site; %shade, percentage of site overshadowed by bank vegetation; Subst, dominant substrate; Bankht, height of bank on highest side; Width, maximum width at site; Depth, maximum depth at site; Kms, distance upstream from junction of the two rivers; Erosn, visible erosion of banks; Stock, obvious trampling by stock; Bankvg, nativeness of bank vegetation; Probability values from Kruskal-Wallis Tests: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; -, $P > 0.05$.

	%shade	Subst	Bankht	Width	Depth	Kms	Bankvg	Erosn	Stock[d]
Form[a]	-	* M	-	*** M	*** M	-	-	* M	-
	-	** SE	-	*** SE	*** SE	-	-	-	-
%shade		-	-	-	-	-	-	-	*** M
		-	-	-0.51 SE	-	-	* SE	-	-
Subst[f]			-	-	* M	* M	*** M	-	** M
			-	-	** SE	-	** SE	-	-
Bankht				-	-	-	-	-	-
				-	-	-	-	-	-
Width					*** M	-0.39 M	-	-	-
					*** SE	-	-	-	-
Depth[b]						** M	* M	* M	-
						-	* SE	* SE	-
Kms							** M	-	** M
							** SE	-	-
Bankvg[e]								** M	*** M
								-	** SE
Erosn[c]									*** M
									-

[SE] South Esk River
[M] Macquarie River
[a] Form of river site, 1=run 2=riffle 3=pool
[b] Depth, 1 = < 1 m, 2= 1-2 m, 3= >2 m
[c] Erosion, 1-3 from none to severe
[d] Stock damage, 1-3 from none to severe
[e] Nativeness of bank vegetation, on a scale of 1-6 from least native to most native
Subst[f], Dominant substratum, 1= mud, 2=mud/rock, 3=gravel, 4=rock

Table 4.2 Correlations between environmental variables and vegetation cover, diversity and richness, divided by river. Spearmans Correlation Coefficients ($P < 0.05$) were used for continuous variables, and Kruskal-Wallis probabilities for categoric variables. Form, form of river site; %shade, percentage of site overshadowed by bank vegetation; Subst, dominant substrate; %cover, percentage of site covered by aquatic and marginal vegetation; Bankht, height of bank on highest side; Width, maximum width at site; Depth, maximum depth at site; Kms, distance upstream from junction of the two rivers; Erosn, visible erosion of banks; Stock, obvious trampling by stock; Exrich, number of exotic species; Totrich, total number of species; Bankvg, nativeness of bank vegetation; Ex/tot, proportion of exotic species; Aqrich, number of aquatic species; Marich, number of marginal species; Aq/tot, proportion of aquatic species; Aqcover, percentage cover of aquatic species; Divers, Shannons diversity. Probability values from Kruskal-Wallis Tests: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; -, $P > 0.05$.

	%cover	Totrich	Exrich	Ex/tot	Aqrich	Marich	Natrich	Aq/tot	Aqcover	Diversity
Form[a]	-	-	-	-	-	-	-	-	-	*[M]
%shade	-0.33[M]	-0.30[M] -0.37[SE]	-	-	-0.30[M] -0.47[SE]	-	-0.29[M] -0.48[SE]	-	-0.34[M]	-0.34[M]
Subst[f]	-	*[M] -	*[M] -	*[M] -	-	-	-	-	-	-
Bankht	-	-	-	-	-	-	-	- 0.34[SE]	-	-
Width	-	0.35[M] -	0.29[M] -	0.27[M] -	-	0.39[M] -	-	-0.43[M] -	-	0.43[M]
Depth[b]	-	*[M] -	*[M] -	*[M] -	-	*[M] -	-	**[M] -	-	**[M] *[SE]
Kms	-	-0.51[M] -	-0.67[M] -	-0.66[M] -	-	-0.65[M] -	-	0.67[M] -	-	-0.31[M]
Bankvg[e]	**[M] **[SE]	***[M] ***[SE]	**[M] -	**[M] -	*[M] ***[SE]	**[M] *[SE]	**[M] **[SE]	**[M] -	- **[SE]	*[M]
Erosn[c]	-	-	-	-	-	-	-	-	-	-
Stock[d]	**[M] -	**[M] ***[SE]	*[M] -	-	**[M] ***[SE]	*[M] *[SE]	*[M] ***[SE]	-	**[M] -	**[M] *[SE]

[SE]South Esk River
[M]Macquarie River
[a]Form of river site, 1=run 2=riffle 3=pool
[b]Depth, 1 = < 1 m, 2= 1-2 m, 3= >2 m
[c]Erosion, 1-3 from none to severe
[d]Stock damage, 1-3 from none to severe
[e]Nativeness of bank vegetation, on a scale of 1-6 from least native to most native
[f]Subst, Dominant substratum, 1= mud, 2=mud/rock, 3=gravel, 4=rock

Table 4.3 Correlations between vegetation cover and richness, divided by river.

Spearmans Correlation Coefficients ($P < 0.05$) were used. %cover, percentage of site covered by aquatic and marginal vegetation; Exrich, number of exotic species; Totrich, total number of species; Ex/tot, proportion of exotic species; Aqrich, number of aquatic species; Marich, number of marginal species; Aq/tot, proportion of aquatic species.

	%cover	Totrich	Exrich	Ex/tot	Aqrich	Marich	Natrich	Aq/tot	Aqcover	Diversity
%cover	-	0.52 M 0.57 SE	0.37 M 0.31 SE		0.52 M 0.58 SE	0.42 M	0.61 M 0.55 SE		0.91 M 0.94 SE	
Totrich		-	0.76 M 0.62 SE	0.56 M	0.60 M 0.81 SE	0.89 M 0.85 SE	0.82 M 0.97 SE	-0.64 M	0.33 M 0.51 SE	0.69 M 0.76 SE
Exrich			-	0.95 M 0.88 SE		0.82 M 0.82 SE	0.35 M 0.43 SE	-0.74 M -0.74 SE		0.46 M 0.48 SE
Ex/tot				-		0.68 M 0.57 SE		-0.70 M -0.77 SE		0.31 M
Aqrich					-	0.42 SE	0.81 M 0.88 SE	0.34 SE	0.53 M 0.66 SE	0.28 M 0.50 SE
Marich						-	0.64 M 0.74 SE	-0.91 M -0.72 SE	- 0.30 SE	0.68 M 0.69 SE
Natrich							-	-0.33 M	0.50 M 0.54 SE	0.57 M 0.71 SE
Aq/tot								-		-0.55 M -0.34 SE
Aqcover									-	
Diversity										-

SE South Esk River
M Macquarie River

Table 4.4 Median values of environmental and richness variables for each bank vegetation type. Significant differences between pairs of bank vegetation type were tested using Kruskal-Wallis tests, then Dunn's Method of pairwise multiple comparisons. Only variables that differed significantly by bank vegetation for at least one river are shown. %shade, percentage of site overshadowed by bank vegetation; Depth, maximum depth at site; Kms, distance upstream from junction of the two rivers; Erosn, visible erosion of banks; Stock, obvious trampling by stock; %cover, percentage of site covered by aquatic and marginal vegetation; Divers, Shannons diversity; Totrich, total number of species; Natrich, number of native species; Exrich, number of exotic species; Ex/tot, proportion of exotic species; Aqrich, number of aquatic species; Marich, number of marginal species; Aq/tot, proportion of aquatic species. n = number of sites

