

**THE NATURE AND INVASION OF RIPARIAN
VEGETATION ZONES IN THE SOUTH WESTERN
CAPE**

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Water Research Commission



THE NATURE AND INVASION OF RIPARIAN VEGETATION ZONES IN THE SOUTH WESTERN CAPE

Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

E1. Introduction

Rationale for the project

The adjective riparian generally refers to biological communities and environments on the shores/banks of rivers, ponds, lakes and wetlands. Though the riparian zone occupies a small area in relation to the greater catchment, its influence on the surrounding landscape, mostly through its vegetation, is great. In particular, bank vegetation affects the flow of the river, inputs leaves and other organic material into the river which is food for aquatic life, acts as a buffer that protects the river from sediments, fertilisers, pesticides and other matter draining downhill through the catchment, and provides food and shelter for people and wildlife. As they are naturally disturbed by floods, which create and remove patches of vegetation habitat, riparian zones are vulnerable to invasion by alien plants and need active management in areas where such species occur.

This three-year project was designed to investigate the effects of woody alien invading tree species on the natural vegetation of Western Cape headwater riparian zones, and the recovery of the indigenous vegetation after aliens had been cleared.

The project objectives, as redefined through the steering committee meetings, were as follows.

1. Identify riparian plant communities of undisturbed and invaded riparian zones in Western Cape rivers, and describe their species composition.
2. Ascertain if each invasive species occurs in one or more lateral riparian vegetation zones.
3. Begin an exploratory investigation into whether or not allelopathy can be detected in selected common invasive woody alien species, and the possible effects of alien species on common soil variables.
4. Monitor the early stages of recovery of indigenous vegetation *in situ* after clearing.

The report consists of five parts. Following the introduction, Part 2 (Chapter 2-5) covers the principal work of the project. Chapter 2 contains the literature review, Chapter 3 the Methods, and Chapters 4 and 5 the characteristics of undisturbed and invaded riparian zones respectively. Part 3 (Chapter 6) reports on the status of recovering indigenous vegetation after different methods of clearing aliens, and Part 4 (Chapter 7) describes early investigations into allelopathy. Part 5 (Chapter 8) presents the conclusions and recommendations. All of the project objectives have been met and are reported on in the appropriate chapters.

E2. Approach to the main study

Overview of approach

The research was confined to:

- river banks, with floodplains and wetlands not addressed;
- the upper reaches of rivers: mountain stream, mountain stream (transitional) and upper foothill zones in Western Cape streams;

- summer data, collected at a time of reasonably constant low flow in 2004/5/6;
- rivers with natural flow regimes;
- reasonably straight sections of channel, so that a grid of sample plots could be laid out along the bank.

Nineteen undisturbed sites were used to define and test a reference condition for the indigenous riparian communities. Six invaded and ten cleared sites were then compared to the reference condition to assess the impacts of invasion and clearance on a number of biotic characteristics.

Data collection

Four sets of data were collected at each site of the plant communities and their physical environment:

- plant species and distributions;
- cross-section measurements of the shape of the channel and banks;
- measurements of some physical and chemical soil parameters, such as pH, texture (particle size) and organic matter content;
- other supporting data, for example the frequency of different sized channel substrata, longitudinal profiles of each river studied and 20 fixed point photographs of the channel and bordering riparian areas at each study site.

Vegetation data were collected from sample grids established on one bank of each site. The sample grid was 20 m long, along the wetted edge of the river, and several metres wide as dictated by the width of the zone of riparian vegetation. The entire grid was divided into a series of 1 x 5 m sample plots. Each sample plot was labelled by number (1 to 'n') to indicate distance from the water in metres, and by letter A to D to indicate its location along the 20 m length of the grid. The number, height, condition and contribution to canopy cover were recorded for every species in every 5 m² plot.

Cross-sections were surveyed across the full width of the macro-channel, from bank top to bank top, through each of the lines A to D of sample plots. Two soil samples were collected from each of the dry and the wet banks and await analysis as part of a post graduate thesis.

Data analyses

Whole site comparisons

A single species list was collated for each study site. The lists for all sites were compared using CLUSTER analysis and Multi-dimensional scaling (MDS) ordination, which measure the similarities between sites. This allowed an overall assessment of whether or not the plant communities of undisturbed sites were basically different from those of disturbed sites.

Within site comparisons

To assess exactly how aliens affected the nature of riparian vegetation communities, it was necessary to continue investigations at the level of each sample plot. Using MDS ordination and CLUSTER analyses of plant species data, groups of similar sample plots within any one site were identified. Over all 18 reference sites, using a simple set of rules based on species present, four common

groupings of sample plots were recognised. These groupings, here called assemblage types, were, from the water's edge upwards across the bank:

- wet bank: Water's Edge (WE); Channel Fringe (CF);
- dry bank: Tree and Shrub (TS) and Outer Transitional (OT).

OT formed the outer boundary of the riparian zone, and the terrestrial vegetation beyond this was recognised in a few sample plots as Non Riparian (NR). The characteristics of each assemblage type, including typical species and typical location on the bank, were summarised using the data from 12 reference sites. These characteristics were then tested using data from the remaining six reference sites, to produce what was considered to be a reasonably robust description of a reference condition.

Invaded or cleared sites could then be compared to this reference condition, in order to assess how much and in what way they had changed. The comparisons were done at the level of the four assemblage types. This required a preliminary identification of their probable locations at each disturbed site, because in many cases the natural clues provided by typical species had been partially or completely obliterated. The probable locations were predicted using a simple physical model.

A predictive model for locating assemblage types

The model took the form of a Classification and Regression Tree (CART). Based on the data from the reference sites, the CART model predicted the height above summer low water and the distance up the bank from the edge of the water where each of the four assemblage types should occur. These rules were used to allocate each sample plot at a disturbed site to an assemblage type. The characteristics of the four groups at each disturbed site could then be compared to the reference condition.

E3. Reference Condition

Reference condition (Chapter 4) was addressed in two ways:

- at the catchment scale (km^2), through the overall species composition of undisturbed riparian zones;
- at the site scale (m^2), through the distribution of species in assemblage types

Catchment-scale patterns

Most reference sites supported a plant community dominated by smaller shrub and tree species, including four common small tree species: *Metrosideros angustifolia* (smalblad), *Brabejum stellatifolium* (wild almond), *Brachylaena neriifolia* (waterwitels) and *Morella serrata* (waterolier). This community is commonly referred to as Riparian Scrub. Three sites supported a community of larger trees such as *Cunonia capensis* (rooiels), *Ilex mitis* (cape holly) and *Rapanea melanophloeos* (cape beech). This community is usually referred to as Afromontane Forest. The two communities may represent different successional stages of riparian vegetation, with the Afromontane Forest community being the more mature and the Riparian Scrub community younger, possibly due to vegetation clearance, fire or other disturbance. The two communities are not exclusive, but do share common species.

One of the two communities occurred at each of the 18 reference sites. The Afromontane Forest community was confined to two reference and one disturbed site on Table Mountain whilst the Riparian Scrub community was at all the other reference sites, scattered widely over the study area. Although one or other community was recognizable at each site, the sites nevertheless also had specific identities. Sites from the same catchment were more similar to each other than to sites from other catchments, and within any one catchment, sites on any one river were more closely related to one another than to sites from another river in the same catchment group. Finally, within any one river, sites within a longitudinal zone were more similar to each other than to sites in an adjacent zone on the same river. In other words, the riparian plant communities had catchment, river and zone signatures. There was no clear indication from physical data collected of why a site supported an Afromontane Forest or a Riparian Scrub community, although higher altitude, narrower valleys and protection from fire and disturbance may favour the former. It is well known that Afromontane Forest requires naturally fire-protected sites (steep kloofs, cliffs, boulder screes etc.) to establish.

Site-scale patterns

The reference condition was defined only for the Riparian Scrub community, as insufficient study sites supported Afromontane Forest to make a confident summary. In the Riparian Scrub sites, the four assemblage types were defined in terms of: species richness per sample plot and per the larger sample grid; growth forms; and two other measures of biodiversity (Table E1). The typical growth forms were outlined and possible indicator species listed. No species was restricted to one assemblage type and thus there were no perfect indicators. Rather, the mix and proportions of species shifted from one to the next assemblage type. Of note were the sedge *Isolepis prolifer* and the shrub *Prionium serratum* (palmiet) which were good indicators of the wet bank, and the restios *Calopsis paniculata* and *Elegia capensis* and the shrub *Erica caffra* (water heath), which were common to CF and TS. Three other species, *Diospyros glabra*, *Pteridium aquilinum* (bracken fern) and *Rhus angustifolia*, were common on the dry bank and most common in OT. *Diospyros glabra* was one of the last indigenous species to persist under heavy invasion.

No one species was an ideal indicator of riparian vegetation as a whole or its component assemblage types. The characteristics described for the reference condition, however, together capture the essence of undisturbed riparian vegetation communities in Western Cape headwaters.

From the physical data from each reference site, the CART model specified where each assemblage type was most likely to occur (Table E2). The probability of locating the correct assemblage types using these rules differed from type to type, mostly relating to uncommon channel or valley shapes (Chapter 4). One recommendation of this project is that the CART model be further refined to accommodate these kinds of sites.

E4. Invaded and Cleared condition

With the reference condition defined, 17 invaded or cleared sites were described and compared to it (Chapter 5).

Table E1. Tentative guidelines for the biological reference condition of Riparian Scrub vegetation assemblage types on the banks of Western Cape headwater streams.

Attribute (50 m ²)	Vegetation assemblage type			
	Wet Edge	Channel Fringe	Tree Shrub	Outer Transitional
Species richness	6.1 ± 4.2	9.1 ± 5.9	8.8 ± 2.9	19.9 ± 7.9
Equitability (H)	per 50 m ² plot: 2.38 ± 0.23			
Relative diversity (J)	per 50 m ² plot: 0.77 ± 0.06			
Growth form	• Sedges most common • Restios common • Rushes present but very rare • Adult Riparian Scrub trees very rare • No large tree species	• Restios most common • Sedges and shrubs rare • Rushes present but rare • All life stages of Riparian Scrub trees rare • No large tree species	• Sedges, restios and shrubs very rare • Rushes absent • Adult Riparian Scrub trees common • Large tree species very rare	• Most growth forms present at low frequency • Rushes absent • Small shrubs most common to this assemblage type • Riparian Scrub trees less common • Large tree species rare
Possible indicator species	<i>Isolepis prolifer</i> prolific <i>Prionium serratum</i> common <i>Calopsis paniculata</i> very common <i>Elegia capensis</i> very rare	<i>Calopsis paniculata</i> very common <i>Elegia capensis</i> very common <i>Erica caffra</i> common <i>Isolepis prolifer</i> common <i>Diospyros glabra</i> very rare <i>Morella serrata</i> and <i>Metrosideros angustifolia</i> seedlings common <i>Morella serrata</i> juveniles common	<i>Calopsis paniculata</i> very common <i>Elegia capensis</i> very common <i>Erica caffra</i> common <i>Isolepis prolifer</i> very rare <i>Diospyros glabra</i> common <i>Metrosideros angustifolia</i> adults prolific; juveniles common <i>Brabejum stellatifolium</i> adults common <i>Morella serrata</i> adults and juveniles common	<i>Elegia capensis</i> and <i>Calopsis paniculata</i> rare <i>Erica caffra</i> , <i>Prionium serratum</i> , and <i>Isolepis prolifer</i> absent <i>Diospyros glabra</i> very common <i>Pteridium aquilinum</i> common <i>Rhus angustifolia</i> rare but most common to this assemblage type All life stages of <i>Morella serrata</i> , <i>Metrosideros angustifolia</i> , <i>Brabejum stellatifolium</i> and <i>Brachylaena neriifolia</i> rare

Note: Prolific = > 50 % frequency of occurrence (f), very common = 35 % < f < 50 %, common = <20 % < f < 35% , rare = 10 % < f < 20 % and very rare = f < 10 %.

Table E2 Tentative physical rules using the CART model for locating assemblage types in undisturbed Riparian Scrub assemblage types on the banks of Western Cape headwater streams.

Assemblage type	Physical rule	Probability of locating correct assemblage type (%)
Wet Edge	Less than 1.5 m distance from summer low-flow water's edge, and less than 0.1 m above the water	82
Channel Fringe	Less than 1.5 m distance from summer low-flow water's edge, and greater than 0.1 m above the water	39
Tree Shrub	Between 1.5-4.5 m distance from summer low-flow water's edge	84
Tree Shrub	Greater than 4.5 m distance from summer low-flow water's edge, where the outer edge gradient is less than 0.2	
Outer Transitional	Greater than 4.5 m distance from summer low-flow water's edge, where the outer edge gradient is greater than 0.2	62

Catchment-scale patterns

Disturbed and undisturbed sites were clearly distinguishable from one another based on simple species presence/absence data. Additionally:

- cleared sites in a catchment were more similar to one another than to uncleared sites within the same catchment;
- disturbed sites retained their catchment identities, but finer definition at the level of river was weak, particularly for invaded (uncleared) sites; in other words, no sites were impacted to the point where their catchment signatures had been obliterated, but they had begun to lose the finer-definition river and zone signatures;
- a site heavily invaded by the gum (*Eucalyptus leucoxylon*), and possibly one invaded by the grey poplar (*Populus X canescens*), appeared most affected in that they no longer grouped by catchment; this was interpreted as a severe loss of catchment identity.
- Sites heavily invaded with various species of *Acacia* appeared less impacted as they remained within their catchment groupings.

Site-scale patterns

The CART model was used to identify the potential bank location of the four assemblage types in the 17 disturbed sites, and the same character descriptors were developed for each. There were considerable differences between the reference condition on the one hand, and the most heavily invaded and most recently cleared sites on the other. For example, comparison of species richness showed that:

- invaded sites generally had lower values than the reference condition (between three and ten species as opposed to an average 23 at the reference sites);
- sites that had been cleared for five to ten years generally had values that were about the same as those of the reference sites (22.7 ± 5.8);
- sites that had only been cleared within the last one to four years generally had higher values than reference sites, probably reflecting opportunistic invasion of the cleared areas by a range of

species, many of which would ultimately disappear again as the riparian community matured (29 to 47 species as opposed to an average 23 at the reference sites).

The other measures of biodiversity - relative diversity (J) and equitability (H) - reflected similar trends.

In terms of growth forms, sites with the oldest recovering vegetation generally showed the closest match with reference conditions. Sites with vegetation less than four years old were least similar to the reference condition. Channel Fringe (CF) seemed the most impacted of all the assemblage types, with higher occurrences of sedges, rushes, grasses and forbs, and also many trees - mostly alien - although none had occurred in any reference site. An initial flush of herbaceous growth characterised the earlier stages of recovery of the wet bank (WE and CF) and for TS of the dry bank.

Of the ten indicator species identified for the reference group, eight were missing from the most severely invaded site - that invaded by *Eucalyptus*. Over all the disturbed sites, the sedge *Isolepis prolifer*, typical found at the water's edge, was one of the first to take advantage of cleared areas, perhaps because of an ability to establish itself quickly in a variety of naturally-disturbed habitats. The restio *Elegia capensis* and the shrub *Erica caffra* were absent from cleared sites up to 13 years later despite being present upstream. They appear among the most heavily impacted by invasion. By contrast, the shrub *Prionium serratum* was noticeably more abundant in disturbed than reference sites, although not in the mostly recently cleared ones. Its higher frequencies at the disturbed sites might suggest the modified conditions provided by alien trees, perhaps through trapped sand deposits, favoured its proliferation. It could also be that the habitat was more favourable for the proliferation of this species prior to the invasion. The shrub *Diospyros glabra* was one of the last indigenous species to persist under severe invasion.

In summary, all of the measures of biodiversity fell outside the reference condition range for all of the sites that were still heavily invaded (Figure E1). After clearance there was a flush of new growth that led to biodiversity values recovering back towards, or exceeding, the reference values. Values later declined to reference levels and remained the same for up to ten years post-clearing. Trends beyond ten years are not clear since only one cleared site had older vegetation and its values at this stage remain somewhat anomalous. These indices should be used in parallel with other information on growth forms and indicator species to assess post-clearing recovery.

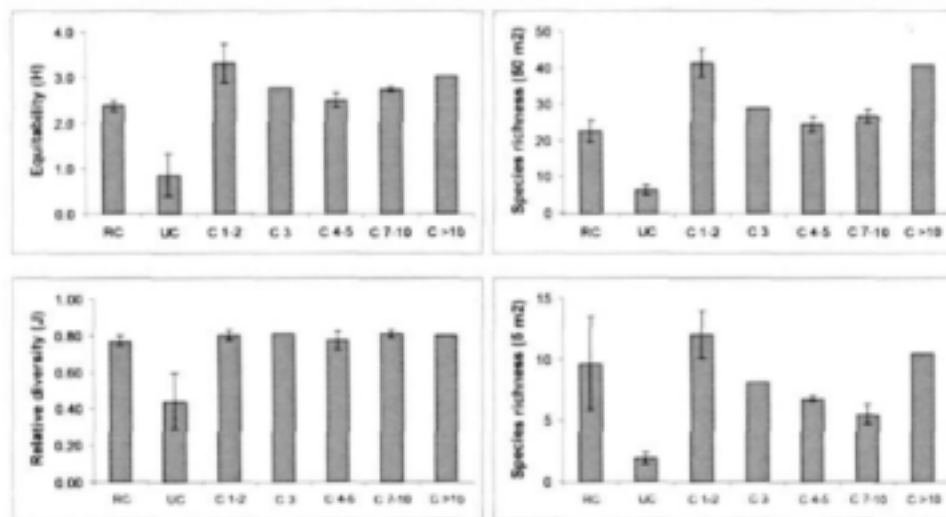
Location of invading species

Most disturbed sites had been invaded by, or cleared of, *Acacia mearnsii*, and its typical location within the vegetation could be described with some certainty. Seedlings were present on the wet and dry banks in all assemblage types but were most common in CF even up to ten years after clearing. Saplings and adults were less common and were also mostly found in CF, followed by TS.

E5 ASSESSMENT OF THE CART MODEL

The physical location of the assemblage types - through a predictive physical model based on height and distance from the water - was a useful way of addressing the problem of what species should have been at heavily invaded or cleared sites. It worked quite well for most of the sites, but was less effective for sites with floodplain development and not effective at the Afromontane Forest sites because of their steep narrow valley shapes. The model needs further development to work well for a wider range of geomorphological site types. A version for the Afromontane Forest sites can only be derived with additional data from more undisturbed Afromontane Forest areas.

Figure E1 Means and standard deviations of biodiversity indices for reference and disturbed sites. RC = reference condition, UC = un-cleared (i.e. heavily invaded), C 1-2 = cleared one to two years ago, C 3 = cleared three years ago etc.



Sample size: RC (n=12), UC (n=4), C 1-2 (n=2), C 3 (n=1), C 4-5 (n=3), C 7-10 (n=3) & C >10 (n=1)

E6 CLEARING METHODS AND POST-CLEARING RECOVERY

A small investigation of alien clearing methods addressed the following questions:

- Is there a significant difference in floristic or growth form composition between reference vegetation and cleared vegetation?
- Is there a significant difference in floristic or growth form composition among the recovering vegetation stands following different clearing treatments?
- Which of the more commonly used clearing methods best facilitates vegetation recovery in the riparian zone?

Only sites cleared at least two years previously were chosen, to allow sufficient time for some post-clearance recovery. Twenty-seven plots on seven rivers were sampled with multiple plots on any one river being at least 200 m apart to provide some independence. Three initial clearing treatments were investigated: Fell Only; Fell & Remove slash; and Fell & Burn slash.

All the cleared sites were significantly different to the reference condition for some of the following variables: indigenous cover, species richness and growth form structure. An overlap in species composition between the unburnt treatment plots and the Reference plot, however, indicated that vegetation recovery following those clearing treatments was moving toward natural conditions. The Fell & Burn treatment showed the poorest recovery relative to the reference condition and it is recommended that fires of unnaturally high severity be avoided in the riparian zone by removing some of the felled and dried alien biomass. Of the treatments tested, Fell & Remove appeared to best promote vegetation recovery in the short-term.

Data from the main study suggested the following trajectory of recovery:

- Phase 1: recruitment of fynbos, scrub and other wet or dry bank species, including aliens and pioneering annuals, takes place in the first year as a flush of new growth.
- Phase 2: herbaceous cover (sedges, rushes, grasses and forbs) establishes between one and four years.
- Phase 3: restios, shrubs and small trees establish in and amongst the herbaceous cover between four and ten years. Woody alien and small Riparian Scrub tree species also establish during this phase.
- Phase 4: long-term recovery occurs that takes longer than a decade because of sensitivity of some species to invasion or clearance, and also due to slow development of a dense canopy cover. *Elegia capensis* and *Erica caffra* are examples of probable sensitive species.

E7 ALIEN TREES AND ALLELOPATHY

A small study of the possible allelopathic effects of alien invasives was also completed.

Allelopathy refers to the inhibitory or stimulatory effect that chemicals (termed allelochemicals) of plant or microbial origin have on the growth, development and distribution of other plants and micro-organisms in natural communities or agricultural systems. The invasive nature of many alien species, including those of interest to this project (eucalyptus, wattle, poplar and pine) may, to some extent, be due to their production of allelochemicals. In South Africa, bare areas around and/or under invasive tree species such as *Eucalyptus* are a common sight both within and outside plantations. Considerable research has been carried out into this topic worldwide, but the relevance of the research findings in South Africa is not clear. Four questions were thus addressed.

1. Do young saplings of selected invasive alien tree species exert an interference effect on indigenous colonizing plants?
2. What is the effect of the litter (leaves, twigs, bark) of invasive species on the germination and growth of indigenous colonizing species?
3. What are the implications of the above for the management of alien-infested lands and for clearing programmes?
4. What is the way forward?

The study results suggest that young alien saplings probably do not exert an interference effect on establishing indigenous seedlings. Field trials should be done to confirm this. The work needs to be extended to examine the effect of mature alien trees. With regard to the impact of litter from alien species, the results suggest that litter from *Eucalyptus* may have some phytotoxic effect on sensitive indigenous species, but that this is not an over-riding effect.

In terms of management implications, this study and the general international literature suggest that of the four species examined in the project, *Eucalyptus* probably has the greatest interference potential. *Eucalyptus* may inhibit seed germination and seedling establishment, perhaps through allelopathic influences but possibly also through competition for resources. The establishment of under-storey vegetation would probably be improved by removal of *Eucalyptus* litter.

A proposed road-map for future research into allelopathy has three main thrusts:

- identification of the most important avenues for research;
- suggestions for useful and necessary research;
- other possible experimental or investigatory approaches.

The recommended primary avenue for research is to investigate effective clearing and management of invaders. Any research on allelopathy should be designed to answer questions about clearing techniques. This should include field trials and the inclusion of fire – a burn will volatilize the allelopathic chemicals in the litter and promote fynbos recruitment.

E8 CONCLUSION AND RECOMMENDATIONS

Management considerations

Protecting remaining indigenous plants

All the heavily-invaded areas investigated during this study supported a number of Riparian Scrub species beneath the dominant alien canopy. In most cases the wet bank was abundantly vegetated with indigenous species whilst the dry bank had a few isolated indigenous shrubs and small trees of either Afromontane Forest riparia or Scrub riparia affiliation. Individuals such as these are important sources of seed in the initial post-clearance recovery. In many areas, most notably on the Molenaars and the Witte Rivers, there was abundant evidence from cleared sites that clearing teams had removed indigenous trees as well as alien ones. Tree species take far longer to re-establish than do smaller herbaceous species, with the data suggesting that more than a decade is needed to approach natural levels of canopy cover and species composition. Clearing programmes would greatly enhance recovery of the riparian vegetation if all operators could effectively distinguish indigenous from alien species, and protection of indigenous vegetation stocks was a strong priority. Failure to target alien species alone, leaving Afromontane Forest and Riparian Scrub woody species in tact during felling operations retards recovery by limiting propagule supply; an unnecessary disturbance. In the absence of herbicide application most woody shrubs and small trees re-sprout but take longer than ten years to establish again. Protecting indigenous stocks is cheaper in the long run than attempting complex revegetation strategies at sites where clearing has removed established indigenous stock.

Re-vegetation strategies

If re-vegetation of cleared areas is attempted, it may be difficult to establish what species should be re-planted. Valuable clues can be gleaned from upstream areas, which would have provided propagules in the past. Failing this, species from neighbouring catchments could be used. As a last resort common riparian species could be planted, and other less common species could be left to colonise the rehabilitated area naturally from the surrounding landscape. A practical manual of concepts and strategies for rehabilitation is needed (Section 8.2). In the meantime the manual for restoration following clearing, in a variety of habitats by Holmes (1998) should be referred to.

Research recommendations

Post-clearing recovery patterns of riparian vegetation may differ according to the invading species present, and thus restoration projects may require different re-vegetation strategies. Several avenues of research could help guide this process, some of which are presently being pursued in a post-graduate thesis:

- Further investigation of the data gathered in this project on possible trends in the trajectory of recovery of cleared sites.
- Further development of the CART model to capture a wider range of bank shapes and different riparian communities.
- Further investigation of the data gathered in this project on indigenous species-specific responses to invasion and clearance.
- Further investigation of the data gathered in this project on the characteristics of identified vegetation assemblage types.
- Data on species distributions and further work, started by Prins et al. (2004), on classifying riparian vegetation community types for the Western Cape - and the rest of South Africa. This would allow better selection of appropriate species for rehabilitation in order to protect genetic stocks and catchment identities. In the meantime it is recommended that genetic stock from the same catchment be used, if possible.
- A practical manual guiding concepts and strategies for riparian rehabilitation, parts of which are already underway Holmes et al. (in press).
- Further studies on the impacts of different follow-up treatments.
- An investigation on the impact of secondary alien invasions by, for instance, kikuyu grass (*Pennisetum clandestinum*) on indigenous vegetation recovery.
- The role of propagules from the surrounding landscape in influencing recovery rate.

Additionally, promising avenues for allopathy research could be as follows.

- Growth trials of indigenous species under alien tree canopies, with and without alien litter, under different soil conditions, and after clearance by a range of methods, especially the role of fire.
- The rate of degradation of allelopathic chemicals under different conditions.
- Inter-country research on the allelopathic potential of *Eucalyptus*.
- Other research topics as listed in Chapter 7.

• E9 CAPACITY BUILDING

The following students have either completed post-graduate theses or benefited from training in field or laboratory techniques:

Theses

- Mr Karl Reinecke is registered for an M.Sc degree and plans to use the data from this project to upgrade to a Ph.D in 2007.
- Mr Jeremy Shelton completed a B.Sc (Hons.) in Zoology in 2004 on aspects of invertebrate recovery following alien clearing on the Silvermine River.
- Mr Gareth Mann completed a B.Sc (Hons.) in Zoology in 2005 on aspects of invertebrate recovery following alien clearing on the Silvermine River.
- Mr Edward Akunji completed a B.Sc (Hons.) in Environmental and Geographical Science in 2003 on aspects of bank erosion and floodplain development following alien clearing on the Silvermine River.

Training

The following students were trained in various aspects of data collection:

- Mr David Miller, Mr Steven Kirkman, Mr Sandile Koni, Ms Victoria Napier, Ms Ruth Richards, Ms Penelope Barber, Mr Adrian Evans, Mr Graeme Ellis, Mr Ross Turner, Mr Ryan Blanchard.

The following students were trained in various aspects of data processing and analysis:

- Ms Andrea Bernatzeder, Ms Bronwyn O'Connel, Mr Blaine Pritchard, Mr Terence Wilson, Mr Tekie Anday, Mr Jeremy Shelton, Ms Claire Malan, Ms Penelope Barber, Mr Steven Kirkman, Ms Michelle Potgieter, Mr Louis Du Boisson, Ms Katherine Watermeyer.

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Mr Pieter Bornman, a quantity surveyor, provided geomatics support for the channel cross-section surveys and data presentation. Mr Dirk Mathee, from the Geomatics Department at the University of Cape Town, is thanked for always providing a vehicle and total station at short notice, for use in the channel surveys.

Plant identifications were done by the Compton Herbarium at the National Botanical Institute, housed at Kirstenbosch National Botanical Garden. Ms Edwina Marinus is thanked for her patience and professionalism.

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1. INTRODUCTION

1.1 RATIONALE FOR THE PROJECT

Riparian generally refers to biotic communities and environment on the shores/banks of rivers, ponds, lakes and wetlands (Naiman et al., 1998). Riparian zones may be defined in at least three ways from a hydrological perspective (Swanson et al., 1982): most narrowly, as the water's edge; in a broader sense, as riverine areas (bed, banks and floodplain) that are periodically inundated on an annual basis; and lastly, as the entire indirect area over which the aquatic and terrestrial environments interact. In arid areas the boundary between the riparian and the terrestrial community is often quite marked, with the riparian zone visible as an obvious band of green against a much drier and less densely vegetated terrestrial landscape higher up the slopes. In these drier environments, riparian zones could be considered as biological oases, often supporting a much greater number and diversity of species than the surrounding catchment (Rood et al., 2003). In some temperate environments it may be difficult to locate the boundary of the riparian zone as precisely (Tickner et al., 2001), as neighbouring areas may also be densely vegetated because of higher rainfalls or lower temperatures.

Though the riparian zone occupies a small area in relation to the greater catchment, its influence on the surrounding landscape, mostly through its vegetation, is greater than predicted by the land-area effect (Gregory et al., 1991). For instance, some of the most important physical attributes of riparian zones are their ability to trap, buffer and transfer sediments and associated nutrients laterally and longitudinally within the riverine ecosystem (Steiger & Gurnell 2002). In particular, their impact on flow, and their input and recycling of allochthonous material from upstream to downstream areas, are critical aspects of riverine ecology (Tabacchi et al., 1998). Further, they regulate sunlight inputs thereby moderating river temperature (Wilson and Imhof 1998), influence bank stability (Rowntree 1991), reduce erosion (Goebel et al., 2003), and provide key wildlife habitat and corridors for wildlife movement in otherwise disturbed areas (Corbacho et al., 2003). Their role as a filter or buffer between the terrestrial and the aquatic ecosystem helps protect both the aquatic ecosystems from many of the negative effects of land-use and the riparian lands from many of the impacts of flooding. The zone as a whole is a vital component of the river ecosystem.

Because of their association with scarce water resources, riparian zones are vulnerable to many anthropogenic disturbances that alter the flow of energy and materials through the landscape. Among the most serious of these globally are: impounding and diversion of water, pumping of groundwater from alluvial aquifers, grazing of livestock, clearing of land for agriculture and to increase water yields, mining, construction of roads, heavy demands for recreational use, and fire (Naiman et al., 2005). In the process, indigenous organisms may be eliminated from the riparian zone and alien species introduced. Ecotones in general, and riparian zones in particular, are known to be sensitive to environmental change (Naiman & Decamps 1987) and particularly prone to invasion by alien plant species (Tickner, Angold et al., 2001). This vulnerability of riparian zones to invasion by non-native plants is particularly pronounced in semi-arid areas (Dye et al., 2001), at least partly due to the dispersal of water-borne alien seed by floods (Knight 1985), the availability of water in otherwise dry

areas, and the dynamic, frequently disturbed nature of riparian systems that creates patches of open sediment ideal for germination (Versveld et al., 1998). Invasion of alien plants into riparian zones in arid regions has important implications for our already scarce water resources, since these species have free access to water and consume more of it than do indigenous riparian species (Versveld et al., 1998). Invasion of riparian zones will change the composition of the native communities and the way the systems respond to natural disturbances (Andrews & Auble 1995), and could result in further invasion and/or soil de-stabilisation (Rowntree 1991), and reductions in river water quality (Le Maitre et al., 1995). Being frequently naturally disturbed, riparian zones require sustained management in areas where invasive species occur (Richardson et al., 1997).

The effect of alien invasive plant species on indigenous hill slope vegetation in the Western Cape (Richardson & van Wilgen 1986, Richardson et al., 1989) revealed a reduction in vegetation cover and total number of species beneath invasive canopies. Richardson & van Wilgen (1986) observed a difference in the vegetative response to the presence of *Pinus radiata* between the hill slope and riverbank vegetation but did not provide detailed information. There are very few detailed studies of the impacts of invasion of riparian zones in the Western Cape. At the conception of this project one consultancy was addressing the impact of *Acacia mearnsii* and *Eucalyptus* sp. on riparian vegetation in the foothills of the Breede river system (Boucher, University of Stellenbosch, pers. comm.). Two other studies, by Prins et al. (2004) and Sieben (2002), were nearing completion, both describing reference conditions for riparian zones of the Breede River system. There had been no studies of the impacts of different methods of clearing aliens from riparian zones and the recovery success of indigenous riparian plant species. Some autecological studies (Pieterse & Cairns 1986, 1988; Pieterse 1997; Van den Berckt 2001) and other studies on invasive litter fall (Milton 1980, Versveld et al., 1988) had demonstrated enriched soil chemistries following invasion of terrestrial communities in the Western Cape and suggested that nutrient enrichment hampered the survival of indigenous species (Musil & Midgley 1990). Again, there are no studies of riparian soil chemistry, in terms of changes caused by alien invasion or recovery after clearing.

To address this knowledge gap, this three-year project was designed as a comparative study of the effects of woody alien invading species on the vegetation communities of riparian zones, and to collect empirical data on the recovery of indigenous riparian vegetation post alien clearing.

1.2 BACKGROUND TO THE PROJECT

This project followed a previous Water Research Commission project entitled 'River rehabilitation: literature review, case studies and emerging principles', and was partially in response to a call for proposals by the Working for Water (WfW) programme (van Wilgen et al., 1998) for research on the impacts of alien clearing on freshwater ecosystems using macro-invertebrates as river health indicators. The project's overall aim was to describe the characteristics of plant communities in undisturbed riparian zones in Western Cape headwater streams, and how these changed with invasion by alien woody species and again during recovery after clearance of the aliens.

Items included in the terms of reference for this project included: a literature review; the main study on community composition of undisturbed, invaded and cleared riparian zones; the building of a botanical herbarium (species reference) collection of riparian plant species that would be housed in the Freshwater Research Unit at the University of Cape Town; and the use of physical and chemical soil variables and seed-bank germination studies to investigate the recovery potential of disturbed and cleared riparian zone soils. Some project objectives were adjusted with the approval of the Steering Committee on 7 October 2003 and 26 October 2004; the final versions are given below.

1.3 PROJECT OBJECTIVES

In summary, the project objectives, as redefined through the steering committee meetings were:

1. Identify riparian plant communities of undisturbed and invaded riparian zones in Western Cape rivers, and describe their species composition.
2. Ascertain if each invasive species occurs in one or more lateral riparian vegetation zone.
3. Begin an exploratory investigation into whether or not allelopathy can be detected in selected common invasive woody alien species, and the possible effects of alien species on common soil variables.
4. Monitor the early stages of recovery of indigenous vegetation *in situ* after clearing.

Objectives 1 and 2 were addressed in a series of data-collection activities during the summers of 2003/4, 2004/5 and 2005/6 by the main researcher on the project, Mr Karl Reinecke. Data on 11 sites from five rivers were collected during the first summer and modifications made to the methods of data collection and analysis, after which data from a further 24 sites on a further six rivers were collected.

Objective 3 was addressed through a series of investigatory experiments into allelopathy by Dr Heather Malan. Allelopathy may be defined as the effect that chemicals (termed allelochemicals) of plant or microbial origin have on the growth, development and distribution of other plants and micro-organisms in natural communities or agricultural systems (Einhellig 1993a).

Objective 4 was met through a field-based comparative study of the recovery of riparian vegetation post-clearance of aliens, by Mr Ryan Blanchard, supervised by Dr Pat Holmes. This formed part of their larger Working for Water programme funded project on 'Targets for ecosystem repair in riparian ecosystems in fynbos, grassland and savanna biomes'.

The project focuses on vegetation aspects of riparian zones. It is acknowledged that other aspects of these zones, particularly their geomorphological and hydrological attributes, are fundamental in understanding the nature and functioning of the plant communities they support. Such a multidisciplinary approach, though ultimately necessary, remained outside the scope of this report.

1.4 PROJECT REPORT

The report consists of five parts. Following this introductory part, Part 2 consists of a five-chapter section on riparian vegetation zones, covering the main literature review and the main study. Part 3 covers the *in situ* comparisons of methods of clearing, and Part 4 the investigations into allelopathy. Part 5 presents the conclusions and recommendations.

2. LITERATURE REVIEW

2.1 DEFINING RIPARIAN ZONES

In general terms a riparian area is an area of land directly influenced by the presence of a permanent freshwater body. As such, riparian systems are associated with nearly all continental waters – lakes, rivers, wetlands, springs and estuaries. Riparian zones are structurally diverse areas, from broad, forested floodplains to narrow, intermittent areas along rivers in incised valleys (Naiman et al., 2005). Where floodplain development is restricted, riparian zones are linear and narrow features of the landscape (Holmes et al., 2005), with vegetation communities that are distinctive in terms of the composition of species and growth forms from the vegetation within the river and the terrestrial vegetation on drier (higher) ground. Riparian zones occupy a three-dimensional (Wilson & Imhof 1998) transitional area (or are ecotones, Swanson et al., 1992) between aquatic and terrestrial ecosystems and serve as conduits for the exchange of materials and energy from the one to the other (Richardson et al. in press). Riparian zones generally exhibit sharp gradients in environmental and ecological processes (Swanson et al., 1992; Naiman et al., 1998), which result in a mosaic of environmental patches (Naiman & Décamps 1997) and a considerable variation in species richness and composition (Corbacho et al., 2003).

In this project the phrase **riparian zone** refers to areas directly adjacent to the active channel of the river that support vegetation communities that are distinctly different to neighbouring terrestrial communities and that show a distributional relationship to the flow regime of the river. As such, the vegetation of active floodplains and terraces immediately adjacent to the river channel is included whilst usually-submerged aquatic communities within the active channel are not. Two main features separate riparian ecosystems in this sense from other wetland ecosystems (Rogers 1995):

1. a linear form due to their close proximity to rivers;
2. an hydrological connection to upstream and downstream areas, at least intermittently.

2.2 THE NATURE OF RIPARIAN ZONES

Riparian zones are complex, dynamic, heterogeneous and multidimensional. There is a considerable body of knowledge on them, and a number of basic concepts as outlined below have emerged regarding their occurrence, structure and functioning.