	1 Willow ($n=2^M,5^{SE}$)	2 Pasture-willow ($n=37^M,18^{SE}$)	3 Exotic-willow ($n=0^M,9^{SE}$)	4 Exotic-native ($n=4^M,11^{SE}$)	5 Native-exotic ($n=7^M,5^{SE}$)	6 Native $n=(4^M,0^{SE})$
%Shade ^{M}	33.5(27-40)	0(0-1)	-	0.5(0.3-1.5)	2(0.5-2.8)	12.8(0.3-27.5)
^{SE}	44.4(20-85)^a	5.5(1.2-30.0)^{ab}	24.2(2.1-39.0)^{ab}	4.3(1.3-14.8)^{ab}	0.8(0.1-3.8)^b	-
Depth[1] ^{M}	3(3-3)	3(2-3)	-	2.5(2-3)	1(1-2.8)	1.5(1-2)
^{SE}	3(1.8-3)^{ab}	3(2-3)^a	2(1.8-3)^{ab}	1(1-2)^b	2(1-2.3)^{ab}	-
Kms ^{M}	10.5(0-21)^a	70(40.5-97.5)^a	-	80.8(77.8-104.3)^{ab}	116.0(60.3-128)^{ab}	132.5(129.5-135
^{SE}	50.2(18.8-72.5)^a	59.8(32-100.5)^a	131(72.8-139.6)^b	103(96.3-119.5)^b	88(84.5-97.5)^{ab}	-
Erosn[2] ^{M}	1(1-1)^{ab}	2(1-3)^b	-	1.5(1-2.5)^{ab}	1(1-1)^a	1(1-1)^a
^{SE}	2(1.8-2.3)	2(1-2)	2(1-2)	2(1-3)	2(1-2.3)	-
Stock[3] ^{M}	1(1-1)^{ab}	3(2-3)^a	-	2(2-2.5)^{ab}	1(1-1)^b	1(1-1)^b
^{SE}	1(1-1.3)^{ab}	2(2-2)^a	2(1-2)^{ab}	1(1-2)^{ab}	1(1-1)^b	-
Divers ^{M}	0.55 (0.38-0.71)^a	0.86(0.77-0.97)^b	-	0.73(0.67-0.76)^{ab}	0.79(0.46-0.88)^{ab}	0.64(0.41-0.77)^a
^{SE}	0.41(0.28-0.54)	0.72(0.47-0.81)	0.62(0.48-0.69)	0.73(0.48-0.90)	0.48(0.35-0.52)	-
Aqcover ^{M}	1(0.9-1)	26.3(8.9-48.3)	-	15.5(7.0-31.8)	21.1(2.4-43)	4(2.7-6)
^{SE}	0(0-1.0)^a	16.9(8.4-47.0)^b	6.7(0.7-19.7)^{ab}	7.8(2.5-13.5)^{ab}	2.8(1.8-16.8)^{ab}	-
%cover ^{M}	4.7 (1.1-8.3)^{ab}	38.8(13.2-76.2)^a	-	15.5(8.7-25.1)^{ab}	29.4(2.7-43.4)^{ab}	3.6(1.8-5.5)^b
^{SE}	0(0-1.7)^a	17.6(11.2-58)^b	12.9(3.7-22.7)^{ab}	10.1(4.3-24.4)^{ab}	13.1(2.3-18.1)^{ab}	-
Totrich ^{M}	6(6-6)^{ab}	14(11-18)^b	-	7.5 (7-8)^{ab}	10(7.5-11)^{ab}	6.5(4-8)^a
^{SE}	0(0-3.25)^a	12(9-15)^b	10(4-12.8)^b	10(5.5-12.3)^b	7(4.5-7.3)^{ab}	-
Natrich ^{M}	4(4-4)^a	11(8-14)^b	-	7(6.5-7)^{ab}	9(7.5-9.8)^{ab}	6.5(4-8)^{ab}
^{SE}	0(0-2.8)^a	11(7-13)^b	7(3.8-10.5)^{ab}	8(5.3-10.8)^{ab}	6(3.8-7.3)^{ab}	-
Exrich ^{M}	2(2-2)^{ab}	3(1-7)^a	-	1(0.5-1)^{ab}	0(0-1)^{ab}	0(0-0)^b
^{SE}	0(0-0.5)	1(0-3)	1(0.8-2)	2(0-2.8)	0(0-1)	-
Ex/totr ^{M}	0.33(0.33-0.33)^{ab}	0.23(0.08-0.36)^a	-	0.10(0.06-0.13)^{ab}	0.00(0-0.1)^b	0.00(0-0)^b
^{SE}	0.14(0-0.29)	0.13(0-0.24)	0.2(0.05-0.35)	0.15(0-0.2)	0(0-0.16)	-
Aqrich ^{M}	2(1-3)^{ab}	8(6-9)^a	-	6(4.5-7.5)^{ab}	6(5.3-7.3)^{ab}	4(2.5-5.5)^b
^{SE}	0(0-2)^a	6.5(5-8)^c	3(1.8-6.3)^b	5(3.3-6.5)^{bc}	3(1.8-4.5)^{ab}	-
Aq/totr ^{M}	0.33(0.17-0.5)^a	0.5(0.41-0.63)^a	-	0.86(0.61-1.0)^b	0.71(0.6-0.8)^{ab}	0.75(0.55-0.92)^{ab}

	SE	0.64(0.29-1)	0.5(0.43-0.62)	0.5(0.31-0.53)	0.54(0.43-0.78)	0.57(0.37-0.69)	-
Marich	M	4(3-5)[ab]	7(3.8-12.3)[a]	-	1(0-3)[ab]	2(2-4.5)[b]	2(0.5-3.5)[ab]
	SE	0(0-1.3)[a]	5(4-8)[b]	4(2-8.3)[ab]	5(1-6)[ab]	3(1.8-4)[ab]	-

[M]Macquarie River
[SE]South Esk River
[a,b,c] different letters indicate a significant difference
[1]depth, 1= <1 m, 2= 1-2 m, 3= >2 m.
[2]erosion, 1=none, 2 = moderate, 3 = severe
[3]stock damage, 1=none, 2 = moderate, 3 = severe

Table 4.5 Median values of environmental and richness variables for each substrate type.

25% and 75% percentiles are given in brackets. Only variables which differed significantly by substrate type for at least one river are shown. Significant differences between pairs of substrate type were tested using Kruskal-Wallis tests, then Dunn's Method of pairwise multiple comparisons.

Vel, slowness of current velocity; Depth, maximum depth at site; Kms, distance upstream from junction of the two rivers; Stock, obvious trampling by stock; Exrich, number of exotic species; Totrich, total number of species; Ex/tot, proportion of exotic species; n = number of sites

		1 mud $n=29^M, 18^{SE}$	2 mud/rock $n=10^M, 6^{SE}$	3 gravel $n=6^M, 15^{SE}$	4 rock $n=9^M, 9^{SE}$
Vel [1]	M	$2(2-3)^a$	$2(2-3)^{ab}$	$2(1-2)^{ab}$	$1(1-2)^b$
	SE	$3(2-3)^a$	$2.5(2-3)^{ab}$	$2(2-2)^b$	$2(1-2.25)^{ab}$
Depth[2]	M	$3(2-3)^a$	$2(1-3)^{ab}$	$1.5(1-3)^{ab}$	$2(1-2)^b$
	SE	$3(2-3)^a$	$2.5(2-3)^{ab}$	$1(1-2)^b$	$2(1-3)^{ab}$
Bankvg[3]	M	$2(2-2)^a$	$3(2-5)^{ab}$	$2(2-2)^a$	$5(4.75-6)^b$
	SE	$2(2-3)^a$	$2(2-4)^{ab}$	$4(2.25-4)^b$	$4(2.75-4.25)^b$
Kms	M	$68(38.75-90.5)^a$	$97.5(86-126.0)^{ab}$	$76(9.8-117.0)^{ab}$	$116(74.88-131.3)^{ab}$
	SE	$66.5(50.2-102)$	$82(51-114)$	$85(49.8-105.8)$	$101(91-129)$
Stock[4]	M	$2(2-3)^a$	$2.5(1-3)^{ab}$	$2(1-3)^{ab}$	$1(1-1.25)^b$
	SE	$1.5(1-2)$	$2(1-2)$	$2(1-2)$	$1(1-1.3)$
Totrich	M	$14(10-18.3)^a$	$10.5(7-15)^{ab}$	$9.5(7-18)^{ab}$	$9(6.75-11.3)^b$
	SE	$8(2-12)$	$11.5(9-15)$	$10(5.5-14.5)$	$8(3-12.8)$
Exrich	M	$3(1-7)^a$	$0.5(0-3)^{ab}$	$1.5(0-4)^{ab}$	$0(0-1)^b$
	SE	$0.5(0-1)$	$2(1-3)$	$1(0.3-7.8)$	$0(0-3.5)$
Ex/totr	M	$0.23(0.09-0.36)^a$	$0.06(0.00-0.21)^{ab}$	$0.18(0.00-0.33)^{ab}$	$0.00(0.00-0.11)^b$
	SE	$0.1(0-0.25)$	$0.17(0.13-0.2)$	$0.15(0.02-0.20)$	$0(0-0.22)$

[M] Macquarie River
[SE] South Esk River
[a,b,c] different letters indicate a significant difference
[1] slowness of current velocity, 1=fast(riffle), 2=moderate/slow(run), 3=negligible(pool)
[2] depth, 1= <1 m, 2= 1-2 m, 3= >2 m.
[3] 'nativeness' of bank vegetation, on a scale of 1-6 from least native to most native
[4] stock damage, 1=none, 2 = moderate, 3 = severe

Table 4.6 Median values of environmental and richness variables for each form of river site. 25% and 75% percentiles are given in brackets. Only variables that differed significantly by form for at least one river are shown. Significant differences between pairs of different forms were tested using Kruskal-Wallis tests, then Dunn's Method of pairwise multiple comparisons. Divers, Shannon's diversity; Vel, slowness of current velocity; Depth, maximum depth at site; Kms, distance upstream from junction of the two rivers; Stock, obvious trampling by stock; Exrich, number of exotic species; Totrich, total number of species; Ex/tot, proportion of exotic species; n = number of sites

		1 runs $n=28^M,26^{SE}$	2 riffles $n=9^M,6^{SE}$	3 pools $n=17^M,16^{SE}$
Divers	M	$0.82(0.74\text{-}0.92)^{ab}$	$0.60(0.47\text{-}0.84)^a$	$0.92(0.73\text{-}0.99)^b$
	SE	$0.51(0.36\text{-}0.74)$	$0.76(0.63\text{-}0.88)$	$0.72(0.49\text{-}0.90)$
Subst[1]	M	$1(1\text{-}2)^a$	$4(2.75\text{-}4)^b$	$1(1\text{-}2)^a$
	SE	$3(1\text{-}3)^{ab}$	$3.5(3\text{-}4)^a$	$1(1\text{-}2)^b$
Width	M	$15.25(10\text{-}26.5)^a$	$9(6.75\text{-}10.5)^a$	$36(26.5\text{-}47.8)^b$
	SE	$18.5(15\text{-}27)^a$	$12.5(9\text{-}14)^a$	$52.5(42.5\text{-}70)^b$
Depth[2]	M	$2(2\text{-}3)^a$	$1(1\text{-}1)^b$	$3(3\text{-}3)^a$
	SE	$2(1\text{-}2)^a$	$1(1\text{-}1)^a$	$3(3\text{-}3)^b$
Erosion[3]	M	$2(1\text{-}3)^a$	$1(1\text{-}2)^b$	$1(1\text{-}2)^{ab}$
	SE	$2(1\text{-}2)$	$2(1\text{-}3)$	$1.5(1\text{-}2)$

[M] Macquarie River
[SE] South Esk River
[a,b,c] different letters indicate a significant difference
[1] Subst, 'rockiness' of dominant substrate type, 1= mud, 2=mud/rock, 3=gravel, 4=rock
[2] depth, 1= <1 m, 2= 1-2 m, 3= >2 m.
[e] erosion, 1 =none, 2 = moderate, 3 = severe

Table 4.7 Median values of environmental and richness variables for each level of stock damage. 25% and 75% percentiles are given in brackets. Only variables that differed significantly by level of stock damage for at least one river are shown. Significant differences between pairs of levels of stock damage were tested using Kruskal-Wallis tests, then Dunn's Method of pairwise multiple comparisons. %shade, percentage of site overshadowed by bank vegetation; Subst, dominant substrate type; Bankvg, bank vegetation type; Kms, distance upstream from junction of the two rivers; Erosn, visible erosion of banks; %cover, percentage of site covered by aquatic and marginal vegetation; Totrich, total number of species; Natrich, number of native species; Exrich, number of exotic species; Aqrich, number of aquatic species; Marich, number of marginal species; n = number of sites.

	1 none $n=16^M,23^{SE}$	2 moderate $n=18^M,24^{SE}$	3 severe $n=20^M,1^{SE}$
%Shade ^{M} ^{SE}	$2.38 (0.50-28.5)^a$ $11.0(2.1-29.4)$	$0.50 (0.00-3.35)^{ab}$ $3.66(0.51-26.01)$	$0.00 (0.00-0.5)^b$ 1.23
Subst[1] ^{M} ^{SE}	$3 (1.5-4)^a$ $3(1-4)$	$1 (1-2)^b$ $2.5(1-3)$	$1 (1-2)^b$ 2
Bankvg[2] ^{M} ^{SE}	$5 (2-5.5)^a$ $4(2-4)$	$2 (2-2)^b$ $2(2-3)$	$2 (2-2)^b$ 2
Kms ^{M} ^{SE}	$113.5 (62.5-130.5)^a$ $97(77.8-129.5)$	$44.5 (37-79.1)^b$ $69(40.7-102.5)$	$88 (68.5-99.5)^{ab}$ 129
Erosn[3] ^{M} ^{SE}	$1 (1-1)^a$ $2(1-2)$	$2 (1-2)^a$ $2(1-2)$	$3 (2-3)^b$ 1
Divers ^{M} ^{SE}	$0.67(0.45-0.8)^a$ $0.49(0.35-0.65)$	$0.89(0.76-0.97)^b$ $0.72(0.5-0.82)$	$0.84(0.74-0.92)^{ab}$ 1.06
%cover ^{M} ^{SE}	$7.17 (2.18-25.2)^a$ $10.11(1.09-16.59)$	$31.1 (7.83-63.6)^{ab}$ $14.82(4.44-54.58)$	$58.25 (15.47-80.4)^b$ 4.83
Aqcover ^{M} ^{SE}	$4.38(2.07-17.5)^a$ $6.62(1.13-14.37)$	$19.22(2.77-42.2)^{ab}$ $11.41(2.21-43.95)$	$38.11(11.86-55.5)^b$ 2.45
Totrich ^{M} ^{SE}	$9 (6-11)^a$ $7 (3-8.75)$ *	$13.5 (8-16)^b$ $12 (9-15)$	$14 (10-18.5)^b$ $21 (21-21)$
Natrich ^{M} ^{SE}	$9 (5.5-9.5)^a$ $5 (3-7)$ *	$10.5 (7-12)^{ab}$ $10 (7.5-13)$	$11 (8-15)^b$ $17 (17-17)$
Exrich ^{M} ^{SE}	$0.5 (0-2)^a$ $1(0-2)$	$1.5 (1-9)^b$ $1(0-3)$	$3 (0-4.5)^{ab}$ 4
Aqrich ^{M} ^{SE}	$5.5(3.5-7.5)^a$ $3(1.25-4.75)$ *	$6.5(4-8)^a$ $6(4.5-8)$	$8(7-9)^b$ $7(7-7)$
Marich ^{M} ^{SE}	$3(2-5)^a$ $2(1-5)$ *	$6(2.5-10)^b$ $5(4-8)$	$6.5(3-13)^{ab}$ $14(14-14)$

124

[a,b,c] different letters indicate a significant difference
*Because one group was very small, Dunn's method of pairwise comparisons could not determine significant differences
[1]Subst, Dominant substratum, 1= mud, 2=mud/rock, 3=gravel, 4=rock
[2] 'nativeness' of bank vegetation, on a scale of 1-6 from least native to most native
[3]erosion, 1=none, 2 = moderate, 3 = severe

Table 4.8 Correlations between percentage shading by willows and macrophyte diversity, percentage cover and richness.

	Spearmans correlation coefficient	P
diversity	-0.44	0.00
% cover	-0.43	0.00
Total richness	-0.42	0.00
Aquatic richness	-0.44	0.00
Marginal richness	-0.31	0.01
Native richness	-0.43	0.00

Table 4.9 Comparison of median values of environmental variables, cover and richnesses in the two rivers.

P-values are from Mann-Whitney Rank Sum Tests. Velocity, slowness of current velocity; %shade, percentage of site overshadowed by bank vegetation; Substrate, dominant substrate type; Bankvg, bank vegetation type; Width, stream width; Depth, maximum depth at site; Erosn, visible erosion of banks; Stockd, damage caused by stock trampling; %cover, percentage of site covered by aquatic and marginal vegetation; Totrich, total number of species; Exrich, number of exotic species; Ex/totr, proportion of exotic species; Aqrich, number of aquatic species; Marich, number of marginal species; Aq/totr, proportion of aquatic species.

	Median in M	Median in SE	*P*
Velocity	2.00	2.00	n.s.
%Shade	0.50	6.58	***
Substrate	1.00	2.50	n.s.
%Cover	24.9	13.0	**
Bankht	1.00	2.00	***
Width	17.5	21.5	*
Depth	2.50	2.00	n.s.
Erosn	2.00	2.00	n.s.
Stockd	2.00+	2.00	**
Exrich	1.50	1.00	n.s.
Totrich	12.00	9.00	**
Bankvg	2.00	3.00	n.s.[1]
Ex/totr	0.14	0.13	n.s.
Aqrich	7.00	5.00	***
Marich	5.00	4.00	n.s.
Aq/totr	0.57	0.50	n.s.

[1]Bank vegetation did vary significantly by river. Most pure pasture sites and most native sites were on the Macquarie. Most of the sites with bushy exotic vegetation (gorse, blackberry etc) and most willow dominated sites were on the SE (Tabulated Statistics on an un-ordered classification of bank vegetation types by River; Chi-Square = 25.812, DF =6, P=0.000).

4.4 Discussion

When describing the effects of environmental variables on aquatic species it is necessary to consider each variable separately. However it is important to remember that aquatic plants do not respond to each variable independently. For example, a plant's growth may be directly influenced by substrate particle size, but it is difficult to separate these effects from those of water velocity, which directly affects the plant growth and also determines substrate particle size. The effects of environmental variables may also interact if suboptimal conditions of one variable effect the tolerance of a species to another variable (Fox 1996).

4.4.1 Effects of distance upstream from the confluence of the two rivers.

The upstream-downstream differences in substrate and bank vegetation type on the Macquarie reflect differences in land use and geomorphology between upstream and downstream areas. The more upstream sites on the Macquarie generally did not run through intensively farmed land, and so had less disturbed bank vegetation than downstream sites. Upstream sites were also narrower, shallower and rockier than downstream sites, due to natural changes in the slope of the land, the volume of water carried and the underlying geology of the river between high and low areas of the catchment.

The decline in species richness and percentage cover with distance upstream on the Macquarie could be due to several factors. It is possible that richness and cover were limited by the higher proportion of sites with a rock substrate occurring upstream. Table 4.5 shows that on the Macquarie sites with a rock substrate have the least total species richness of all sites. This relationship needs to be treated with caution, however, as more of the rock sites were upstream on the Macquarie (see table 4.5), and so the apparent low species richness on rock substrates could have been caused by upstream-downstream variation in other factors. It has also been shown that aquatic vegetation traps sediments (Sand-Jensen 1998; French and Chambers 1996) and so causes a finer substrate to develop over time, so it is difficult to separate cause and effect between macrophyte presence and substrate type. Stream velocity has been shown to

have a strong effect on both substrate type and species cover and richness (Butcher 1933, Haslam 1978). Stream velocity was not measured directly in this study, but was derived from the 'river form' of each site: riffle=fast velocity, run=slow velocity, and pool= negligible velocity. River form did not vary significantly with distance upstream, but it is possible that this is not a good substitute for independent current velocity measurements. There is a markedly steeper river slope in the upper part of the Macquarie (see figure 2.5), which would be likely to create higher velocities in this section. Slope has been shown to be negatively associated with aquatic species richness in a study of the river-edge vegetation on the Murrumbidgee River in New South Wales (Roberts 1994), but it is not included as a separate variable here.

The change in bank vegetation type from the mid to the higher reaches of the study area on the Macquarie could at least partly account for the upstream-downstream variation in species richness. The upstream section of the Macquarie had more sites with native bank vegetation than the lower reaches, and thus many sites in the upper section were not invaded by pasture species from adjacent agricultural land. Pasture species in the marginal vegetation accounted for a large proportion of the total species richness and for almost all of the exotic species richness in sites in the mid and lower reaches of the Macquarie.

The DPIF (1996) study of the rivers for its State of the Rivers Report found that there was an upstream-downstream gradient in several water quality variables, which could also have contributed to the variation in vegetation. Dissolved inorganic nitrogen levels increased downstream, as did levels of Total Kjeldahl Nitrogen (mostly composed of organic nitrogen). The downstream increase in nutrient levels was most likely due to agricultural activity and the impact of sewage treatment outflows in the lower parts of the catchments (figure 2.4 on page 19 shows the variation in landuse between different parts of the catchment). High levels of nutrients in the water column have been found to increase plant growth and biomass, but decrease diversity (see Demars and Harper 1998; Haslam 1978,1990). The former appears to be the case in this study but not the latter. More detailed studies of nutrient levels in the two rivers, particularly in relation to rainfall, are needed to determine the effects of agricultural chemicals on aquatic macrophyte richness and abundance.