2.2.1 Rivers in the landscape

Natural rivers manifest a diversity of landscape elements (Ward et al., 2002). Their ecological nature and functioning are influenced primarily by river size, position in the catchment's drainage network, the hydrologic regime and local geology and geomorphology (Naiman and Décamps 1997). Riparian zones may be small along headwater streams and completely embedded in forest; wider along mid-sized rivers, forming distinct bands within the landscape that are determined by long-term (>50 yrs) channel dynamics and annual discharge; or well-developed, physically-complex floodplains that

experience seasonal flooding and lateral channel migration with diverse vegetation communities and moist soils. Study of them thus recognises three main perspectives:

- longitudinal - from the river source to its mouth;
- vertical - between the bank, river bed and fluvial aquifers;
- lateral across the floodplain.

The principal driver is the hydrological regime of the system, which in turn works on its geomorphic features to produce a dynamic and constantly changing physical template (Lorenz et al., 1997) for the biotic component of the riparian zone. These two principal drivers are considered further below.

2.2.2 Hydrology

Gradients and patterns of zonation in aquatic and riparian biotas result from the spatial and temporal variation in the input, retention and flow of matter along a river's length (Lorenz et al., 1997). Several authors have recognised bands of different kinds of plant communities up river banks from the water's edge to the outer edge of land influenced by flooding. Taman (2001), for instance, recognised:

- the 'submergent zone': contains surface water most of the year; submerged plants are rooted beneath the surface though their leaves may float at the surface;
- the 'emergent zone': supports plants with roots that are submerged for at least some of the year and with leaves and stems above the water surface;
- the 'damp zone': permanently damp for most of the year and experiencing flow during flood events;
- the 'ephemeral zone': dry for most of the year, and may become wet during floods.

Similarly Thayer et al. (2005) divided riverine forests into six zones using an elevation gradient from the water's edge up the bank reflecting the flood-recurrence interval in each case. All zones are not always present, nor will the pattern of zonation necessarily follow the expected progression from I to VI.

- Zone I is the main channel with 100% flood probability.
- Zones II-V constitute the active floodplain:
 - Zone II is the deepwater swamp (backwater) with near 100% probability of flooding;
 - Zone III is semi-permanently flooded with a 51-100% probability of prolonged annual flooding;
 - Zone IV is seasonally flooded with a 51-100% chance of short-term annual flooding;
 - Zones II to IV provide seasonal spawning, nursery and foraging habitat for fish when inundated;
 - Zone V is only temporarily flooded with an 11-51% probability of annual flooding.
- Zone VI is the floodplain-upland transition, intermittently flooded with a 1-10% chance of annual flooding.

Boucher (2003) recognised three principal zones (aquatic, wet bank and dry bank) subdivide into six subzones: one aquatic, the rooted aquatic macrophyte subzone; two wet bank, the fringing sedge subzone and the shrub or willow subzone; three dry bank, the lower dynamic subzone, the tree/shrub

subzone and the back dynamic subzone. The wet bank is determined by within year flows while the location of the dry bank is determined by floods with recurrence intervals of more than one year.

Recent research on integrated management of river flows has reflected a new understanding of the significance of a river's flow regime in maintenance of the nature and functioning of the whole river ecosystem. It is now generally recognised that the whole flow regime is important for river maintenance (King et al., 2003) including:

- the dry-season low flows;
- the small floods that occur every year;
- the intermediate floods with occurrence intervals of two to about five years;
- the rare, larger floods that can be catastrophic for the system;
- natural flow variability at daily, monthly annual and inter-annual levels.

This approach has shown for several rivers across southern Africa, for instance, that the 1:2 year flood correlates with the lowest edge of the main band of woody vegetation and thus may be responsible for controlling encroachment of trees and shrubs into the active channel (Tharme & King 1998, King et al., 2000). The largest of the intra-annual floods similarly correlates with the dynamic band of pioneer species assemblages next lowest in elevation below the trees and shrubs – in the longitudinal strip sometimes referred to as the Fishermen's Walk. This strip may be too elevated to support sedges and reeds and too low for trees to establish because of regular annual flooding.

The recognition that bands of different species assemblages occur up river banks was one of the fundamental concepts built into design of the study programme for this project.

2.2.3 Geomorphology and geology

The basic premise of fluvial geomorphology is that "rivers adjust their morphology (width, depth, slope and planform) to carry the water and sediment supplied from the drainage basin: during the passage downstream the caliber of the bed material declines as channel gradient decreases. These changes allow the river to achieve a balance of energy and material" (Newson et al., 2002). Rowntree and Wadeson (1999) and Rowntree (2001) developed a hierarchical geomorphological classification system for South African rivers that encapsulated the changing downstream nature of rivers. In this classification system, river channel zonation patterns are assessed in terms of gradient, valley form and characteristic channel features (substratum and reach types). The classification divides a river longitudinally within its catchment through a nested hierarchy of segments, zones, reaches and morphological units. Each level of the hierarchy reflects the changing physical nature of both the river bed and the banks. Upper reaches usually consist of narrow streams in narrow valleys, and so the riparian zones tend to be poorly developed with indistinct or incomplete lateral zonation of plant communities up the banks. The width of the riparian zone tends to increase with distance downstream as valleys widen, resulting in less lateral constraint of river flow. Flood terraces and floodplains become a more obvious feature of the riverine landscape, with a consequent increase in the extent and complexity of the riparian vegetation.

Riparian vegetation is shaped by disturbance regimes of the surrounding landscape, such as wind and fire, and by those associated with lotic and lentic systems, such as flooding, debris flows and sedimentation processes (Holmes et al., 2005). The distribution of riparian vegetation is determined by gradients of available moisture, oxygen and nutrients, in part determined by altitude, underlying geology (Sieben 2002) and the development of post disturbance successional phases of vegetation (Holmes et al., 2005).

2.2.4 Freshwater ecology

Recent years have seen a proliferation in concepts on the nature and functioning of river ecosystems. Key concepts are outlined below, with comment on their relevance for riparian zones.

- The River Continuum Concept (Vannote et al., 1980) explained downstream (longitudinal) ecological change as a function of changes in channel geometry, riparian vegetation and organic matter (productivity), assuming maximum biodiversity in the middle river reaches. There was no consideration of temporal changes, or of lateral and vertical dimensions in the ecosystem.
- Patch dynamics theory described the physical river as a discontinuum (mosaic) of patches formed by the combination of different environmental conditions and disturbance/succession processes through time (Poole 2002). Swanson et al. (1992) separated geomorphic (as a result of sediment movement) and non-geomorphic (due to topographic position, for example) patch-forming processes or disturbances. Riparian vegetation communities are patchily distributed responding both to localised conditions (availability of nutrients and moisture) and the disturbance regimes of upslope (overland flow and fire) and upstream processes (sediment delivery and bank erosion).
- The flood pulse concept (Junk et al., 1994) related ecological response to seasonal hydrological change while emphasizing lateral connectivity and the role of seasonal variation in structuring recruitment of obligate riparian species (Richards et al., 2002). It is increasingly being acknowledged that a more holistic view of riparian zones is necessary for successful management; one that includes a four dimensional view: lateral, vertical, horizontal transfer of materials and energy through time.
- The telescoping ecosystem model (Fisher et al., 1998) viewed rivers as a series of nested subsystems. This concept has been absorbed into riparian ecological thinking in order to capture the multidimensional influences on riparian structure and community composition.
- The intermediate disturbance hypothesis described a trade off between competitive and dominant species' monopolies on stable habitats, and other fugitive species' tolerance of high instability levels (Richards et al., 2002). Higher species richness is expected during colonization of newly formed habitat patches and is expected to decrease as the stability and age of the patch increases.

The flood-pulse concept and intermediate disturbance hypothesis are inter-related through patch dynamics and together are particularly pertinent for riparian systems as they deal with channel dynamics that create a diversity of habitat patch sizes, and with lateral and vertical linkages.

These concepts help formulate a useful framework in which to consider data collection and organisation, particularly in terms of the longitudinal dimension of stream ecosystems. They focus very poorly, however, on riparian zones and transitions within them and between them and other neighbouring ecosystems (Ward & Tockner 2001). Further focus on the nature of riparian zones comes from a growing body of specialised riparian studies.

2.2.5 Riparian species ecology and adaptations

The mosaic of constantly changing channel and floodplain features creates complex heterogeneous habitats (Stanford et al., 1996). Thus, for any one riparian plant species, the resources needed to sustain growth and reproduction are distributed patchily within the riparian zone. Further, the plants must continually resist the occasional or sustained physical force of moving water in order to persist at a particular location. As a result, riparian plant species tend to occur in patterned locations reflecting their adaptation to the frequency and duration of flood pulses (Stanford et al., 1996) and the various habitat effects caused by them.

Though physically harsh, the riparian zones are suited in many other ways for extended plant growth and nutrient uptake: soil moisture is available all year; the humidity is relatively high, which buffers against excessive evapo-transpiration in summer; temperatures are generally lower than in the surrounding landscape due to evaporative cooling; and there is considerable protection from the wind. As a result, the zones are ideal for prolonged metabolic activity, and their status as ecotones results in them supporting disproportionately species-rich communities compared to neighbouring ecosystems (Swanson et al., 1982). Though the overall distribution pattern of the plant communities reflects flood recurrence intervals, species-specific reproductive and physiological adaptations determine actual colonisation, establishment, and succession patterns. Adaptations include species that grow on large woody debris (Rutherford et al., 2000), those that succeed on mineral floodplain soils, obligate hydrophytes growing in flooded soils; and those with mechanisms to cope with flooding, sediment deposition, physical abrasion and stem breakage. Functional adaptations fall into four categories (Naiman et al., 1998):

- invaders produce large numbers of wind- and water-disseminated propagules that colonise alluvial substrata;
- endurers resprout after breakage or burial of either their stem or roots from floods;
- resisters withstand flooding for weeks during the growing season;
- avoiders lack adaptations to specific disturbance types.

Stresses associated with inundation can be coped with for varying lengths of time, depending on the species. Some adaptations include adventitious roots, stem buttressing, root and stem flexibility (Thayer et al., 2005); aerenchyma or air spaces between cells in roots and stems, common in the

Cyperaceae and Juncaceae, to cope with anoxia by facilitating diffusion of air from aerial parts of the plant to submerged parts; and pneumatophores or air roots that grow above the anoxic zone and enable oxygen uptake (Naiman et al., 1994).

The timing of seed production (phenology) to coincide with flood events, which create suitably open and moist regeneration sites (safe sites: Cellot et al., 1998), is critical for regeneration of woody species. Generally seeds are produced to coincide with timing of the flood recession, suggesting the evolution of dispersal strategies that maximise opportunities for successful regeneration and even suggest that species on a particular river might respond to catchment-specific hydrology (Naiman et al., 1998). This is not the case for unspecialised plant fragments however; dispersal of these may take place at any time of the year, with stem fragments often producing roots upon breakage to boost germination success once deposited on land (Riis & Sand-Jensen 2006).

Hydrochory

Hydrochory may be defined as the dispersal and transport of seeds and other plant propagules (rhizomes, stolons, tubers, stem fragments and turions, Nilsson & Svedmark 2002) by flowing water (Naiman et al., 1998). Germination success is influenced by an appropriate flow regime and flooding pattern, soil characteristics such as particle size and organic matter content, temperature fluctuations and light conditions (Kellog et al., 2003). In addition to seed buoyancy, dispersal efficiency depends on the number of seeds produced and alternative means of transport: anemochory (wind dispersal) and zoochory (animal dispersal, Coops & van der Velde 1995). Hydrochory is an effective means of seed dispersal even for short-floating seeds, and was shown to increase the diversity of plant communities in controlled plots by facilitating long-distance dispersal (Jansson et al., 2005, Budelsky & Galatowitsch 2000). Sites that become isolated from inundation appear more likely to experience local extinction as competitive species, entering via means other than water, colonize successfully, and the transfer of propagules is halted (Nilsson and Svedmark 2002). Inundated sites continually receive propagules with floodwaters, being disturbed but in this way maintaining diversity (Goodson et al., 2001).

Biodiversity and species richness

Biodiversity, species numbers (alpha diversity) and distribution (beta diversity) are primarily determined by the availability of resources for reproduction and maintenance of individuals (Stanford et al., 1996). The riparian species pool contains terrestrial and aquatic communities that inhabit lotic, lentic and hyporheic habitats across a range of spatio-temporal scales (Ward et al., 2002). The characteristic mosaic of landforms and diversity of abiotic and biotic influences on riparian landscapes has led many to consider riparian zones to be, "...the most diverse, dynamic, and complex biophysical habitats on the terrestrial portion of the earth..." (Naiman et al., 1993). Though much studied, few have focused on the causes of their spatial patterns of plant diversity (Tabacchi et al., 1996). Some have suggested that the middle reaches of rivers are the most species rich, reflecting the intermediate

disturbance hypothesis (Tabacchi et al., 1998). Naiman et al. (1993) posit four reasons for the exceptional diversity of riparian vegetation:

- the intensity and frequency of floods;
- small-scale variations in topography and soils as a result of lateral migration of river channels and bank adjustments;
- variations in climate from source to mouth or across biomes;
- disturbance regimes imposed by upland environments.

The riparian zones provide many ecological benefits, including providing migratory corridors and breeding, feeding and nursery grounds that support floral/faunal communities in possibly otherwise dry, hostile or transformed environments (Corbacho et al., 2003); controlling or ameliorating river temperature through shading; inputting organic matter to sustain lotic and lentic food chains; enhancing stream stability and buffering/storing nutrient-rich sediments draining from the landscape; and maintaining soil moisture via capillary action.

2.2.6 Riparian zones in the Western Cape

Despite extensive research in the Fynbos biome, its riparian vegetation has not been intensively studied until recently and there is no formal classification of riparian vegetation communities for the Western Cape (Prins et al., 2004) or the rest of Southern Africa. Riparian vegetation is normally easily distinguished from the surrounding vegetation (Boucher 1978) and has been alternately described as hygrophilous mountain fynbos (Taylor 1978), closed-scrub fynbos (Campbell 1985, Cowling & Holmes 1992) or broad sclerophyllous closed scrub (Cowling et al., 1997). Cowling & Holmes (1992) described the vegetation as similar to forest and thicket, with a relatively high cover of mesophyllous non-proteoid woody plants, but dissimilar in its high cover of Restionaceae and the presence of Ericaceae. Taylor (1978) provided an overview of the succession of hygrophilous fynbos through two stages of evergreen temperate forest: the first is dominated by *Brabejum stellatifolium* and *Metrosideros angustifolia* and the second by *Maytenus acuminata* and *Hartogiella schinoides*. The former usually develops into the latter, which is often referred to as Afromontane Forest, after about 50 years without fire (McKenzie et al., 1977). It tends to be restricted to steep kloofs sheltered from fire, and is described by Campbell (1985) as "Low or tall microphyllous evergreen forest usually with a spare ground layer" and essentially as a feature of coastal mountains.

Two recent papers and a thesis addressed Western Cape riparian vegetation communities. Sieben (2003) completed a phyto-sociological study of riparian vegetation communities in the upper reaches of five rivers in the Hottentots Holland Mountains near Cape Town. Sieben described three environmental gradients determining riparian vegetation community structure, listed from most to least important: the geographical gradient influenced by large-scale climatic processes; the lateral gradient determined by inundation frequency and streampower and the longitudinal gradient determined by altitude. He found the most species rich communities furthest from the water's edge at intermediate altitudes. Prins et al., (2004), defined reference conditions for south-western Cape rivers. The identified four prospective plant communities that formed a continuum with the two most

separated communities differing in soil pH reflecting underlying geology. They concluded that riparian specialists are widespread. Galatowitsch & Richardson (2005) assessed recovery of riparian vegetation communities in the south-western Cape following the clearing of woody alien species and synthesized various descriptions of plant communities into a database of 350 Western Cape riparian species. They concluded that indigenous tree regeneration was very low following clearing and was not disturbance triggered. Thus slow recovery is likely to result without restoration intervention. These studies were useful in providing lists of species that could be referred to in the present project, but differences in methodology, in some cases, excluded direct comparison of their community descriptions (Boucher 2002). One of the first tasks in this WRC project was to assess how others had studied riparian plant communities and adopt or develop a suitable approach to meet the project's objectives.

2.3 IMPACTS OF ALIEN INVASIONS ON RIPARIAN ZONES

Biological invasions are the second largest threat (after habitat destruction) to global biodiversity (Richardson & van Wilgen 2004). Semi-arid riparian zones are particularly prone to invasion by alien plant species (Dye et al., 2001), to a large degree because of the availability of water in otherwise dry areas (Versveld et al., 1998). They are frequently disturbed by floods (Richardson et al. in press), which uproot plants and create new habitat patches (Versveld et al., 1998) through fluvial deposition and erosion of sediments. These sites for germination are provided with suitable material - water-borne rhizomes, seeds, and vegetative fragments - by the floods, which distribute the material longitudinally along the system and up the banks (Tickner et al., 2001). Being frequently naturally disturbed, riparian zones require sustained management in areas where invasive species occur (Richardson et al., 1997).

One of the most frequently cited impacts of woody alien invasion of riparian zones is the excessive use of surface and ground water by the aliens compared to the volumes used by indigenous riparian vegetation (Dye & Poulter 1995, Versveld et al., 1998; Calder & Dye 2001). In fact, the recovery of streamflow following clearance of alien-infested catchments, was one of the primary motivating factors for the Working for Water programme (van Wilgen et al., 1998) based on the premise that indigenous forest or scrub uses less water (Scott & Lesch 1996; Dye et al., 2001). Woody alien species have additional impacts, such as fundamentally altering the vegetation-mediated processes caused by changes in canopy structure and in the abundance and variety of species and growth forms present. Essentially, a mixed community is replaced by a woody monoculture. This alters the flow, availability and/or quality of nutrient resources within biogeochemical cycles, trophic resources within food webs, and physical resources such as light, sediment, space or water. Alien species that change the physical structure of the ecosystem in this way are sometimes called 'transformers' (Richardson et al., 2000) or 'ecosystem engineers' (Crooks 2002).

The level to which riparian ecosystem processes are altered depends upon the type and density of the alien cover (Richardson et al. in press), its degree of consumptive use of water (Tucker et al., 2001) and its effect on the hydraulic resistance (or roughness) of the riparian area. In general, bank

vegetation reduces bank shear stress, promoting sediment deposition, and binds the soil, increasing resistance to erosion, but different kinds of vegetation achieve this to different extents. Grasses and other herbaceous vegetation have low biomass and are shallow rooting offering good cover against surface scour but no defense against mass bank failure. On the other hand, trees lack a dense surface root mat and have poor ground cover but are deeply rooted and thus increase protection from mass bank failure (Thorne 1990). Alien woody invasives change these processes, affecting flooding patterns, sediment deposition, water table fluctuations and soil moisture conditions (Tickner et al., 2001).

Once they appear in riparian zones, many woody aliens exploit invasion windows created by flood events and anthropogenic disturbance to further establish themselves. Once established, positive feedback mechanisms may promote their further spread via habitat alteration and increased pressure of propagules (Richardson et al. in press). This has been shown for *Sesbania punicea* in South Africa (Hofmann & Moran 1988). Other localised impacts recorded at the site scale include:

- suppression and replacement of indigenous vegetation (Holmes et al., 2005);
- increased transpiration, leading to a reduction in flows due to increased biomass when compared to indigenous vegetation (Holmes et al., 2005);
- reductions in rainfall-runoff into rivers and increased flow resistance caused by dense woody stands, resulting in sediment deposition and changes in channel shape (Rowntree 1991);
- local channel widening in headwater areas, with lateral erosion of channel banks (Rowntree 1991);
- deepening and narrowing of lowland rivers as sediment is trapped and stored (Rowntree 1991);
- alterations to soil chemistry, for example increases in soil nitrogen by *Acacia saligna* (van den Berck 2001) that may promote colonization by uncharacteristic indigenous species or secondary invasion (Holmes et al., 2005), usually by nitrophilic (nitrogen-loving) species (Yelenik et al., 2004);
- lowering of the water table, which reduces the availability of suitable amphibian habitat for sensitive species (Baard et al., 2001);
- reducing the canopy cover of indigenous trees in favour of shrubs, with associated reductions in species richness and indigenous tree recruitment (Galatowitsch & Richardson 2005);
- changes in woody biomass and litter fall, which increase the flammability and heat generated by fires, leading to 'heat scars' and the death of indigenous seeds in surface soil layers (Cilliers 2002).

Changes in invaded areas should be interpreted with caution, as invasion by alien species may be a consequence of change rather than a cause. *Tamarix* species in the arid parts of western USA, for instance, was attributed with a suite of impacts on invaded channels, including increases in the width:depth ratio, salinization of river bank soils and modifications to existing habitat (Richardson et al. in press). Later studies showed *Tamarix* did not consume more water than indigenous vegetation, and that reduced flows downstream of flow-regulating reservoirs were responsible for increased sedimentation, with invasion by *Tamarix* being a secondary consequence of these reduced flows and not a cause.

Secondary ecosystem-level impacts of alien invasion are less well studied, and most evidence remains at the level of undocumented observations. Richardson & van Wilgen (2004) discussed some anecdotal evidence of alterations in the provision and delivery of riparian/fluvial good and services other than water, and highlighted the need for further research:

- increased amount and diversity of seed resources for frugivorous birds and decreased availability of food supplies for insectivorous bird species;
- increased biomass and woody fuel loads, leading to increased susceptibility to fire and soil erosion;
- increased runoff in catchments devoid of topsoil and groundcover causing increased severity of flooding, damage to property and siltation of reservoirs;
- decreased beach replenishment of fine sediments through stabilisation of coastal sand dunes by, for instance, *Acacia cyclops*;
- compromised fishing in rivers because of invasion of channels by floating aquatics and of riverbanks by trees;
- increased sediment delivery coupled with decreased flows, leading to a lower probability of estuarine river mouth breaching, which impacts on the recruitment of marine species with estuarine-dependent life stages.

The impacts listed above, though few in number, illustrate that alien invasions may be felt far beyond the area of invasion. Research into these wider issues is being conducted through the Working for Water (WfW) programme. WfW was initiated by the Department of Water Affairs and Forestry in 1994 and pioneered an approach of maximising a specific ecosystem service - the delivery of water - whilst eliminating invading plants, and at the same time promoting social equity through job creation (van Wilgen et al., 1998). The impetus behind the programme was the relatively low cost of clearing when compared to that of developing additional water-supply schemes (van Wilgen et al., 1997). Of equal importance were the restoration and conservation of biodiversity, and enhancement of the quality of life of previously-disadvantaged peoples. Research on more fundamental scientific questions is still needed: whether or not the predictions of significant benefits arising from alien control can be substantiated by good science, and whether or not the threat of invasive alien species can be curbed (van Wilgen 2004).

2.4 STUDYING RIPARIAN PLANT COMMUNITIES AND THE IMPACTS OF INVASION

The concept of a plant community

A plant community is defined as a collection of plant species growing together in a particular location, where the species show an association or affinity with each other that is greater than would be expected by chance (Kent & Coker 1992). Two opposing views on plant communities are those of Clements and Gleason, which are summarised by Kent & Coker (1992).

Clements (1916) saw a plant community 'as a clearly recognisable and defined entity that repeated itself with great regularity over a given region of the earth's surface'. This was linked to the concept

of a climax community; he believed long-term stability over time favoured communities at equilibrium within the prevailing climate. Gleason (1926) on the other hand saw plant communities as continua, with the species responding individually to variations in environmental factors over time and space and the community thus subject to species immigrations and extinctions. The combination of species at any point in space was therefore unique and dependant upon a combination of environmental factors and the tolerances of the invading and resident species. Since the idea of a community was not static, samples could never be generalised into defined plant communities.

Kent & Coker (1992), in common with most modern plant ecologists, suggested that plant communities lie somewhere between being continua and clustered units. In any region, broadly similar conditions of environmental factors and biotic pressures will occur. Where these conditions repeat themselves the vegetation type will be repeated (like pieces of a mosaic), will have definite structure and could be seen as a plant community. There are also other groups of species, however, which are transitional between recognisable communities and have properties common to more than one group. These ecotones or transition areas form borders between different plant communities that may not be clear.

This raises the question of how to treat these transition areas, and how to distinguish at what point a transitional group becomes a community. Two different approaches have emerged for studying plant communities and dealing with the transition areas. In the Braun-Blanquet method (Werger 1974) transition areas are ignored in order to strengthen group structure. In the numerical methods the transitions are themselves seen as 'communities'.

Phytosociology and the Zurich-Montpellier (Braun-Blanquet) school of subjective vegetation classification

The Braun Blanquet (BB) approach was devised and largely applied in Europe. Kent & Coker (1992) summarise the method as follows.

1. The vegetation is sampled in a relevé. The position of the relevé is deliberately chosen to be representative of a particular vegetation type and thus is sited non-randomly.
2. The vegetation within the relevé should be uniform and homogeneous, implying species should exist within the relevé over a sizeable area without any obvious variations.
3. Transitions between community types are purposefully avoided.
4. The minimal area method (Werger 1972) must be used to determine the area of the relevé.
5. The sampled relevés are sorted manually into associations by re-arranging both the species and relevé positions in the data table. The exact method by which this is done varies and is not well described.
6. The resulting associations (plant communities) are 'abstract' in that they are not considered to be located in any particular space. These associations may be described as 'concrete' if, when collecting the species data, the location of the sampled communities was mapped.

In this approach, the location of recognisable plant communities is determined *a priori* by visual assessment, purposefully avoiding areas judged to be transitional between the selected community

types. Different sized relevés are used to sample vegetation of differing size (e.g. larger relevés for trees than for ferns). A cover-abundance scale is used to record the composition of species within each relevé. The BB relevés are re-organised into a phytosociological table such that species common across the sampled relevés are excluded as much as is possible from the described communities; community descriptions are based upon key (isolated) species occurrences through the phytosociological table. Since this is based upon specialist knowledge and a certain intuition, different researchers are likely to recognise different arrangements of vegetation assemblages in the data table.

Numerical classification – objective vegetation classification

Numerical methods do not recognise the location of plant communities *a priori*. Data are collected systematically over a wide area, and data-reduction techniques used to identify assemblages based on the grouping of similar samples. Samples falling outside these groups of similar samples may represent transitions between groups, or they may be samples where too few species were present for a proper identity of the sample to be made.

The goals of numerical classification are the same as for the tabular re-arrangement in the Braun-Blanquet method: the grouping of a set of individuals (quadrats or vegetation samples) into classes on the basis of their attributes (floristic composition). The numerical methods rely on a set of rules dictating how the groups of individuals or samples are arranged and so, for any one set of data, any researcher using a particular method should produce the same result.

Method requirements for this project

During this project, a key requirement was the need for a repeatable and consistent method that could be applied by biologists with no specific training in the study of Western Cape riparian communities. The Braun-Blanquet method did not fit this requirement as it requires specialist knowledge to identify communities *a priori* and select suitably sized quadrats for the different communities present. A more fundamental problem with the Braun-Blanquet method was seen as the somewhat circular logic of defining communities *a priori*, and then using the species present in each to define the communities.

Kent & Coker (1992) considered phytosociological methods unsuitable for use in studying dynamic ecotone environments such as riparian zones, as they are based on assumptions of community stability at larger scales and were not designed for use in highly variable, narrowly-linear environments. The Braun-Blanquet approach works best where the vegetation community being sampled is truly homogeneous and not an edge or ecotone between other vegetation types.

Its requirement to avoid transitions between communities was seen as causing exclusion of important data on the fundamental transitional and patchy nature of the riparian zone. Systematic information would not be provided on the change in plant species from the dry-season water's edge to the outer riparian edge, and so it would have been difficult to identify the boundaries of different bands/patches of vegetation in relation to this relatively fixed location. It was vital to be able to make this link

between water's edge and elevation boundaries of each plant assemblage, as the assemblages themselves would be partially or wholly obliterated in invaded sites. The measurements from water's edge would then become a vital guide as to where each indigenous plant assemblage should have been, this in turn allowing calculation of the changes in species richness and other biodiversity measures of each assemblage as a result of invasion.

These short-comings led to the choice of numerical methods for data collection and analysis. Two methods were used: CLUSTER analysis and non-metric multi-dimensional Scaling (MDS) ordination. CLUSTER analysis (or classification) aims to find 'natural' groupings of samples such that samples within a group are more similar to one another generally, than to samples in different groups (Clarke & Warrick 2001). MDS ordinations are similar in that they are designed to construct a 'map' showing the relationships between different samples based on the similarity between samples (Manly 1992) but differ from CLUSTER analyses in that they portray the gradation between the grouped samples graphically (Clarke and Warrick 2001). Ideally each group, whether revealed from CLUSTER or MDS ordination analyses, should contain quadrats with very similar species composition; these define the plant assemblages for the area under study (Kent & Coker 1992).

Cluster analyses

Many methods of clustering exist. Clarke & Warrick (2001) chose to concentrate on one technique of widespread utility in ecological studies. They emphasised the arbitrariness of all classification techniques and stressed the need to perform cluster analysis in conjunction with a range of other methods such as ordination or statistical testing, to obtain balanced and reliable conclusions. Methods of hierarchical agglomerative clustering, chosen for use in this project, are the most commonly used clustering techniques. Data are reduced to a similarity matrix from which samples are fused into groups, starting with the highest mutual similarities and ending with a sample matrix that contains all the samples. The results are portrayed on a dendrogram (or tree diagram) with the x axis representing the full set of samples and the y axis defining the level of similarity. The analysis attempts to group samples into discrete clusters and not display their inter-relationship on a continuous scale (Clarke and Warrick 2001). Cluster analyses are seen as being useful to determine 'true groups' in classifications (Manly 1992).

Ordination of samples

In contrast to cluster analysis, ordination shows the inter-relationships between samples on a continual scale. It is widely recommended that it is performed in conjunction with cluster analysis since agreement between the two methods strengthens the belief and adequacy of each.

There are a number of ordination methods. The earliest was the Bray & Curtis polar ordination (PO) followed by Principal Components Analysis (PCA), reciprocal averaging (RA) and correspondence analysis (CA) and then detrended correspondence analysis (DCA). Canonical correspondence analysis (CCA) is another method, differing from those already mentioned in that it incorporates the correlation and regression between floristic data and the environmental variables within the ordination, whereas the other methods (PO, PCA, RA, CA and DCA) are all indirect methods that produce the ordination

independently of the environmental data. In these indirect methods, the explanatory environmental variables are then superimposed onto the ordination afterwards. The mathematical algorithms for all these methods vary in their complexity and numbers of assumptions made regarding the relationship between samples and the nature of the data. Kent & Coker (1992), Clarke & Warrick (2001) and Manly (1992) provided detailed descriptions and comparisons between the different methods.

The general consensus is that no one method is better/more important than any other, and there is no clarity as to which might give the least distortion to the data (Kent & Coker 1992). Certain methods have gained popularity and are used more often than others in different parts of the world. At the present time DCA and CCA are widely accepted as 'best methods' but each has its problems.

In this project, non-metric multi-dimensional scaling (MDS), which is an indirect method producing an ordination independently of environmental data in the same way that PO, RA and DCA do, was chosen. MDS ordinations make few assumptions about the form of the data or the inter-relationship between samples (Clarke & Warrick 2001). The starting point is the similarity matrix among samples which can take whatever form is biologically relevant to the nature of the questions being asked. There is flexibility in: 1) the choice of coefficient and possible transformation or standardisation, 2) whether or not to ignore joint absences or emphasize similarity in common or rare species, and 3) whether to compare using only percent composition or to allow sample totals to play a part. The MDS ordination is a map showing the distance between samples, with less distance indicating greater similarity. The 2-D ordination is a stressed representation of a 3-D plot, with low stress values ($x < 0.1$) indicating a good ordination with no real prospect of misleading interpretation. Stress values ($0.1 < x < 0.2$) indicate a potentially useful 2-D picture although for values at the upper end of this range the plot should be cross checked against an alternative technique (e.g. the superimposition of cluster groups). Stress values of ($x > 0.3$) indicate that the points are close to being arbitrarily placed in the 2-D ordination space. By superimposing groups from a cluster analysis onto an ordination plot, the adequacy and mutual consistency of both representations can be checked.

3. METHODS

3.1 APPROACH

An assessment of the impact of alien invasive trees on riparian zones has to start with an understanding of the natural (i.e. undisturbed) condition. This acts as a reference condition against which to evaluate how each cleared or invaded (i.e. disturbed) site differs from natural. With this in mind, the research was designed to use river sites along a trajectory from undisturbed, through heavily invaded to recovering following clearance of the invader species. Ideally, such sites should be situated as follows and in order of preference:

- invaded and/or cleared sites downstream of undisturbed reference ones in the same longitudinal zone of the same river (e.g. all in the mountain stream zone);
- sites as above, but in different longitudinal zones (e.g. in mountain stream and foothill zones).

The research was confined to:

- river banks, with floodplains and wetlands not specifically addressed;
- the upper reaches of rivers: mountain stream (MS), mountain stream transitional (MST) and foothill (FH) zones;
- summer data, collected at a time of reasonably constant low flow;
- rivers with natural flow regimes;
- reasonably straight sections of channel, so that a grid of sample plots could be laid out along the bank.

3.2 STUDY SITES

Suitable sites were sought on rivers within a radius of approximately three hours drive from the city of Cape Town: as far as the Hex River valley in the north, Clanwilliam in the north west and Gansbaai in the east. Discussions with officials from the South African National Parks, CapeNature and Working for Water programme, researchers from various faculties at the University of Cape Town and Stellenbosch University, and various private freshwater consultants led to a list of rivers where suitable sites might be located. Ninety-eight possible sites situated on 47 rivers in the Cape Peninsula, False Bay and Indian Ocean coastal area, and the Berg, Breede and Olifants River systems were visited during 20 days of travel between September 2003 and January 2004. The criteria used for evaluating each site are shown in Table 3.1.

Only one river, the Elands/Molenaars, presented a set of suitable sites that met the first criterion of sites in different states in the same longitudinal zone. The four most common situations encountered were:

- river banks completely invaded or disturbed in some other way from source to mouth (i.e. no reference site upstream of an invaded site);

- river banks with indigenous and invaded riparian areas in different longitudinal zones (i.e. no reference site on the same river and zone as the infested site);
- river banks with a mixture of alien species (i.e. no stands of single-species invasions except in one or two cases on non-perennial rivers);
- river banks that had been cleared or burnt within the last ten years and that were at various stages of recovery, either with or without the presence of alien species.

Table 3.1 The criteria used for evaluating potential study sites, ranked by priority.

Rank	Criterion
1	Dense single-species infestations with an upstream indigenous (reference) area in the same longitudinal zone.
2	Dense same-genus invasions with an upstream indigenous area in the same longitudinal zone.
3	Mixed-genera stands with an upstream indigenous area in the same longitudinal zone.
4	Dense single-species infestations with an upstream indigenous area in a different longitudinal zone e.g. an invaded foothill downstream of a pristine mountain stream.
5	Dense same-genus invasions with an upstream indigenous area in a different longitudinal zone.
6	Mixed-genera invasions with an upstream indigenous area in a different longitudinal zone.
7	Rivers with two pristine and contiguous longitudinal zones.
8	Rivers with two pristine sites in the same longitudinal zone.
9	Dense single-species infestations with no upstream indigenous area (control) e.g. an invaded foothill or mountain stream.
10	Dense same-genus invasions with no upstream indigenous area (control).
11	Dense mixed-species stands with no upstream indigenous area (control).
12	Single adult alien trees within an otherwise pristine riparian stand.
13	Cleared and recovering areas with a single alien species present as re-growing juveniles.
14	Cleared and recovering areas with alien species from the same genus present as re-growing juveniles.
15	Cleared and recovering areas with a mixture of different alien species present as re-growing juveniles.
16	Non-perennial rivers, or rivers where no flow was observed.
17	Rivers where the riparian areas have been cleared or disturbed for agricultural or other purposes.
18	An isolated indigenous riparian area that is unsuitable due to significant catchment disturbance, being in the incorrect geomorphological zone, or some other confounding factor.

Such conditions did not allow each disturbed study site to have its own reference site in the same longitudinal zone. Thus, the planned design was modified to provide a number of undisturbed sites that would jointly provide a description of a reference condition against which each invaded or cleared site could be compared.

The 35 study sites selected (Table 3.2) consisted of 19 undisturbed sites, six invaded ones and ten cleared ones, in three longitudinal zones (Rowntree 2001: Table 3.3). Data collection was done over a six month period in each of two successive summers (Table 3.4).

Table 3.2 Location of study sites. Site codes as listed, with 1 being the most upstream site on that river. Altitudes are in metres above sea level. Asterisked (*) sites support Afromontane Forest.

Catchment	Mountain Range	River	Code	Gradient	Altitude	Aspect	Coordinates
Olifants	Cedarberg	Rondegat	Ron1	0.085	624	SW	S32°23.764', E019°05.384'
			Ron2	0.085	624	SW	S32°23.762', E019°05.368'
			Ron3	0.029	501	ENE	S32°22.599', E019°04.015'
			Ron4	0.029	497	ENE	S32°22.569', E019°04.002'
			Ron5	0.025	335	SW	S32°20.480', E019°01.270'
			Ron6	0.025	333	W	S32°20.103', E019°01.211'
		Heks	Hek1	0.023	245	ENE	S32°26.123', E019°00.530'
			Hek2	0.023	244	ENE	S32°26.116', E019°00.518'
			Hek3	0.018	167	NW	S32°26.187', E018°58.883'
			Hek4	0.018	175	N	S32°26.209', E018°58.872'
Breede	Hawequas	Witte	Wit1	0.027	285	NW	S33°34.311', E019°08.317'
			Wit2	0.027	281	NW	S33°34.293', E019°08.323'
			Wit3	0.005	258	NNW	S33°33.355', E019°09.125'
			Wit4	0.005	253	S	S33°33.344', E019°09.138'
		Elands	Ela1	0.054	519	E	S33°45.654', E019°07.705'
			Ela2	0.054	505	ENE	S33°45.636', E019°07.694'
			Ela3	0.017	450	NW	S33°44.410', E019°06.791'
			Ela4	0.017	446	NW	S33°44.361', E019°06.786'
		Molenaars	Mol1	0.012	406	N	S33°43.437', E019°08.863'
			Mol2	0.012	375	S	S33°43.387', E019°10.762'
			Mol3	0.006	282	NW	S33°42.580', E019°11.848'
			Mol4	0.006	258	NNE	S33°41.773', E019°12.893'
		Assegaaibos	Ass1	0.024	275	NNW	S33°58.036', E019°04.862'
			Ass2/3	0.024	295	ENE	S33°58.058', E019°04.777'
Berg	Hottentots Holland	Eerste	Eer1	0.040	360	S	S33°59.625', E018°58.531'
			Eer2	0.040	314	NNE	S33°59.224', E018°57.389'
		Sir Lowry's	SLP1	0.087	315	N	S34°05.629', E018°56.801'
			SLP2	0.067	293	NNE	S34°05.686', E018°56.694'
			SLP3	0.042	189	N	S34°06.182', E018°55.908'
			*Cec1	0.167	250	N	S33°59.829', E018°25.315'
	Table Mountain	Disa	*Dis1	0.053	123	ESE	S34°00.246', E018°23.438'
			*Dis2	0.053	105	NW	S34°00.320', E018°23.420'
		Silvermine	Sil1	0.050	305	WNW	S34°05.310', E018°25.140'
			Sil2	0.035	114	N	S34°06.256', E018°25.253'

3.3 DATA COLLECTION

Four sets of data were collected at each site, in order to describe the composition of the plant assemblages, the distribution of species and the supporting physical environment:

- vegetation data;
- cross-section measurements of the shape of the channel and banks;
- soil data;

- other supporting data.