Turbidity also generally increased downstream. Turbidity has been found to reduce macrophytic growth by reducing light penetration in the water (Haslam 1978), and would have a stronger effect on the aquatic species than the marginal species. This could partly explain the decrease in aquatic vegetation cover in the upper parts of the Macquarie.

Electrical conductivity would also be expected to affect the aquatic vegetation rather than the bank vegetation. Electrical conductivity increased with distance downstream in the Macquarie, with dilution occurring at the junction with each major tributary. However the levels were low throughout the catchment, well below the ANZECC standards for the protection of ecosystems (ANZECC 1992).

In a study of the bank (marginal) vegetation along two Swedish rivers by Nilsson *et al.* (1989), it was found that 'natural' species richness was highest in the mid-reaches of both rivers, whereas 'ruderal' species showed a significant, monotonic increase with distance downstream. Although the present study area does not cover the entire length of either river, the richness patterns observed appear to correspond to those found by Nilsson *et al.* (1989). The decrease in exotic species richness with distance upstream on the Macquarie would be likely to continue above the study area, as the higher reaches of the Macquarie, although disturbed by siltation from forestry activities (Askey-Doran 1993), do not flow through agricultural land. Downstream of the confluence of the Macquarie with the South Esk, there may not be an increase in exotic species richness, but there is unlikely to be a dramatic decrease as the landuse remains dominantly agricultural. Total species richness and marginal species richness were strongly correlated with exotic species richness on both rivers, and so varied in a similar way.

It is likely that the trend towards highest aquatic species richness in the mid-reaches of the study area on the Macquarie would become clearer if the entire length of the river was studied. Aquatic species richness is likely to be lower in the higher reaches than the mid-reaches included in the present study, because of steeper, rockier terrain, faster current velocity and greater shading by native bank vegetation (see Askey-Doran (1993) for a brief description of

the aquatic communities in the Upper Macquarie). In the lower reaches of the South Esk, below the confluence with the Macquarie, the physical nature of the river with a high flow, steep banks and more turbid water does not provide optimal habitat for aquatic communities. Higher species richness in the mid-reaches is consistent with the intermediate disturbance hypothesis (Connell 1978; Huston 1979; Ward and Stanford 1983), which proposes that species diversity is maximised by the environmental heterogeneity which results from an intermediate level of disturbance.

4.4.2 Effects of shading

The relationship between percentage shading and low levels of stock damage on the Macquarie was probably due to the presence of bank vegetation preventing stock access to the river. It was probably also partly due to the fact that the sites with the highest levels of stock damage were the sites that had cleared pastoral land right to the river edges, and therefore had low levels of shade.

The relationship between percentage shading and vegetation cover and richness is probably mainly due to the direct effect of lower light levels on vegetation growth (Haslam 1978, Fox 1996). It could also be caused by the effects of willow roots on aquatic vegetation in downstream areas. Willow roots form a dense network and reduce the available substrate for aquatic macrophyte colonisation.

4.4.3 Effects of bank vegetation type

The differences in richness and cover between sites with different bank vegetation types were at least partly related to shading on the South Esk- willow dominated sites were most shaded, then willow/exotic sites, then native sites. Pasture sites were least shaded (table 4.4). Species richness was also higher in pasture sites because of the invasion of pasture species into the marginal vegetation.

Willows are members of the genus *Salix* and are not native to Australia. Willows were originally planted along watercourses to control riverbank erosion. The early varieties were

either wholly male or wholly female, so fertile seeds were not produced. However recently introduced willow varieties have cross-pollinated with varieties already growing in Australia, allowing the release of millions of seeds which are distributed long distances by wind or water (see Trounce 1999). It is now widely acknowledged that willow infestation has an adverse effect on most aspects of natural river ecosystems (see Frankenberg 1992). See Chapter 5 for a more detailed discussion of the management issues related to willows.

4.4.4 Effects of stock damage

Table 4.7 shows that stock damage was greatest in the middle areas of the catchments, where there was more intense agricultural activity and stock often had direct access to the river. This was particularly the case on the Macquarie, and the Macquarie had a higher number of sites with severe stock damage than the South Esk (Chi-square Test, P = 0.000). The areas with a high level of stock damage generally had no native bank vegetation and pasture species grew adjacent to the river margins, explaining the relationship between higher levels of stock damage and lower percentage shading and high exotic species richness. The middle and lower reaches of the rivers also tended to be the parts of the rivers with the highest percent cover of aquatic and marginal vegetation and the highest species richness, most likely because of the gentle slope of the river, and nutrient input from the agricultural land as well as sewage treatment plant outflows.

It is also possible that trampling and grazing by stock may have preferentially increased the cover of some species in the macrophytic vegetation. Brock and Casanova (1991) found that trampling stimulated new growth from vegetative fragments and the growth of lateral shoots in *Myriophyllum variifolium*. Blanch and Brock (1994) studied the effects of grazing and water depth on *Myriophyllum variifolium* and *Eleocharis acuta*. They found that *Myriophyllum variifolium*, with its large number of dispersed, above-ground meristems, was able to increase its vegetative reproduction under a light grazing regime. However *Eleocharis acuta* was not able to reproduce vegetatively in this way, and both species were adversely effected by grazing to below water level. It also appeared that low intensities of cattle and sheep grazing may have been beneficial by increasing species diversity. The present study supports this finding, as

131

sites with moderate levels of stock damage had a significantly higher macrophyte diversity than sites with no stock damage. However it is important to note here that both the extent of stock damage and the macrophyte species diversity were affected by other factors, such as percentage shading and bank vegetation type.

4.4.5 Effects of erosion

Erosion is a natural stream process, as streams are very dynamic systems. However European settlement has introduced additional episodes of erosion and bank instability, caused by changes in flow patterns, gradient and bed and bank conditions (Frankenberg 1992). Particularly relevant to this study are increased flows due to catchment clearing, changes in seasonal flow regimes because of river regulation, and removal of bank vegetation by clearing and grazing. The higher levels of erosion at sites with high levels of stock damage were probably caused by the trampling of the riverbanks by many hard hooves. This also partly explains the higher level of erosion at pasture sites on the Macquarie. The loss of the stabilising effects of native bank vegetation could also increase erosion at these sites.

4.4.6 Effects of substrate type

Effects of substrate type cannot be interpreted without reference to water velocity, which is the major determining force for both substrate type and macrophyte growth (Butcher 1933; Haslam 1978). Effects of water velocity are discussed in a separate section below.
The association of difference species with different particle sizes in the substrata has been described in other studies (see Butcher 1933, Haslam 1978, Fox 1996). The findings of the present study support those of Baattrup-Pedersen and Riis (1999), who found that submerged species were primarily associated with coarser-textured substrata, whereas species growing both submerged and emergent and species growing only emergent were associated with finer – textured substrata. With the exception of four or five submerged species, the aquatic plants in the present study were mostly found growing on a fine (mud) substrate. It is difficult to determine whether the plants preferentially colonised areas with finer substrate, or whether the

finer substrate developed secondarily in response to the presence of the plants. It has been found that macrophyte beds can produce both sufficient organic material and sufficient slowing of water movement to allow the sedimentation of suspended particles. This sediment accumulation may then allow less hydrodynamic species to colonise (Haslam 1978; Fox 1996; Sand-Jensen 1998).

4.4.7 Effects of river form

Variation in the resistance of underlying rocks determines erosional channel features such as runs, riffles and pools (Fox 1996). The relationships found in this study between river form and depth and substrate were probably due to the effects of stream depth on stream velocity, and of stream velocity on the river substrate (Butcher 1933; Haslam 1978). Table 4.1 shows that the stream velocity decreased with increasing width and depth on both rivers. See below.

4.4.8 Effects of differences in stream velocity

Increased water movement has been thought to increase the growth of macrophytes in rivers, through an increase in plant exposure to nutrients and carbon dioxide for photosynthesis (Fox 1996). Water movement also helps with dispersion of propagules. However fast flowing water can decrease the cover of macrophyte species through mechanical damage, problems with propagule establishment and the indirect effects of current velocity on substrate and fauna (Fox 1996). The hydraulic resistance of individual plants depends on their dimensions relative to the direction of current velocity. Plants with long narrow leaves have a greater resistance to damage caused by high water velocities than plants with many branches and a complex, bushy structure. The root system also plays a key role in protecting plants from uprooting in fast-flowing streams. Species with a well-developed root and rhizome system that winds securely around the stones in the substrate will most easily survive in faster-flowing water. However some studies (e.g. Pitlo and Dawson 1990) have shown that if the macrophyte bed has an overall streamlined shape, this can counter the water-resistance effect of bushy species, as long as the bed establishes in a period of slower current velocity. The individual stems are protected from sudden increases in velocity by the significant reduction of velocity within the bed.

In this study the fastest flowing stretches were sparsely vegetated. *Isolepis fluitans, Neopaxia australasica* and *Triglochin* species were the species most commonly found in fast flowing sites (riffles), all of which have fine, narrow or strap-like leaves and well-developed root systems. The stretch of river with the highest macrophyte richness was the middle stretch of the Macquarie (see figure 4.1), which was generally narrow with a slow to moderate current velocity. This result supported that of Nilsson (1987), who found that the number of species in the water in a Swedish stream reached a peak at an intermediate current velocity, consistent with the predictions of the intermediate disturbance hypothesis (Connell 1978; Huston 1979). Nilsson (1987) suggested that substratum type was partly responsible for this pattern of species richness along the stream. The zone of intermediate current velocity provided the most heterogenous environment in the substrate, which is often associated with a peak in both coexistence of species and utilisation of space.

Plate 5

Erosion of the riverbanks of the Macquarie River

Plate 6

Severe stock damage along the mid-reaches of the Macquarie River

Chapter Five

Conservation values of the aquatic and marginal vegetation and related management issues

5.1 Introduction

A healthy river from an ecological viewpoint is one in which the native communities of flora and fauna are healthy and diverse, and the essential processes of nutrient cycling and waste assimilation are intact (Amos *et al.* 1993; Bunn *et al.* 1999; Gaffney *et al.* 1999). The health of the aquatic and marginal vegetation is an essential component of river health. Along the mid and lower reaches of the Macquarie and South Esk Rivers, there were very few areas of aquatic, marginal or bank vegetation that had not been impacted upon by human activity. In some areas human activities have had a deleterious effect on the vegetation, whereas other areas appeared to be relatively healthy. Common disturbances were:

1. land clearing adjacent to the riparian area, including the removal of native vegetation from the riverbanks with subsequent accelerated erosion and a reduction in shading;

2. the planting of willows to prevent riverbank erosion, causing an increase in shading and depletion of aquatic biota;

3. trampling and grazing damage by stock, causing erosion, the spread of exotic plant species, local native plant damage and water pollution;

4. the invasion of exotic plant species into the marginal and aquatic vegetation;

5. the input of agricultural runoff and sewage treatment plant effluent, causing an increase in nutrients in the water column and sediment;

6. increased sediment loads from forestry and agricultural activity.

As there is no information on the species composition or cover of aquatic and marginal vegetation communities along the two rivers prior to European settlement, it is not possible to quantitatively describe the changes that have occurred since. However it is likely that all of the above disturbances would have affected the river vegetation to some extent. For large stretches of the banks and margins of both rivers, the concept of the maintenance of native vegetation is meaningless, as the vegetation is either entirely exotic or non-existent. The aquatic vegetation has retained a higher proportion of native species, with only one exotic species occurring in the study sites. It is possible that human disturbance- an increase in nutrients and the removal of shade-trees in particular- has led to an increase in the species richness and cover of native aquatic vegetation in some areas (see Chapter 4).

The fourth aim of this thesis is to identify conservation values and discuss management issues relevant to the conservation of the aquatic macrophyte communities. This chapter describes the health and conservation values of the aquatic macrophyte communities along the two rivers. It then discusses threats to the health of the macrophyte communities in the context of the human-induced disturbances noted above, and gives an overview of management options which would assist in the maintenance or restoration of the health of the macrophyte communities.

5.2 The health and conservation values of the macrophyte communities

5.2.1 Macrophyte community health

There is a high degree of natural variation in the richness, diversity and cover of aquatic macrophytes along river systems. This variation is related to the geomorphological and hydrological variation along the river system, and the complex interactions of biotic and abiotic factors, as has been discussed in the previous chapters.

In relatively large (in a Tasmanian context) lowland rivers such as the Macquarie and South Esk, human disturbance tends to increase in severity with distance downstream from the river

source. As a result the riparian vegetation in upland areas tends to be in a more or less pristine condition, but there is then increasing degradation as the land use intensifies with distance downstream. Therefore it can be difficult to find 'natural' or undisturbed areas of vegetation in lowland areas with which to compare the existing communities, in order to determine the relative health of the ecosystem. A comparison with the undisturbed upstream areas is likely to be meaningless due to the natural variation in both abiotic and biotic factors between upstream and downstream areas. For these reasons the following discussion is not based on the comparison of disturbed sites with ideal 'natural' sites, but focuses instead on the instream-values of various macrophyte communities along the two rivers.

Species rich macrophyte communities on the Macquarie and South Esk have been found to support a diverse array of invertebrate fauna (Davies and Humphries 1996), which is generally regarded as a sign of a healthy river ecosystem (see Bunn *et al.* 1999). Coverage and diversity of macrophyte communities are positively related to the heterogeneity of the substrate (Baattrup-Pedersen and Riis 1999), and the existence of suitably shallow, clear and slow to moderately fast flowing water. Many of the richest and most diverse macrophyte communities on the Macquarie and South Esk were found in areas with highly modified bank vegetation and intensive agricultural or pastoral use of adjacent land. On the Macquarie in particular this relationship is probably due to preference of both macrophytes and farmers for the flat areas with rich soils found along the alluvial plains in the lowland areas. The gentle slope of the riverbanks along these sections provides large areas of suitable habitat for macrophyte communities. The growth of macrophytes in agricultural areas could also be partly influenced by the lack of shading and addition of nutrients to these areas (see Chapter 4).

5.2.2 Conservation values

The protection of endangered, rare, vulnerable or endemic plant species or communities is one of the important roles of riparian vegetation management. *Persicaria decipiens*, which was positively identified in the marginal vegetation of two sites on the South Esk and one on the

Macquarie, is listed as vulnerable (Kirkpatrick and Gilfedder 1999). *Persicaria* species were recorded at 30 other sites on the two rivers, but could not be identified to the species level as no flowering parts were present. It is likely that some of these plants were the vulnerable *P. decipiens*, and it is possible that the endangered species *P. subsessilis*, which has been recorded along rivers in northern Tasmania (Kirkpatrick and Gilfedder 1999), was also present. Another vulnerable species that has been found occasionally along rivers in the Midlands is *Myiophyllum integrifolium*. This species was not identified at any of the sites in this study.

The large and stable macrophyte beds along the Macquarie and South Esk Rivers are a functionally important part of the river ecosystems. As well as providing food and shelter for macroinvertebrates and fish, they are important in the maintenance of high water quality through their ability to trap and process nutrients and sediments, and maintain dissolved oxygen levels during low flows (Davies and Humphries 1996). Therefore the areas of the two rivers that support rich and diverse macrophyte communities are of a high conservation value and warrant protection (Davies and Humphries 1996).

The invasion of exotic species, changes in flow regimes and changes in water quality are three factors that could have a deleterious effect on these vulnerable species and important communities. The present extent of these threats and possible management options are discussed below.

5.3 *Elodea canadensis*- an exotic aquatic species

5.3.1 The biology of *Elodea canadensis* and the extent of the problem

Elodea canadensis has spread around the temperate world from North America. At times it dominates the aquatic environment, and in New South Wales and Victoria it has been a serious problem in irrigation channels. However, in many river systems, after an initial period of rapid growth, it has been found to die back and thereafter exist as a balanced component of the aquatic plant population (Sainty and Jacobs 1981; Nichols and Shaw 1986). It is thought that

its growth may be limited over time by the concentration of a key nutrient (perhaps iron) in the sediment (Sainty and Jacobs 1981).

A study of the ecological life history of *Elodea canadensis* by Nichols and Shaw (1986) found that vegetative reproduction in this species allows it to rapidly invade areas which have been disturbed by natural causes or humans. They noted that "the disturbance may be obvious or it may be subtle such as accelerated eutrophication". The opportunistic nature of *Elodea canadensis* with regard to nitrogen and phosphorus uptake allows it to utilise nutrients from both soil and water without being solely dependent on either. It also has a more efficient photosynthetic mechanism than many species, giving it a competitive advantage in low light intensities, and is a cool weather strategist which does not die off completely in winter, even surviving under ice (Nichols and Shaw 1986).

Where the conditions are favourable for the growth of *Elodea canadensis*, it can displace other macrophytic species (Nichols and Shaw 1986). However, Nichols and Shaw (1986) point out that *Elodea* does provide some benefits to the ecosystem, through its roles in harbouring invertebrates and providing cover for fish. It also increases the productivity of the water column by recycling nutrients from the sediment into the water column. This may or may not be seen as a benefit, depending on whether the increased productivity is channelled into the growth of desirable or undesirable species.

Elodea canadensis has been in Tasmania since the late nineteenth century (Sculthorpe 1967). Its spread would have been limited by the need for assistance in vegetative dispersal between river systems, and its preference for moderately high levels of nutrients, deep water (1-12 m) and a fine substrate (Nichols and Shaw 1986). It is not known how long *Elodea* has been in the Macquarie and South Esk Rivers.

Elodea canadensis was the only exotic aquatic species found in this study. The presence of *Elodea canadensis* at a site was significantly positively related to the vegetation cover at the site, the total species richness (and thus the exotic species richness and aquatic species richness) at the site, and the proportion of exotic species in the marginal vegetation (table 5.1). In other words, sites with a high macrophytic vegetation cover and richness and a high proportion of exotic marginal species were most likely to have been invaded by *Elodea*

canadensis. These sites were also most likely to have a high level of stock damage and a high level of erosion, see Chapter 4, and so levels of erosion and stock damage were also positively correlated with presence of *Elodea canadensis*.

There was a much higher proportion of sites containing *Elodea canadensis* on the Macquarie River (14 sites) than the South Esk River (4 sites). On the Macquarie, all sites were downstream of the township of Ross, where the sewage treatment plant releases treated effluent into the river. There was a cluster of sites containing *Elodea canadensis* just downstream from Ross, then another cluster just downstream from the confluence with the Elizabeth River (figure 5.1), where the sewage effluent from Campbelltown enters the Macquarie. The other sites with *Elodea canadensis* present were scattered down the remainder of the river. This distribution pattern suggests that the presence of nutrient-enriched water from the sewage treatment plants has encouraged the establishment of *Elodea canadensis* in the river downstream.

5.3.2 Management of *Elodea canadensis*

Once established *Elodea canadensis* is very difficult to eliminate from a water course (Sainty and Jacobs 1981). Considering the time the species has been present in Tasmania, and its current distribution and abundance, *Elodea canadensis* does not appear at this time to present a serious problem in the Macquarie or South Esk Rivers. However the tendency for *Elodea canadensis* to occur in areas enriched by point sources of nutrients suggests that it could potentially create a greater problem if the water quality of the rivers were to deteriorate.