Data collection centred on sample grids adapted from the Modified-Whittaker nested vegetation sampling method (Stohlgren et al., 1995, which were established on one bank of each site. The sample grid was 20 m long, along the wetted edge of the river, and several metres wide as dictated by the width of the zone of riparian vegetation (Figure 3.1). In some cases, where the riparian species extended into mini-floodplains or seeps, the width of the plot was restricted to no more than 16 metres. The entire grid was divided into a series of 1 x 5 m sample plots labelled by number (1 to 'n'), to indicate the distance from the water in metres, and by the letter A to D, to indicate its location along the 20 m belt with A at the upstream end (Figure 3.1).

Table 3.3 Longitudinal zonation and status of the 35 study sites. Longitudinal zones were assigned according to guidelines described by Rowntree (2001). Site codes are listed with 1 being the most upstream site on that river. Criteria (Crit.) met as per Table 3.1. Longitudinal zone: MS = mountain stream zone, MST = mountain stream transitional zone and FH = upper foothill zone. U = undisturbed, I = invaded and C = cleared.

River zone									
MS			MST			FH			
River & site	Code	Crit.	River & site	Code	Crit.	River & site	Code	Crit.	
U Elands 1	Ela1	7	Witte 1	Wit1	8	Elands 3	Ela3	7	
Elands 2	Ela2	7	Witte 2	Wit2	8	Elands 4	Ela4	7	
Disa 1	Dis1	8	Heks 1	Hek1	7	Molenaars 2	Mol2	7	
Disa 2	Dis2	8	Heks 2	Hek2	7	Heks 3	Hek3	7	
Eerste 1	Eer1	8	Rondegat 3	Ron3	7	Heks 4	Hek4	7	
Eerste 2	Eer2	8	Rondegat 4	Ron4	7				
Rondegat 1	Ron1	7							
Rondegat 2	Ron2	7							
I Cecelia 1	Cec1	13	Rondegat 6	Ron6	2	Molenaars 4	Mol4	1,4	
			Assegai. 2	Ass2	9	Witte 3	Wit3	4	
			Sir Lowry's 3	SLP3	9				
C Sir Lowry's 1	SLP1	13	Assegai. 1	Ass1	13	Molenaars 1	Mol1	1,4	
Sir Lowry's 2	SLP2	13	Assegai. 3	Ass3	13	Molenaars 3	Mol3	1,4	
Silvermine 1	Sil1	12	Silvermine 2	Sil2	12	Witte 4	Wit4	4	
			Rondegat 5	Ron5	2				

3.3.1 Vegetation data

The following sets of vegetation data were collected for each site.

Cover: Cover, estimated visually as a percentage of each plant species in each sample plot. Stratification or multiple layering of vegetation in a sample plot resulted in total cover values of over 100 percent in some cases.

Position: The rooted position and number of tree species in five height classes (<0.3 m (seedlings), 0.3-2.0 m (juveniles), 2.0-5.0 m, 5.0-10.0 m and >10.0 m), as well as the number of each shrub species.

Table 3.4 The schedule of field work for data collection.

River	Site code	Vegetation data (# days)	Cross-sections and soils
Disa	Dis1	12 Feb to 24 Feb 2004 (9)	08 Mar 2006
	Dis2	04 Feb to 10 Feb 2004 (7)	08 Mar 2006
Cecelia	Cec1	26 Feb to 01 Mar 2004 (4)	08 Mar 2006
Assegaaibos	Ass1	16 Mar to 21 Apr 2004 (6)	13 Feb 2006
	Ass2	23 Mar to 01 Apr 2004 (4)	13 Feb 2006
	Ass3	02 May to 05 May 2005 (4)	13 Feb 2006
Molenaars	Mol1	21 Apr to 25 Apr 2004 (5)	14 Feb 2006
	Mol2	27 Apr to 01 May 2004 (5)	14 Feb 2006
	Mol3	15 Apr to 19 Apr 2004 (5)	17 Feb 2006
	Mol4	04 Apr to 09 Apr 2004 (6)	17 Feb 2006
Eerste	Eer1	24 May to 27 May 2004 (4)	06 Mar 2006
	Eer2	17 May to 20 May 2004 (4)	06 Mar 2006
Witte	Wit1	26 Jan to 30 Jan 2005 (5)	04 Mar 2006
	Wit2	01 Feb to 05 Feb 2005 (5)	04 Mar 2006
	Wit3	06 Feb to 10 Feb 2005 (5)	05 Mar 2006
	Wit4	11 Feb to 15 Feb 2005 (5)	05 Mar 2006
Elands	Ela1	26 Apr to 28 Apr 2005 (3)	16 Feb 2006
	Ela2	29 Apr to 01 May 2005 (3)	16 Feb 2006
	Ela3	23 Feb to 25 Feb 2005 (3)	15 Feb 2006
	Ela4	01 Mar to 05 Mar 2005 (5)	15 Feb 2006
Rondegat	Ron1	16 Apr to 18 Apr 2005 (3)	26 Feb 2006
	Ron2	19 Apr to 21 Apr 2005 (3)	26 Feb 2006
	Ron3	07 Mar to 09 Mar 2005 (3)	28 Feb 2006
	Ron4	10 Mar to 12 Mar 2005 (3)	28 Feb 2006
	Ron5	15 Mar to 17 Mar 2005 (3)	26 Feb 2006
	Ron6	18 Mar to 20 Mar 2005 (3)	28 Feb 2006
Heks	Hek1	03 Apr to 05 Apr 2005 (3)	02 Mar 2006
	Hek2	06 Apr to 08 Apr 2005 (3)	02 Mar 2006
	Hek3	09 Apr to 11 Apr 2005 (3)	01 Mar 2006
	Hek4	12 Apr to 14 Apr 2005 (3)	01 Mar 2006
Silvermine	Sil1	12 May to 14 May 2005 (3)	09 Mar 2006
	Sil2	09 May to 11 May 2005 (3)	09 Mar 2006
Sir Lowry's Pass	SLP1	18 May to 20 May 2005 (3)	06 Mar 2006
	SLP2	21 May to 23 May 2005 (3)	06 Mar 2006
	SLP3	24 May to 25 Jun 2005 (2)	06 Mar 2006

Identification: Three specimens of each of the 528 species collected were pressed, dried and catalogued into three separate herbaria: one for field reference; one for the Freshwater Research Unit; and one for specialists to use in identification. Three hundred and eighty five specimens were identified to species, 62 to genus, 46 to family and 35 could not be identified. All identifications were done by plant taxonomists from the Compton Herbarium at Kirstenbosch National Botanical Gardens in Cape Town.

Photographic record: In excess of 1000 photographs of the plant specimens were taken and are filed as digital photographic records accompanying the specimen herbaria.

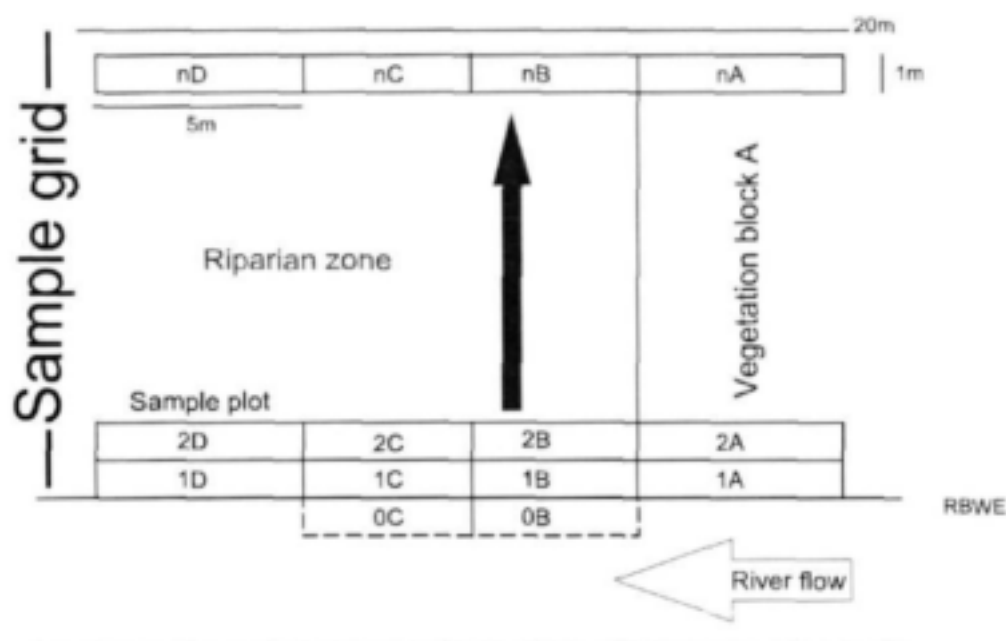


Figure 3.1 Sample grid showing the matrix and numbering of sample plots. RBWE = right bank water's edge. A few sample plots were located in the channel (shown by the dotted lines) to record the position of non-aquatic species rooted on islands or cobble bars, or when the edge of channel was not straight. The first entire sample row of sample plots was always numbered 1.

3.3.2 Cross-section data

Four cross-sections were surveyed at each site using an electronic theodolite (Leica TC307 model) and a standard Leica prism on a staff. One cross-section was surveyed through each of the four vegetation blocks, A through D, the cross-sections thus being 5 m apart. The data were stored in EXCEL and are presented in Appendix 3.1.

3.3.3 Soil data

Eight soil samples were collected from the banks of each site. Four were taken within a distance of 2 m from the water's edge, where the wet bank assemblage types were estimated to be. A further four

samples were taken higher up the bank, usually between 4-8 m from the water's edge, at a point close to the middle of where the dry-bank assemblage types were estimated to occur. In total, 136 samples were collected for analysis. Each sample consisted of approximately 200 grams of soil removed with a hand held trowel to a depth of no greater than 0.2 m from beneath the surface debris and leaf litter. Samples were spread out in thin layers in brown paper bags to air dry. Once dry, the samples were passed through a 2 mm sieve (Boone et al., 1999) and sent to Bemlab (Pty) LTD for the following analyses:

- pH (KCl)
- Resistance (Ohm)
- H^+ (cmol/kg)
- Stone (%vol)
- P Bray II (mg/kg)
- K (mg/kg)
- Exchangeable cations (cmol(+)/kg); Na, K, Ca and Mg
- % C
- Base saturation (% Na, K, Ca and Mg; T-Value c mol/kg)
- Particle size (% clay, sand and silt; classification).

The data were stored in WORD files and will form part of more detailed analyses in Karl Reinecke's thesis.

3.3.4 Other supporting data

Substrata: The percent frequency of each substratum type was calculated according to the Wentworth scale (Rowntree and Wadeson 1999). The raw data consisted of the length of the shortest axis of the maximum projection plane (B; Gordon et al., 1992) of 100 stones from the riverbed at each site.

Longitudinal profiles: These were derived from 1:50 000 topographic maps.

Gradients: The gradient of each study site was calculated, both through measurement at the site and, for a more general slope for the river reach, from a 1:50 000 topographic map.

Photographs: Twenty fixed-point photographs of the channel and bordering riparian areas were taken at each site.

3.4 STATISTICAL ANALYSIS

3.4.1 Whole-site comparisons

A single species list was collated for each study site based on the total percent cover of each species per site. This list was transformed to presence/absence data and the Bray-Curtis similarity coefficients

between all the sample grids computed. Transforming the data in this way has the effect of down-weighting the importance of highly abundant species so the similarities between sites depend not only on their presence but on those of common species as well (Clarke & Warwick 2001). These similarities were investigated using CLUSTER analysis and Multi-dimensional scaling (MDS) ordination (Clarke & Gorley 2006), with agreement between their outputs re-enforcing the robustness of each. Groups of sample plots selected within the analyses were further investigated for their validity as discrete vegetation entities, as described below.

Comparison of growth forms of the groups

The total cover recorded for each species at each site was summed and reduced to a percentage of the total cover per growth form per site (Table 3.5). Species were classified into one of the ten growth forms based on their potential height according to Goldblatt & Manning (2000). These percentage covers were averaged across all the sites present in each of the selected groups to give the mean percent cover for each of the ten growth form categories per group. A Kruskal-Wallis ANOVA by ranks for multiple independent samples was performed on each of the growth groups. This test searches for differences between the mean values of each growth form in each group.

Table 3.5 Growth forms assigned to species, with heights referring to the adult of the species. Growth form nomenclature follows Goldblatt & Manning (2000).

Growth form	Definition
1 forb	A broad leaved herbaceous plant other than graminoids (grasses, sedges and rushes) and restios.
2 geophyte	A perennial plant that propagates by underground bulbs or tubers or corms.
3 rush	Plants in the family Juncaceae.
4 sedge	Plants in the family Cyperaceae.
5 grass	Plants in the family Poaceae.
6 restio	Plants in the family Restionaceae.
7 small shrub	A low woody perennial plant often with multiple stems (<1m).
8 shrub	A medium sized woody perennial plant often with multiple stems (1-2m).
9 small tree	A large woody perennial plant usually with multiple stems or with main trunk (2-10m).
10 tree	A tall woody plant with main trunk, branches and a distinct elevated crown (>10m).

Comparison of family composition of the groups

The total cover recorded for each species at each site was summed and reduced to a percentage of the total cover per family per site. These percentage covers were averaged across all the sites present in each of the selected groups to provide the mean percent cover per family per group. The families within each group were ranked by cover dominance with the frequency of occurrence also shown.

3.4.2 Within-site analyses

The species level cover data for all sample plots (each 5x1m block) at each study site were 4th root transformed in order to boost the presence of smaller species at lower covers, and a similarity analysis

of sample plots was completed using MDS ordination and CLUSTER analyses. Groups of sample plots with greater than 40% similarity were tentatively recognised, along with a few clusters of sample plots with a lower similarity but obvious cohesion as a group. These groups were investigated in terms of possible driving environmental variables, using BIOENV (Clarke & Gorley 2006), which assessed nine variables in terms of their ability to distinguish between groups:

- distance from water's edge (metres);
- elevation from water's edge (metres);
- the percentages (by cover) of:
 - water;
 - bedrock;
 - boulder;
 - cobble;
 - gravel;
 - sand;
 - debris.

The analysis identifies the best fitting combination of physical variables that matches with the outputs from the biological analyses (MDS and CLUSTER) and is thus considered to explain the community pattern (Clarke & Warwick 2001). Across the nineteen undisturbed sites the most consistently selected variables were distance (16 of 19), followed by elevation (9 of 19) and then percent water (8 of 19). Based on this, the groups tentatively recognised in the similarity analysis were found to be coherent in terms of elevation and distance from the water's edge, and were accepted as vegetation assemblages.

Assemblages were numbered from 1, closest to the water's edge, and in ascending order towards the top of the bank. Those with greater than 50 or 60% similarity and no discernable difference in species composition were combined. Species cover data for each assemblage were ranked by frequency of occurrence, with 100% indicating a species presence in all sample plots of the assemblage, with average cover per 5 m² sample plot also shown.

Assigning assemblages to an assemblage type

Each site produced several assemblages numbered from 1 upwards. These were assigned to assemblage types in order to produce a standard set of vegetation types across the sites. The process of deciding on the assemblage types was:

- an initial recognition of two outer boundaries: the aquatic zone (in the water) and the non-riparian zone (at the top of the bank and beyond);
- recognition of transition areas within these two boundaries with two generally distinct vegetation types: a wet bank (closer to the water) and dry bank (higher up the bank);
- ignoring the aquatic vegetation, which was not addressed in this project, five vegetation assemblages were recognised:
 - at the water's edge and moving up the bank, assemblage type one was the Wet Edge (WE);

- assemblage type two was the Channel Fringe (CF), at the outer limit of the wet bank;
- assemblage type three was the Tree Shrub (TS), on the lower dry bank;
- assemblage type four was the Outer Transitional (OT), representing the highest extremity of riparian vegetation;
- assemblage five was essentially outside the influence of the river and was assigned Non Riparian (NR).

Each species had to be assigned to one of these assemblage types in order to recognise which assemblage type any one assemblage (group of sample plots) in the similarity analyses belonged to. This was done by synthesising information on their habitat preferences (Goldblatt & Manning 2000), as summarised in Appendix 3.2. Species that occur on or near streamsides, seeps, rivers and watercourses were considered to be riparian (wet) species. Those described as occurring on rocky slopes and outcrops or mountain slopes were considered to be non-riparian (dry) species. Finally any species described as occurring in bush, woodland or forests were considered to be forest species. Using these assignments the following logic was applied in order to assign a particular assemblage to one of the five assemblage types:

- starting at the outer extremity of the riparian zone, any assemblages that contained no riparian (or wet) species were assigned to NR;
- those assemblages containing a mixture of riparian and non-riparian species, were assigned to OT;
- since Western Cape riparian zones may contain both a mixture of forest and scrub species (Cowling & Holmes 1992), TS was assigned to assemblages that contained both these kinds of species and no fynbos or other terrestrial-habitat species;
- certain species are considered to be obligatory riparian (or wet) and tend to occur at or immediately adjacent to the water's edge; examples include *Salix mucronata*, *Isolepis prolifer* and *Isolepis digitata*. Assemblages that contained a mixture of these typically wet species as well as recognised TS species were assigned to CF;
- finally, assemblages that had a high occurrence of 'typically wet' species and that occurred immediately adjacent to the water's edge were assigned to WE.

3.4.3 A predictive model for reference condition

From the above analyses, a reference condition was defined and tested (Chapter 4), and then used to assess the impacts of alien invasive trees at disturbed sites (Chapter 5). Reference states (i.e. restoration targets) are one of several pieces of information required for restoration initiatives. Other necessary data include quantitative data on the current composition and structure of the riparian corridor, environmental conditions affecting or likely to affect community composition and structure including diversions from natural conditions and spatial associations between environmental conditions and streamflow (Harris 1999). Definitions of reference states typically consist of descriptions of community composition and structure for each environmental condition and each community to be restored. Using multivariate CLUSTER analysis for estimating reference conditions is not new for classifying plant communities, but its application in restoration has rarely been exploited.

In order to assess this impact, the defined reference condition should ideally allow prediction of *where* each vegetation assemblage type should occur at a disturbed site, and *what* its biological attributes should be. To aid this process, a classification tree was employed (Breiman et al., 1984).

This uses measurements of one or more predictor variables (in this case, measured physical variables) to assign cases (i.e. individual sample plots) to one of a fixed number of classes (i.e. assemblage types). The tree is produced by the Classification and Regression Tree module (CART) of STATISTICA (v 7.0) (Statsoft 1995) and is arranged as a series of nodes and splits. Each split is based on a rule using measurements of one of the physical (predictor) variables and leads to two nodes. Each of the nodes is assigned membership to one of the classes of the dependant variable (i.e. an assemblage type).

In this project, CART determined all the possible splits in the tree from the learning sample (i.e. the raw data from the undisturbed sites on the Rondegat, Heks and Elands Rivers) to produce a set of physical rules of where each assemblage type should occur. These were tested using data from additional undisturbed sites (Chapter 4) before being applied to the disturbed sites (Chapter 5).

A number of potential predictor variables were investigated in the construction of the classification tree. These were, for each sample plot or group of plots:

1. distance from summer low-flow water's edge;
2. elevation from summer low-flow water's edge;
3. gradient 1, over the first three sample plots (from water's edge upwards);
4. gradient 2, covering sample plots four to six (4-6 m distance from water's edge up the bank);
5. the difference between gradients 1 and 2 (a negative value indicated a concave bank and positive value a convex bank);
6. whether the river bank overall was convex or concave;
7. gradient 3, over the last three sample plots (the steeper this gradient the narrower the valley);
8. longitudinal river zone;
9. ratio of wetted channel length:the riparian zone length (floodplains were expected to differ to narrowly restricted riparia);
10. wetted channel width:wetted channel depth ratio (riffles with a greater width to depth ratio were expected to differ to pools, where the width to depth ratio is lower);
11. percentage of sand per sample plot;
12. percentage of water per sample plot.

The classification tree for the physical reference condition is reported on in Section 4.4.3.

3.4.4 Applying the CART model to the disturbed sites

The CART model was used to determine the position of the four assemblage types at each of the disturbed sites in turn. Species frequency and abundance data were summarised for all assemblage

types present at these disturbed sites (as done for the reference sites) to produce lists of species ranked first by frequency and then abundance (% cover). These disturbance data were summarised and reduced in exactly the same way as was the reference data so that direct comparisons could be made between the two data sets. Comparisons between the observed and expected conditions are presented in Section 5.4.1.

4. REFERENCE CONDITIONS

4.1 INTRODUCTION

Reference conditions may be defined as any historical, predicted, or existing condition or site against which a restored area may be compared (Thayer et al., 2005). In this project the term refers to a condition where there appears to be undisturbed indigenous vegetation with no or a minimal presence of alien invasive plants. This is assumed to be the undisturbed and natural or near-natural condition. In this chapter, reference conditions for the plant communities of riparian zones of Western Cape headwater streams are defined by the vegetation characteristics of 12 undisturbed sites and this definition is then tested on another six undisturbed sites. The final form of the reference condition is thereafter used to evaluate the impact of selected invasive woody plant species on indigenous riparian communities and to gauge recovery towards the reference condition post clearing of these invasive species (Chapter 5).

Reference conditions are addressed in two ways in this chapter:

- at the catchment scale (km^2), through the overall species composition of study sites in riparian zones of many rivers (Section 4.2);
- at the site scale (m^2), through the distribution of species in sub-zones from water's edge to the highest flood level (Section 4.3).

4.2 CATCHMENT SCALE PATTERNS

For analytical details please refer to Section 3.4.

4.2.1 Catchment groupings

The study sites were located in rivers that originated in five adjacent mountain ranges and included both undisturbed and disturbed riparian areas in either the mountain stream, mountain-stream transitional, or upper foothill zone (Tables 3.2 and 3.3).

The focus of this chapter is the undisturbed sites, but an initial assessment was made of whether or not those identified as such *a priori* were distinguishable from those classified as disturbed. A presence/absence list of riparian vegetation species was collated for each study site, and the Bray-Curtis similarity coefficients between all sites computed. The results were displayed as a cluster analysis (Figure 4.1) and a multi-dimensional scaling (MDS) ordination (Figure 4.2) (Clarke & Gorley 2001).

There are three main groups (Figure 4.1):

1. undisturbed and disturbed sites from the Cedarberg and Hawequas mountain ranges, together with two undisturbed sites from the Hottentots Holland range (Group 1);
2. disturbed sites from the Table Mountain and Hottentots Holland ranges (Group 2);

3. two near-pristine and one disturbed site from the Table Mountain range (Group 3).
4. One outlier, SLP3 in the Hottentots Holland range, is the only site heavily invaded with *Eucalyptus leucoxylon*.

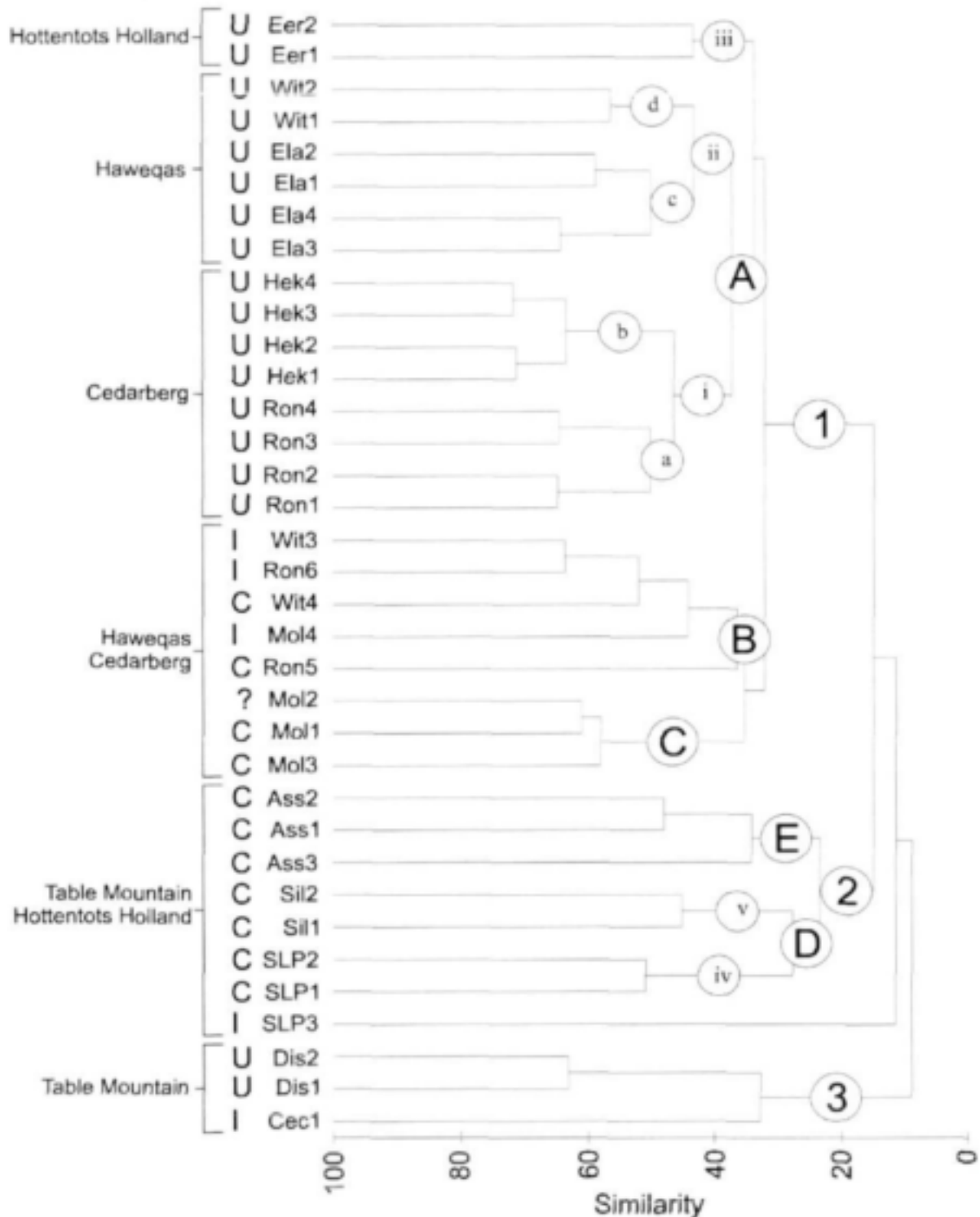
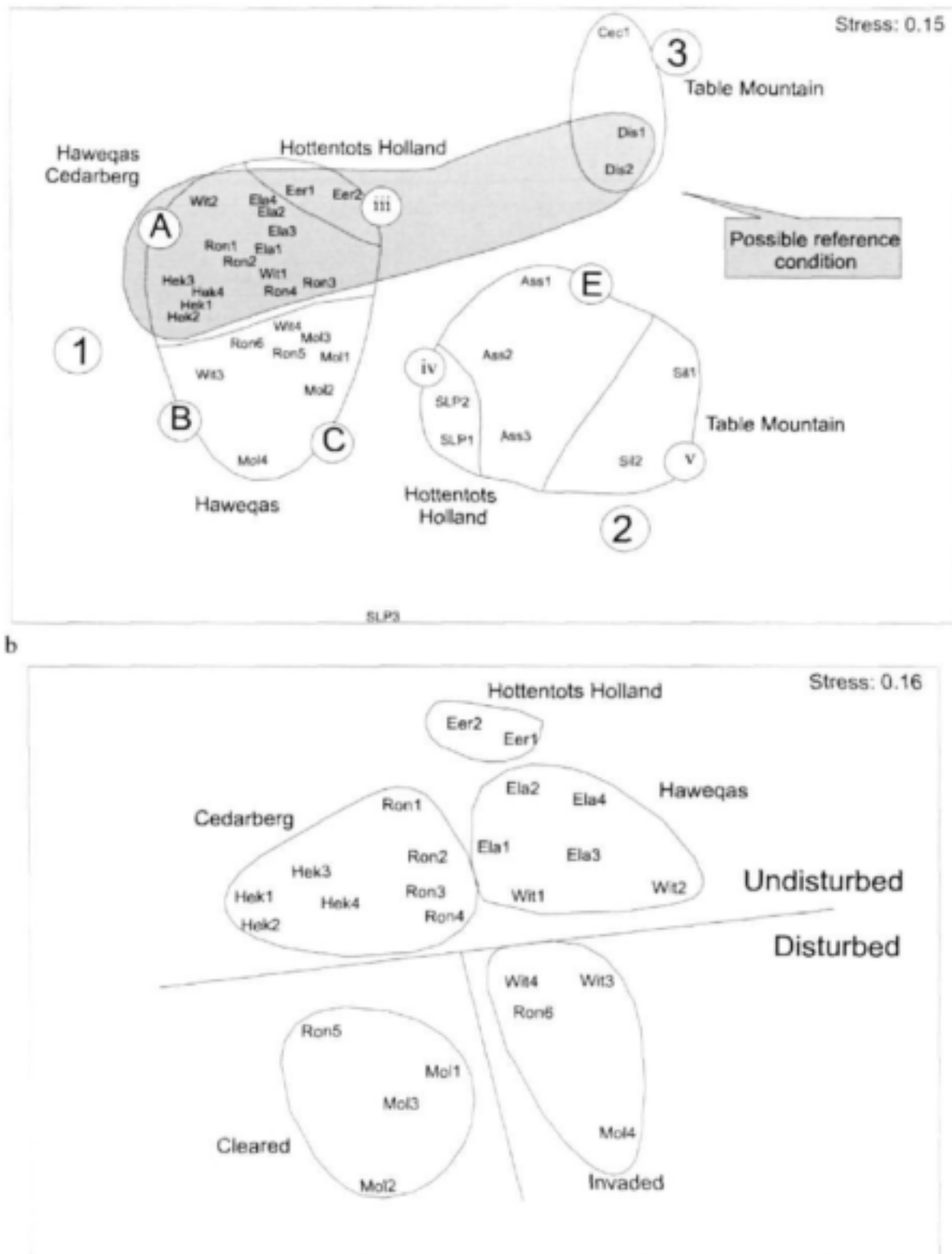


Figure 4.1 Cluster analysis of Bray-Curtis similarities between all 35 study sites. Multiple sites on rivers are numbered 1 to 6. Site codes as per Table 3.1. U = undisturbed, I = invaded and C = cleared.



Group 1 contains undisturbed sites (A) and disturbed sites (B & C) from the Cedarberg and Hawequas mountain ranges and two Eerste River sites (Eer1 and Eer2) from the Hottentots Holland range. Within group (1A), the undisturbed sites separate further into catchment groups (i) to (iii). The four sites each on the Heks and Rondegat Rivers (i), both part of the Cedarberg group, separate from the sites on the Witte and Elands Rivers in the Hawequas group (ii) and from the two Eerste River sites in the Hottentots Holland range (iii). Within the undisturbed catchment groups containing more than one river (i) and (ii) a further separation of sites occurs by river (a = Rondegat; b = Heks; c = Elands; d = Witte). A final separation to zone occurs within each of the river groups (a) to (d). For example, within Group (i) the four sites on the Rondegat River (group a) split into two mountain stream sites (Ron1 and Ron2) and two mountain stream (transitional) sites, Ron3 and Ron4.

The same pattern is evident in other parts of Group 1. For example, group (b) on the Heks River splits into two mountain stream (transitional) sites and two upper foothill sites; whilst group (c) on the Elands splits into two mountain stream sites and two upper foothill sites. The two sites each on the Witte and the Eerste Rivers, groups (d) and (iii) respectively, also group together but separate by river.

These patterns suggest that there are characteristic riparian plant communities that distinguish the larger river systems and, within their catchments, further distinguish both individual rivers and zones along those rivers. Catchments that are geographically closer tend to be more similar in riparian community composition, and the Table Mountain range has the least similar sites. The invaded or cleared sites appear in this pattern in ways described below.

Groups B and C contain sites judged as disturbed (either invaded or cleared) with one exception. Mol2 on the Molenaars River, was designated undisturbed by Boucher (1988) and so selected here as a reference site for the three disturbed sites on the same river. In this analysis Mol2 groups closely with the two cleared sites (Mol1 and Mol3) and thus has been excluded from the analyses of undisturbed sites that follow and, due to this uncertainty, will be designated a disturbed site. It seems probable that all three sites are close to the reference condition but have not quite achieved it.

Group B consists of five sites in the Hawequas and Cedarberg ranges: three are heavily invaded with *Acacia mearnsii*, and two were cleared approximately eight years ago (Table 4.1). One of the cleared ones (Wit4) has had no follow-up treatment since then, and the other (Ron5) is 200 meters upstream of the heavily-invaded section at Ron6.

Group C consists of two sites from the Hawequas range that were cleared seven to ten years ago (Mol3 and Mol1 respectively) plus the possibly undisturbed Mol2 mentioned above.

The separation of Group B from Group C sites suggests that time since clearance is one of the factors to be considered when distinguishing vegetation communities. Another important factor is intensity of invasion at the landscape scale (alien density and/or length of invasion), which is not known for most sites. The Group B sites were either heavily invaded or were cleared less than eight years ago, whilst the Group C sites were cleared more than seven years ago or were possibly undisturbed. Nevertheless,

even the most heavily invaded sites still clustered within their parent Cedarberg-Hawequas group, indicating that their catchment identities had not been completely lost.

Table 4.1 Invasion status of disturbed sites. Site codes as per Table 3.2. Invasion status (as percentage projected alien canopy cover in this study) H = >75%, M = 25 – 50%, L = <25%. Cleared = time of first clearing operation. Clearing method: F = Fell, H = herbicide applied to cut stumps, S = hacked material stacked, B = stacked material burnt, Rs = recruiting seedlings foliar sprayed with herbicide, R = felled material removed, P = recruiting seedlings hand pulled. Burnt = wild fire. Age = vegetation age in years at time of sampling.

Site	Invasion	Cleared	Method	Burnt	Age	Alien species
Wit3	H	-			-	<i>Acacia mearnsii</i> , <i>A. melanoxylon</i>
Ron6	H	-			-	<i>Acacia mearnsii</i> , <i>A. longifolia</i> , <i>Eucalyptus</i> sp.
Wit4	H	1997	F,H	2001	4-8	<i>Acacia mearnsii</i> , <i>A. melanoxylon</i>
Mol4	H	-			-	<i>Acacia mearnsii</i>
Ron5	H	1998	F,H,S,B		7	<i>Acacia mearnsii</i> , <i>A. longifolia</i> , <i>Eucalyptus</i> sp.
Mol2	?	?	?		?	
Mol1	H	1994	F,H,S,B,Rs		10	<i>Acacia mearnsii</i>
Mol3	H	1997	F,H,S,B,Rs		7	<i>Acacia mearnsii</i>
Ass2	M	2000	F,R		4	<i>Pinus pinaster</i>
Ass1	M	2002	F,R		2	<i>Pinus pinaster</i>
Ass3	M	2004	F,B,P		1	<i>Acacia longifolia</i> , <i>A. mearnsii</i>
Sil2	H	2000	F,H,S,B,P	2000	5	<i>Acacia saligna</i> , <i>A. longifolia</i>
Sil1	H	2000	F,R,Rh	2000	5	<i>Pinus pinaster</i>
SLP2	H	2002	F,H,S,B,P		3	<i>Acacia mearnsii</i> , <i>A. longifolia</i> , <i>A. saligna</i> , <i>Pinus pinaster</i>
SLP1	H	1992	F,H,S,B,P		13	<i>Acacia mearnsii</i> , <i>A. longifolia</i> , <i>A. saligna</i> , <i>Pinus pinaster</i>
SLP3	H	-			-	<i>Eucalyptus leucoxylon</i> , <i>Acacia mearnsii</i>
Dis2	L	?			65	<i>Acacia melanoxylon</i> , <i>Quercus robur</i>
Dis1	L	?			65	<i>Acacia melanoxylon</i> , <i>Quercus robur</i>
Cec1	H	2004	F,R		?	<i>Populus X canescens</i>

Group 2 in Figure 4.1 consists of two sites from the Table Mountain range and five sites from the Hottentots Holland range. All have been cleared of aliens and are in various stages of recovery (Ass2 is the same plot as Ass3; the data for Ass2 is the before-clearance data). Again, the sites cluster by river, but there are too few sites to distinguish any possible groupings by zone. It seems probable that time since clearance is playing a role in the grouping: the Group (2D) sites on Table Mountain (Sil 1 and Sil2) and one set of Hottentots Holland sites (SLP1 and SLP2) were cleared five to thirteen years ago, whilst the Group 2E sites, also in the Hottentots Holland range (Ass1-3) were cleared one to four years ago. The age of SL1 indicates that age is not the only factor playing a role here as it is much older than the others in groups (D) and (E). Thus, the major distinction in Group 2 seems to be by catchment, but with a secondary influence reflecting the degree of recovery toward a native community of species.

Group 3 contains three sites, all on the Table Mountain complex. The two sites on the Disa River were relatively undisturbed although there were isolated *Acacia melanoxylon* and *Quercus robur* trees nearby, whilst the Cecelia site was heavily invaded with *Populus X canescens*. Some thinning out of sapling and juvenile *Populus X canescens* took place in 2004 but this did not obviously affect the alien

canopy structure. Again, rivers were distinguished by the site groupings with the two Disa sites grouping separately from the Cecelia site, although this may have been due to the latter being heavily disturbed rather than through natural differences in community structure. These three sites did not cluster with the two Table Mountain sites in Group (D), possibly because the latter (Sil1 and Sil2) were in a much more open landscape some distance from the river's source as opposed to the Disa and Cecelia ones, which were closer to their sources and in fire-protected areas. Instead the two Group (D) Table Mountain sites on the Silvermine River grouped with the Sir Lowry's Pass and Assegaaibos Rivers at the East side of the Cape Flats to form Group (2). The disturbed sites making up this group showed strong similarities in their vegetation, mostly through a paucity of the species typical of Group (1).

The overall picture is one of riparian communities being distinguished by catchment, river and zone, as a result of differences in the species present. The only sites that have not grouped within their larger geographical area are the two Eerste sites, which are Hottentots Holland sites grouped with the Hawequas/Cedarberg sites in Group (1). These two sites are least like the rest of Group (1), and may be grouped there because of their undisturbed condition: the other sites in Group (2), which contains the remaining Hottentots Holland sites, are all classified as disturbed. There is an overlay on this basic pattern that reflects various levels of disturbance due to alien invasion and recovery post clearing, but none of these levels have completely obliterated the natural catchment identities.

The MDS ordination reveals the same pattern (Figure 4.2a). The same three major groups and one outlier can be distinguished. Agreement between these two types of analysis re-enforces the robustness of each, and the stress of 0.15 in the 2-d representation of the proximity (i.e. similarity) of the sites indicates a potentially useful to good ordination with very little chance of a misleading interpretation (Clarke & Warwick 2001). A closer inspection of Group 1 reveals an arrangement that possibly reflects several driving forces (Figure 4.2b). An east-west axis across the middle of the figure separates the undisturbed sites at the top from disturbed ones at the bottom. In the top half of the figure, the Cedarberg sites cluster to the left, the Hawequas sites to the right, and the two Hottentots Holland sites to the top; there is thus a geographic distinction. In the lower half of the figure the three cleared sites and Mol2 – the anomalous site – are to the left and the heavily infested sites, together with Wit4 where no follow-up clearing has taken place, are to the right.

The arrangement of disturbed and undisturbed sites in Group 3 is the opposite to that in Group 1 (Figure 4.2a), with the undisturbed sites to the bottom end of that ellipse instead of at the top as in Group 1. It could be speculated that the top half of the Group 1 ellipse and the bottom half of the Group 3 ellipse represent part of a 'space' that defines the reference condition. The other halves of the two ellipses, plus the total Group 2 ellipse (E, iv and v), sit outside that reference condition to varying degrees. There is no clear trend in the MDS plot of sites moving back toward the central reference condition with time after clearance, although there is a slight suggestion that the most heavily invaded sites sit toward the outside of the whole plot.

The same approach was used to investigate the relationship between the undisturbed sites only. The CLUSTER analysis and the MDS ordination (figures not shown) reveal the same pattern of four main river groups, delineated by the mountain ranges they drain. Within these main groups, individual rivers and zones separate out clearly.

In summary, the trend in terms of species composition of riparian plant communities along Western Cape headwaters seems to be as follows:

- undisturbed sites from the same catchment are more similar to each other than to sites from other catchments;
- within any one catchment, multiple undisturbed sites on a river will be more closely related to one another than to sites from another river in the same catchment group;
- within any one river, sites within a longitudinal zone will be more similar to each other than to sites in an adjacent zone on the same river;
- these similarities in presence or absence of species decrease to varying extents in sites with alien invaders, but in none of the sites studied had the catchment identity completely disappeared;
- cleared sites may be showing an intermediate position in terms of similarity, with a possible positive trend between the time since clearing and the level of recovery to reference condition;
- sites that were cleared as long as twelve years ago were still not fully recovered to what is considered to be the reference condition.

An analysis of similarity of the undisturbed sites (ANOSIM, Clarke & Gorley 2001) using the same presence-absence vegetation data as above revealed that the four main groupings were significantly different (data not shown here), but provided no new insights on the relationships between rivers and zones. This was probably mainly due to the paucity of replicates, which in turn was caused by a lack of suitable sites. Thus, an analysis of similarity patterns remains the most suitable approach to begin an understanding of the subtle relationships between sites in a study such as this.

The next step was to probe further into the vegetation data to explain what might be causing the groupings described above. Growth forms and family and species-level data are analysed in the following sections.

4.2.2 Comparison of growth forms in undisturbed sites

The total cover recorded for each species from each site was summed and reduced to growth form cover as a percentage of the total cover per site. This was averaged across all the sites present in each of the four catchment groups to give a mean for each of the ten categories of growth form (Table 3.5) in each catchment group (Table 4.2). All species from all sites are listed in three appendices. Appendix 3.2 shows the growth form assigned to each (nomenclature follows Goldblatt & Manning 2000). Species are arranged in the phylogenetic classification described by Leistner et al. (2000) in Appendix 4.1. Finally in Appendix 4.2 the occurrence of each species at each study site is shown.

Forbs (growth form 1), grasses (growth form 5), shrubs (growth forms 7 and 8) and trees (growth forms 9 and 10) were generally well represented. The Table Mountain group had less restio cover (growth form 6) and more large trees (growth form 10) than the other three groups, as well as having the highest recorded covers of sedges (growth form 4) and grasses. The Hottentots Holland, Cedarberg and Hawequas groups all had higher covers of small trees (growth form 9) than did the Table Mountain group.

Table 4.2 The mean (and standard deviation) percentage cover of each growth form in each of the four catchment groups (undisturbed sites only). Growth form categories as per Table 3.5. (n) = the number of sites in each group and (N) = the # of sites where this growth form was present in each group. From the Kruskal-Wallis ANOVA, * against two groups denotes a significant difference between them. ^ denotes a large difference that was not significant.

Growth form	Forb	Geophyte	Rush	Sedge	Grass	Restio	Small shrub	Shrub	Small tree	Large tree	Unknown
Table Mountain n=2								^	*		
Mean	23.35	0.03	6.00	9.62	12.86	0.12	0.00	23.40	5.36	18.45	0.32
SD	2.88	0.0	5.6	10.9	8.7	0.2	0.0	4.2	3.9	5.6	
N	2	1	2	2	2	1	0	2	2	2	
Hottentots Holland n=2											
Mean	11.57	0.40	0.00	7.44	6.37	17.08	0.40	13.90	22.03	10.70	9.71
SD	13.6	0.6	0.0	2.5	2.5	11.4	0.6	8.2	2.9	6.0	
N	2	1	0	2	2	2	1	2	2	2	
Hawequas n=6							^				
Mean	8.78	0.00	0.02	3.61	11.45	15.64	2.47	25.93	24.25	7.86	0.10
SD	7.92	0.0	0.1	2.7	6.9	3.3	2.4	13.9	6.1	5.0	
N	6	0	1	6	6	6	5	6	6	6	
Cedarberg n=8							^	^	*		
Mean	10.98	0.02	2.37	4.79	9.32	15.69	0.20	12.26	36.67	7.42	0.34
SD	11.9	0.1	4.3	3.5	9.3	6.7	0.4	3.5	16.3	4.8	
N	8	1	3	8	8	8	3	8	8	8	

A Kruskal-Wallis ANOVA by ranks for multiple independent samples was performed on each of the growth groups (Table 4.2). This test searches for differences between the mean values of each growth form in each group. Only the presence of small trees in the Cedarberg group and the Table Mountain group were significantly different. These same two groups of sites had a noticeable difference in the abundance of shrubs (growth form 8), though not significant. Similarly there was a noticeable difference in the cover of small shrubs (growth form 7) between the Cedarberg and Hawequas groups, but again this was not significant.

From these patterns it can be speculated that it is the dominance of large tree species and paucity of small trees that separates the Table Mountain group from the other three. Several authors, such as Taylor (1978), Campbell (1987) and Galatowitsch & Richardson (2005) recognize a Riparian Scrub set of species, with lower growth forms including small tree species, and an Afromontane set, with larger trees, within the fynbos biome. The literature suggests that differences in the fire history drive the continuum between Riparian Scrub and Afromontane Forest (Taylor 1978). The family and species level investigations reported on next are expected to show the more fire-protected Table Mountain sites to typically have Afromontane Forest species, while sites of the other three groups, with possibly less fire protection and more harvesting, will have Riparian Scrub species. This would then suggest a major reason for the relationship of the groups shown in the dendrographs and MDS plots.

4.2.3 Families and species

The total cover recorded for each species at each site was summed and used to calculate a percentage of the total cover per family for each site. These percentage covers were averaged across all the sites present in each of the four catchment groups to give the mean percent cover for each of the families represented in each catchment group. The total list of families represented was sorted per group, and the dominant ones by percent cover and frequency of occurrence were selected for further analysis (Table 4.3). The dominant families fall into four main groups: cosmopolitan families that were well represented in all four catchments; those dominant in the Cedarberg-Hawequas-Hottentots Holland groups; those dominant in the Table Mountain group and those more prominent at the disturbed sites (disturbed conditions are discussed in Chapter 5, Section 5.2.4).

Within the cosmopolitan group of families, the Poaceae (grasses) and Cyperaceae (sedges) were dominant in terms of percent cover in all four catchment groups. They are among the top ten most speciose families in Western Cape fynbos (Cowling & Holmes 1992). Generally, there were different species of grass and sedge in each catchment and on each river, with some species occurring along more than one river and in more than one catchment. Overall, *Ehrhata* spp. were the most common grass species, and *Ficinia* spp. the most common sedges. One grass species *Pennisetum macrourum* was always and only found in the Hawequas sites.

The other three families listed in the cosmopolitan group, the Dennstaedtiaceae, Ebenaceae and Osmundaceae, were mostly found in all catchment groups in similar proportions. The Osmundaceae is represented by a single species, *Todea barbara*, which is a woody rhizomatous fern found at all the Table Mountain and Hawequas sites but only at half of the Hottentots Holland and Cedarberg sites. It was also found by Sieben (2003) but not by Galatowitsch & Richardson (2005) or by Prins et al. (2004) (Table 4.4). Two different species were responsible for the dominant cover of each of the Dennstaedtiaceae and Ebenaceae. In the Table Mountain sites, *Pteridium aquilinum* and *Histiopteris incisa* (Dennstaedtiaceae) and *Diospyros whyteana* (Ebenaceae) were common. Neither *Diospyros whyteana* nor *Histiopteris incisa* were found in the other three catchment groups, where the families

were represented by *Pteridium aquilinum* and *Diospyros glabra*. Galatowitsch & Richardson (2005) and Prins et al. (2004) also listed these two species as common.

Table 4.3 Mean percentage cover for each family in each catchment group of undisturbed sites. (n) = the number of sites in each catchment group. (N) = the # of sites in which the growth form occurred in each group.

	Hawequas (n=6)			Cedarberg (n=8)			Hottentots Holland (n=2)			Table Mountain (n=2)		
	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N
1. Cosmopolitan families												
Poaceae	11.3	6.8	6	9.3	9.6	8	6.4	2.4	2	12.9	8.8	2
Cyperaceae	3.6	2.7	6	4.6	3.4	8	11.0	7.5	2	9.6	10.9	2
Dennstaedtiaceae	2.3	2.6	4	6.9	9.3	4	5.0	2.8	2	3.3	2.2	2
Ebenaceae	1.5	0.8	6	3.3	3.1	7	1.8	0.9	2	1.5	2.0	2
Osmundaceae	1.8	2.4	6	2.1	4.9	5	0.4	0.6	2	2.5	1.3	2
2. Riparian Scrub affiliation families												
Restionaceae	15.6	3.3	6	15.1	6.6	8	17.1	11.4	2	0.1	0.2	1
Ericaceae	7.4	3.6	6	3.1	4.7	4	10.4	4.7	2	0.5	0.2	2
Asteraceae	6.9	4.2	6	6.4	4.8	8	4.1	5.7	2	0.8	0.9	2
Myrtaceae	11.6	3.0	6	22.3	9.6	8	11.6	0.6	2			
Myricaceae	4.9	4.3	6	9.1	7.6	8	5.4	6.2	2			
Proteaceae	4.6	3.3	6	6.0	6.5	8	5.8	5.0	2			
3. Forest affiliation families												
Asparagaceae	0.0	0.1	1				0.1	0.1	2	20.3	4.6	2
Blechnaceae	1.1	1.7	4	0.7	1.8	3	0.4	0.3	2	10.0	7.8	2
Myrsinaceae				0.1	0.2	1				7.3	4.2	2
Juncaceae	0.0	0.1	1	0.7	1.9	2				6.0	5.6	2
Cunoniaceae	1.7	2.9	4				0.3	0.4	2	5.0	0.1	2
Fabaceae	0.4	0.3	5	0.0	0.1	2	0.4	0.5	2	2.5	0.2	2
Rubiaceae	3.0	4.6	3	0.2	0.3	3				3.2	2.4	2
Apocynaceae										1.6	2.1	2
4. Other families prominent at disturbed sites												
Prioniaceae	10.1	15.2	4	1.0	2.2	4	1.7	2.1	2			
Anacardiaceae	0.2	0.4	1	3.1	2.8	7	2.6	2.1	2			
Scrophulariaceae	0.0	0.0	1	1.8	2.1	6	1.3	1.0	2	1.9	1.4	2
Campanulaceae				0.1	0.2	4				0.2	0.3	1
Podocarpaceae	0.1	0.2	1							0.8	1.1	1
Salicaceae	0.6	1.5	1	0.0	0.1	1						
Bruniaceae	2.4	4.3	4				0.1	0.1	2			
Haloragaceae				0.0	0.0	1				0.0	0.1	1
Thymeleaceae	0.1	0.2	1				0.1	0.1	2	0.0	0.1	1
Pinaceae												
Aizoaceae				0.0	0.1	2						
Celastraceae	1.8	1.8	5	0.8	1.6	4	0.3	0.4	2	0.2	0.3	2
Phytolacaceae												
Polypodiaceae										0.2	0.3	1

Six dominant families were recorded in the Cedarberg-Hawequas-Hottentots Holland group (Table 4.3), the first three - the Restionaceae (restios), Ericaceae (ericas) and Asteraceae - being in the top ten most abundant fynbos families (Cowling & Holmes 1992). Two restio species, *Calopsis paniculata* and *Elegia capensis*, were present at all sites in the Hawequas, Cedarberg and Hottentots Holland catchment groups. The dominant presence of *Elegia capensis* is confirmed by Prins et al. (2004) and of *Calopsis paniculata* by Sieben (2003). The dominant erica, *Erica caffra*, was found on all studied rivers in the Table Mountain, Hawequas and Hottentots Holland catchment groups, and also on one of the Cedarberg rivers (Rondegat) but not the other (Heks). Many species of Asteraceae were recorded in all sites, most of them terrestrial species. One dominant species commonly found in riparian areas, however, was the Riparian Scrub tree *Brachylaena neriifolia*, which occurred at all the Hawequas sites and half the Cedarberg and Hottentots Holland sites but not at the Table Mountain sites.

Table 4.4 Rivers investigated in three recent riparian studies.

Sieben (2003)	Prins et al., 2004	Galatowitsch (2005)
Eerste	Eerste	Eerste
Riviersonderend	Steenboks	Waterval
Berg	Molenaars	Jakkals
Palmiet	Palmiet	Molenaars
Lourens	Rooiels	Louws
	Wit	Silvermine
		Elands

The next two families in this group, the Myrtaceae and Proteaceae, contain two of the most frequently cited riparian species *Metrosideros angustifolia* and *Brabejum stellatifolium* respectively. These two species commonly occurred in the study sites, their cover dominating all the sites in the Hawequas, Cedarberg and Hottentots Holland catchment groups. *Brabejum stellatifolium* was also found at one of the Table Mountain sites (Dis1) but was not dominant. The final dominant family in this group was the Myricaceae, due solely to the cover of *Morella serrata* (formerly *Myrica serrata*). This species has not often been cited as a common riparian species in the Western Cape, with both Galatowitsch & Richardson (2005) and Prins et al. (2004) not recording it. It was, however, listed by Sieben (2003). In this study it was recorded in every site from the Hawequas, Hottentots Holland and Cedarberg catchment groups.

The third group of families was most abundant at the Table Mountain sites (Table 4.3). The most dominant by cover was the Asparagaceae, due to a single species *Asparagus scandens* that was also found in the Hottentots Holland system. This species is known to occur in high numbers in forest communities (Glyphis et al., 1978). Other species within the Asparagaceae, *Asparagus africanus* and *Asparagus rubicundus*, were found at single sites in the Hawequas and Cedarberg groups respectively. The next most dominant family was the Blechnaceae: in the Table Mountain group due mostly to *Blechnum capense* along with *Blechnum punctulatum*, with *Blechnum australe* in half the Hottentots Holland and half the Hawequas sites and a quarter of the Cedarberg sites.

High covers of Myrsinaceae, due to *Rapanea melanophloeos*, were only found at the Table Mountain sites, with a single occurrence of *Myrsine africana* at one site in the Cedarberg group. *Cunonia capensis*, responsible for the high cover of Cunoniaceae in the Table Mountain group, was also recorded at one site in the Hottentots Holland system and four (on the Elands River) out of six sites in the Hawequas group, along with another member of this family *Platylophus trifolius*. The Table Mountain group had the highest recorded cover for the Juncaceae, through three species, in order of dominance: *Juncus effusus*, *Juncus lomatophyllus* and *Juncus capensis*. *Juncus capensis* was also found at a single site in both the Hawequas and Cedarberg groups. The Fabaceae was represented solely by the tree *Virgilia oroboides*, which occurred in none of the other groups. Two species were responsible for the dominance of Rubiaceae in both the Table Mountain and Hawequas groups: *Canthium ventosum*, found only at the Table Mountain sites, and *Anthospermum spathulatum*, recorded with a relatively high percentage cover at one Hawequas site and low percentage at two Cedarberg sites.

All the analyses to this point showed the Table Mountain group of sites to be very different from the others, and most different from the Cedarberg and Hawequas groups. There were differences in growth form, specifically in the higher numbers of large trees and lower numbers of small trees at the Table Mountain sites. Families and species cited as being characteristic of Afromontane Forest (Campbell 1987, Galatowitsch & Richardson 2005; Taylor 1978) such as Myrsinaceae (*Rapanea melanophloeos*), Fabaceae (*Virgilia oroboides*) and the Cunoniaceae (*Cunonia capensis*), were found either only in the Table Mountain group where they had high percentage covers at all sites, or at much reduced covers in one or more of the other three groups.

4.2.4 Summarising catchment-wide community patterns

Two main community types emerge from this analysis – a community dominated by large tree species at the Table Mountain sites and a community dominated by smaller shrub and tree species at the other undisturbed sites. Species commonly found in this study have been listed by others as typical of Afromontane Forest or Riparian Scrub communities (Table 4.5).

Species cited as indicators of Afromontane Forest were found at the Table Mountain sites, as were some others recorded as dominant in this study but not cited as such elsewhere. Species cited as indicators of Riparian Scrub were found at the Cedarberg-Hawequas-Hottentots Holland sites, as were some others recorded as dominant in this study but not cited as such elsewhere (e.g. *Morella serrata*).

Slow growing, shade-tolerant Afromontane Forest species require the cover of well established and enclosing scrub to germinate (van Wilgen et al., 1998). In this study they tended to occur in areas sheltered from fire and other agricultural or anthropogenic disturbances. The shrubby growth forms and smaller trees species typical of Riparian Scrub re-generate by sprouting or from seeds stored in the canopy or soil (Holmes 1998) and so can recover more quickly from fire or disturbances such as harvesting. In this study they tended to occur in less sheltered areas than the larger tree species typical of Afromontane Forest. Naturally, the two community types form part of a continuum, and there was

no clear differentiation in these analyses between the two community types in terms of altitude or slope (Table 3.2).

Table 4.5 Indicator species for Riparian Scrub and Afromontane Forest communities. Asterisk (*) species are those also cited in the literature as such: sources are Taylor (1978), Campbell (1987) and Galatowitsch & Richardson (2005). (n) = the number of pristine sites, F = frequency of occurrence in the relevant group of study sites. # = unknown, as *Psoralea* genus under revision. Bolded species were allocated to cosmopolitan families (Table 4.3).

Family	Species	F (%)
Riparian Scrub (n=16)		
Myrtaceae	<i>Metrosideros angustifolia</i> *	100
Restionaceae	<i>Elegia capensis</i> *	100
Restionaceae	<i>Calopsis paniculata</i>	100
Myricaceae	<i>Morella serrata</i>	100
Ebenaceae	<i>Diospyros glabra</i>	94
Proteaceae	<i>Brabejum stellatifolium</i> *	88
Asteraceae	<i>Brachylaena neriifolia</i> *	81
Ericaceae	<i>Erica caffra</i> *	75
Osmundaceae	<i>Todea barbara</i>	69
Dennstaedtiaceae	<i>Pteridium aquilinum</i>	63
Prioniaceae	<i>Pronium serrata</i> *	56
Scrophulariaceae	<i>Freylinia lanceolata</i> *	31
Anacardiaceae	<i>Rhus angustifolia</i> *	31
Fabaceae	<i>Psoralea pinnata</i> *	#
Salicaceae	<i>Salix mucronata</i> *	25
Restionaceae	<i>Cannamois virgata</i> *	13
Juncaceae	<i>Juncus lomatophyllus</i> *	13
Scrophulariaceae	<i>Halleria elliptica</i> *	13
Afromontane Forest (n=2)		
Asparagaceae	<i>Asparagus scandens</i>	100
Blechnaceae	<i>Blechnum capense</i>	100
Poaceae	<i>Ehrharta erecta</i>	100
Myrsinaceae	<i>Rapanea melanophloeos</i> *	100
Juncaceae	<i>Juncus effusus</i>	100
Dennstaedtiaceae	<i>Histiopteris incisa</i>	100
Cunoniaceae	<i>Cunonia capensis</i> *	100
Osmundaceae	<i>Todea barbara</i>	100
Rubiaceae	<i>Canthium ventosum</i>	100
Blechnaceae	<i>Blechnum punctulatum</i>	100
Ebenaceae	<i>Diospyros whyteana</i>	100
Fabaceae	<i>Virgilia oroboides</i> *	100
Kiggelariaceae	<i>Kiggelaria africana</i> *	100
Aquafoliaceae	<i>Ilex mitis</i> *	100
Scrophulariaceae	<i>Halleria lucida</i> *	100
Podocarpaceae	<i>Podocarpus</i> sp. *	50
Apocynaceae	<i>Secamone alpinii</i> *	50
Dennstaedtiaceae	<i>Pteridium aquilinum</i>	50

In summary, the riparian zone of Western Cape headwater streams are composed of a mix of forest (Afromontane), riparian (Riparian Scrub) and fynbos (cosmopolitan) species that is considered to be typical of such zones (Sieben 2003). This also accords well with the description of Cowling & Holmes (1992), who describe riparian areas as being similar to forest and thicket in that they have a high cover of non-proteoid mesophyllous shrubs, but dissimilar in their higher cover of Restionaceae and Ericaceae.

The status of a new site in terms of reference condition and whether it is predominantly Afromontane Forest or Riparian Scrub could be assessed through the check list in Table 4.5. The species listed for Afromontane Forest were only recorded from two sites so are very initial approximations at this stage. The cosmopolitan species also shown in this table provide more insight into the community likely to be found, but it is suggested they not be used to assess reference condition as the species mix differed considerably from site to site.

Schael & King (2005) found a similar pattern of catchment and river identities to that described here in their study of aquatic invertebrates of invertebrates of Western Cape headwater streams. They termed these identities catchment and river signatures. They concluded that the present national approach of allocating lengths of the country's rivers to ecoregions and then sub-ecoregions based on longitudinal river zones bypasses the vitally important spatial unit of catchment. Catchments may be more important, or at least equally as important, as either of the other two units in guiding the management of biodiversity at scales from microhabitat to landscape.

4.3 SITE LEVEL PATTERNS

4.3.1 Overall approach

The catchment patterns and reference condition described above offer a perspective on the overall nature of Western Cape riparian communities in headwater areas. To assess the impact on these communities of alien invasive plants, however, the detailed structure and characteristics of undisturbed sites need to be understood so that these can be compared with those of disturbed sites. This was done through meticulous recording of the position, number, growth form and height, and condition of all plants found in 20 metre-long sample grids along the river length at each of the study sites (Section 3.3). Within the sample grids (Figure 3.1), 1 m-wide x 20 m-long bands were each divided into four 1 x 5 m-long sample plots (A to D); sample plots were adjacent to one another. The number of these bands, from water's edge to bank top, was dictated by the presence of riparian plant species, whilst the total array of 1 x 5 m sample plots within the sample grid was designed to allow detection of where vegetation assemblages changed between water's edge and bank top. A series of environmental variables was also measured (Section 3.3), either per sample plot or per sample grid, to aid interpretation of patterns of assemblage distributions.

As explained in Section 3.3, no *a priori* assumptions were made about the nature and location of different vegetation assemblages and instead the data would be used to define these from first

principles. Different vegetation communities up the banks have been described by Boucher (2002) and Sieben (2002), but these were based on pre-identification and delineation of the various communities. As this would probably not be possible in heavily-invaded sites, the approach of making no *a priori* decisions on community identification and location seemed more appropriate in this project on the impact of aliens on indigenous riparian vegetation. This also entailed not using any names for the communities/assemblages that are given elsewhere, to avoid confusion.

4.3.2 Preliminary data management

The species-level cover data from all the sample plots at each study site were 4th root transformed before being analysed using a non-metric Multi-dimensional Scaling ordination and a CLUSTER analysis, both based on the Bray-Curtis similarity coefficient between each of the sample plots. Transforming the data in this way has the effect of downweighting the importance of highly abundant species so the similarities depend not only on their presence but those of common species as well (Clarke and Warwick 2001). Groups of sample plots with a natural coherence were identified; these usually showed 40% or more within-group similarity. Each group was recognized as a possible vegetation assemblage and allocated a number, with 1 being closest to the water's edge and numbers increasing with physical distance from the water's edge. Each assemblage so identified was assessed in terms of its species composition and, in cases of two assemblages with an overall 50-60% similarity and no substantial difference in the composition or abundance of species, the groups were merged.

When searching for the dominant or typical species of each assemblage, species-cover data were ranked per assemblage by frequency of occurrence (100% = a species occurred in all sample plots comprising the assemblage in question) with additional consideration of cover (the average over all sample plots within the assemblage). Ranking by frequency allows assemblages to be defined primarily by species that are generally or always present rather than by species that contribute the most cover, thus allowing smaller, common species to contribute towards the identity of the assemblage.

Assigning assemblages to an assemblage type

Cluster analysis and MDS ordination distribute the vegetation samples, which probably represent a continuum of species changes, into subjective groups. In order to reduce the confusion of possibly dozens of assemblages, all differing from site to site and river to river, these may be allocated to a smaller number of assemblage types that are recognizable across the sites. This was done as described in Section 3.4.2.

With this preparation, the distribution of vegetation assemblages of three groups of four reference sites – on the Rondegat, Heks and Elands Rivers – are described in detail in the following sub-sections. In each case, the four reference sites exist within two different longitudinal zones (Table 3.3). These twelve sites are used to create a tentative definition of the reference condition, which is then tested on the remaining six undisturbed sites (Section 4.4.4).

4.3.3 The Rondegat River (Cedarberg – Olifants system)

The four sites on the Rondegat River consisted of two in the mountain stream zone and two in the mountain stream (transitional) zone (Plate 1). Each site is discussed in turn below and then a summary is provided for the river.

Ron1: mountain stream zone (riffle)

Ron1 was situated alongside a fast-flowing turbulent riffle, which was a high point in the channel bed. Eight assemblages were recognised in the CLUSTER and MDS ordination analyses (Figure 4.3). Assemblage 1, found at the water's edge, separated from the two other groups, one containing assemblages 2, 3 and 4 and the other assemblages 5, 6, 7 and 8. This latter group was furthest and highest from the water's edge. In the ordination there was a trend of those samples closest to the water's edge appearing on the left and those on the right furthest and highest from the water.

The species found in each assemblage are summarised in Table 4.6 and the position of each assemblage on the bank in relation to the water's edge on the four surveyed cross-sections is shown in Figure 4.4. All five assemblage types were present and are discussed below in terms of outstanding features of each assemblage type, in order from the water's edge upwards and outwards across the river bank.

Assemblage 1 in the similarity analysis was assigned as WE, even though the height range was slightly below the summer water level (-0.12 - -0.08m). This apparent anomaly occurred because each cross-section was surveyed through the middle of a vegetation block that was 5 m in length (along the bank), and kinks in the channel edge resulted in the survey line sometimes being under water when plants nearby within the same sample plot were not. The sedge *Isolepis prolifer* occurred in every sample from the WE assemblage and reached its highest abundance of any assemblage type here. There were smaller levels of frequency and occurrence of seedlings of the small tree *Metrosideros angustifolia*, the shrub *Erica caffra*, and the riverine restio *Calopsis paniculata*, but for none of these three species was this their assemblage type of highest occurrence.

The CF assemblage (number 2) occurred in close proximity to the water's edge and up to an elevation of 0.91 m above water level, with 19% of the area under water. This was the highest-elevation assemblage type in which *Isolepis prolifer* occurred and the only assemblage type supporting the fern *Todea barbara* and the sundew *Drosera* spp. It marked the first appearance of juvenile (0.3-2.0 m) individuals of the small trees *Metrosideros angustifolia*, *Brachylaena nerifolia*, *Brabejum stellatifolium* and *Morella serrata* as well as scattered older (2-5 m) individuals of all these species and seedlings of the last three. It also marked the first appearance of the restio *Elegia capensis* and the grass *Ehrharta ramosa* ssp. *aphylla*.

The Tree Shrub (TS) assemblage type occurred at an elevation of 0.56-1.22 m above water level and encompassed assemblages 3 and 4. It marked the first and only appearance of mature (2-5 m)

individuals of *Metrosideros angustifolia* and *Brachylaena neriifolia* and the upper limit of juveniles and seedlings of the same species. Seedlings, juveniles and adults of *Morella serrata* reached their outermost point of distribution in this assemblage type as did *Erica caffra* and juveniles of *Brabejum stellatifolium*. It supported the only individuals recorded of the fern *Schizaea tenella*, and the only mature specimens of *Hartogiella schinoides* and *Brachylaena neriifolia*. Several species and life stages reached their highest cover and frequency values in this assemblage type: seedlings of *Metrosideros angustifolia*, *Brachylaena neriifolia* and *Brabejum stellatifolium*; juveniles of *Brachylaena neriifolia*; adults of *Metrosideros angustifolia*; and *Erica caffra* and *Calopsis paniculata*.

The Outer Transitional (OT) assemblage type occurred at an elevation of 0.93-1.55 m and encompassed assemblages 5 and 6. It supported the outermost occurrence of *Brabejum stellatifolium*, in the form of some seedlings and the highest abundance in any assemblage type of adults. *Calopsis paniculata* and *Diospyros glabra* also reached their outer limit. Some species present in TS reached their highest abundance in OT, among them *Ehrharta ramosa* ssp. *aphylla* and *Pteridium aquilinum*, whilst others, such as *Aristea capitata* and *Ischyrolepis gaudichaudianus*, a common terrestrial species, occurred only in this assemblage type. Many species that were abundant in the Non Riparian (NR) assemblage type made their first appearance in OT: *Ischyrolepis sieberi*, *Myrsine africana* and *Anthospermum spathulatum* among others.

The Non Riparian (NR) assemblage type occurred at an elevation of 1.43-1.80 m and encompassed assemblages 7 and 8. It contained less rock than the lower zones and a good accumulation of sand or other finer particles, presumably because it was too high for regular scouring of fines by floods. NR was dominated by typical terrestrial species, with only three species that occurred in lower-elevation assemblage types: a grass, a small tree and the fern *Pteridium aquilinum*. The mix of terrestrial species occurring in NR and OT tended to differ from site to site and is not discussed further here and in any detail during the site descriptions.

The assemblage types were well distributed along the four cross-sections (Figure 4.4). Vegetation block A had a representative of each assemblage type and in order from WE through to NR. Block B did not contain a CF assemblage and blocks C and D had no NR assemblage.

Ron2: mountain stream zone (pool)

Ron2 was situated immediately downstream of Ron1 alongside a pool. The narrow channel was covered to some extent by the growth of the riparian canopy. Eight assemblages were formed (Figure 4.5), again in three groups, with those on the left of the MDS plot being closest to the water and those on the right furthest from it. Assemblage 1 was allocated to the CF assemblage type, and 2, 3 and 4 to the TS assemblage type. The OT consisted of assemblages 5, 6 and 7, with assemblage 8 representing the NR. There was no WE group, assemblage 1 being assigned to CF rather than to WE because it contained species that were frequent and abundant in the drier assemblage types (TS and OT) (Table 4.7).

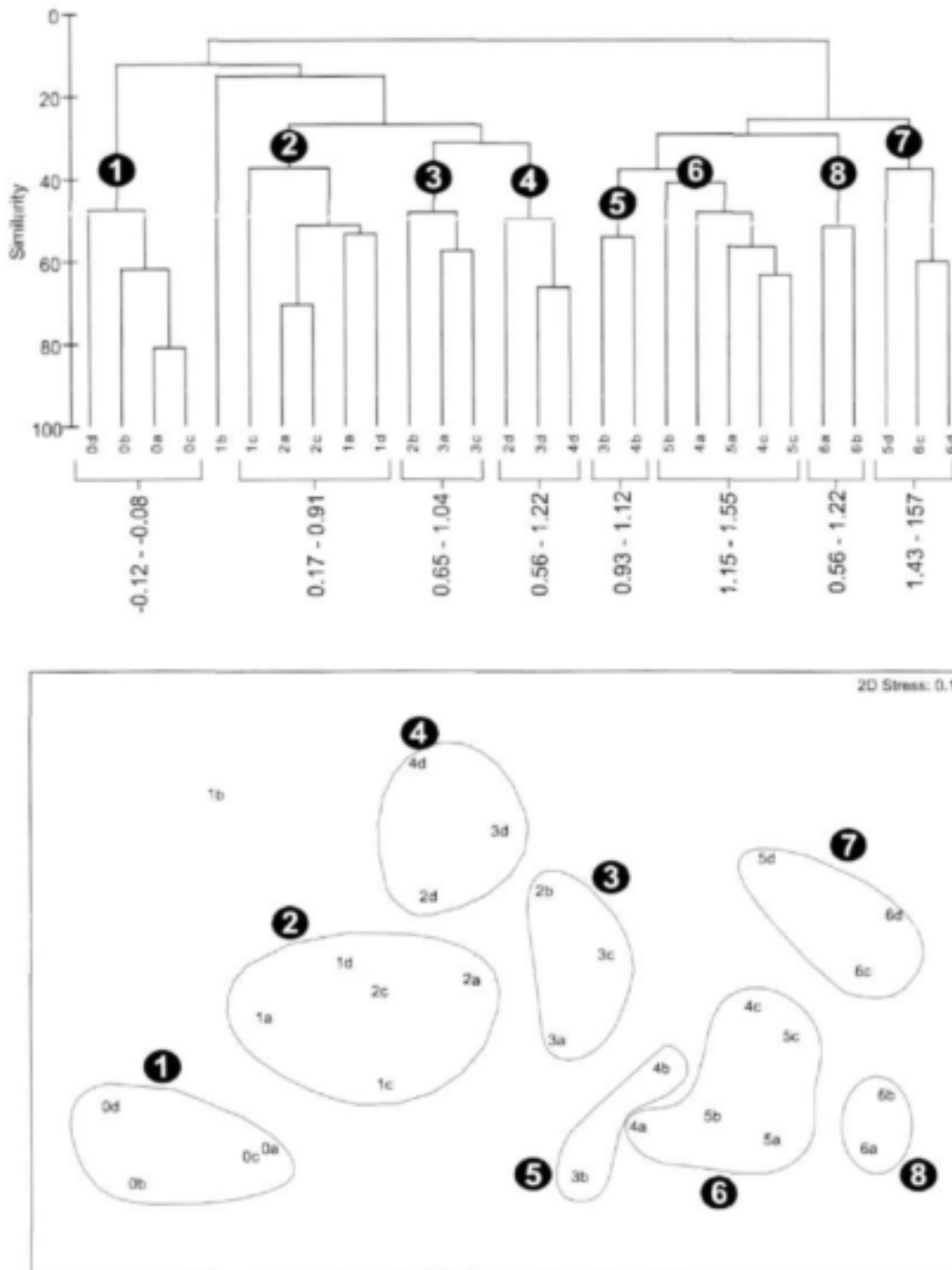


Figure 4.3 CLUSTER analysis and Non-metric MDS ordination for all samples at Ron1 on the Rondegat River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level is shown on the dendrogram.