Figure 5.1 Geographical distribution of *Elodea canadensis*
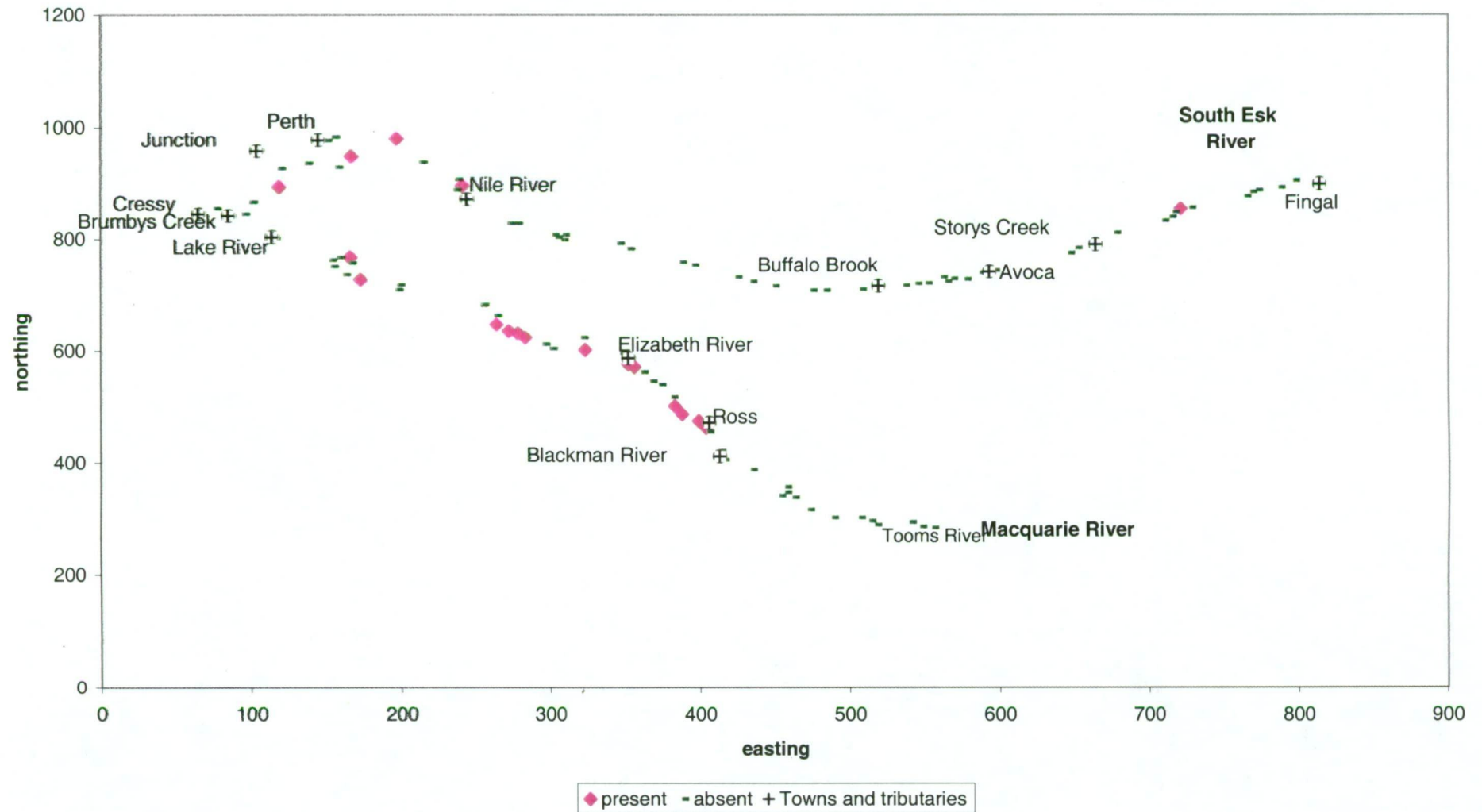
Table 5.1 Median values and significant differences in environmental and richness/cover variables between sites with *Elodea canadensis* present and sites with *Elodea canadensis* absent.

Erosion, visible erosion of banks; Stockd, obvious trampling by stock; %vegcover, percentage of site covered by aquatic and marginal vegetation; Totrich, total number of species; Exrich, number of exotic species; Ex/tot, proportion of exotic species; Aqrich, number of aquatic species. Significance is from Mann-Whitney Rank Sum tests: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; -, $P > 0.05$. n= number of sites. 25 and 75 percentiles given in brackets.

	Present n=18	Absent n=84	P
Erosion	2 (2-3)	2 (1-2)	*
stockd	2 (2-3)	2 (1-2)	*
%vegcover	37.4 (14.63-75.1)	13.0 (4.07-34.9)	**
Totalrich	13 (10-18)	10 (7-14)	*
Exrich	3 (2-4)	1 (0-3)	***
Ex/tot	0.25 (0.15-0.33)	0.09 (0.00-0.22)	**
Aqrich	8 (7-9)	5 (3-7)	***

5.4 Exotic Marginal Species

5.4.1 The extent of the problem

There was a high degree of invasion of exotic pasture species into the marginal vegetation on the Macquarie River. Invasion by pasture species was significantly related to bank vegetation type and therefore to landuse. The highest numbers and proportion of exotic marginal species occurred in sites in agricultural areas that had been cleared to the water edge. Most exotic marginal species were opportunistic species such as *Lysimachia nummularia, Lotus* species, *Trifolium* species, *Rumex crispus, Agrostis stolonifera* and *Festuca* species.

On the Macquarie, both the exotic marginal species richness and the proportion of exotic species in the marginal and aquatic vegetation were significantly related to substrate type, stream width and depth, distance upstream and bank vegetation type. Level of stock damage was significantly related to exotic marginal species richness, but not to proportion of exotic species, see Chapter 4. These environmental variables were all inter-related, with substrate type, stream width and depth, bank vegetation type and level of stock damage all varying with distance upstream. There was no correlation between exotic marginal richness and environmental variation on the South Esk.

5.4.2 Management of exotic marginal species

Most of the exotic marginal species were opportunistic species that had colonised disturbed areas along the river margins. The proximity of pastoral land to the river margins would make it very difficult to stop these species taking advantage of open areas caused by erosion, flooding or stock damage. Native riverbank species such as *Carex* and *Juncus* species were also common in the sites with a high exotic marginal species richness. The maintenance of the integrity of less-disturbed sections of the bank vegetation would reduce the invasion of exotic species. Unfortunately it is too late for this to be of benefit along most of the mid to lowland sections of the Macquarie and South Esk Rivers.

The establishment of 'buffer zones' of native vegetation along riverbanks has been suggested as a useful means of conserving or restoring native flora and fauna (see Large and Petts 1994). Many benefits would result from the establishment of buffer zones along the South Esk and Macquarie Rivers, for example, the filtering of nutrients and sediment from surrounding farmland, stabilisation of the riverbanks and the re-establishment of native flora. However it would be important to firstly determine the potential impact of buffer zones on opportunistic native species such as *Persicaria* species, some of which are of high conservation value. Controlled grazing of buffer zones can sometimes be beneficial (Frankenberg 1992). The fencing of riverbank areas to provide a buffer zone has also been known to lead to an increase in exotic plant species. In such cases an active management program involving the planting of

native species and control of exotics is necessary to enable the native vegetation to re-establish (Gaffney *et al.* 1999).

5.5 Exotic bank species

5.5.1 Willows

5.5.1.1 the extent of the problem

Willows, members of the genus *Salix*, were introduced to Australia, mainly from Asia and Europe. Willows have been used extensively to stabilise riverbanks and prevent erosion, as they are easily obtained, grow quickly and create a solid hedge that effectively stabilises the banks. It is only recently that the disadvantages of willows have been recognised (Frankenberg 1992).

The first varieties of willow imported into Australia were either entirely male or entirely female, and were not usually planted close enough to a compatible partner to produce viable seed. However over the last two decades, there have been new imports of willow varieties that can self pollinate or cross pollinate with trees already growing in Australia. As a result millions of seeds have been released and seedlings are establishing, sometimes forming forests or thickets that are capable of blocking the flow of the stream by build up of debris and sediment (Trounce 1999). Willows also spread readily through vegetative means, as every branch that breaks off and floats downstream can take root wherever it lodges on the riverbank (Frankenberg 1992). Willows prevent the growth of any other vegetation by shading out all competition, provide very little terrestrial habitat, and support few insects on the leaves and bark, which discourages birdlife. Being deciduous, they provide a completely unnatural food supply to Australian streams, as all the leaves fall in the autumn, compared to the summer peak in leaf fall found in the native vegetation (Frankenberg 1992).

In this study, of the 54 sites on the Macquarie, there were 13 with willows present on the banks, and 2 in which willows completely dominated the bank vegetation. On the South Esk,

146

with 48 sites in total, 23 had willows present and 5 were completely dominated by willows. Of these 5, 3 had no aquatic or marginal vegetation (Table 5.2).

Table 5.2 Presence and dominance of willows (*Salix* spp.) at sites on the Macquarie and South Esk Rivers. 'Willows dominant' indicates that no other bank species were recorded for that site.

	Total no. of sites	Sites with willows present	Sites with willows dominant	Sites with no other vegetation
Macquarie River	54	13	2	0
South Esk River	48	23	5	3

5.5.1.2 Management of willows on riverbanks

Willow infestation of the riverbanks provides perhaps the greatest threat to the health of the aquatic macrophyte communities in the Macquarie and South Esk Rivers. Dense growths of willows effectively remove all suitable habitat for macrophyte species along the affected sections of the river. Recent introductions of willow species that produce viable seeds, and the discovery of seedlings of older species once believed to be sterile, have increased concern about the potential for willows to spread.