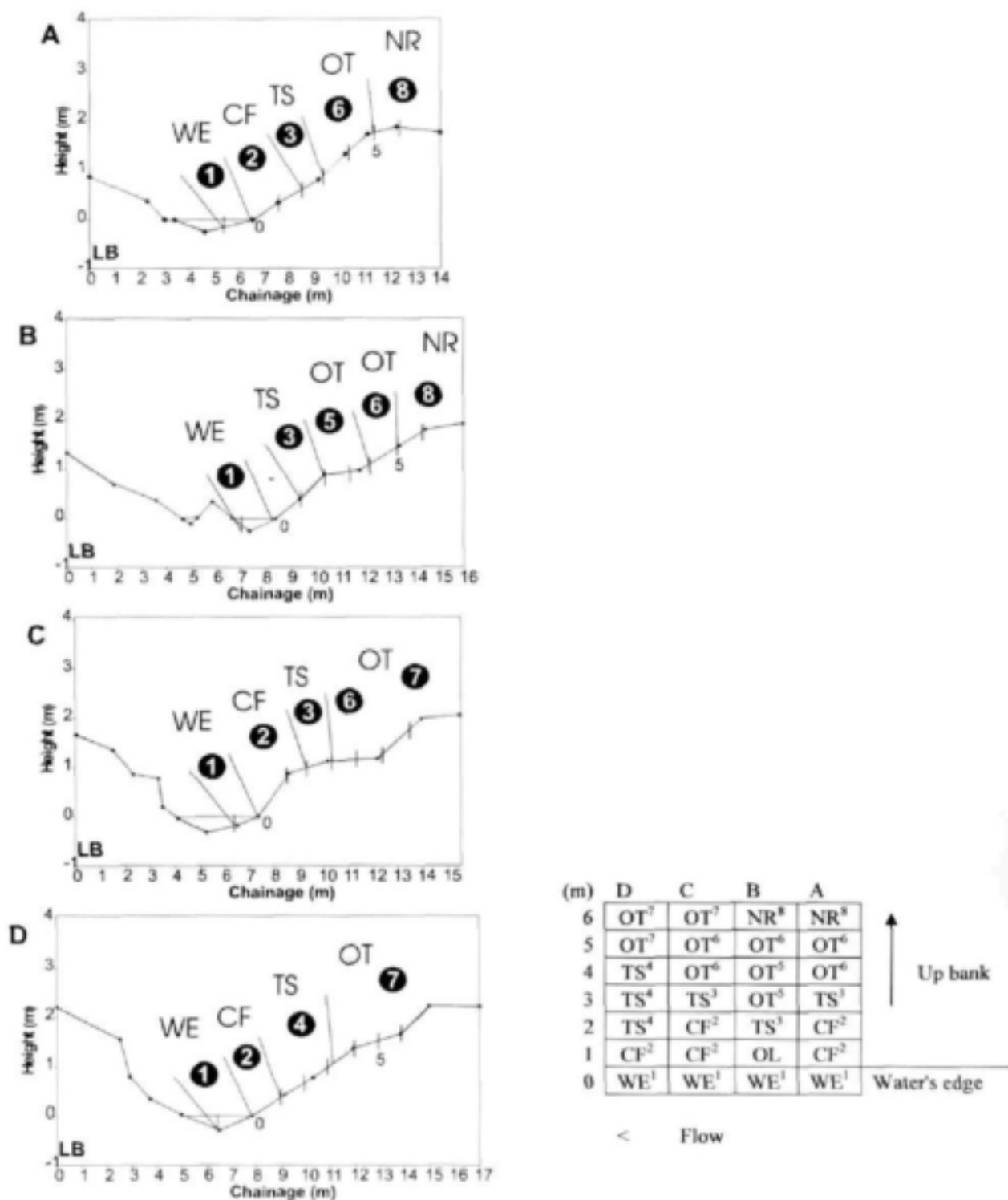


Figure 4.4 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.3 and the assemblage types they represent (Table 4.6) in the four vegetation blocks (A through D) at Ron1 on the Rondegat River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier.

Table 4.6 The percent frequency (F) and the average cover in each assemblage type for all species at Ron 1. The assemblage type assigned to the eight assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type																
	1 (n=4)		2 (n=5)		3 (n=3)		4 (n=3)		5 (n=2)		6 (n=5)		7 (n=3)		8 (n=2)	
Physical variables	Wet Edge		Channel Fringe		Tree Shrub		Outer Transitional		Non Riparian							
% sand	5		13		7		30		8		20		40		43	
% rock	95		87		93		70		93		80		60		58	
% water	78		19		2		0		0		0		0		0	
Elevation above summer low water (m)	-0.12 - -0.08		0.17-0.91		0.65-1.04		0.56-1.22		0.93-1.12		1.15-1.55		1.43-1.57		1.65-1.80	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Isolepis prolifer</i>	100	4.3	60	2.6												
<i>Metrosideros angustifolia</i> seedling	25	0.1	60	0.9	67	1.3										
<i>Erica caffra</i>	25	0.8	20	1.2	33	1.7	33	1.0								
<i>Todea babara</i>			60	1.2												
<i>Drosera</i> spp.			20	0.4												
<i>Metrosideros angustifolia</i> (0.3-2m)			80	9.6	33	1.3	67	3.0								
<i>Brachylaena neriifolia</i> (0.3-2m)			40	10.8	100	9.7										
<i>Brabejum stellatifolium</i> (0.3-2m)			80	3.6			33	3.0								
<i>Morella serrata</i> (0.3-2m)			40	3.0			33	1.3								
<i>Elegia capensis</i>			40	2.2			100	15.7					33	1.67		
<i>Morella serrata</i> (2-5m)			20	1.4			33	4.0								
<i>Morella serrata</i> seedling			20	0.4			33	0.7								
<i>Metrosideros angustifolia</i> (2-5m)					100	35.0	100	17.3								
<i>Brachylaena neriifolia</i> (2-5m)							100	31.7								
<i>Schizaea tenella</i>							33	0.7								
<i>Hartogiella schinoides</i> (2-5m)					33	1.7										
<i>Brachylaena neriifolia</i> seedling			20	0.1	33	0.2										
<i>Calopsis paniculata</i>	50	1.5	100	7.4	33	11.7	33	1.3			20	4.0				
<i>Brabejum stellatifolium</i> seedling			80	3.0	100	4.0	67	2.7	50	0.5	20	0.2				
<i>Brabejum stellatifolium</i> (2-5m)			20	2.0	67	13.0	67	9.0	100	40.0						
<i>Diospyros glabra</i>					33	1.3			50	1.5	20	1.0				
<i>Ehrharta ramosa</i> subsp. <i>aphylla</i>			20	0.4	67	18.3			100	6.0	100	24.0	100	6.00	100	15.0

	1 (n=4)	2 (n=5)	3 (n=3)	4 (n=3)	5 (n=2)	6 (n=5)	7 (n=3)	8 (n=2)				
	Wet Edge	Channel Fringe	Tree Shrub		Outer Transitional		Non Riparian					
<i>Pteridium aquilinum</i>			67	5.7	50	5.0	100	13.6	33	1.33	100	3.5
<i>Aristea capitata</i>					50	1.0	80	2.6				
<i>Hartogiella schinoides</i> (0.3-2m)			33	1.0			20	2.0	67	4.33		
<i>Phylica oleaefolia</i> (0.3-2m)					50	0.5	40	1.4			50	2.0
<i>Ischyrolepis gaudichaudianus</i>							20	0.6				
<i>Asteraceae</i> sp.20							20	0.4				
<i>Ficinia acuminata</i>							40	2.4	67	4.0		
<i>Clusia</i> cf. <i>ericoides</i>							20	0.4	67	1.3		
<i>Euryops abrotanifolius</i>							40	0.8	33	0.7	50	3.0
<i>Ischyrolepis sieberi</i>							20	0.8			100	9.0
<i>Cliffortia ruscifolia</i>							20	0.6	100	7.0	50	2.5
<i>Myrsine africana</i>							20	0.4			100	3.0
<i>Anthospermum spathulatum</i>							20	0.2			100	6.5
<i>Protea</i> sp.1 (0.3-2m)									100	5.0	50	6.0
<i>Willdenowia incurvata</i>									67	6.0		
<i>Pelargonium scabrum</i>									67	1.7	50	1.0
<i>Elytropappus intricate</i>									33	8.3	50	10.0
<i>Pentastichis</i> 4									33	1.3		
<i>Dodonaea viscosa</i> (0.3-2m)									33	1.0		
<i>Stoebe plumosa</i>									33	0.7	50	2.5
<i>Phylica oleaefolia</i> seedling									33	0.3		
<i>Metastasia dregeana</i>											100	6.5
<i>Pentastichis</i> sp.2											50	2.5
<i>Thesium</i> sp.1											50	2.0
<i>Protea</i> sp.1 seedling											50	1.5
<i>Wahlenbergia rubioides</i>											50	0.5

In contrast to Ron1, CF was situated close to the water's edge up to an elevation of 0.11 m (Figure 4.6), where a WE assemblage might have been expected. As with Ron1, CF was the highest-elevation occurrence of *Isolepis prolifer* (Table 4.7). It contained a mix of species found in WE and CF at Ron1, namely *Todea barbara*, *Erica caffra*, *Calopsis paniculata* and *Elegia capensis*. No individuals of the small tree species found at Ron1 were present in CF at Ron2.

TS was the most speciose assemblage type, and was dominated by seedlings, juveniles and adults of all of the main small tree species (*Brabejum stellatifolium*, *Metrosideros angustifolia*, *Morella serrata* and *Brachylaena neriifolia*). With two exceptions (*Calopsis paniculata* and *Elegia capensis*) the CF species petered out in TS, and a few species were restricted to this assemblage type, including *Schizaea tenella* (also restricted to TS in Ron1) and *Blechnum capense*. The grass *Ehrharta ramosa* ssp. *ramosa* first appeared in TS, as did the fern *Pteridium aquilinum*. As with Ron1, *Metrosideros angustifolia* reached its outermost distribution in this assemblage type, along with adult *Brabejum stellatifolium*, which reached into OT at Ron1. Only seedlings of the latter reached into OT here. OT ranged from 0.91 – 1.68 m, very similar to the range at Ron1. The other main riparian small tree species – *Morella serrata* and *Brachylaena neriifolia* – reached their outer limits in OT, as did *Pteridium aquilinum*, *Elegia capensis* and *Calopsis paniculata*. Several species occurred only in OT, including *Oftia africana* and *Willdenowia incurvata*, both of which occurred in OT or NR at Ron1.

NR occurred above 1.07 m elevation compared to above 1.43 m at Ron1. It contained several species that had also been present in OT or NR at Ron1.

The three assemblage types were well represented in all four vegetation blocks, with NR being absent from blocks B and C. CF was situated lower down the bank than at Ron1, while TS, OT and NR occurred over approximately the same elevation range. The major difference between the two sites was that the WE type was not present at Ron2. Being a pool, the channel at Ron2 was much deeper than at Ron1 and there was no gradual edge change from a rock-bottom channel over a cobble/gravel bar onto the bank of the river. Instead a steep bank edge abutted the pool, leaving no space for development of a WE assemblage.

Ron3: mountain stream (transitional) zone (riffle)

Ron3 was beside a riffle in the Mountain Stream (transitional) zone. The valley was wider and flatter than at Ron1 and Ron2, and the river reach studied had a series of small side channels, resulting in an overall floodplain effect for many tens of meters from the wetted channel. Sample plots thus were not laid out over the whole width of the riparian band but were restricted to the first eight meters from the water's edge.

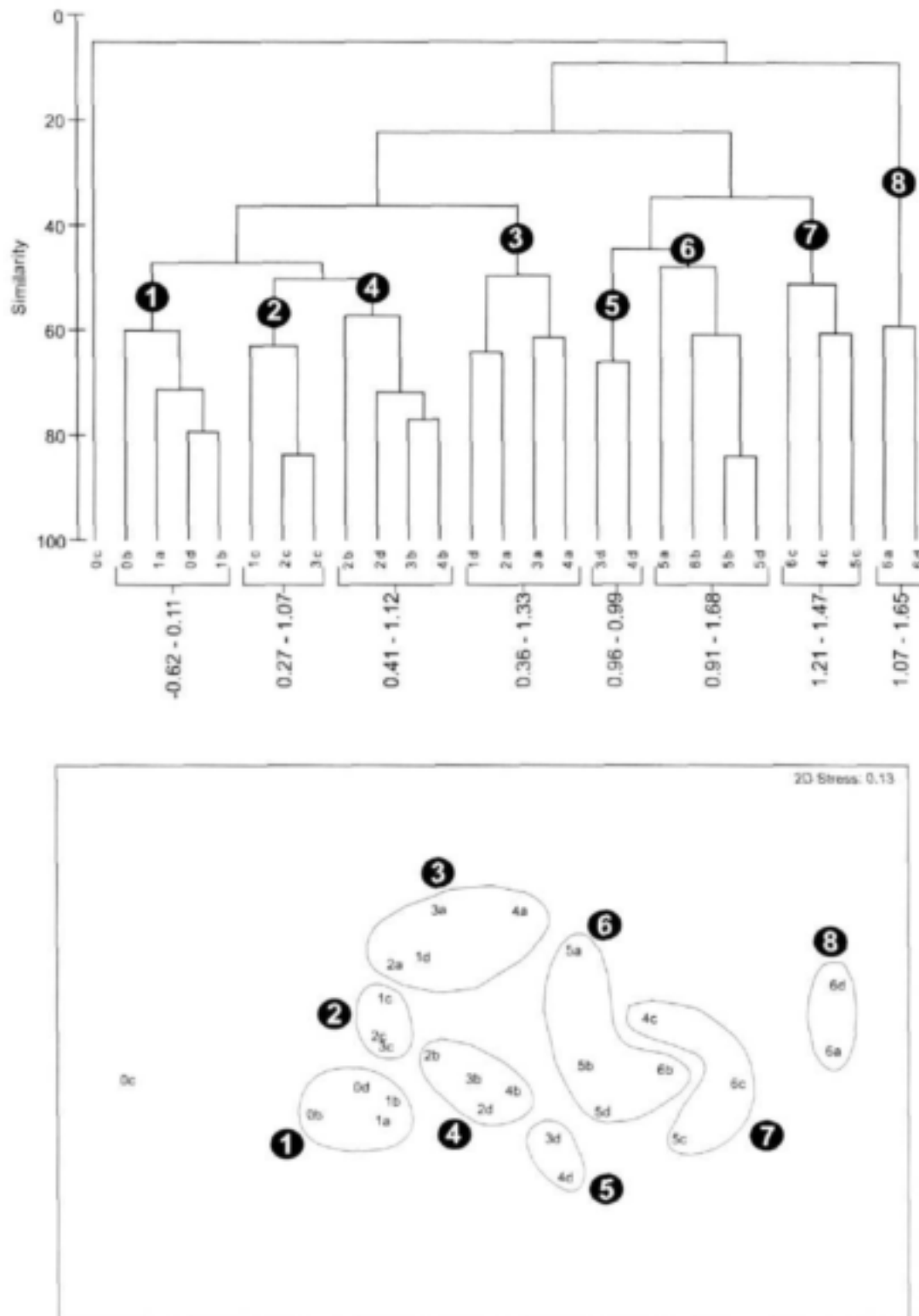


Figure 4.5 CLUSTER analysis and Non-metric MDS ordination for all samples at Ron2 on the Rondégat River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level is shown on the dendrogram.

Table 4.7 The percent frequency (F) and the average cover in each assemblage type for all species at site Ron2. The assemblage type assigned to the eight assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type																
	1 (n=4)		2 (n=3)		3 (n=4)		4 (n=4)		5 (n=2)		6 (n=4)		7 (n=3)		8 (n=2)	
Physical variables	Channel Fringe		Tree Shrub				Outer Transitional						Non Riparian			
% sand	25		70		60		90		100		30		67		60	
% rock	50		30		40		10		0		70		33		40	
% water	100		17		25		10		0		0		0		0	
Elevation above summer low flow (m)	-0.62-0.11		0.27-1.07		0.36-1.33		0.41-1.12		0.96-0.99		0.91-1.68		1.21-1.68		1.07-1.65	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Isolepis prolifer</i>	25	1.0														
<i>Erica caffra</i>	50	3.8	33	3.3	50	1.0										
<i>Todea babara</i>	75	11.0	100	20.3	100	26.3	100	9.0								
<i>Calopsis paniculata</i>	100	6.3	67	4.7	25	2.5	25	2.5					33	3.3		
<i>Brabejum stellatifolium</i> (2-5m)			100	23.3	25	0.5	50	10.0								
<i>Metrosideros angustifolia</i> (2-5m)			33	3.3	50	8.8	50	3.0								
<i>Morella serrata</i> seedling			33	1.3	50	1.3	25	0.8	36	1.111						
<i>Metrosideros angustifolia</i> seedling					100	2.9										
<i>Brabejum stellatifolium</i> (0.3-2m)					50	2.5										
Species 18					50	2.5										
<i>Brabejum stellatifolium</i> seedling					50	1.8	25	1.0	25	0.917						
<i>Schizaea tenella</i>					50	1.5										
<i>Brachylaena neriifolia</i> seedling					50	1.3										
<i>Blechnum capense</i>					25	0.5										

	1 (n=4)		2 (n=3)		3 (n=4)		4 (n=4)		5 (n=2)		6 (n=4)		7 (n=3)		8 (n=2)	
	Channel Fringe		Tree Shrub						Outer Transitional						Non Riparian	
<i>Elegia capensis</i>	100	21.3	100	15.0	100	22.3	100	35.0	100	11.5	75	9.8				
<i>Brachylaena neriifolia</i> (2-5m)			100	15.3	50	7.0			50	2.5	25	2.5				
<i>Morella serrata</i> (0.3-2m)			33	1.0	100	4.8					75	3.0	33	1.7		
<i>Morella serrata</i> (2-5m)					75	5.5	100	20.0			25	2.5	33	3.3		
<i>Metrosideros angustifolia</i> (0.3-2m)					50	3.3					25	7.5				
<i>Brachylaena neriifolia</i> (0.3-2m)					25	2.5					25	1.0				
<i>Ehrhata ramosa</i> subsp. <i>ramosa</i>					25	3.8	25	0.5					100	23.3	100	10.0
<i>Pteridium aquilinum</i>							100	13.5	100	10.0	100	13.5	100	28.3		
<i>Oftia africana</i>									50	2.0						
<i>Clusia cf. ericoides</i>									50	1.5						
<i>Peucedanum galbanum</i> (0.3-2m)									50	1.0						
<i>Pelargonium scabrum</i>											100	9.0	33	1.7	100	17.0
<i>Asteraceae</i> sp.20											25	1.0				
<i>Heeria argentea</i> (0.3-2m)													33	3.3		
<i>Willdenowia incurvata</i>													33	1.3		
<i>Elytropappus intricate</i>															50	10.0
<i>Ficinia acuminata</i>															50	4.0
<i>Cliffortia ruscifolia</i>															50	1.0

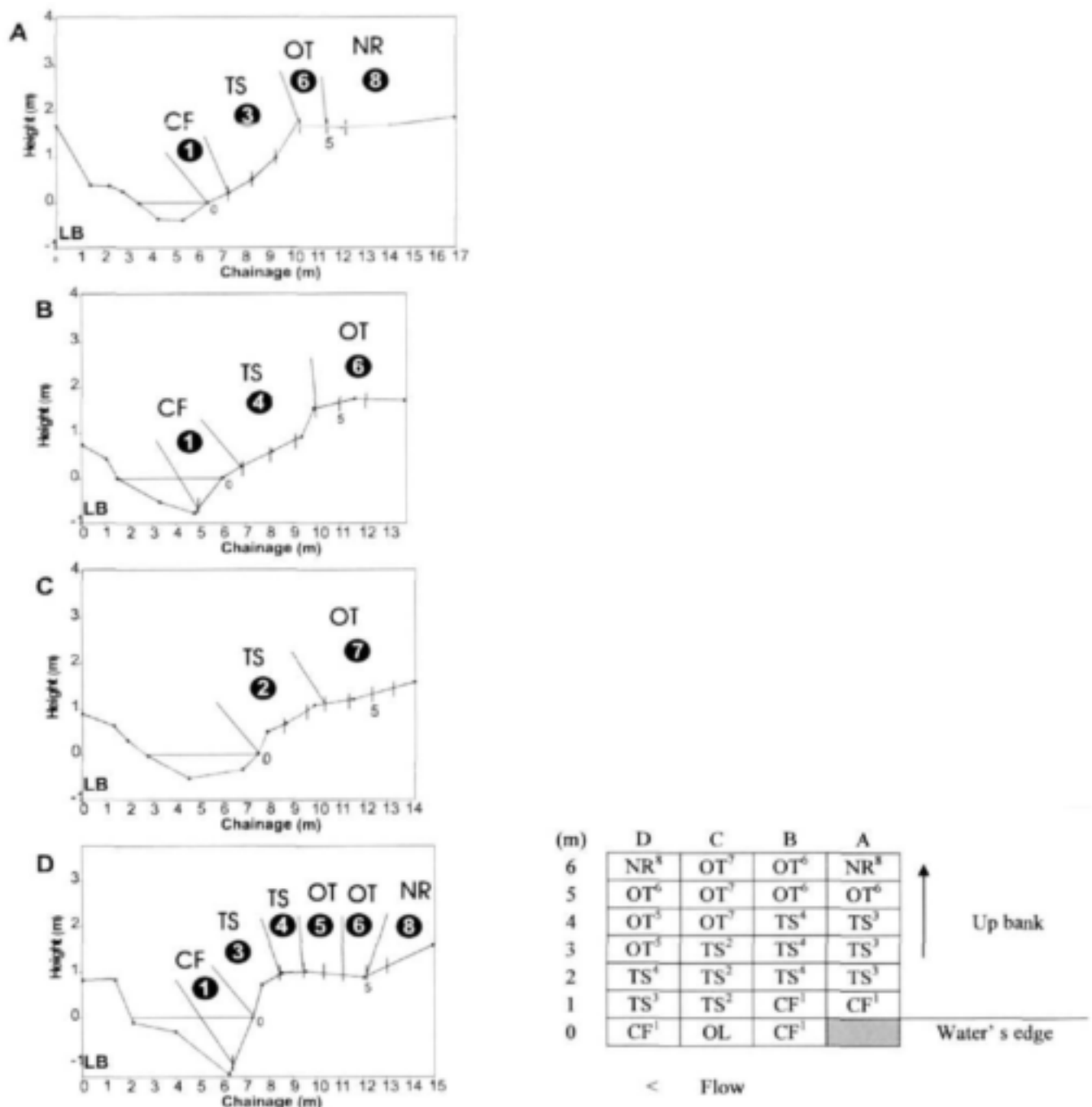


Figure 4.6 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.5 and the assemblage types they represent (Table 4.7) in the four vegetation blocks (A through D) at Ron2 on the Rondégat River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier, grey box = no sample.

Seven assemblages in fairly poorly-defined groups were recognized for this site, with the trend on the MDS plot being from the lower-elevation assemblage types on the left to the higher ones on the right (Figure 4.7). Only three assemblage types – WE, CF and TS – were assigned; with no OT and NR assemblages as no samples formed a separate group containing species normally associated with drier environments.

As with Ron1, WE (assemblage 1) was located at the water's edge (Figure 4.8) and was dominated by *Isolepis prolifer* with smaller occurrences of the restio *Elegia capensis* and the shrub *Erica caffra* (Table 4.8). Species at WE but not recorded at Ron1 or Ron2 were the rush *Juncus lomatophyllus* and the forb *Wimmerella arabidea*. Only *Isolepis prolifer* was confined to WE.

CF contained a mixture of the common Riparian Scrub tree species and characteristic wetland species. *Brabejum stellatifolium*, *Metrosideros angustifolia* and *Morella serrata* were all present as seedlings, juveniles and adults, with only *Brachylaena neriifolia* being limited to adults; no seedlings of these species occurred outside this assemblage type. Another small tree species, *Rhus angustifolia*, not collected from Ron1 and Ron2 did occur, and among the small trees was a mix of species from typical wetland families such as the Juncaceae and Cyperaceae (see Table 4.8), and species typical of the CF at the upstream sites such as *Calopsis paniculata*, *Drosera* spp., and *Ehrharta ramosa* ssp. *ramosa*.

TS occurred at an elevation of 0.76-1.91 m or higher, and contained mostly species also present in CF plus some with a first occurrence in this assemblage type. Mature individuals of the common Riparian Scrub small tree species were more common here than in CF and some new small tree species occurred: *Maytenus oleoides*, *Hartogiella schinoides* (also in TS at Ron1) and a new large tree *Kiggelaria africana*. Many of the wetland species common in CF were not present, but some such as *Elegia capensis*, *Erica caffra* and *Calopsis paniculata* extended into this assemblage type as they did at Ron1.

In summary, the three assemblage types present were well distributed along the four cross-sections (Figure 4.8) with a representative of each assemblage type present in each of the four vegetation blocks, other than WE which was absent from vegetation block A. WE and the CF were situated at similar elevation ranges to those at Ron1, while the TS was found both further and higher up the bank at Ron3 than at Ron1. The valley shape of the two sites, Ron3 and Ron4, situated in the mountain stream (transitional) zone differed in being wider and flatter than found higher up at Ron1 and Ron2. This resulted in a riparian zone at these mountain stream (transitional) sites that was wider and less steep with a much less distinctive transition from riparian to terrestrial vegetation. Hence, no OT and NR assemblage types were recorded at Ron3 although, of course, they would have existed beyond the chosen plot area.

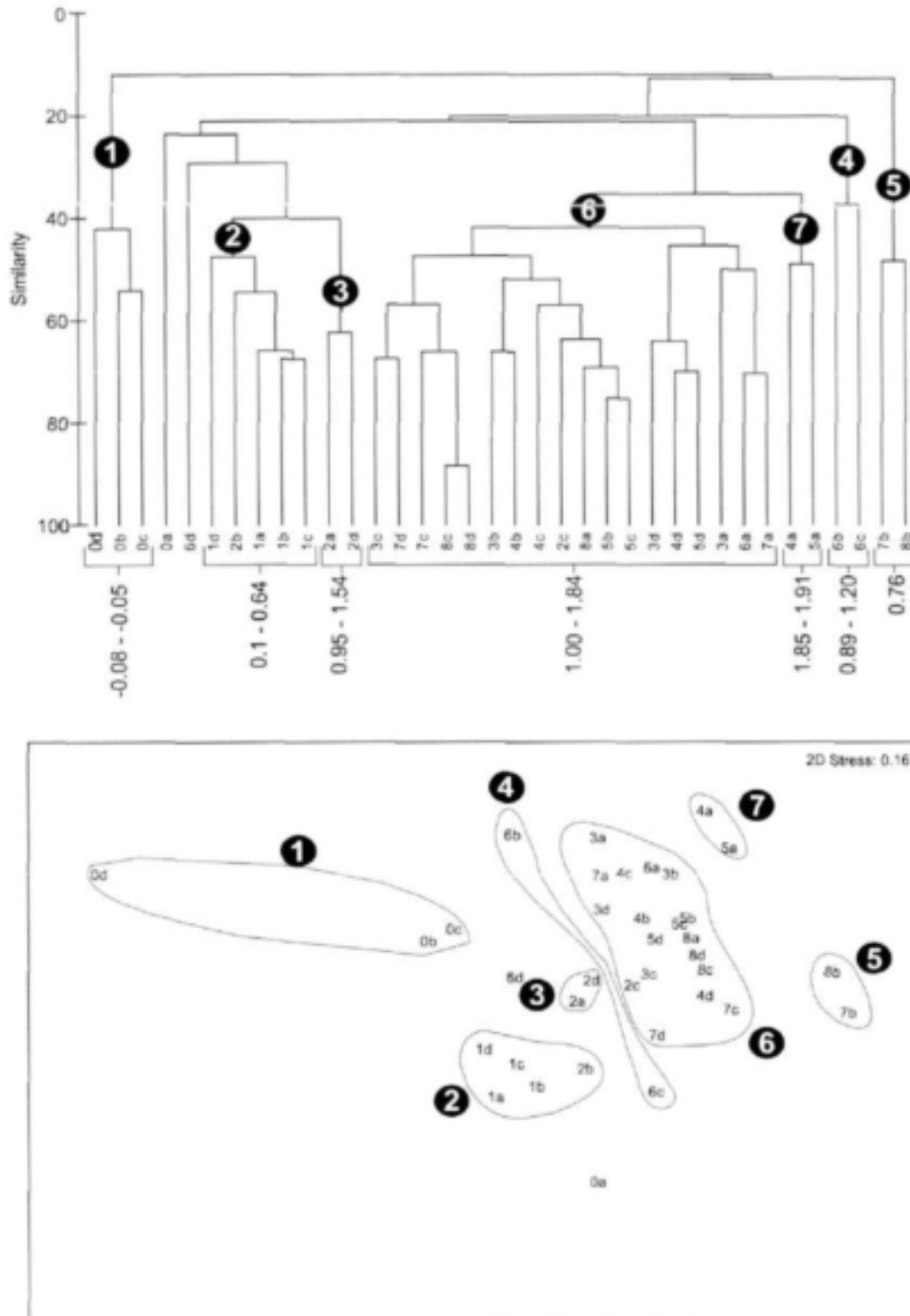


Figure 4.7 CLUSTER analysis and Non-metric MDS ordination for all samples at Ron3 on the Rondegat River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level is shown on the dendrogram.

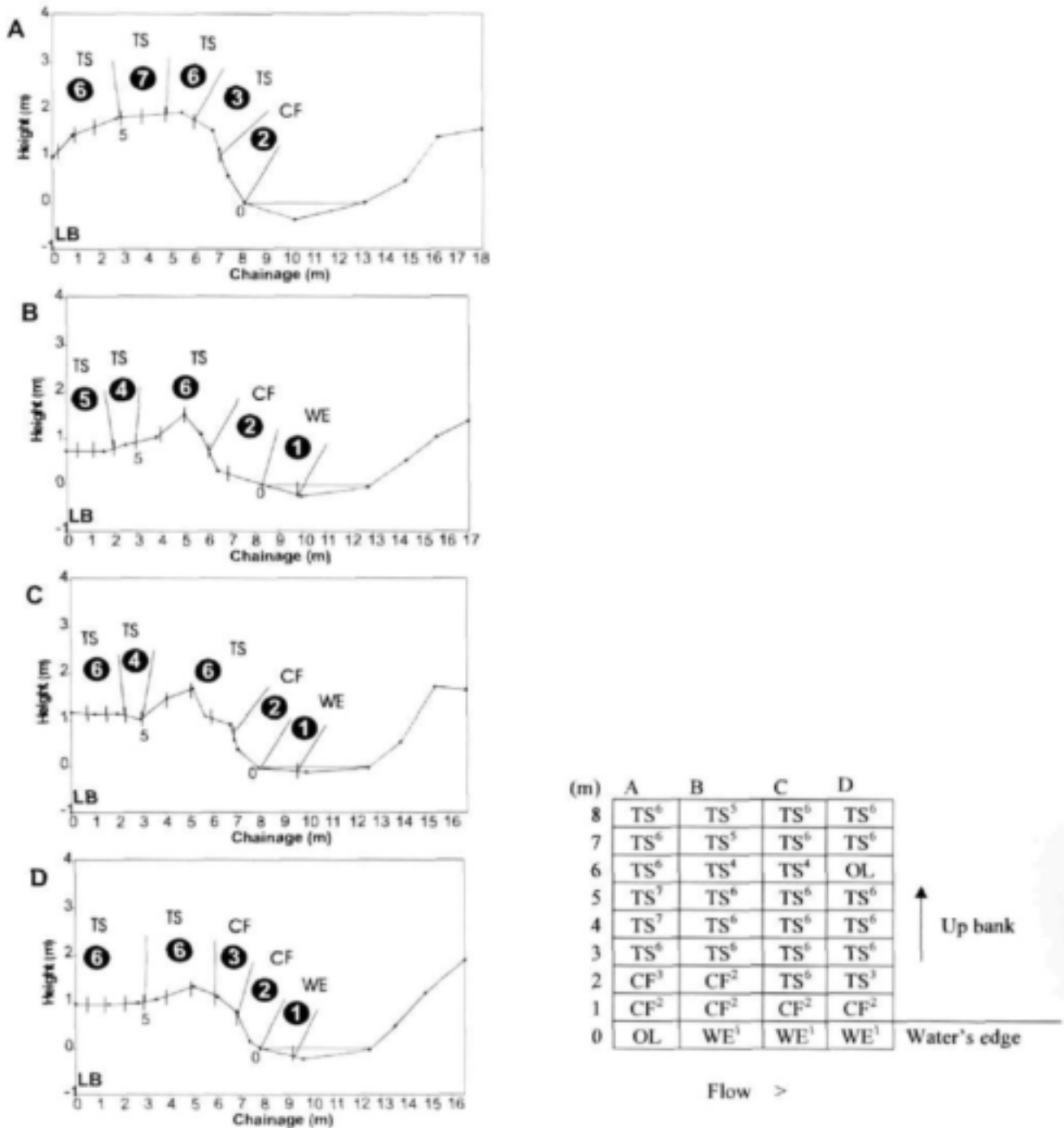


Figure 4.8 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.7 and the assemblage types they represent (Table 4.8) in the four vegetation blocks (A through D) at Ron3 on the Rondegat River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier.

Table 4.8 The percent frequency (F) and the average cover in each assemblage for all species at Ron3. The assemblage type assigned to the seven assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type															
	1 (n=3)		2 (n= 5)		3 (n=2)		4 (n=2)		5 (n=2)		6 (n=18)		7 (n=2)		
Physical variables	Wet Edge		Channel Fringe				Tree Shrub								
% sand	10		30		35		100		100		92		100		
% rock	90		70		65		0		0		8		0		
% water	70		16		0		0		0		0		0		
Elevation above summer low water (m)	-0.08 - -0.05		0.1-0.64		0.95-1.54		0.89-1.2		0.76		1.00-1.84		1.85-1.91		
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	
<i>Isolepis prolifer</i>	100	1.7													
<i>Juncus lomatoophyllus</i>	33	0.7	100	20.6											
<i>Wimmerella arabidea</i>	33	0.2	40	0.8											
<i>Isolepis digitata</i>			80	13.0											
<i>Paspalum urvillei</i>			40	1.4											
<i>Restionaceae</i> sp.9			20	1.0											
<i>Morella serrata</i> (0.3-2m)			20	0.6											
<i>Laurembergia repens</i>			20	0.4											
<i>Juncus effusus</i>			20	0.2											
<i>Pelargonium tabulare</i>			20	0.1											
<i>Morella serrata</i> seedling			80	1.4	100	0.8									
<i>Drosera</i> spp.			60	1.6	50	0.3									
<i>Brabejum stellatifolium</i> seedling					100	0.8									
<i>Morella serrata</i> (2-5m)					50	2.5									
<i>Metrosideros angustifolia</i> seedling			100	2.4	100	2.0					6	0.4			
<i>Calopsis paniculata</i>			80	4.2	100	2.5	50	2.0			22	1.4			
<i>Elegia capensis</i>	67	1.3	80	7.4	100	10.0	100	6.5			89	6.9			
<i>Erica caffra</i>	33	1.7	80	9.5	100	13.5					33	4.7			
<i>Ehrhata ramosa</i> subsp. <i>ramosa</i>			40	0.8	50	2.0					17	0.4			

	1 (n=3)	2 (n=5)	3 (n=2)	4 (n=2)	5 (n=2)	6 (n=18)	7 (n=2)			
	Wet Edge	Channel Fringe		Tree Shrub						
<i>Rhus angustifolia</i>	40	7.0		50	0.5	33	3.1			
<i>Metrosideros angustifolia</i> (2-5m)	20	0.4			100	18.5	61	13.4		
<i>Metrosideros angustifolia</i> (0.3-2m)			50	5.0			17	0.5		
<i>Blechnum australe</i>	20	0.4	100	2.5			56	5.1	100	1.5
<i>Pteridium aquilinum</i>			100	6.5			94	9.1	100	10.0
<i>Brabejum stellatifolium</i> (0.3-2m)			50	0.5			11	0.2	50	2.5
<i>Diospyros glabra</i>			50	1.5			17	1.1		
<i>Todea bahara</i>				100	6.5		6	0.2		
<i>Cyperus demidatus</i>				50	1.0					
<i>Brachylaena neriifolia</i> (2-5m)			50	3.0	50	10.0	50	37.5	11	1.7
<i>Halleria elliptica</i>				50	7.5	50	1.5	28	2.1	
<i>Maytenus oleoides</i> (2-5m)				50	7.5				50	25.0
<i>Brabejum stellatifolium</i> (2-5m)							56	8.6	100	12.5
<i>Rhus lucida</i> forma elliptica							11	0.5	50	2.0
<i>Clusia</i> sp.2							6	0.1	50	2.0
<i>Hartogiella schinoides</i> (2-5m)									50	10.0
<i>Ficinia indica</i>							6	0.3		
<i>Helichrysum</i> cf. <i>odoratissimum</i>							6	0.2		
<i>Restionaceae</i> sp.9							6	0.2		
<i>Mariscus thunbergii</i>							6	0.1		
<i>Kiggelaria africana</i> (0.3-2m)							6	0.1		
<i>Maytenus oleoides</i> seedling							6	0.0		

Ron4: mountain stream (transitional) zone (pool)

Ron4 was situated beside a pool in the same general terrain of a flatter bank as Ron3. Six assemblages were recognised (Figure 4.9). Two of these (numbers 1 and 2) were assigned to the WE; the third group (3) to CF and assemblages 4 to 6 to the TS assemblage type.

The two WE groups were quite different. WE assemblage 1, in vegetation blocks A and B (Figure 4.10), was situated on a small cobble bar within the wetted channel. Cross-section A was surveyed just upstream of this bar and cross-section B just downstream of it. This is the reason that assemblage 1 on cross-section A (and assemblage 2 on cross-section B) appear to 'float' in the main channel. The cobble bar supported mainly the shrub *Prionium serratum* (Table 4.9) together with a number of species already recorded in WE from the upstream study sites, particularly Ron3, that were less frequent and in some cases at very low average percentage covers here; including *Isolepis prolifer*, *Juncus lomatophyllus*, *Wimmerella arabidea*, *Erica caffra*, *Calopsis paniculata* and *Drosera* spp. The first two, plus *Pennisetum macrourum* and *Blechnum australe* were confined to WE. Also present were seedlings of *Metrosideros angustifolia* and *Brachylaena neriifolia*, as well as juveniles of *Brachylaena neriifolia* and a few adult *Metrosideros angustifolia*. The presence of these Riparian Scrub small trees was not characteristic of WE at the other Rondegat sites.

WE assemblage 2 contained just four species. One, *Wimmerella arabidea*, was found only in the WE at this site and in WE and CF at Ron3. *Erica caffra* and *Elegia capensis* occurred at all four sites, in either WE and/or CF. Adult *Metrosideros angustifolia* mirrored the situation in WE assemblage 1.

The CF assemblage type, consisting of assemblage 3, was quite speciose, with six species common, as they were at one or more of the other sites: the restios *Elegia capensis* and *Calopsis paniculata*, the shrub *Erica caffra*, adults of *Metrosideros angustifolia* and *Brabejum stellatifolium*, and the ubiquitous fern *Pteridium aquilinum*. *Morella serrata* occurred only in CF, as seedlings through to adults, whilst seedlings of the other Riparian Scrub tree species petered out in this assemblage type. There were fewer wetland species than at Ron3, but some, such as *Drosera* spp., *Prionium serratum* and *Mariscus thunbergii* were recorded.

The TS assemblage type (assemblages 4-6) was characterized by juvenile and mature trees of the common scrub tree species, and the ferns *Todea barbara*, *Blechnum capense* and *Pteridium aquilinum*. Of these three, *Todea barbara*, was confined to CF in Ron1 and Ron2, but also occurred in TS at Ron3 and this site, suggesting an ability to expand its living area on shallower-sloped banks. *Pteridium aquilinum* was not found below the TS assemblage type in the two upper sites but extended down into WE and CF at the two lower sites. Other species reasonably common and restricted to TS were *Rhus lucida* forma *elliptica* and *Diospyros glabra*. The latter species was consistently present in TS more than in any other assemblage type at the Rondegat sites.