Willows can be removed by cutting and applying herbicide, or by hand if small enough (Trounce 1999). However, willow control can cause severe damage to streams if not undertaken sensitively. Care needs to be taken to replace willows with native species to stabilise banks, as the removal of willows leaves the riverbanks open to erosion (Glazic and Rudman 1999). Native riverbank species grown from local seed are usually effective in providing long-term bank stability, especially if grass species and native emergent macrophyte species are used as well as tree species (Frankenberg 1992). It is generally recommended that willows be removed from upstream areas first, as vegetative fragments from upstream willows can wash downstream and take root along the riverbanks.

<u>5.5.2 Gorse, blackberry and hawthorn</u>

All three of these weed species were found growing along the Macquarie and South Esk Rivers, in some places so thickly that there was little other bank vegetation. These are opportunistic species that are spread by seed and rapidly colonise disturbed areas, outcompeting native species. They are frequently found along riverbanks. Control of these weeds is difficult but possible, usually involving the application of herbicides (see Kirkpatrick and Gilfedder 1999). Again, the presence of a healthy area of native vegetation along the riverbanks would discourage the establishment and spread of these three weed species. The sections of the riverbanks in which native vegetation is still intact, for example large sections of the upstream areas of the Macquarie River, have been protected from these weed species. The maintenance of the native bank vegetation will keep these areas relatively weed free.

5.6 The potential impact of changes in flow regimes

Davies and Humphries (1996) have studied in some detail the effects of low flows on the Macquarie and South Esk Rivers during the irrigation season. It was found that the current levels of abstraction were not posing a significant risk of habitat loss for aquatic biota on the South Esk. However on the Macquarie it was found that the river flow during the irrigation season was often low enough to pose a serious threat to the macrophyte communities. Although historically the Macquarie catchment has very low flows in summer, increasing irrigation abstractions have the potential to dewater macrophyte beds that are usually protected by their location in deeper pools and runs (Humphries *et al.* 1996). Dewatering of macrophyte beds occurred at flows less than the natural (pre-irrigation) median summer discharge of $1m^3s^{-1}$. Although macrophyte communities were able to shift to lower elevations in the channel during periods of low flow, this movement was limited by the steep dropoff that was usually found on the instream edge of platforms on which they were established.

Davies and Humphries (1996) found that the greatest abundances of invertebrates were associated with the most structurally complex macrophyte species (e.g. *Myriophyllum* species),

148

which also occurred in the shallowest depth zone. However as water levels and other environmental conditions changed , the macrophyte species supporting the highest taxonomic richness of invertebrates also changed. Davies and Humphries (1996) wrote that

"Water allocations for instream purposes must therefore be commensurate with the requirements of all species of macrophytes. It may be that by maintaining the heterogeneity of this type of habitat, a major step in ensuring both biodiversity and riverine health are maintained".

5.7 The potential impact of changes in water quality

Despite intensive agricultural landuse in the lower areas of the South Esk basin, and the point source input of nutrients from sewage treatment plants, there are still healthy, diverse aquatic plant and animal communities in the mid to lowland reaches of these rivers. Nutrient enrichment from surrounding agricultural areas may have actually increased the richness and abundance of macrophyte communities in some areas. However, if the level of artificial enrichment increases, this is unlikely to continue to be the case. Compared with the large lowland rivers in mainland Australia, water quality in the Macquarie and South Esk is relatively high. There are not at present the large-scale problems of salinity and eutrophication that have plagued river systems such as the Murray-Darling. Both salinity and eutrophication reduce the diversity of macrophyte species in rivers, favouring those species with a high tolerance of the altered conditions (Fox 1996; Haslam 1978). Eutrophication can lead to an increase in the abundance of nuisance exotic weed species and algal growth (Jacobs 2000). While dense algal growth was noted in several sites on the Macquarie River, this was concentrated in sites just downstream from sewage outflows. The exotic species *Elodea canadensis* was also more abundant in these areas. This gives some indication of the problems that could occur if water quality were to deteriorate in these rivers. Maintenance of the species and communities of high conservation value requires the maintenance of water quality in the Macquarie and South Esk.

Plate 7

Willows on the South Esk River

The mid-reaches of the South Esk River

The Lower South Esk near Perth

Plate 8

Mixed native/exotic bank vegetation on the Macquarie River

Plate 9

Algal growth on the Macquarie River near Ross

Chapter 6

Overall Discussion and Conclusion

6.1 Variation in macrophyte communities along the South Esk and Macquarie Rivers

The third aim of this thesis was to determine the environmental correlates of variation in aquatic macrophyte species composition. It was found that the species composition of the marginal and aquatic macrophyte communities in the Macquarie and South Esk Rivers differed between rivers and between different reaches within each river. Both the communities of sites grouped by similar compositions of aquatic macrophyte species and those grouped by similar compositions of marginal species differed significantly with distance upstream, stream width, substrate type and bank vegetation type. The aquatic communities also differed significantly with river form (which is in part a basic measure of current velocity), river depth and percentage shading.

The second aim was to compare the cover, species richness and diversity of the aquatic macrophyte communities in the Macquarie and South Esk Rivers, and to relate these variables to the environmental characteristics of the two rivers. The cover and species richness of the macrophytic vegetation differed significantly between the two rivers, with the Macquarie having a higher percentage cover, higher total aquatic and marginal species richness and higher aquatic species richness. Several physical variables also differed significantly between rivers, with the Macquarie having a significantly lower percentage shading, a lower average bank height and stream width, a higher proportion of sites with pure pasture as the bank vegetation, a lower proportion of willow-dominated sites and sites infested by gorse or blackberry, and a higher level of stock damage. All of these inter-related variables could have contributed to the differences in macrophyte species richness, diversity and cover between the two rivers.

There were other factors that differed between the two rivers and between reaches within the rivers which were discussed in a general sense, but were not included as variables in this study. These include flow regime, water quality parameters and river slope, all of which are likely to

have influenced the distribution, richness and cover of macrophyte communities. For example, Wiegleb (1984) found that the chemical parameters that differed most among vegetation types-water oxygen content, acidity and calcium- were as significant as the physical parameters of current velocity and turbidity in determining the distribution of vegetation types in three rivers in Germany. The cross-sectional profile of the river is another important factor that was not included in this study. Macrophytes can only establish in sites where there is a suitably shallow platform or gently sloping bank which provide the shallow water and high light levels needed by most species. Sites with almost-vertical banks dropping straight down into deep water would not facilitate the establishment of macrophyte species. However once established macrophyte communities have an effect on the river profile, by trapping sediments and so reducing depth and increasing the suitability of the site for further macrophyte colonisation. Future studies could include a more detailed analysis of the effect of site profiles on the species composition and abundance of aquatic macrophytes. Similarly, further research on the relationships between water chemistry and the macrophyte communities in the Macquarie and South Esk Rivers would help to determine more of the environmental causes of the variation in species distribution, vegetation richness and abundance.

Many studies have shown that physical and chemical parameters have a considerable influence on the composition of riverine macrophyte communities (e.g. Butcher 1933; Wiegleb 1984; Haslam 1987; Penuelas and Sabater 1987; Ferreira 1994; Ferreira and Moreira 1999; Riis *et al.* 2000). The parameters found to be significantly associated with the composition of the vegetation in the Macquarie and South Esk Rivers were similar to those recorded in previous studies in various countries around the world. For example, in a comparable study in southern Iberia, Ferreira and Moreira (1999) found that altitude, conductivity, river width, pH, percentage of hard substrates and fine particulate matter on the river bed, average rainfall and temperature and human-related disturbance were significantly related to the aquatic species distribution. Similarly, in a recent Danish study, alkalinity and stream size were the most important chemical and physical variables separating plant communities (Riis *et al.* 2000).

In Australia, most of the studies on the distribution and environmental relationships of riverine macrophyte communities in the literature refer to large regulated river systems such as the

Murray-Darling and the Murrumbidgee. The richness of aquatic vegetation along the river-edges of the highly regulated Murrumbidgee River was found to be affected by river slope and the variability of the water regime (Roberts 1994). A study on the effects of water level changes induced by weirs on the distribution of littoral plants along the river Murray, South Australia, found that plant species varied in their tolerance of water level fluctuations. The influences of physical channel characteristics such as bank slope, bank erosion and sediment composition were not so clear, perhaps because of the relationships between these characteristics and the water level gradient, which was reset at each weir (Walker *et al.* 1994). There has also been some work on the aquatic macrophytes of the Fitroy River Catchment and other smaller streams in Queensland (see Duivenvoorden 1992; Bunn 1998), but as these are tropical rivers the flow regimes, seasonal growth patterns and management problems tend not to be directly relevant to the present study.

Hughes (1987b) found that the longitudinal distribution of aquatic macrophyte species in two rivers on Tasmania's east coast reflected the patchiness of suitable environments in which to colonise. Well-defined groupings of plant communities did not exist. The clearest factors associated with the variation in aquatic communities at the whole-river scale were water chemistry, which separated saline estuarine communities from freshwater communities, and substrate, which separated the communities in pebbly upstream areas from those in the mid and lower reaches. Species diversity and richness were highest in the mid-reaches of both rivers. At the plot scale aquatic communities were influenced by shading from riparian vegetation and substrate, but predictions of species composition and distribution at the plot or stream-reach scale were found to be problematic because of unpredictable hydrological variability. The present study did not include an analysis of variation in macrophyte community composition over time, so it is not possible to compare these results. However the importance of shading and substrate in determining the distribution of aquatic plant communities is supported by the present study. The whole-river patterns of species richness and diversity found by Hughes (1987b) for the east coast rivers were also similar to those found in the present study. The highest species richness and diversity were found in the mid reaches of the Macquarie, and it is probable that in a whole-river context this would also be the case in the South Esk.