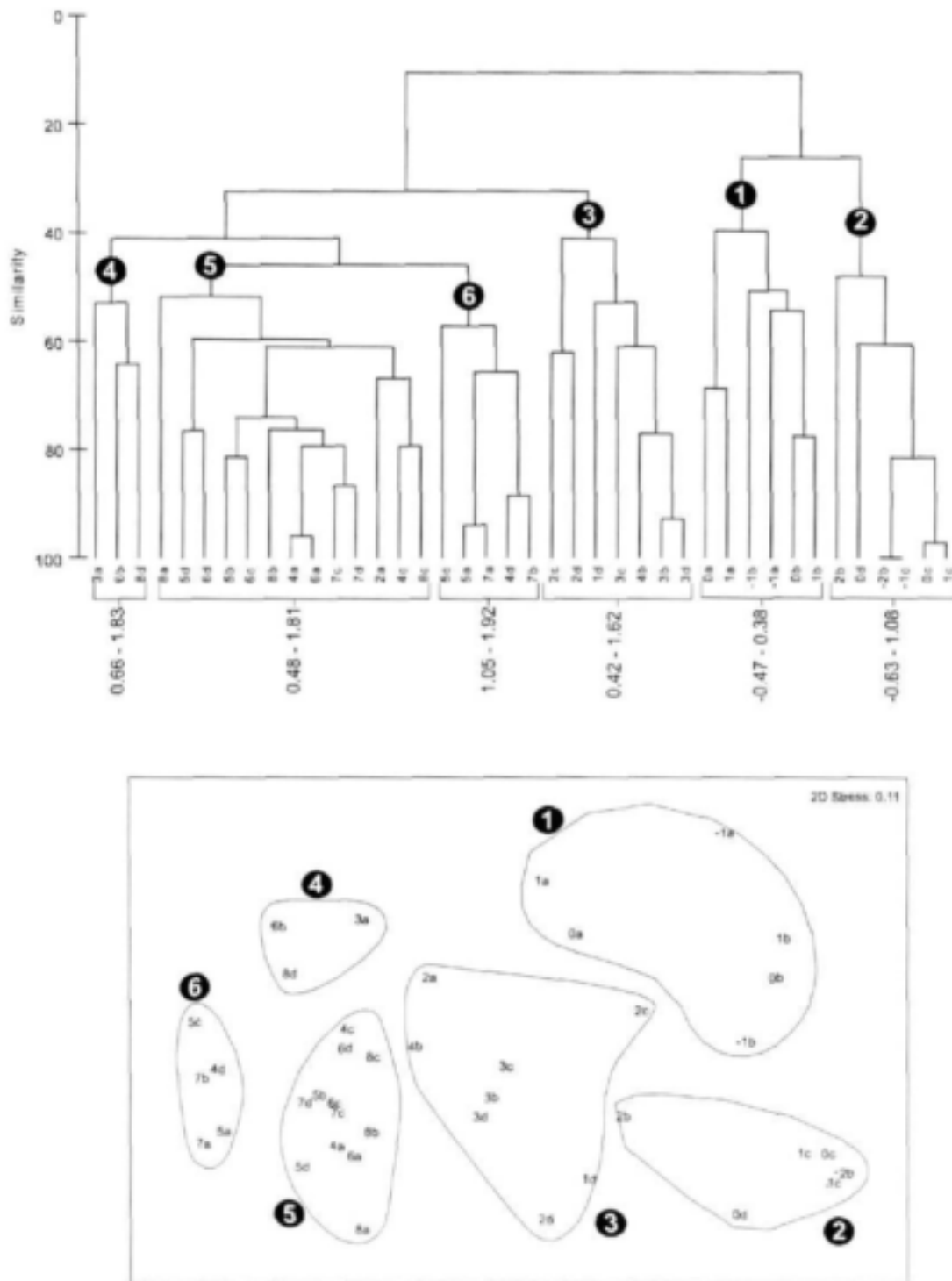


Figure 4.9 CLUSTER analysis and Non-metric MDS ordination for all samples at Ron4 on the Rondegat River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level is shown on the dendrogram.

Table 4.9 The percent frequency (F) and the average cover in each assemblage type for all species at Ron4. The assemblage type assigned to the seven assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type												
	1 (n=6)		2 (n=6)		3 (n=7)		4 (n=3)		5 (n=12)		6 (n=5)	
Physical variables	Wet Edge				Channel Fringe		Tree Shrub					
%sand	35		18		69		93		92		90	
% rock	63		53		31		7		8		10	
% water	97		72		36		0		0		0	
Elevation above summer low water (m)	-0.47-0.38		-0.63- 1.08		0.42-1.62		0.66-1.83		0.48-1.81		1.05-1.92	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Isolepis prolifer</i>	83	6.8										
<i>Blechnum australe</i>	33	1.3										
<i>Pennisetum macrourum</i>	33	0.8										
<i>Juncus lomtophyllus</i>	17	0.3										
<i>Wimmerella arabidea</i>	83	2.2	17	0.1								
<i>Prionium serratum</i>	100	12.5			14	0.7	33	5.0				
<i>Erica caffra</i>	83	10.3	100	15.8	86	8.1						
<i>Elegia capensis</i>			17	1.7	71	6.1						
<i>Calopsis paniculata</i>	50	1.0			86	5.6						
<i>Brachylaena neriifolia</i> (0.3-2m)	33	1.3			14	0.6						
<i>Brachylaena neriifolia</i> seedling	33	0.7			29	0.4						
<i>Metrosideros angustifolia</i> seedling	33	0.5			14	0.3						
<i>Drosera</i> spp.	17	0.3			29	0.7						

	1 (n=6)		2 (n=6)		3 (n=7)		4 (n=3)		5 (n=12)		6 (n=5)	
	Wet Edge				Channel Fringe		Tree Shrub					
<i>Morella serrata</i> (0.3-2m)					43	2.4						
<i>Mariscus thunbergii</i>					29	0.9						
<i>Morella serrata</i> (2-5m)					14	1.4						
<i>Morella serrata</i> seedling					14	0.1						
<i>Metrosideros angustifolia</i> (2-5m)	17	6.7	17	4.2	86	11.1			100	23.8		
<i>Pteridium aquilinum</i>	33	2.0			86	5.4	100	20.3	100	23.6	100	20.0
<i>Blechnum capense</i>	17	0.2			14	0.1			8	0.0		
<i>Brabejum stellatifolium</i> (2-5m)					57	16.4	100	25.3	25	3.3		
<i>Metrosideros angustifolia</i> (0.3-2m)					14	0.3	33	3.3	8	0.3		
<i>Todea babara</i>					14	0.1			25	0.9	40	3.6
<i>Brabejum stellatifolium</i> (0.3-2m)							33	1.7	25	2.1		
<i>Rhus lucida</i> forma elliptica							33	0.2			20	3.2
<i>Diospyros glabra</i>									17	0.8		
<i>Brachylaena neriifolia</i> (2-5m)									8	1.3		

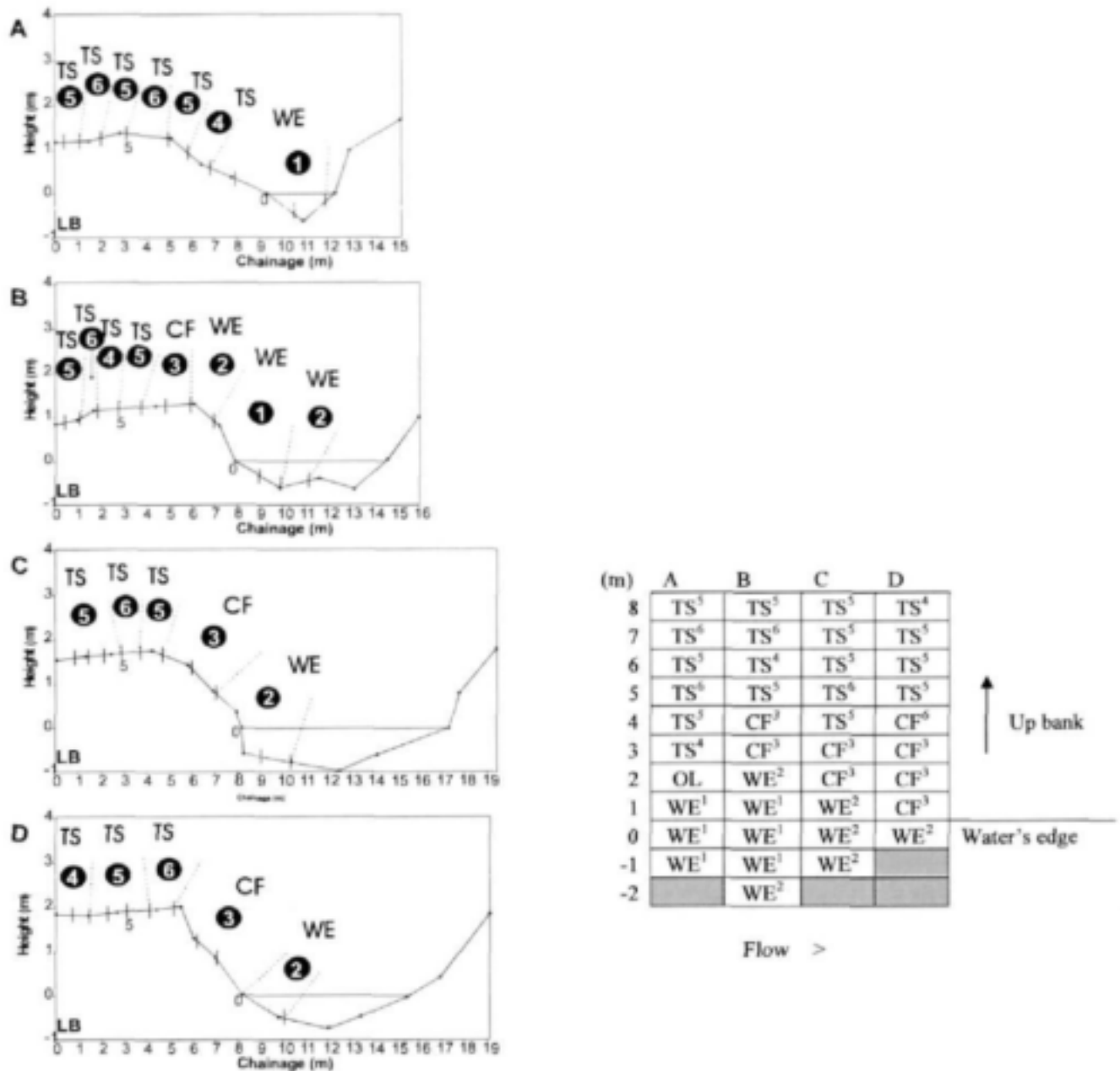


Figure 4.10 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.9 and the assemblage types they represent (Table 4.9) in the four vegetation blocks (A through D) at Ron4 on the Rondegat River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier, grey box = no sample.

The progression of species and assemblage changes from the water's edge to the top of the bank followed the pattern described for the three upstream sites. At this site all four vegetation blocks contained all three assemblage types in order from WE to TS. The height and position of the assemblage types was the same as that described for upstream.

Summary of Rondegat sites

The sites in the two different zones - the mountain stream and the mountain stream (transitional) - differ in that no OT or NR assemblage types were assigned to the mountain stream (transitional) samples at Ron3 and Ron4. This was because their flatter bank gradient resulted in a wider riparian zone that could not be fully sampled. Species typical of OT and NR would have been encountered at the lower two sites if the sample plots extended to the outer limits of the riparian zone.

TS and CF, present at all four sites, covered the largest area of each sample grid and essentially constituted what is normally thought of as the riparian zone. WE was not always present but tended to occur where there was a shallow gradient from the water's edge up the bank, such as across a cobble bar. It was poorly formed or missing where the bank rose abruptly from the wetted channel.

To a large extent the four sites had the same species and there were no obvious discriminating species between sites and within zones. Further, there was not always a logical progression from smaller typically wet-habitat species, such as rushes and sedges, through larger riparian shrubs and trees, to shrubs and grasses more typical of the neighbouring drier landscape. Nevertheless the rushes and sedges were more prominent nearer the water and the tree species, although widely spread as seedlings and juveniles, mostly persisted into maturity in TS.

A plot of the elevation above and distance from the low-flow water's edge, for every sample taken from all four sites on the Rondegat River shows a gradual progression from WE to NR at the two upper sites, where the valley was narrow and the river banks steep (Figure 4.11a) and from WE to TS at the two lower sites, where the valley was more shallow (Figure 4.11b). The same sequence of assemblage types occurred. WE was always at, or extended into, the wetted channel. CF lay within a band from the channel edge to an elevation of 1.0 m and distance from water of 2.0 m (mountain stream) or 1.7 m elevation and 4.0 m distance (mountain stream [transitional]). TS sprawled over the widest range of elevations and distance and, along with OT, would undoubtedly have been shown to have an even wider range if the full riparian zone had been sampled at the lower two sites (Figure 4.11b). Nevertheless its elevation range was still restricted to 0.3 to 1.5 m in the mountain stream zone and 0.8 to 2.0 m in the mountain stream (transitional) zone. Despite the overlap, any one sample could only have occurred in a maximum of two assemblage types.

4.3.4 The Heks River (Cedarberg – Olifants system)

The Heks River is part of the Olifants River system, its sub-catchment bordering that of the Rondegat River. Of its four study sites, two were in the mountain stream (transitional) zone and two in the

foothill zone (Plate 2). Pristine foothill zones are rare in Western Cape rivers and sites representing them are restricted in this study to this river and the Elands River (Section 4.3.5). The four sites on the Heks are described below.

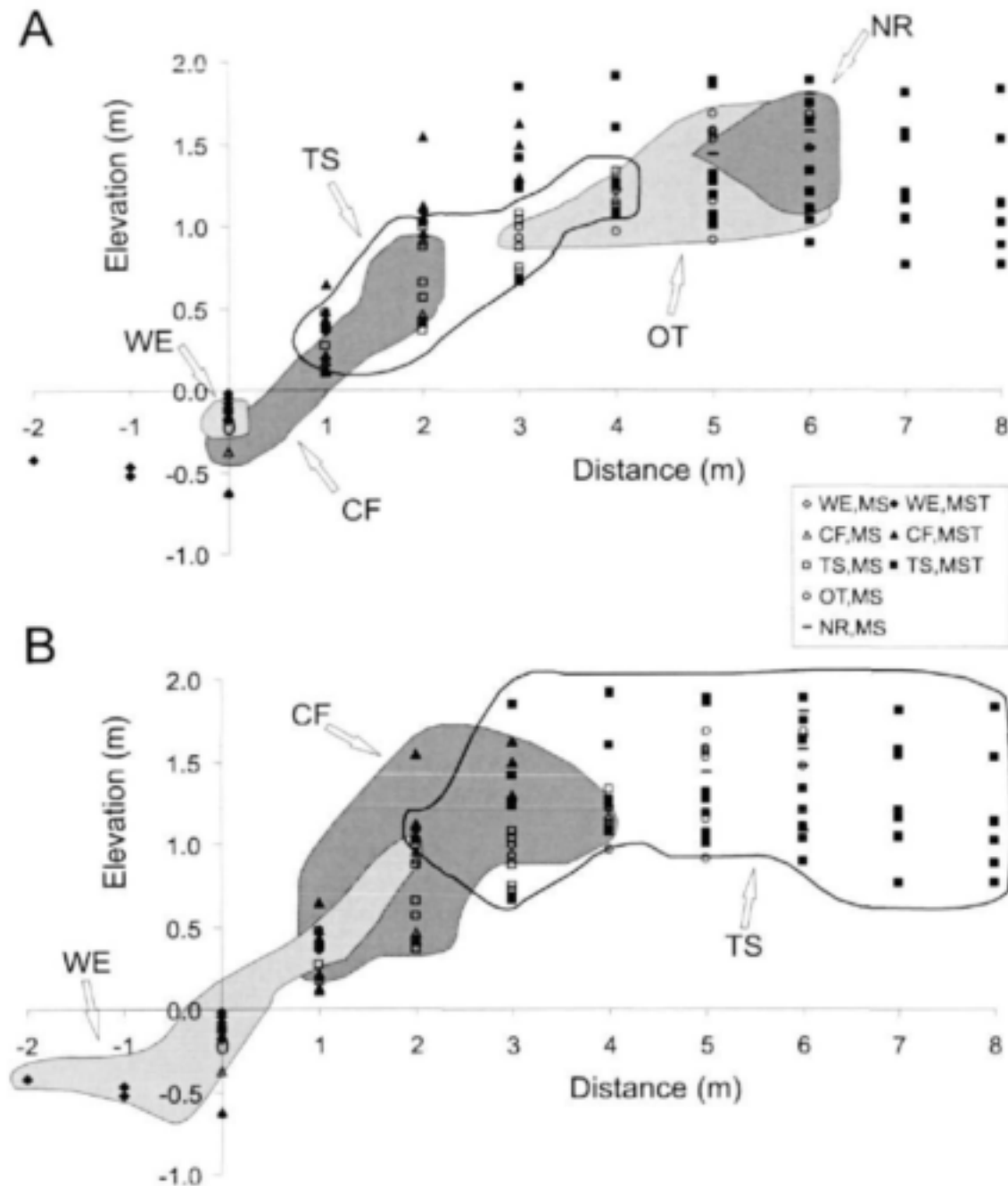


Figure 4.11 Elevation and distance from low flow water's edge for all sample plots at the four Rondegat River sites. Outline (A) are sample plots at Ron1 & Ron2 in the mountain stream [MS] and outline (B) are sample plots at Ron3 & Ron4 in the mountain stream (transitional) [MST] zones respectively. The five assemblage types are shown: WE = Water's Edge, CF = Channel Fringe, TS = Tree Shrub, OT = Outer Transitional and NR = Non Riparian.

Hek 1: mountain stream (transitional) zone (pool)

Hek1 was situated alongside a pool. It consisted of a well-defined riparian zone within the confines of a well defined macro-channel. The riparian zone canopy was dense and closed with two stratified layers: a tall canopy cover of mature Riparian Scrub trees beneath which were juveniles and seedlings of these same trees and forbs and sedges.

Three main groupings were recognized, each split into two assemblages (Figure 4.12): WE and CF (assemblages 1 and 2 respectively), TS (assemblages 3 and 4) and OT (assemblages 5 and 6).

WE reached from below water level to an elevation of 0.26 m, and contained species already familiar from the Rondegat River (Table 4.10): *Isolepis prolifer*, *Calopsis paniculata*, juveniles and seedlings of *Morella serrata* and seedlings of *Brabejum stellatifolium*. A new species considered to be obligatory riparian, *Salix mucronata* (the Cape willow), was the most abundant and frequent plant, along with the riverine restio *Calopsis paniculata*.

CF covered an elevation range from just below water level to 0.80 m (Figure 4.13), and contained all species found in WE other than *Salix mucronata*, but each with a reduced frequency and cover. The sedge, *Isolepis prolifer*, found mainly in the WE assemblages of the Rondegat River, was most abundant in CF at this site. Species common in CF assemblages at Rondegat that made their first appearance in CF at this site were *Metrosideros angustifolia* seedlings, *Prionium serratum* and *Elegia capensis*, while those not recorded at Rondegat included the sedge *Cyperus glomerata*, the shrub *Freylinia lanceolata* (restricted to CF at this site) and the grass *Panicum schinzii*.

TS ranged from 0.15-1.57 elevation, and was the second most speciose assemblage type. It was dominated particularly by juveniles and adults of *Metrosideros angustifolia* and *Morella serrata*, with seedlings and juveniles of *Brabejum stellatifolium* and *Brachylaena neriifolia* respectively also present. TS marked the outer limit of distribution of *Calopsis paniculata*, *Isolepis prolifer*, *Prionium serratum*, *Elegia capensis* and *Cyperus denudatus* among others. *Panicum schinzii* reached its highest frequency and cover, and the sedge *Mariscus thunbergii*, the small tree *Rhus angustifolia*, the grass *Ehrharta rehmannii* and the shrub *Diospyros glabra* first appeared in TS. There was a first occurrence of some species typical of drier habitats, such as *Stoebe plumosa* and *Elytropappus intricata*.

OT occurred between 1.16 and 2.34 m elevation and was the richest in species. Adults of the small trees *Metrosideros angustifolia* and *Morella serrata* persisted into this assemblage type, but were more abundant in TS. Mixed with them was a small tree species typical of outer riparian zones, *Rhus angustifolia*, and a large array of species common to drier habitats (Table 4.10). Species prominent in OT and NR on the Rondegat River and also found in OT at this site included *Ficinia indica*, *Diospyros glabra*, *Pelargonium scabrum*, *Cliffortia ruscifolia*, *Elytropappus intricata* and *Dodonaea viscosa*.

The distribution of the assemblage types up the bank followed the same pattern as that recorded for the Rondegat River (Figure 4.13). The heights and positions of the assemblage types are similar to those found on the Rondegat River, with WE below and in line with the water's edge, CF up to almost 1 m

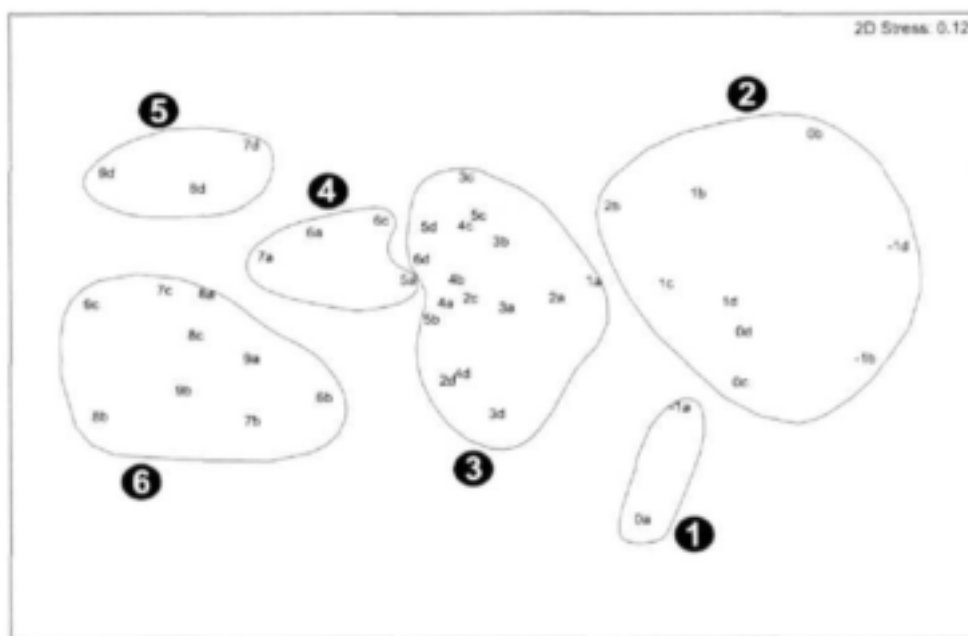
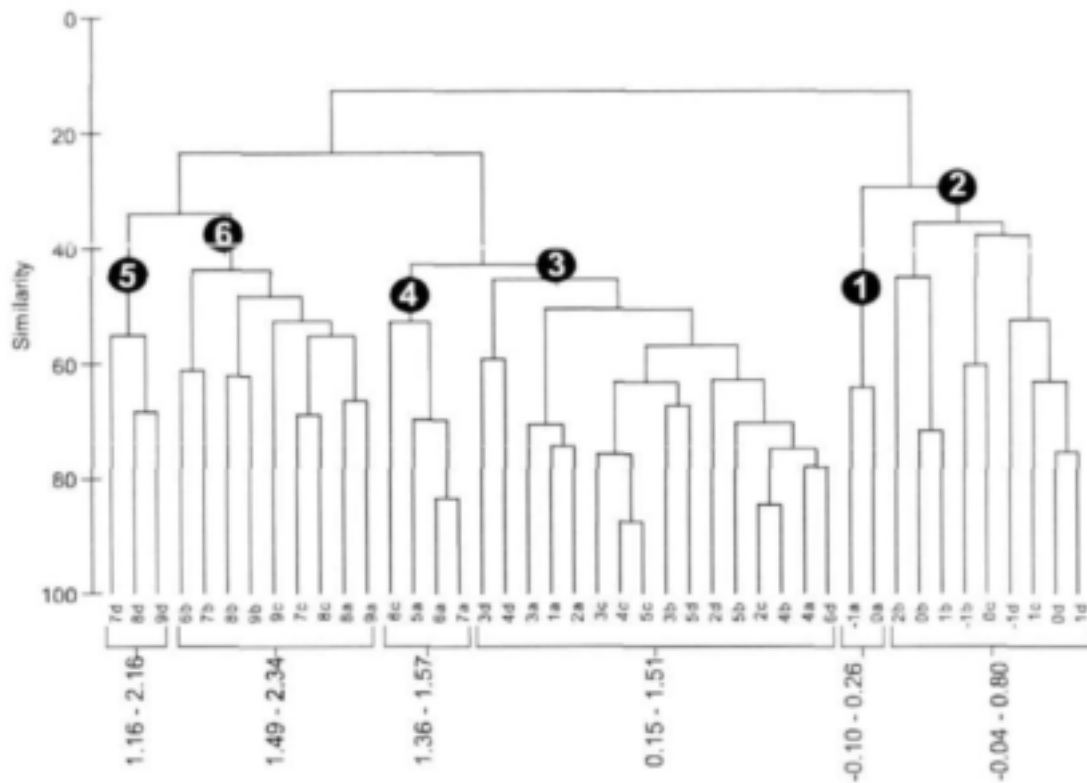


Figure 4.12 CLUSTER analysis and Non-metric MDS ordination for all samples at Hek1 on the Heks River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level, are shown on the dendrogram.

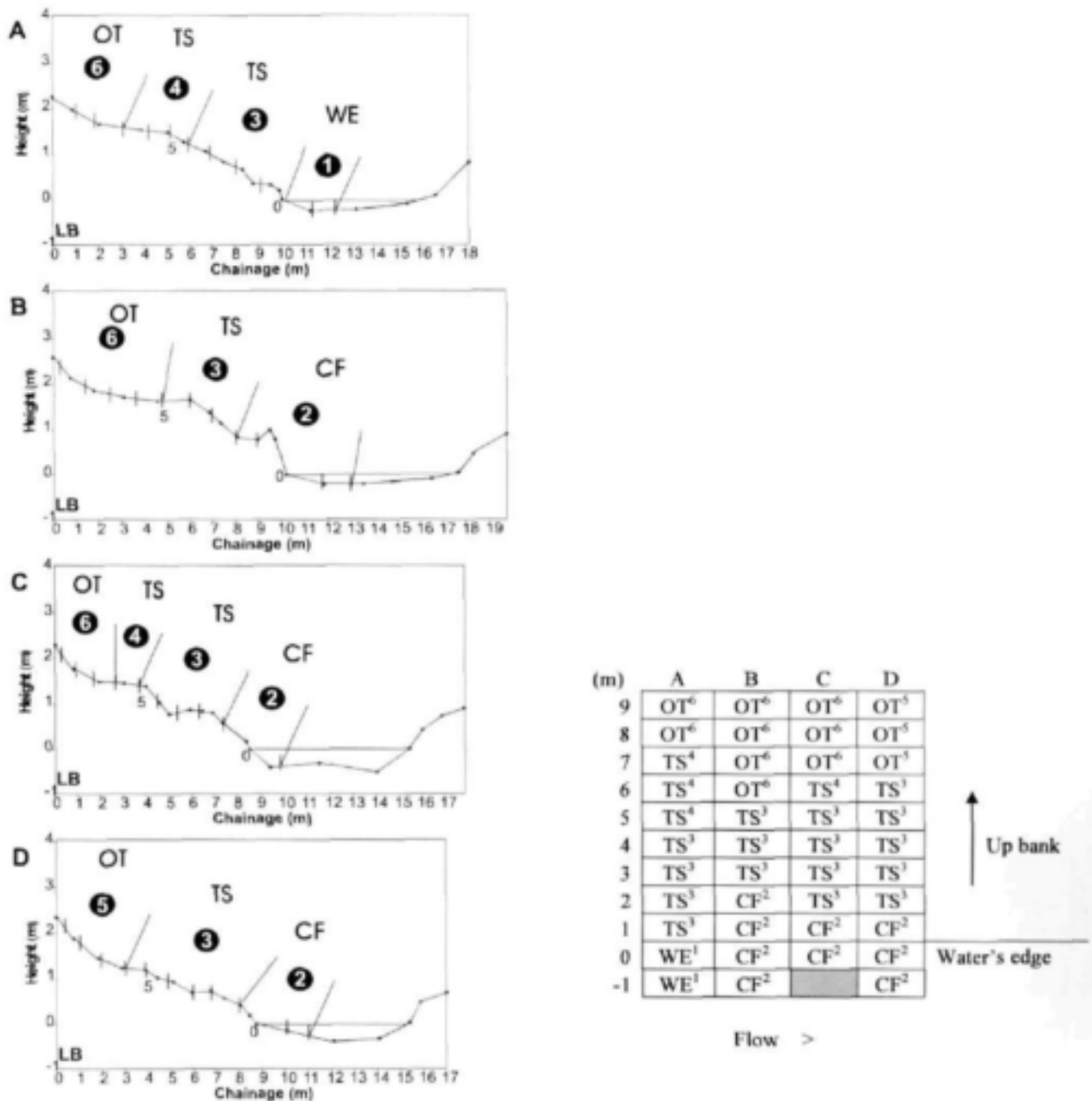


Figure 4.13 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.12 and the assemblage types they represent (Table 4.10) in the four vegetation blocks (A through D) at Hek1 on the Heks River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. Grey box = no sample.

Table 4.10 The percent frequency (F) and the average cover in each assemblage type for all species at Hek1. The assemblage type assigned to the six assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type												
	1 (n=2)		2 (n=6)		3 (n=3)		4 (n=14)		5 (n=2)		6 (n=9)	
Physical variables	Wet Edge		Channel Fringe		Tree Shrub		Outer Transitional					
% sand	8		18		72		69		33		42	
% rock	93		77		28		31		67		56	
% water	95		74		11		0		0		0	
Elevation above summer low water (m)	-0.10-0.26		-0.04-0.80		0.15-1.51		1.36-1.57		1.16-2.16		1.49-2.34	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Salix mucronata</i> (0.3-2m)	100	3.5										
<i>Salix mucronata</i> seedling	100	1.0										
<i>Isolepis prolifer</i>	50	1.5	100	17.2	19	3.4						
<i>Calopsis paniculata</i>	100	10.0	67	14.4	100	17.0	50	0.2				
<i>Morella serrata</i> (0.3-2m)	50	1.5	11	0.2	56	3.5	75	0.3			11	1.0
<i>Brabejum stellatifolium</i> seedling	50	0.5			6	0.1						
<i>Morella serrata</i> seedling	50	0.3	33	1.2	19	0.4					11	0.2
<i>Prionium serratum</i>			33	9.4	6	0.1						
<i>Elegia capensis</i>			33	2.0	63	11.2	25	0.2				
<i>Carpha glomerata</i>			22	1.2	19	1.2						
<i>Cyperus demidatus</i>			22	0.4	31	1.9						
<i>Metrosideros angustifolia</i> seedling			22	0.4								
<i>Freylinia lanceolata</i> (2-5m)			11	0.3								
<i>Pennisetum macrourum</i>			11	0.2	38	3.8						
<i>Brachylaena nerifolia</i> (0.3-2m)					6	0.1						
<i>Psoralea</i> sp.2							25	0.1				
<i>Panicum schinzii</i>			22	0.6	69	7.3	75	0.8	33	0.2		

	1 (n=2)	2 (n=6)	3 (n=3)	4 (n=14)	5 (n=2)	6 (n=9)		
	Wet Edge	Channel Fringe	Tree Shrub		Outer Transitional			
<i>Mariscus thunbergii</i>			75	6.9	25	0.2	11	0.4
<i>Morella serrata</i> (2-5m)			69	9.8	100	0.5	22	0.9
<i>Stoebe plumosa</i>			19	1.9			67	0.3
<i>Metrosideros angustifolia</i> (0.3-2m)			56	7.4			67	0.3
<i>Metrosideros angustifolia</i> (2-5m)			88	28.8	100	31.3	67	0.3
<i>Ehrharta rehmannii</i>			13	1.8	75	0.4	100	28.3
<i>Diospyros glabra</i>			6	0.1	100	0.4	100	0.4
<i>Elytropappus intricate</i>					75	0.5		33
<i>Rhus angustifolia</i>					25	0.2		100
<i>Rhus lucida</i> forma elliptica							100	0.3
<i>Oscularia ornate</i>							67	0.1
<i>Crassula rupestris</i> subsp. <i>rupestris</i>							33	0.3
<i>Ficinia indica</i>							33	0.0
<i>Pelargonium scabrum</i>							33	0.0
<i>Cliffortia ruscifolia</i>								44
<i>Eragrostis sarmentosa</i>								33
<i>Phylica oleaefolia</i> (2-5m)								11
<i>Ischyrolepis sieberi</i>								11
<i>Anthospermum spathulatum</i>								11
<i>Dodonaea viscosa</i> (0.3-2m)								11
<i>Dodonaea viscosa</i> seedling								11
<i>Asparagus rubicundus</i>								11

above summer low-flow level and TS up to 1.5 m above it. The lower limit of OT is more than 1 m above the low-flow level and peters out just above 2.0 m.

Hek 2: mountain stream (transitional) zone (riffle)

Hek2 was situated alongside a riffle just downstream of the pool at Hek1. Again the riparian zone vegetation was confined within the macro-channel. The structure and canopy of the riparian zone was similar to that at Hek1.

Five main groups were revealed in the CLUSTER and MDS ordinations (Figure 4.14): assemblage 1 (WE), 2 and 3 (CF), 4 (TS) and 5 (OT).

WE occurred from just below the water line to 0.15 m elevation above it and was unusually rich in species. There was an abundant mix of seedlings of *Metrosideros angustifolia*, *Brachylaena neriifolia*, *Morella serrata* and *Salix mucronata*, along with occasional adults of *Morella serrata* (Table 4.11). Among these were high covers of typical wetland species such as *Calopsis paniculata*, *Isolepis prolifer* and *Wimmerella arabidea*, the first two species also being abundant in WE at Hek1.

As with WE, the CF assemblage type was unusually high in species numbers, many being species that first appeared in WE and reached their outer distribution limit in CF: *Calopsis paniculata*, *Cyperus denudatus*, *Pennisetum macrourum* and *Salix mucronata* among others. Some reached their highest abundance in CF: *Panicum schinzii* and adults and juveniles of *Morella serrata*, for instance. Typical CF species from the Rondegat River, such as *Elegia capensis* and the sedge *Carpha glomerata* only occurred in this assemblage type, as did *Brabejum stellatifolium* (adults) which were more typical of TS or OT on the Rondegat. Some species characteristic of the Rondegat's outer riparian zone also appeared in CF, such as *Rhus angustifolia*, suggesting that there were patches of higher or drier ground in this assemblage type or that tongues of underground seepage were facilitating extension of CF assemblages further up the bank than usual.

TS was located at 1.22-2.68 m above summer low water level (Figure 4.15) and was the poorest assemblage type in species numbers. It consisted almost entirely of juveniles and adults of *Morella serrata* and *Metrosideros angustifolia*, with a few species typical of the outer riparian zone at the Rondegat (e.g. *Diospyros glabra*, *Rhus angustifolia*) or drier landscapes (e.g. *Arctotis revoluta*, *Eragrostis sarmentosa*).

OT occurred from 1.43 to 3.04 m elevation, and had a wide variety of species. The tree species mentioned for TS and the grass *Ehrharta rehmannii* showed a decline in cover, and the species from drier habitats generally became more abundant, as at Hek1 and some of the Rondegat sites. Other species found in the OT assemblage type both here and at Rondegat included *Dodonaea viscosa*, *Pelargonium scabrum*, *Maytenus oleoides* and *Ficinia indica*.

The same distribution of assemblages up the bank was evident as at Hek1 and the Rondegat sites (Figure 4.15). Hek2 differed, however, in supporting species not found at the Rondegat sites, and having a more speciose WE and CF and a depauperate TS that covered a relatively small area.

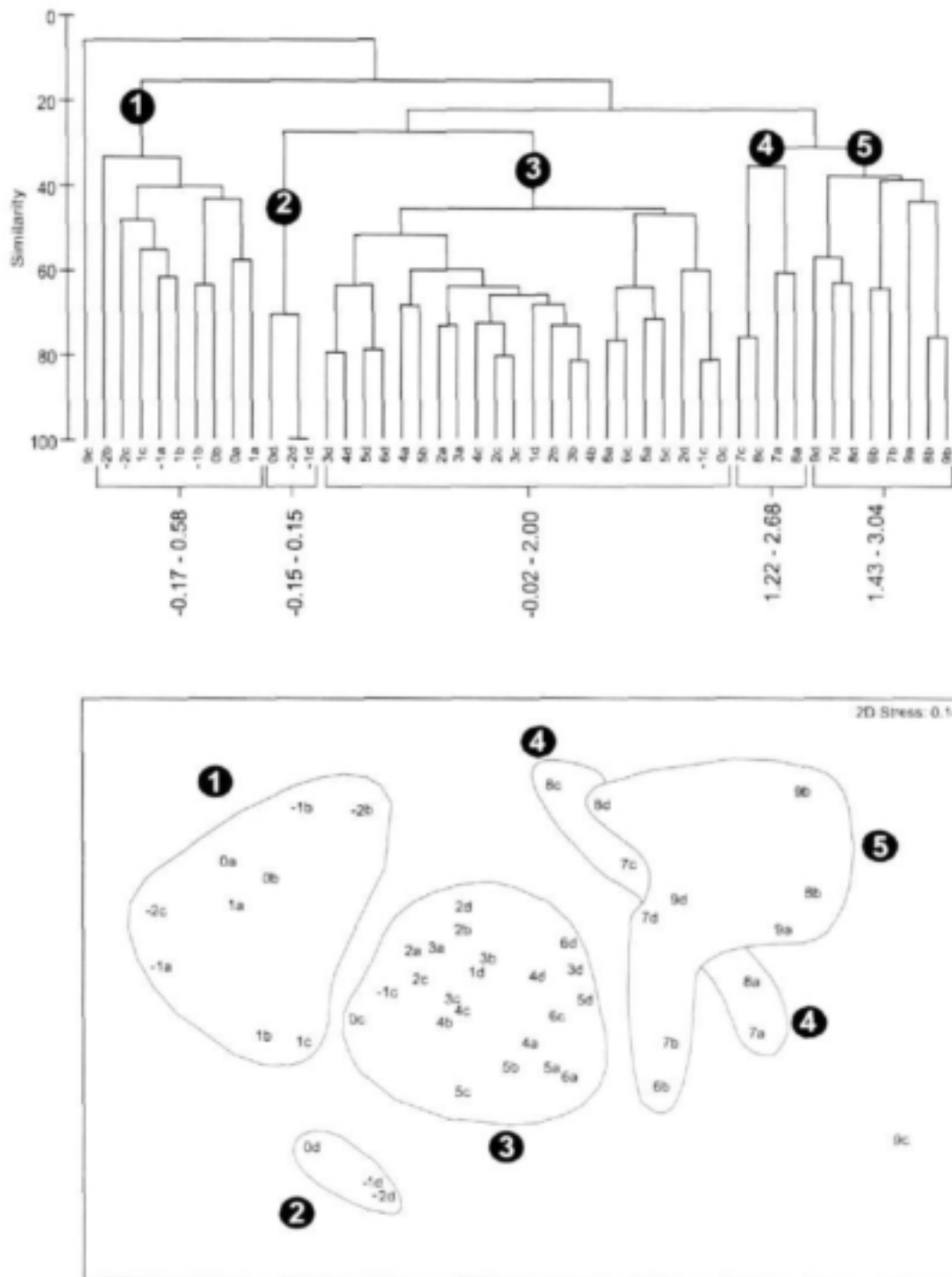


Figure 4.14 CLUSTER analysis and Non-metric MDS ordination for all samples at Hek2 on the Heks River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level, are shown on the dendrogram.

Table 4.11 The percent frequency (F) and the average cover in each assemblage type for all species at Hek2. The assemblage type assigned to the five assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type										
	1 (n=9)		2 (n=3)		3 (n=21)		4 (n=4)		5 (n=8)	
Physical variables	Wet edge		Channel fringe		Tree/shrub		Outer transitional			
% sand	0		9		60		9		21	
% rock	85		91		40		91		79	
% water	67		72		13		0		0	
Elevation above summer low water (m)	-0.15-0.15		-0.17-0.58		-0.02-2.00		1.22-2.68		1.43-3.04	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Metrosideros angustifolia</i> seedling	44	0.7								
<i>Brachylaena neriifolia</i> seedlings	44	0.5								
<i>Prionium serratum</i>	11	0.2								
<i>Wimmerella arabidea</i>	22	0.8								
<i>Isolepis prolifer</i>	67	17.9	33	5.0	18	3.0				
<i>Panicum schinzii</i>	22	2.2	100	56.7	95	23.1			25	7.5
<i>Calopsis paniculata</i>	100	21.1			59	12.4				
<i>Cyperus denudatus</i>	33	0.6			5	0.1				
<i>Morella serrata</i> seedlings	22	0.2			18	0.3				
<i>Pennisetum macrourum</i>	11	2.8			36	4.6				
<i>Freylinia lanceolata</i> 2-5	11	0.7			18	3.4				
<i>Salix mucronata</i> seedling	11	0.1			5	0.0				
<i>Carpha glomerata</i>					14	0.8				
<i>Elegia capensis</i>					9	0.9				
<i>Brabejum stellatifolium</i> 2-5					9	0.3				
<i>Psoralea</i> sp.2					5	0.2				
<i>Freylinia lanceolata</i> 0.3-2					5	0.2				
<i>Kiggelaria africana</i> seedlings					5	0.0				

	1 (n=9)		2 (n=3)		3 (n=21)		4 (n=4)		5 (n=8)	
	Wet edge		Channel fringe		Tree/shrub		Outer transitional			
<i>Metrosideros angustifolia</i> 0.3-2	44	2.1	41	3.7	50	11.8	13	0.3		
<i>Morella serrata</i> 0.3-2	22	1.0	64	4.0			25	3.4		
<i>Morella serrata</i> 2-5	11	0.2	77	16.2	25	3.0	38	8.1		
<i>Metrosideros angustifolia</i> 2-5			73	19.8	75	30.0	25	5.0		
<i>Mariscus thunbergii</i> (Vahl) Schrad.			59	4.3			13	0.4		
<i>Diospyros glabra</i>			36	4.2	100	3.5	100	16.0		
<i>Ehrharta rehmannii</i>			27	5.0	75	13.8	75	7.3		
<i>Rhus angustifolia</i>			14	1.1	50	20.5	50	6.6		
<i>Rhus lucida</i> forma elliptica			9	0.9			100	13.5		
<i>Cliffortia ruscifolia</i>			5	0.2			25	2.3		
<i>Arctotis revoluta</i>					50	2.8				
<i>Eragrostis sarmentosa</i>					25	3.8				
<i>Crassula rupestris</i> Thunb. subsp. <i>rupestris</i>					25	1.0	13	1.3		
<i>Anthospermum spathulatum</i>							38	1.5		
<i>Ischyrolepis gaudichaudianus</i> var <i>gaud.</i>							25	1.9		
<i>Maytenus oleoides</i> 0.3-2							25	1.1		
<i>Euryops abrotanifolius</i>							25	0.8		
<i>Pelargonium scabrum</i>							25	0.4		
<i>Olea</i> sp.1 2-5							13	1.0		
<i>Kiggelaria africana</i> 0.3-2							13	0.6		
<i>Phyllica oleaefolia</i> 0.3-2							13	0.5		
<i>Oscularia ornata</i> (L. Bolus) H.E.K. Hartmann							13	0.5		
<i>Ficinia indica</i>							13	0.4		
<i>Dodonaea viscosa</i> 0.3-2							13	0.4		
<i>Chelianthes contracta</i>							13	0.1		

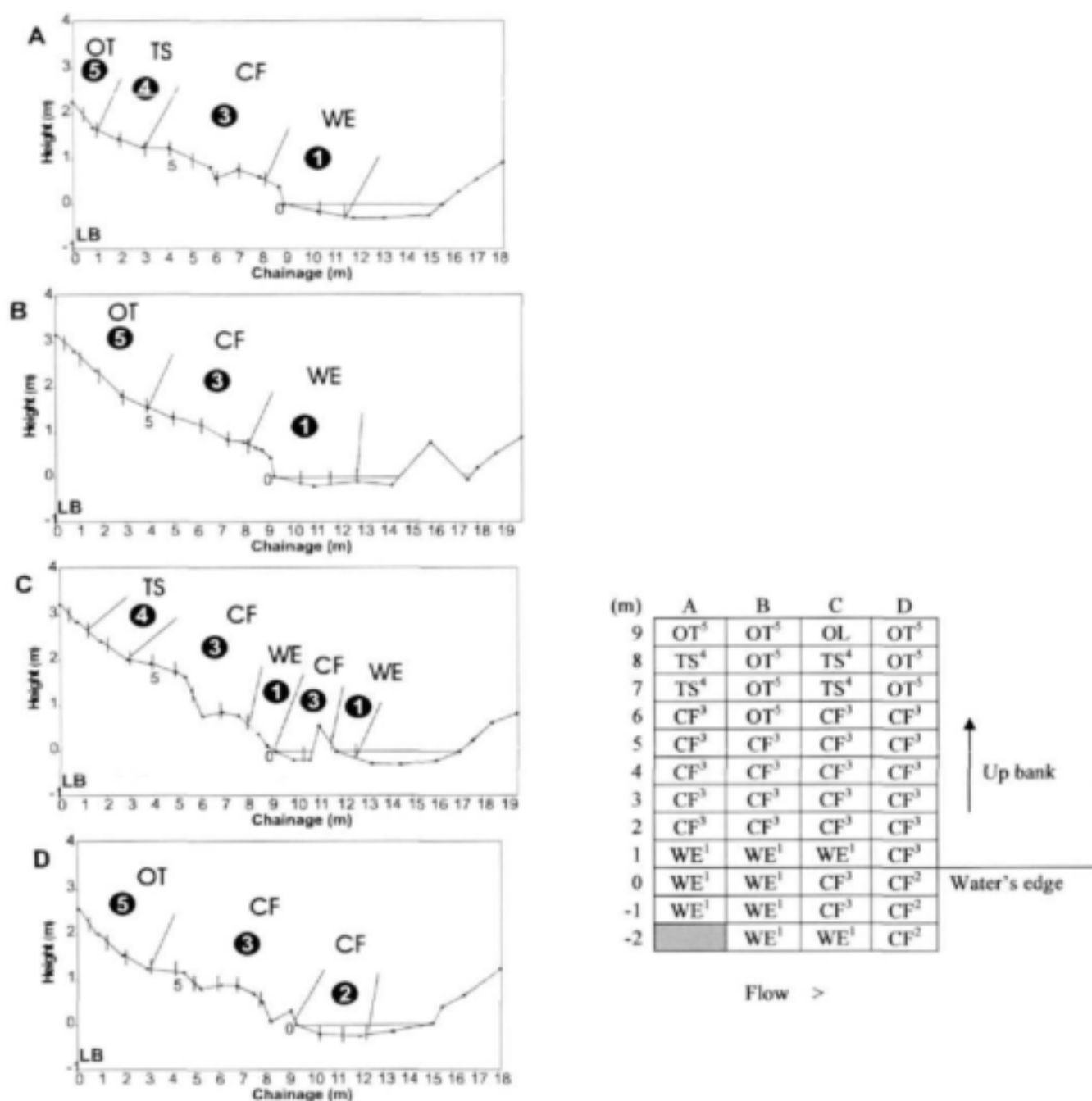


Figure 4.15 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.14 and the assemblage types they represent (Table 4.11) in the four vegetation blocks (A through D) at Hek2 on the Heks River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier, grey box = no sample.

Hek 3: foothill zone (pool)

Hek 3 was situated alongside a pool in a much wider valley than occurred at the upper two sites. The riparian vegetation was less dense and generally more prominent alongside the channel, and in some places extended sparsely out onto a floodplain with secondary flood channels.

Four main groups separated from one another in the CLUSTER analysis (Figure 4.16): assemblage 1 (assigned WE), assemblages 2 and 3 (assigned CF), assemblages 4 and 5 (assigned TS) and assemblage 6 (assigned OT). Again the inaccuracy of the cross-sections to record the channel edge makes it appear as if WE is under water (Figure 4.17).

WE supported only three species. Two of these - *Isolepis prolifer* and the very common *Calopsis paniculata* - were characteristic of this assemblage type at other Heks sites as well as at the Rondegat ones (Table 4.12), while the third - *Panicum shinzii* - occurred in WE and CF at Hek1 and Hek2.

CF was located between 0.20 and 0.79 m elevation, and was quite speciose. All three species from WE were present, with *Calopsis paniculata* reaching its highest cover in this assemblage type. Three of the four small tree species listed in the sites above were common, mostly as seedlings, juveniles and adults, with only *Brabejum stellatifolium* absent. Mixed with these were characteristic wetland species, such as *Drosera* spp., *Elegia capensis* and *Cyperus denudatus*, all but the last one confined to CF. This is in contrast to the Rondegat sites where *Elegia capensis* was prolific and tended to occur from CF through to OT.

TS ranged through elevations 0.80 to 1.49 m, and was dominated by juveniles and adults of *Metrosideros angustifolia* and *Morella serrata* and the shrub *Freylinia lanceolata*. There was a lower cover of *Brachylaena neriifolia* adults and a single seedling of *Brabejum stellatifolium*. Several species were unique to TS, including outer riparian ones such as *Rhus angustifolia* and *Maytenus oleoides*, along with a few species from drier habitats, such as *Stoebe plumosa*, which was found in a similar position at Ron1 and Hek1. Other species typical of TS at this and other Heks sites were *Diospyros glabra* and *Ehrharta rehmannii*.

OT, situated at 1.10 – 1.59 m elevation, was poor in species and numbers of sample plots. It was dominated by *Diospyros glabra* and *Elytropappus intricata*, with a smaller cover of *Ehrharta rehmannii*, *Stoebe plumosa* and *Rhus angustifolia*.

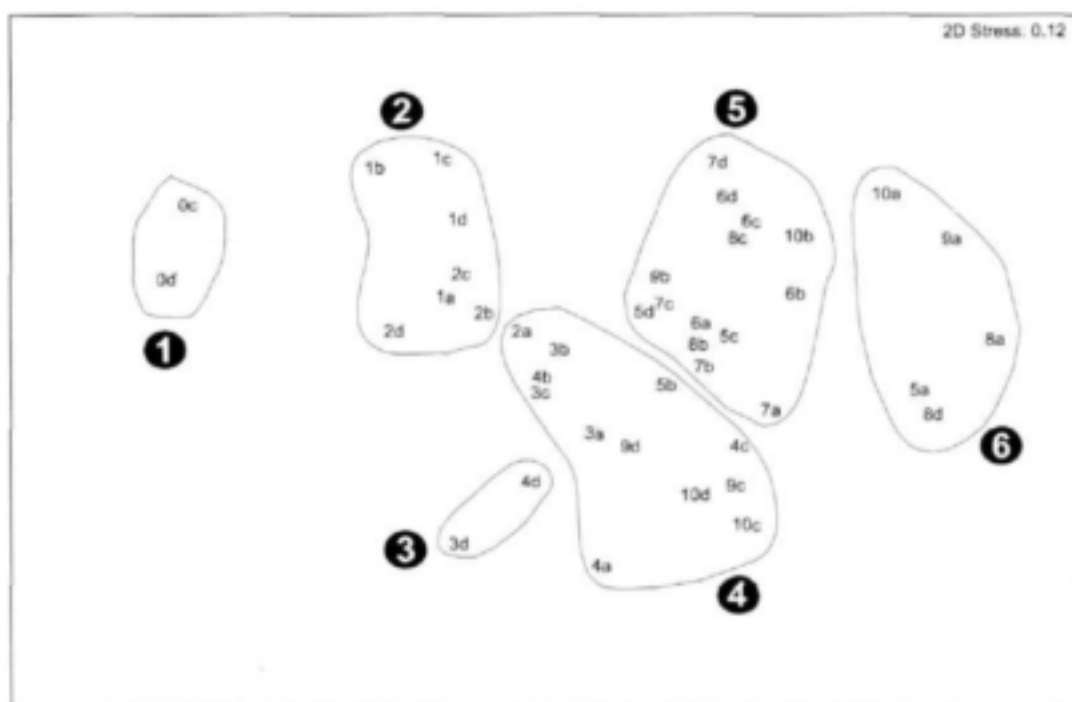
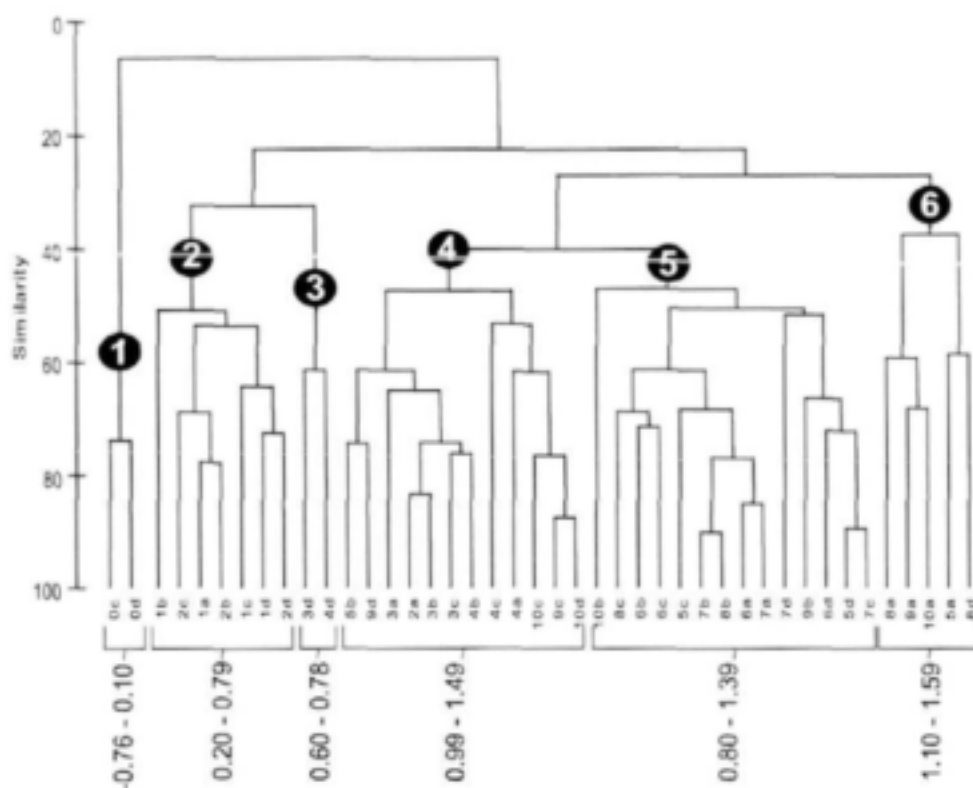


Figure 4.16 CLUSTER analysis and Non-metric MDS ordination for all samples at Hek3 on the Heks River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level, are shown on the dendrogram

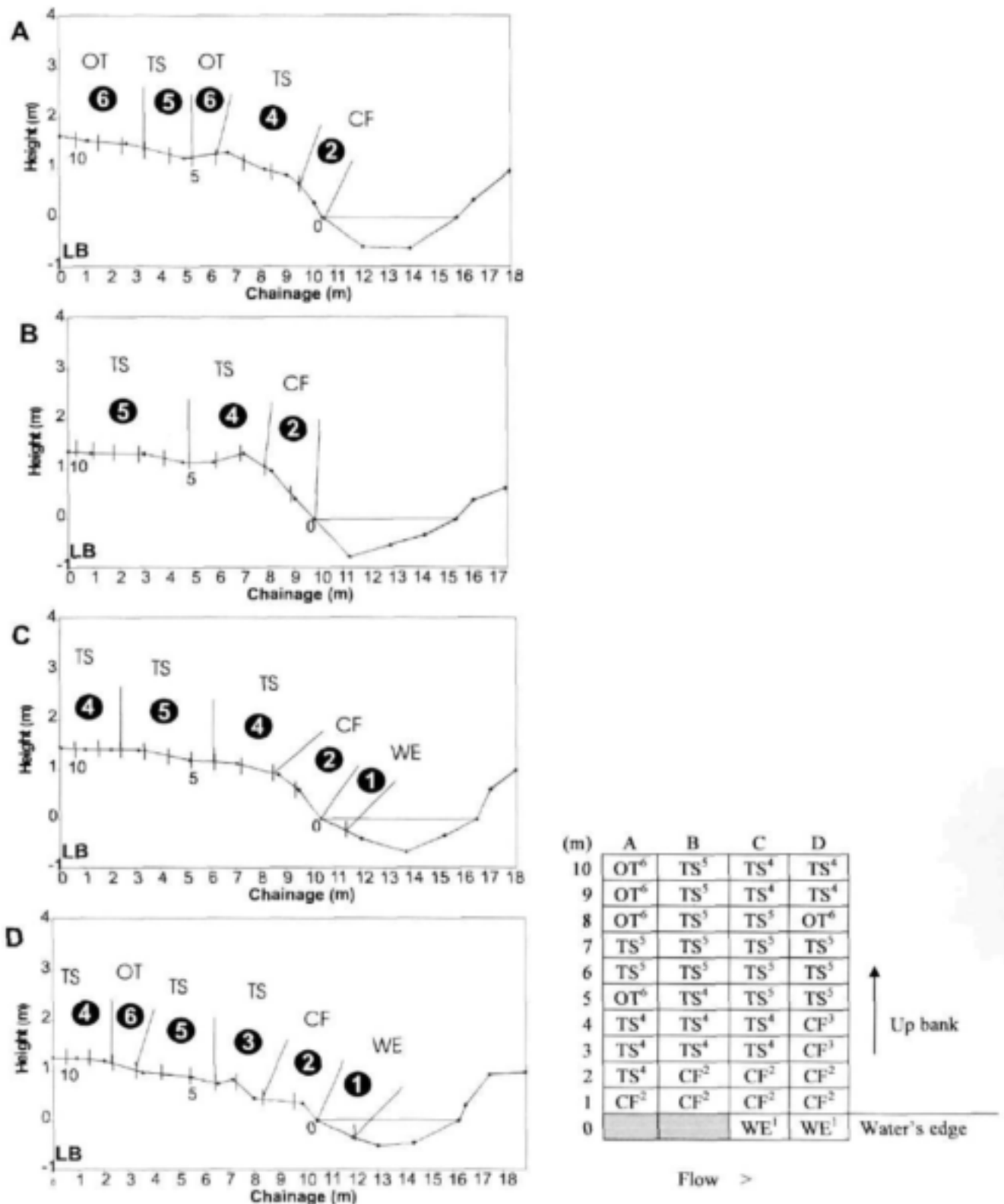


Figure 4.17 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.16 and the assemblage types they represent (Table 4.12) in the four vegetation blocks (A through D) at Hek3 on the Heks River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. Grey box = no sample.

Table 4.12 The percent frequency (F) and the average cover in each assemblage type for all species at Hek3. The assemblage type assigned to the six assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type												
	1 (n= 7)		2 (n=7)		3 (n=2)		4 (n=7)		5 (n=14)		6 (n=5)	
Physical variables	Wet Edge		Channel Fringe		Tree Shrub		Tree Shrub		Outer Transitional		Outer Transitional	
% sand	9		43		50		42		40		36	
% rock	91		57		50		58		60		64	
% water	95		33		0		0		0		0	
Elevation above summer low water (m)	-0.76- -0.10		0.20-0.79		0.60-0.78		0.99-1.49		0.80-1.39		1.10-1.59	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Panicum schinzii</i>	100	5.0	57	3.9								
<i>Isolepis prolifer</i>	50	3.0	14	0.9								
<i>Drosera</i> spp.			71	2.7								
<i>Cyperus demidatus</i>			71	2.4			8	0.3				
<i>Metrosideros angustifolia</i> seedling			71	1.6								
<i>Elegia capensis</i>			43	5.9								
<i>Brachylaena neriifolia</i> (0.3-2m)			29	0.4								
<i>Isolepis digitata</i>			14	1.4								
<i>Calopsis paniculata</i>	100	7.5	100	16.9			33	3.2				
<i>Elegia capensis</i>							42	5.8				
<i>Metrosideros angustifolia</i> (2-5m)			71	17.4	100	26.5	100	32.0	57	9.1		
<i>Morella serrata</i> (2-5m)			71	6.1	50	2.0	58	10.7	93	20.6		
<i>Metrosideros angustifolia</i> (0.3-2m)			71	5.0	50	8.0			29	1.5		
<i>Brachylaena neriifolia</i> (2-5m)			43	5.6	100	46.0	8	0.4				
<i>Morella serrata</i> seedling			29	0.7	50	0.5	17	0.3	14	0.1		
<i>Morella serrata</i> (0.3-2m)			86	3.1					43	2.5	20	1.6

	1 (n= 7)	2 (n=7)	3 (n=2)	4 (n=7)	5 (n=14)	6 (n=5)
	Wet Edge	Channel Fringe		Tree Shrub		Outer Transitional
<i>Mariscus thunbergii</i>					7 0.2	
<i>Eragrostis sarmentosa</i>					7 0.1	
<i>Ischyrolepis sieberi</i>					7 0.1	
<i>Brabejum stellatifolium</i> seedling					7 0.1	
<i>Freylinia lanceolata</i> (2-5m)				67 8.4		
<i>Rhus lucida</i> forma elliptica				17 0.3		
<i>Freylinia lanceolata</i> (0.3-2m)				8 1.7		
<i>Maytenus oleoides</i> (0.3-2m)				8 0.3		
<i>Dodonaea viscosa</i> (0.3-2m)				8 0.2		
<i>Diospyros glabra</i>				92 4.8	100 8.0	100 5.4
<i>Ehrharta rehmannii</i>				8 0.2	43 5.4	40 1.8
<i>Stoebe plumosa</i>				8 0.1	14 1.5	20 0.8
<i>Rhus angustifolia</i>					50 3.6	20 3.0
<i>Elytropappus intricate</i>						60 4.8

The distribution of the assemblage types at this site was relatively patchy. WE only occurred in vegetation blocks C and D and OT in blocks A and D. The transition from TS to OT took place in the pattern described for earlier sites but for a patch of OT found within TS on cross-sections A and D. The lower limits of the height ranges for the assemblage types agree with those given on the Rondegat River. The upper limits of all assemblages are one metre higher on the Heks.

Hek 4: foothill zone (riffle)

Hek4 was situated just downstream of Hek3 alongside a riffle, a high point in the channel, and in the same terrain as described for Hek3.

Three main groups were formed from all samples at this site; assemblages 1 (WE) and 2 (CF), assemblages 3 to 6 (TS) and lastly assemblage 7 (OT) (Figure 4.18).

WE contained only the sedge *Isolepis prolifer*, recognized throughout these sites as characteristic of this assemblage type (Table 4.13).

CF also contained a high cover of *Isolepis prolifer*, along with *Calopsis paniculata* and lower covers of other typical species such as *Drosera* spp., *Cyperus denudatus* and *Mariscus thunbergii*. The remaining species in CF were the common small trees *Brachylaena neriifolia*, *Morella serrata* and *Metrosideros angustifolia*, present mostly as seedlings and juveniles.

TS encompassed most of the sample plots and assemblages, ranging in elevation from 0.26-1.24 m. It was dominated by the small tree species commonly listed in earlier sites, and included *Brabejum stellatifolium* and *Freylinia lanceolata*, mostly as juveniles and adults but with some seedlings. Many species, such as *Calopsis paniculata*, *Cyperus denudatus* and *Mariscus thunbergii*, reached their outer distribution limit in TS and many (Table 4.13) were only recorded there. The sedge *Isolepis digitata*, also recorded upstream at Hek3, was frequent adjacent to the water, while *Elegia capensis* was the only species prominent in TS but absent from all other assemblage types.

OT ranged from 0.73-1.06 m elevation, and was dominated by the small tree species and mix of outer-riparian and dry-habitat species listed for earlier sites. *Morella serrata* and *Metrosideros angustifolia* were abundant and occurred as seedlings, juveniles and adults, while *Brachylaena neriifolia* (juveniles) and *Freylinia lanceolata* were scarce and present in only one life stage each. *Diospyros glabra* dominated the shrubs, with most other abundant species being outer-riparian species or ones from drier habitats (e.g. *Stoebe plumosa*, *Ehrharta rehmannii* and *Cliffortia ruscifolia*). Unusually, OT occupied a larger area than at any other site (Figure 4.19), and most of its species occurred at low frequencies and abundances since their distribution among the samples of assemblage 7 was sparse. The area may have been recently disturbed, perhaps by fire, but no records of this could be located. If it is disturbed, it might be expected to recover towards the same kind of community as upstream at Hek3 within ten to fifteen years.

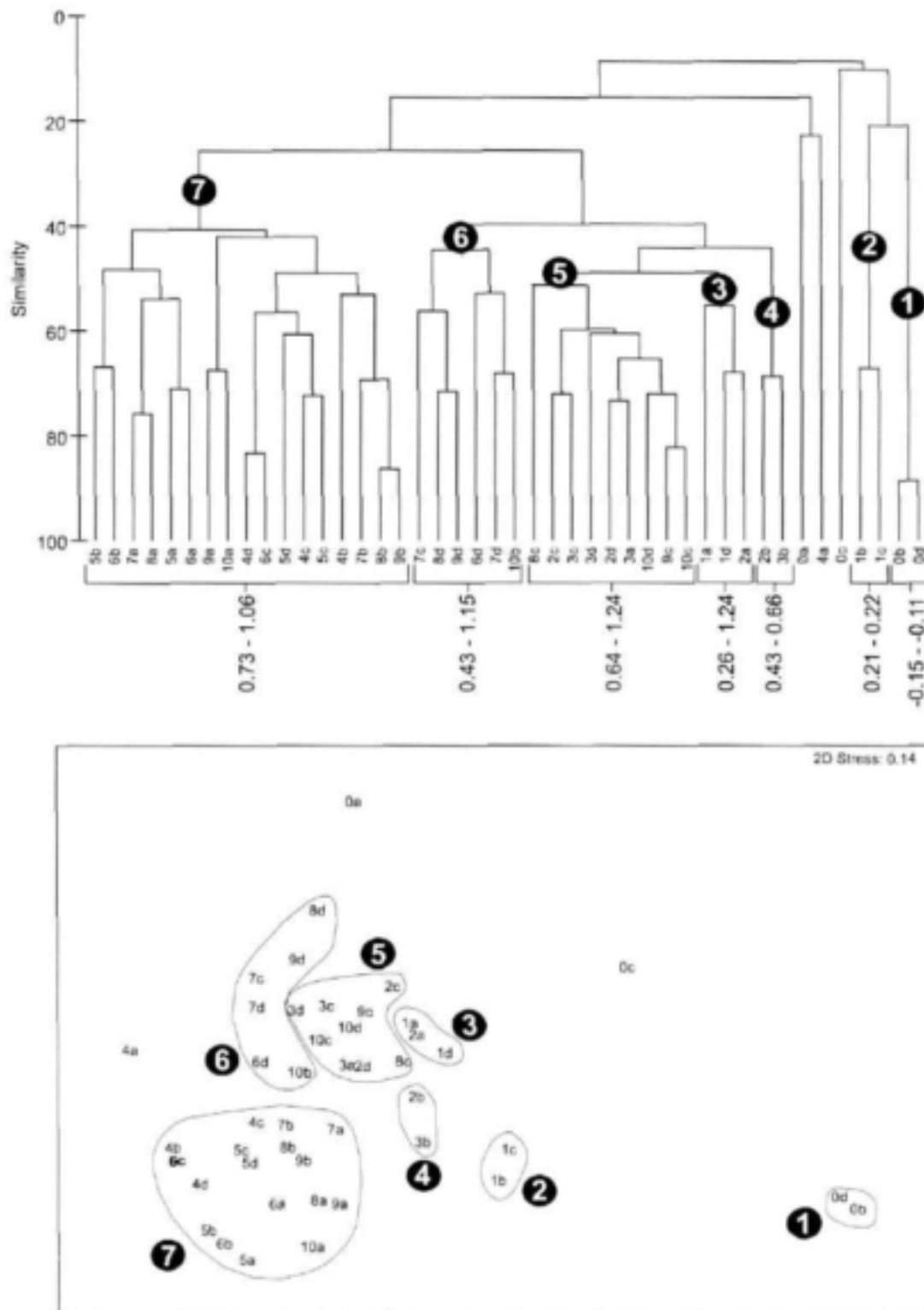


Figure 4.18 CLUSTER analysis and Non-metric MDS ordination for all samples at Hek4 on the Heks River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level, are shown on the dendrogram.

Table 4.13 The percent frequency (F) and the average cover in each assemblage type for all species at Hek4. The assemblage type assigned to the seven assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type														
	1 (n=2)		2 (n=2)		3 (n=2)		4 (n=2)		5 (n=9)		6 (n=6)		7 (n=17)	
Physical variables	Wet Edge		Channel Fringe		Tree Shrub								Outer Transitional	
% sand	0		25		35		13		26		43		26	
% rock	100		75		65		88		74		58		74	
% water	100		73		25		0		0		0		0	
Elevation above summer low water (m)	-0.15- -0.11		0.21-0.22		0.26-1.24		0.43-0.66		0.64-1.24		0.43-1.15		0.73-1.06	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Isolepis prolifer</i>	100	4	100	12.5	33	2.0								
<i>Drosera</i> spp.			50	3.0	67	2.7								
<i>Brachylaena neriifolia</i> seedling			50	0.5	33	0.3								
<i>Calopsis paniculata</i>			100	30.0	67	6.0	100	7.0	78	7.4				
<i>Cyperus denudatus</i>			50	1.5	67	3.3	50	1.5	22	1.1				
<i>Mariscus thunbergii</i>			50	3.0			100	5.0	44	1.3				
<i>Brabejum stellatifolium</i> (0.3-2m)					67	1.7	100	3.5	11	0.3				
<i>Isolepis digitata</i>					67	8.3								
<i>Elegia capensis</i>					100	23.3			100	10.9	50	1.7		
<i>Freylinia lanceolata</i> (0.3-2m)							50	3.0	11	0.4	17	0.8		
<i>Pelargonium scabrum</i>									22	0.4	33	2.3		
<i>Brabejum stellatifolium</i> (2-5m)									11	1.6				
<i>Brachylaena neriifolia</i> (2-5m)											17	5.0		
<i>Phyllica oleaefolia</i> (2-5m)											17	1.3		
<i>Rhus lucida</i> forma elliptica											17	0.2		
<i>Elytropappus intricate</i>											17	0.2		
<i>Morella serrata</i> (0.3-2m)			100	3.5	100	2.7	100	5.5	22	1.8	50	3.3	100	8.0
<i>Metrosideros angustifolia</i> seedling			100	3.0	67	1.7			33	0.3			12	0.2
<i>Morella serrata</i> seedling			100	2.0	33	0.7			11	0.1	17	0.2	24	0.3
<i>Brachylaena neriifolia</i> (0.3-2m)			50	2.0					22	1.1			6	0.2

	1 (n=2)	2 (n=2)	3 (n=2)	4 (n=2)	5 (n=9)	6 (n=6)	7 (n=17)					
	Wet Edge	Channel Fringe	Tree Shrub				Outer Transitional					
<i>Metrosideros angustifolia</i> (2-5m)			100	18.3	50	5.0	89	14.0	100	31.8	6	0.9
<i>Metrosideros angustifolia</i> (0.3-2m)			100	6.3	100	11.0	100	16.3	50	5.8	65	6.3
<i>Morella serrata</i> (2-5m)			67	6.0			22	3.3	83	7.0	12	1.2
<i>Freylinia lanceolata</i> (2-5m)			33	5.0			22	5.4	17	1.0	6	0.5
<i>Diospyros glabra</i>							100	2.8	67	3.3	88	4.8
<i>Rhus angustifolia</i>							11	0.1			6	0.1
<i>Ischyrolepis gaudichaudianus</i> var <i>gand</i>									33	1.2	24	1.1
<i>Stoebe plumosa</i>											53	2.6
<i>Ehrharta rehmannii</i>											35	4.6
Species 17											35	2.1
<i>Cliffortia ruscifolia</i>											29	2.0
<i>Pelargonium scabrum</i>											29	1.2
<i>Ficinia indica</i>											24	0.6
<i>Willdenowia incurvata</i>											12	0.6
<i>Elytropappus intricate</i>											12	0.6
<i>Ischyrolepis gossypina</i>											12	0.5
<i>Crassula rupestris</i> . subsp. <i>rupestris</i>											12	0.2
<i>Rhus lucida</i> forma <i>elliptica</i>											12	0.1

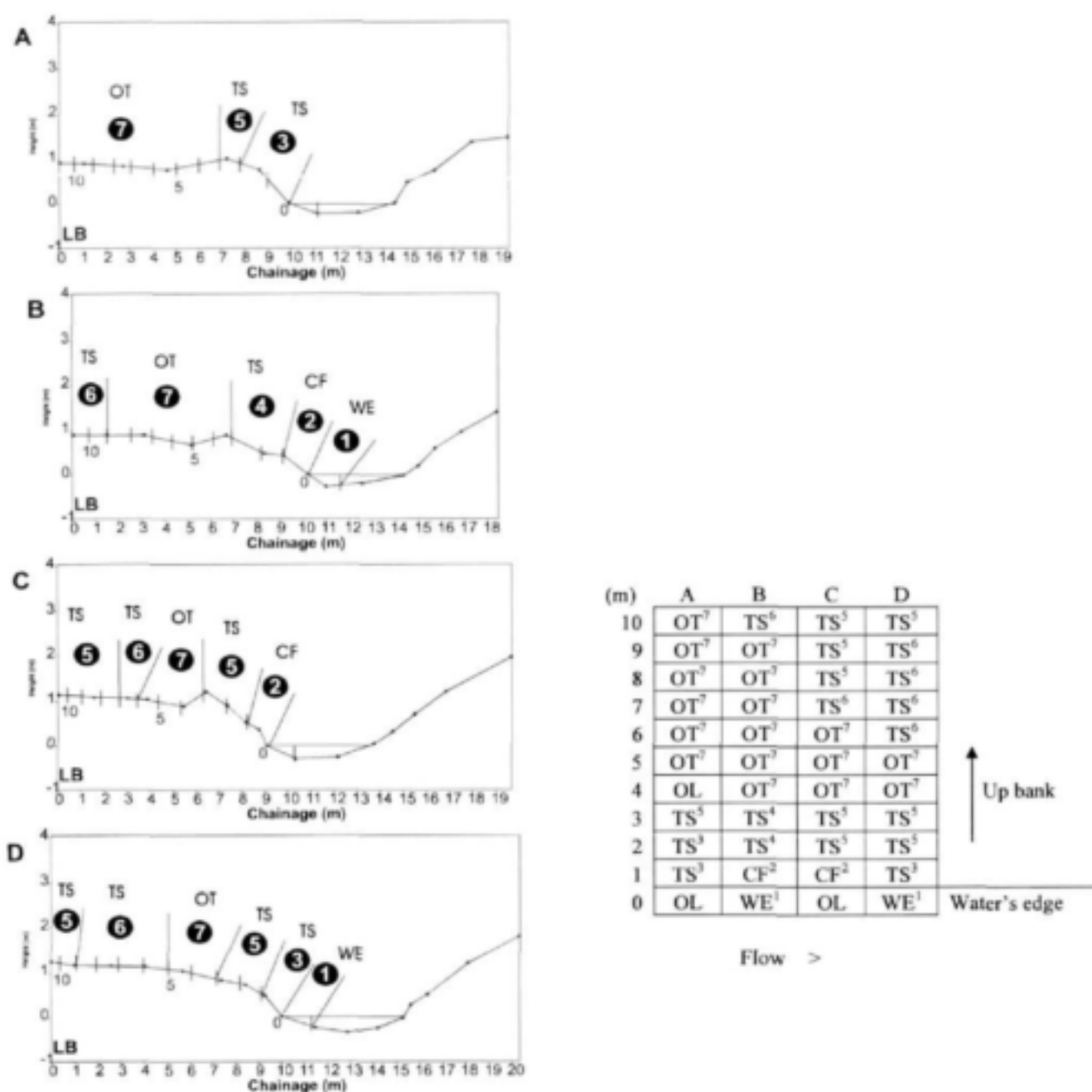


Figure 4.19 Surveilled cross-sections showing the position of vegetation assemblages recognised in Figure 4.18 and the assemblage types they represent (Table 4.13) in the four vegetation blocks (A through D) at Hek4 on the Heks River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier.