It is necessary to be cautious when discussing cause and effect between the species composition of aquatic vegetation and environmental variables, as many of the environmental variables are inter-related (see Westlake 1973; Wiegleb 1984). For example, stream width and depth, bank vegetation type and substrate are all related to distance upstream. The scale of the analysis is also important, as an environmental gradient which may appear uniform at a large scale may be discontinuous at finer resolutions (see Walker 1994). For example, current velocity is related to river slope at the whole-river scale, but varies according to river form (riffle, run or pool) at the reach scale, and is even more variable at the plot scale because of the obstructions caused by rocks, logs and macrophyte beds. Wiegleb (1984) has described many of the problems commonly encountered when attempting to relate riverine plant community data to ecological data. Included are problems with the inter-related nature of the variables, the temporal variability of both the vegetation communities and the physical and chemical parameters, and the lack of a general model on the causal relationship between ecological parameters and the occurrence of species. Nonetheless it is often possible to establish general relationships between the species composition of the aquatic vegetation and environmental variables, particularly if a large number of sites are used across different catchments, and if the relationships are studied over a period of time to avoid the confusing effects of short-term instability of communities.

6.2 The use of aquatic macrophytes for water quality assessment

Butcher (1933) was a pioneer of studies relating plant groups in rivers to variables such as geology, channel gradient, altitude, substrate and current velocity. Butcher's classification system for rivers on the basis of aquatic plant communities has been developed and refined in several more recent studies, culminating in the identification of the 10 river community types and their 38 sub-types presently established for the UK (see Holmes et al. 1998). The association of these aquatic plant river community types and sub-types with particular environmental conditions has been used to assess the health of rivers. The classification system described by Holmes et al. (1998) has been used extensively in the UK since the early 1980s, mainly for nature conservation assessment. In more recent times it has been applied to the

Mean Trophic Rank (MTR) system for assessing trophic enrichment in British rivers. In this system all aquatic macrophyte species are assigned a number from 1 to 10 depending on their tolerance to, or preference for, nutrient-enriched (1) or nutrient-poor (10) water. Early indications were that the system was a very effective tool in water quality monitoring, especially when used alongside invertebrates and other biota (Holmes *et al.* 1998).

Other European studies have described in detail the changes in aquatic vegetation along rivers (e.g. Wiegleb 1984; Penuelas and Sabater 1987; Ferreira 1994; Ferreira and Moreira 1999; Riis *et al.* 2000), but classificatory systems have rarely been developed. Ferreira and Moreira (1999) studied the environmental factors influencing the distribution of river plants in a southern Iberian river basin. They found that the underlying geomorphology in southern Iberian rivers was spatially heterogeneous, creating variations in channel slope and riffle and pool sequences along the length of the river systems, rather than the steeper upper reaches and flatter lower reaches described in the British studies. Several physical and chemical parameters were related to the species distribution, but they noted that the abiotic variables frequently explained only a small part of the species variability in southern Iberian rivers, and they found that a clear separation of river plant groups was difficult. Ferreira (1994) found that human disturbance, enrichment and silting also tended to reduce the differences between groups. For these reasons river plant assemblages have not been developed into a successful indicator system of either aquatic regions or river conditions in southern Iberia.

Thus it appears that not all regions or river systems have aquatic macrophyte communities that can be easily classified into groups that indicate underlying environmental factors. Complicating factors can include the uniformity produced by human-induced disturbance (e.g. Ferreira and Smeding 1990), or the existence of a naturally homogeneous environment (e.g. Riis *et al.* 2000), an underlying heterogeneity of geological and geomorphological factors that obscures other environmental influences (e.g.Ferreira and Moriera 1999), or a very variable flow regime that creates random responses in plant species abundances over time (e.g Hughes 1987b, 1990).

Biological assessment of river health in Australia has to date mostly involved the use of invertebrates. RIVPACS, the River Invertebrate Prediction and Classification System, was developed in the UK and introduced to Australia in the 1990s. This approach is based on comparing monitored river sites against reference unimpacted, or least-impacted sites. The potential for the complementary use of fish, diatoms, phytoplankton and macrophytes is being investigated (Schofield and Davies 1996). Work on the development of macrophyte-based systems for the assessment of water quality and river health has commenced in Australia. It has been limited by the need for research on the interpretation of species absences, the role of epiphytes, applicability of the community concept, species presence/abundance variations at different time scales and species response to water and sediment quality (Schofield and Davies 1996). Recent studies have addressed some of these issues (see the CSIRO 1999), and a wetland monitoring system using macrophytes has been described by at least one author (see Jacobs 2000).

It is possible that a macrophyte indicator system could be developed for water quality assessment in Tasmanian rivers. The RIVPACS (River Invertebrates Prediction and Classification System) is already in place, and it is hoped that complementary systems, including the use of macrophyte communities, will be included in the development of a "toolkit of reliable bioassessment methods with sound national protocols and guidelines for their most appropriate uses" (Schofield and Davies 1996:43). The baseline data collected for this study could be used in the development of an indicator system for water quality in the Macquarie and South Esk catchments. A potential problem associated with the development of macrophyte-based assessment of river health across the whole of Tasmania is that rivers in some regions of the state are characterised by very few macrophyte species (Hughes 1987b). The macrophyte communities in these areas may not provide enough information to be used in water quality assessment. Further research is also needed on the stability of macrophyte communities in different regions of Tasmania over time, as temporal fluctuations in macrophyte communities could confuse water quality assessments. Holmes et al. (1998), when using macrophytes to classify rivers in the UK, suggested that in the absence of natural stress or human impact, most communities are sufficiently robust to remain stable over time. This is in contrast to the findings of Hughes (1987b, 1990) that variation in macrophyte community composition over

time is significant and not necessarily predictable in two rivers in eastern Tasmania. The robustness of macrophyte communities depends on the frequency and severity of disturbances and the time-scale in which the stability of communities is considered.

6.3 Management of aquatic macrophytes in the Macquarie and South Esk Rivers

The fourth aim of this thesis was to identify conservation values and discuss some of the management issues relevant to the conservation of the aquatic macrophyte communities. The species rich and diverse macrophyte communities along the middle reach of the Macquarie River and marginal communities containing vulnerable species are considered to have high conservation value. Of particular concern are the findings of Davies and Humphries (1996) that on the Macquarie River the current volume of water abstracted for irrigation is endangering the macrophyte beds of run and pool sections of the river. These beds provide habitat for a diverse array of invertebrates and several native fish species, plus the highly valued exotic brown trout, and their conservation has been noted as being of high priority (Davies and Humphries 1996). In contrast, current irrigation abstractions do not appear to be endangering macrophyte communities on the South Esk River, as the flow of this river during the summer irrigation season is greater.

The potential for the spread of willows along the riverbanks is also a threat to the health of the macrophyte communities in the South Esk and Macquarie Rivers. One-quarter of the sites on the Macquarie and almost half of the sites on the South Esk had willows on the banks, and a small proportion of these had become so densely infested with willows that no other vegetation was present. Assessment and careful removal of those willow species that can produce viable seed (see Askey-Doran 1993; Trounce 1999) and the removal of willow saplings that have spread through vegetative means would lessen this threat.

The maintenance of water quality in the rivers, through the avoidance of substantial increases in nutrient inputs or other pollutants, is seen as being essential for the longterm health of the macrophyte communities of the two rivers. The development of buffer zones of native bank

vegetation along the rivers would help to maintain the water quality of these rivers. Buffer zones provide shade, filter out nutrient runoff from agricultural land, minimise further invasion of the river margins by exotic pasture species, prevent erosion of the riverbanks, and prevent direct stock access to the river (Large and Petts 1994). These benefits would prevent the problems caused by eutrophication, help conserve the areas of macrophytic vegetation that are still in a natural state, and perhaps start the journey towards restoration of some areas of the river in which human impact has had a negative effect on the macrophyte communities.

Hughes (1987b: 248) wrote that "managing riverine plant communities is an activity that can only occur appropriately at the catchment scale. Reservation of small stretches of river (stream-side reserves) is unsuitable for conserving rare aquatic species, due to the changing and mobile nature of the communities". This was based on her study of two rivers on Tasmania's east coast. Whether it is the case for all Tasmanian rivers has not been determined. Anecdotal evidence has suggested that the macrophyte communities along pools in the Macquarie and South Esk Rivers are relatively stable over time (see Davies and Humphries 1996). A longer term study is required to determine the nature of temporal change in these communities. Management at the catchment scale is obviously the preferred option, as disturbances caused by irrigation abstractions, diffuse inputs of pollutants and increased sedimentation effect the whole river system. However local management of areas of high conservation value may also be an option, particularly in the case of stable communities such as those growing on the margins of large pools. Local protection could regulate grazing by stock, which would help protect vulnerable native species in the bank and marginal vegetation.

6.4 In Conclusion

The data collected in this study provide baseline information on the distribution and composition of aquatic macrophyte communities along the mid- to lower reaches of the South Esk and Macquarie Rivers. This information may be used as a reference point for future comparative studies. Information on the nature and extent of the aquatic plant communities along the mid to lower Macquarie and South Esk Rivers complements previous studies, such as Askey-Doran's (1993) study of the riparian vegetation of Midland Tasmania, Hughes'(1987b)

159

survey of macrophyte communities in a regional context across the state, and Hughes' (1987b, 1990) more detailed studies of the riverine vegetation of the Swan and Apsley Rivers on Tasmania's east coast.

This study also describes some of the environmental correlates of the variation in the aquatic macrophyte communities along the two rivers. This provides information that can be used by land managers to plan for the protection of areas identified as being of high conservation value. Although management at the catchment scale would provide the best protection to aquatic macrophyte communities, local actions such as the removal of willow seedlings and the development of buffer zones of native vegetation would also have some benefits.

Aquatic macrophytes are an integral part of river ecosystems. Any impact that adversely affects the macrophyte communities inevitably affects the health of the river. Sections of the Macquarie and South Esk Rivers contain species rich and abundant macrophyte communities that provide numerous benefits to the river ecosystems. The conservation of these communities should be a priority when planning for the management of the rivers.

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166

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