Summary of Heks sites

The four sites in the two zones - the mountain stream (transitional) and the foothill - were similar in that four of the five assemblage types were assigned at each site, but they differed in terms of which

assemblage types were dominant. Hek1 consisted mainly of TS, Hek2 of CF, Hek3 of TS, and Hek4 equally of TS and OT. Some possible reasons for these differences are:

- the high number of wetland species and hence the abundance of CF at Hek2 may have been due to underground seepage from a nearby tributary.
- Hek4 may have been recently disturbed, possibly by a fire, and this could have caused the paucity of typically wet species and the abundance of drier terrestrial species in OT.

In contrast to the Rondegat sites there was no NR. Prominent species found at the Heks sites but not at Rondegat included *Salix mucronata* in WE, *Panicum schinzii* (mainly in WE) and *Freylinia lanceolata*. Generally, the distribution of typical wet-habitat species and the riparian shrubs and trees again followed the pattern seen on the Rondegat, with mostly wet-habitat species more prominent nearer the water and trees persisting as adults mainly in TS although their seedlings and juveniles were more widely spread. At all sites other than Hek4 there was a logical progression from WE up the bank through the assemblage types.

A plot of the elevation above and distance from the low-flow water's edge, for each sample taken from the four sites on the Heks River shows a gradual progression from WE to OT at the two upper sites where the valley was narrow and the channel confined (Figure 4.20a) and at the two lower sites where the bank gradient was less steep (Figure 4.20b). The same sequence of assemblage types as at the Rondegat occurred up the bank. WE was always at, or extended into, the wetted channel. CF ranged from the channel edge to an elevation of 2.2 m and distance from water of 6.0 m (mountain stream [transitional]) or elevation of 1.0 m and 4.0 m distance (foothill). TS again sprawled over a wide range of elevations and distances and, as at the Rondegat lower floodplain sites, would have shown a wider range if the sample plots had extended to the edge of the floodplain (Figure 4.20b). The elevation range of TS was restricted from 0.15 m to 2.7 m in the mountain stream (transitional) and from 0.4 m to 1.5m in the foothill. The two upper sites on the Rondegat and the Heks Rivers displayed similar patterns for the WE, CF and OT assemblage types and bank profile. The two lower sites on each river were similar in that each had a small floodplain with flood channels beyond the macro-channel; they differed, however, in the abundance and density of riparian scrub in the floodplain, with Rondegat having the more dense foliage.

4.3.5 The Elands River (Hawequas - Breede System)

The Elands is part of the Breede River system, in the Hawequas mountain range. Of its four study sites, two were in the mountain stream zone and two in the foothill zone (Plate 3). The four sites on the Elands are described below.

Ela1: mountain stream (pool)

Ela1 was situated in the mountain stream zone of this river alongside a deep pool, where the valley was narrow and the river banks rocky. The riparian vegetation was relatively sparse compared to the other two rivers, with scattered patches along the river interspersed with large boulders or bedrock.

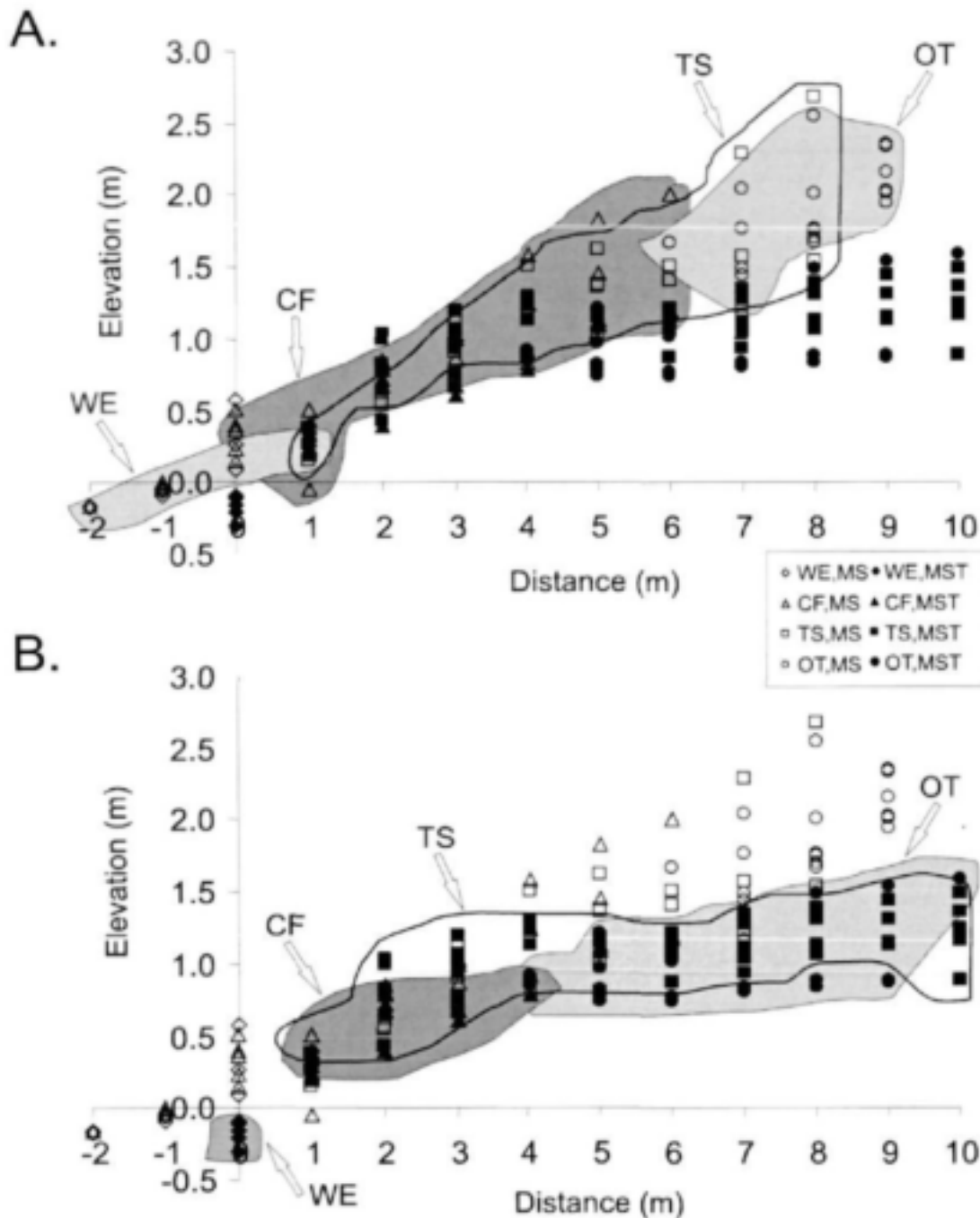


Figure 4.20 Elevation and distance from low flow water's edge for all sample plots at the four Heks River sites. Outline (A) are sample plots at Hek1 & Hek2 in the Mountain stream (transitional) [MST] and outline (B) are sample plots at Hek3 & Hek4 in the Foothill [FH] zones respectively. Four of the five assemblage types are shown: WE = Water's Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Five groups formed in the CLUSTER and MDS ordination analyses and allocated to assemblage types as follows: assemblage 1 (WE), 2 (CF), 3 and 4 (TS) and 5 (OT) (Figure 4.21).

WE covered an elevation range from just below water level to 0.01 m above it and was dominated by species shown to be typical of this assemblage type on the two previous sets of study sites: *Isolepis prolifer*, *Prionium serratum* and *Todea barbara* (Table 4.14). Seedlings of *Metrosideros angustifolia*, juvenile *Brachylaena neriifolia* and the shrub *Erica caffra* also occurred at lower abundances and frequencies, as did two species not recorded before: a grass *Pentameris distichophylla* and a shrub *Pseudobaeckia africana*.

CF occurred higher up the bank than expected, ranging from elevations of 1.08 – 2.29 m. The small tree species were represented by *Brachylaena neriifolia* juveniles and adults, and *Metrosideros angustifolia* seedlings, all reasonably frequent but at relatively low cover. Grasses and shrubs were abundant: *Pseudobaeckia africana*, *Ehrharta* sp.2 and *Pentaschistis pallida*, the latter being only found at this site and assemblage type. Three other species typical of CF in the other rivers were also common: *Elegia capensis*, *Todea barbara* and *Erica caffra*.

TS also occurred over an unusual elevation range, from water level to 2.13 m. The species count was high, with a mix of typical small tree species, some Afromontane tree species, other riparian species and some species from drier habitats. *Brachylaena neriifolia*, *Metrosideros angustifolia*, *Morella serrata* and *Brabejum stellatifolium* were all represented by seedlings, juveniles and adults, while scattered adults of the Afromontane species *Platylophus trifolius* and *Ilex mitis* and seedlings of *Canonia capensis* occurred. None of the tree species dominated, with the highest frequencies and cover being from the restio *Elegia capensis* and the shrubs *Pseudobaeckia africana* and *Erica caffra*. Among these was a mix of wetland and drier-habitat species (Table 4.14).

OT sat within the same elevation range as TS and had few unique species. It marked the highest abundance of the grass *Pentameris distichophylla* and the restio *Ischyrolepis subverticillata*. All of the small tree species were absent from this assemblage type except a low cover of juvenile *Brabejum stellatifolium*. The other species present were mostly those named for earlier sites as outer riparian or terrestrial. The riparian zone at this site was narrow and in some cases TS occurred on the water's edge (Figure 4.22, vegetation blocks C and D). The anomalies in elevation of the various assemblage types can be explained by the variation of bank shape within vegetation blocks that was not captured by the single cross-section per block. Thus, the height of CF in block A, for instance, appears higher than its actual elevation. In vegetation blocks C and D, TS was located as low as the water's edge, and as such had a very different height range to TS on the other two rivers. At the earlier sites WE occurred in this area, on cobble bars on deposits of smaller substrata. Perhaps the relative lack of gravels and sands on the banks at this site precluded the establishment of WE species. The main difference between this site and those on the Rondegat and Heks Rivers was the presence of forest species.

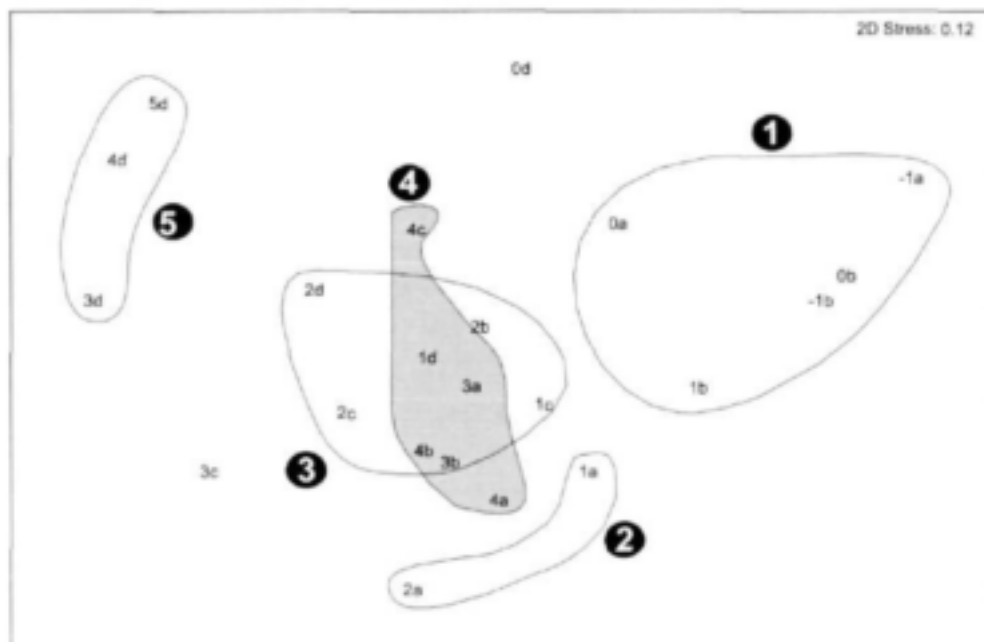
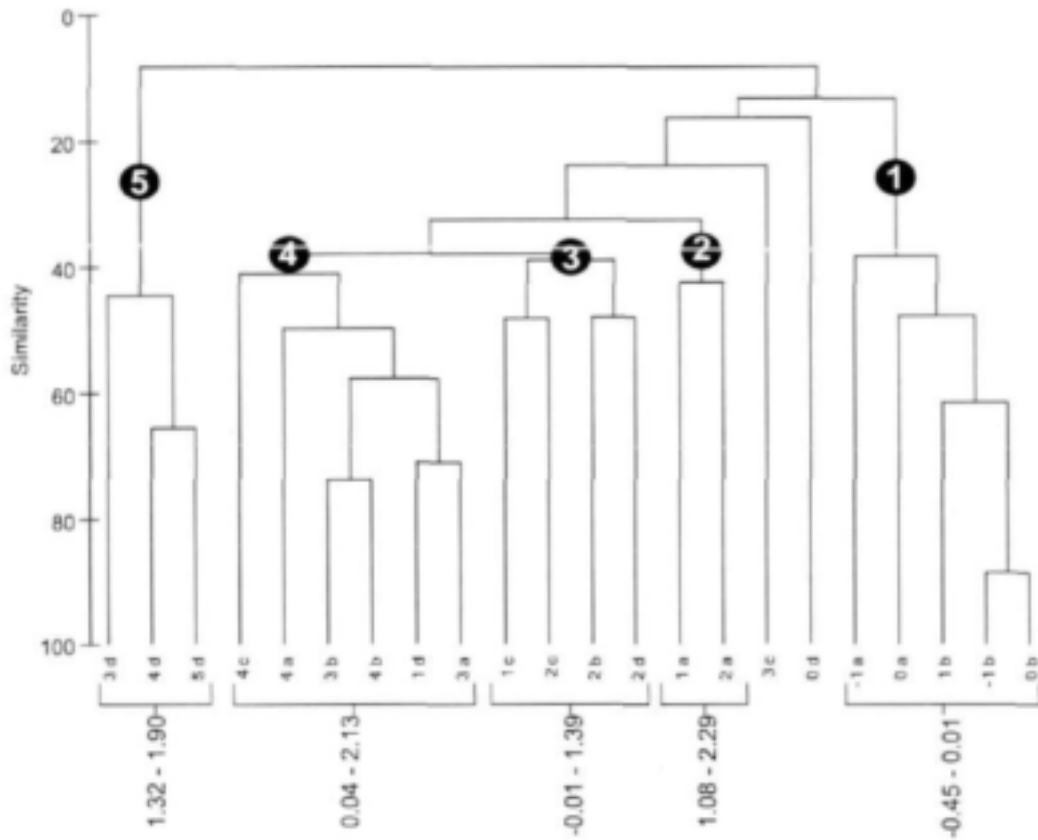


Figure 4.21 CLUSTER analysis and Non-metric MDS ordination for all samples at Ela1 on the Elands River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level, are shown on the dendrogram.

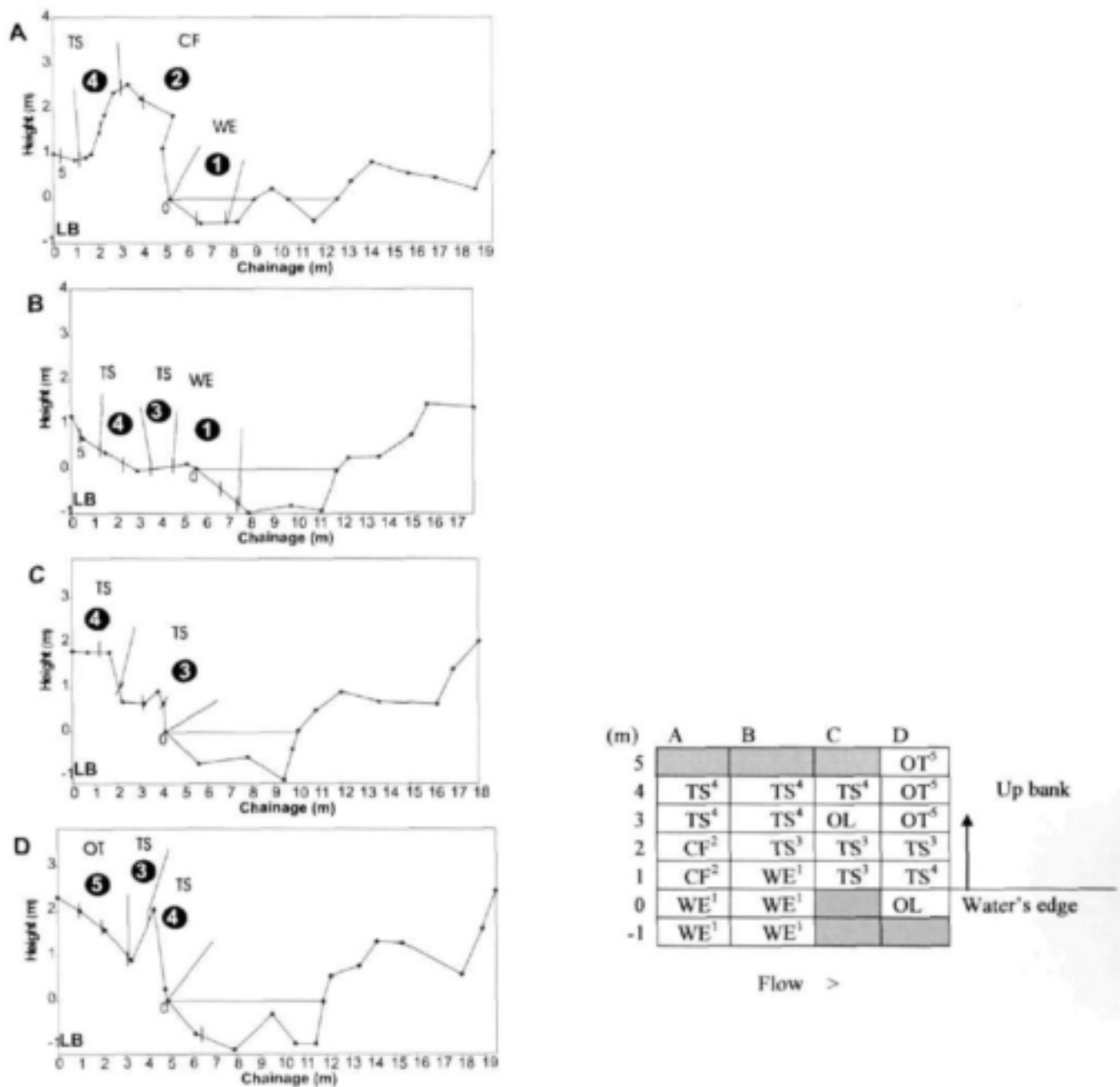


Figure 4.22 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.21 and the assemblage types they represent (Table 4.14) in the four vegetation blocks (A through D) at Ela1 on the Elands River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier, grey box = no sample.

Table 4.14 The percent frequency (F) and the average cover in each assemblage type for all species at Ela1. The assemblage type assigned to the five assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type										
	1 (n=5)		2 (n=2)		3 (n=4)		4 (n=6)		5 (n=3)	
	Wet Edge		Channel Fringe		Tree Shrub		Tree Shrub		Outer Transitional	
% sand	0		3		20		16		0	
% rock	100		98		80		84		100	
% water	61		5		14		13		0	
Elevation above summer low water (m)	-0.45- -0.01		1.08-2.29		-0.01-1.39		0.04-2.13		1.32-1.90	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Isolepis prolifer</i>	100	4.0			25	2.8				
<i>Prionium serratum</i>	80	2.6			25	0.8				
<i>Todea babara</i>	60	1.3	50	1.0	50	1.8	66	7.3		
<i>Pseudobaeckia africana</i>	40	1.0	100	4.0	100	8.3	100	9.5		
<i>Metrosideros angustifolia</i> seedling	20	0.6	50	1.0	25	1.3	66	2.0		
<i>Brachylaena neriifolia</i> (0.3-2m)	20	0.4	50	2.5	75	3.8				
<i>Erica caffra</i>	20	0.2	50	1.0	100	8.0	100	8.2		
<i>Pentameris distichophylla</i>	20	0.2			25	4.0	16	0.7	100	6.7
<i>Brachylaena neriifolia</i> (2-5m)			50	3.0	25	1.3	33	3.3		
<i>Elegia capensis</i>			50	2.5	100	9.5	83	6.7	33	1.3
<i>Ehrharta</i> sp.2			100	2.0			33	1.0		
<i>Pentaschistis pallida</i>			100	1.5						
<i>Blechnum australe</i>			50	0.5						
<i>Morella serrata</i> (0.3-2m)					75	3.8				
<i>Cyclopia</i> sp.1					50	2.0				
<i>Ficinia</i> sp.2					50	1.8				
<i>Morella serrata</i> (2-5m)					25	1.3				
<i>Aristea capitata</i>					25	1.0				
<i>Morella serrata</i> seedling					25	0.4				

	1 (n=5)	2 (n=2)	3 (n=4)	4 (n=6)		5 (n=3)		
	Wet Edge	Channel Fringe	Tree Shrub				Outer Transitional	
<i>Metrosideros angustifolia</i> (0.3-2m)			50	4.5	16	0.5		
<i>Restio perplexus</i>			25	2.8	16	1.3		
<i>Calopsis paniculata</i>			25	1.3	33	1.5		
<i>Drosera</i> spp.			25	1.3	33	1.3		
<i>Metrosideros angustifolia</i> (2-5m)			25	2.3	83	11.0		
<i>Schizaea tenella</i>			25	1.0	83	10.0		
<i>Ischyrolepis subverticillata</i>			50	3.8			100	6.7
<i>Cliffortia ruscifolia</i>			25	1.5			67	4.7
<i>Hartogiella schinoides</i> (0.3-2m)			25	1.0			67	2.3
<i>Diospyros glabra</i>			25	1.0			67	2.7
<i>Brabejum stellatifolium</i> (0.3-2m)			25	0.8			67	1.0
<i>Epischoenus gracilis</i>					50	2.5	67	2.3
<i>Canonia capensis</i> seedling					33	0.5		
<i>Brabejum stellatifolium</i> seedling					33	0.5		
<i>Ilex mitis</i> (2-5m)					16	3.3		
<i>Platylophus trifolius</i> (2-5m)					16	1.3		
<i>Brachylaena neriifolia</i> seedling					16	0.5		
<i>Podalyria</i> sp.1					16	0.3		
<i>Ischyrolepis sieberi</i>							67	3.0
<i>Pteridium aquilinum</i>							33	3.3
<i>Ehrharta ramosa</i> subsp. <i>ramosa</i>							33	1.3
<i>Protea laurifolia</i> seedling							33	1.0

Ela2: mountain stream (rapid)

Ela2 was situated downstream of Ela1 alongside a rapid. The valley floor and bank structure was much the same as upstream. A seep was located outside of the riparian zone for some distance up the valley slope, and so in some parts of this site vegetation on the outer edges of the riparian zone consisted of wetland rather than fynbos species.

Eight assemblages were recognized, each containing very few sample plots (Figure 4.23), and each quite dissimilar to the others (< 40% similarity). This was unlike all the other sites discussed so far, due to these weak relationships. It was difficult to assign assemblage types to the eight groups and so the patterns of distribution outlined for the other sites had to be used as a guide to allocate each group to an assemblage type.

WE (assemblage 1) contained only *Prionium serratum* and juvenile *Metrosideros angustifolia*. The cover of vegetation was low and the water's edge rocky (Table 4.15).

TS (assemblages 2 to 6) ranged from 0.15 to 2.48 m elevation on 100% rocky ground and had no clear dominant species. The group as a whole contained the small trees typical of Riparian Scrub (adults and juveniles of *Brachylaena neriifolia*, *Brabejum stellatifolium* and *Metrosideros angustifolia* and seedlings of *Brabejum stellatifolium*) and more generally ubiquitous species such as *Pteridium aquilinum*, *Blechnum capense*). Mixed with this were some forest and dry-habitat species, such as *Hartogiella schinoides*, *Phyllica imberbis* and *Stoebe plumosa*, and species found in OT assemblages upstream (*Ischyrolepis sieberi*) and at other sites (*Ehrharta ramosa* ssp. *aphylla* and *Ficinia indica*).

OT (assemblages 7 and 8) occurred from 1.68 to 2.93 metres on ground that was mainly rocks. It contained species that occurred from CF through to NR on the other two rivers as well as a long list of species reported for the first time, many of which are normally found in mountain seeps as well as along rivers (e.g. *Leucadendron salicifolium* and *Cannamois virgata*). The mix of species in assemblages 7 and 8, together with their position on the MDS plot decided their allocation to OT. OT contained three forest species (*Cunonia capensis*, *Platylophus trifolius* and *Hartogiella schinoides*) and juveniles and adults of the common small tree species (*Morella serrata*, *Brachylaena neriifolia*, *Brabejum stellatifolium*). True to the literature, this site more than any of the others adhered to the general description of south-western Cape riparian zones as containing a mixture of scrub and fynbos species, many of which are commonly found in other wet non-riverine habitats. *Elegia capensis*, *Blechnum capense*, *Pteridium aquilinum* and the restio *Askidiosperma chartaceum* were common with high cover. Dry-habitat species present such as *Erica bergiana*, *Erica canescens*, *Phyllica imberbis*, *Ursinia abrotanifolia* and *Hackea sericea* were not recorded at the earlier sites.

Overall, these two mountain stream sites differed to those previously discussed in that there was not a dominant species or suite of species, nor clearly delineated assemblage types. They also differed in the presence of the Afromontane tree species (*Platylophus trifolius* and *Cunonia capensis*). The vegetation of both these Elands sites was difficult to classify into assemblage types since the species within the assemblages were patchily distributed (Figure 4.24) and consisted of a mixture of forest,

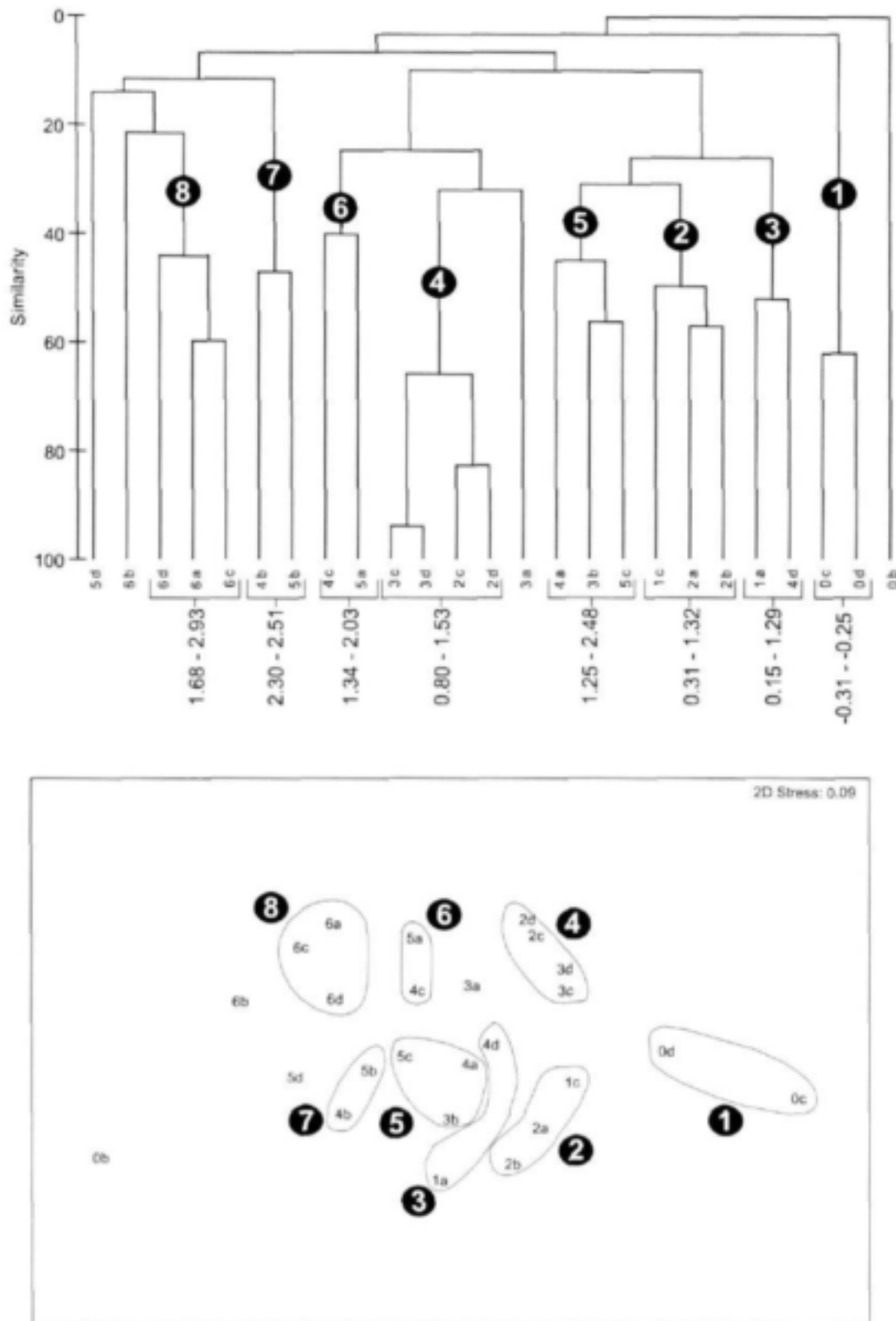


Figure 4.23 CLUSTER analysis and Non-metric MDS ordination for all samples at Ela2 on the Elands River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level, are shown on the dendrogram.

Table 4.15 The percent frequency (F) and the average cover in each assemblage type for all species at Ela2. The assemblage type assigned to the eight assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number																	
	1 (n=2)		2 (n=3)		3 (n=2)		4 (n=4)		5 (n=3)		6 (n=2)		7 (n=2)		8 (n=2)		
	Wet Edge		Tree Shrub										Outer Transitional				
% sand	0		0		0		0		0		0		0		23		
% rock	100		100		100		100		100		100		100		77		
% water	40		0		0		0		0		0		0		0		
Elevation above summer low water (m)	-0.31- -0.25		0.31-1.32		0.15-1.29		0.80-1.53		1.25-2.48		1.34-2.03		2.30-2.51		1.68-2.93		
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	
<i>Prionium serratum</i>	100	2.5															
<i>Metrosideros angustifolia</i> (0.3-2m)	50	1.5	33	1.7	50	2.5	50	2.0									
<i>Metrosideros angustifolia</i> (2-5m)			100	12.3	100	15.5			100	16.7							
<i>Brabejum stellatifolium</i> seedling			33	0.7					33	0.7							
<i>Brachylaena neriifolia</i> (2-5m)					100	18.5											
<i>Brachylaena neriifolia</i> (0.3-2m)					100	16.5							100	17.5			
<i>Brabejum stellatifolium</i> (0.3-2m)					50	1.0							100	3.5			
<i>Pseudobaeckia africana</i>					50	1.0											
<i>Hartogiella schinoides</i> (2-5m)									67	6.7							
<i>Erica caffra</i>					50	4.0	100	11.3	33	1.3	100	4.5					
<i>Phylica imberbis</i>											50	2.5			67	2.3	
<i>Stoebe plumosa</i>											50	1.5					
<i>Ficinia indica</i>											50	1.5					
<i>Pentameris distichophylla</i>					50	2.0					50	2.0	50	12.5			
<i>Epischoenus gracilis</i>									33	2.7			50	2.0			
<i>Ehrharta ramosa</i> subsp. <i>aphylla</i>											50	2.0	50	1.5			
<i>Brabejum stellatifolium</i> (2-5m)									100	21.7			50	1.5	33	0.7	
<i>Pteridium aquilinum</i>									33	3.3	100	3.5	100	21.0	33	2.0	

	1 (n=2)	2 (n=3)	3 (n=2)	4 (n=4)	5 (n=3)	6 (n=2)	7 (n=2)	8 (n=2)				
	Wet Edge	Tree Shrub					Outer Transitional					
<i>Elegia capensis</i>					33	1.7	100	4.0	100	8.7		
<i>Ischyrolepis sieberi</i>					33	1.0	50	2.5	33	2.7		
<i>Blechnum capense</i>					33	5.0	50	1.5	100	7.7		
<i>Askidiosperma chartaceum</i>							50	1.5	100	4.0	67	8.3
<i>Cliffortia pterocarpa</i>							50	5.0				
<i>Ehrhata</i> sp.2							50	1.5				
<i>Platylophus trifolius</i> (2-5m)							50	1.5				
<i>Cliffortia ruscifolia</i>							50	1.0				
<i>Anthospermum spathulatum</i>									100	24.3		
<i>Cullumia ciliaris</i>									100	7.3		
<i>Cyclopia</i> sp.1									100	6.7		
<i>Cannomois virgata</i>									67	5.0		
<i>Erica bergiana</i>									67	4.7		
<i>Leucadendron salicifolium</i>									67	3.7		
<i>Erica canescens</i>									67	3.0		
<i>Hartogiella schinoides</i> (0.3-2m)									67	2.0		
<i>Cunonia capensis</i> (2-5m)									33	10.0		
<i>Hartogiella schinoides</i> (2-5m)									33	5.0		
<i>Cunonia capensis</i> (0.3-2m)									33	2.0		
<i>Mariscus thunbergii</i>									33	1.7		
Asteraceae sp.18									33	1.7		
Asteraceae sp.19									33	1.7		
<i>Morella serrata</i> (2-5m)									33	1.0		
<i>Ursinia abrotanifolia</i>									33	1.0		
<i>Hackea sericia</i> (2-5m)									33	1.0		
<i>Cunonia capensis</i> seedling									33	0.7		
<i>Calopsis paniculata</i>									33	0.7		
<i>Brachylaena neriifolia</i> seedling									33	0.3		

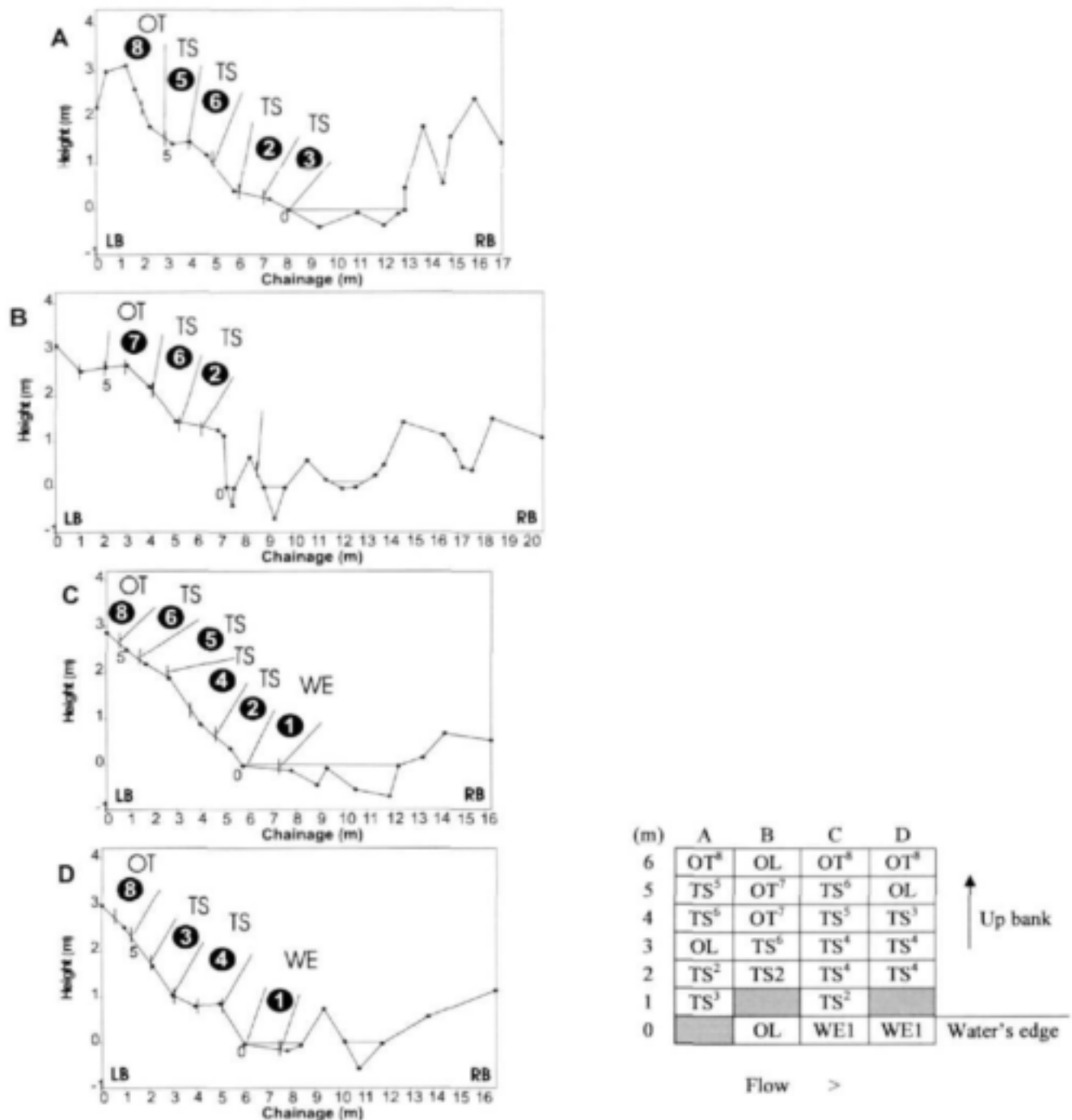


Figure 4.24 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.23 and the assemblage types they represent (Table 4.15) in the four vegetation blocks (A through D) at Ela2 on the Elands River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier, grey box = no sample.

Riparian Scrub, seepage and non-riparian species. Perhaps this area is in transformation from one riparian community to another – from Riparian Scrub to Afromontane Forest, for example or perhaps it represents an early successional stage driven by high-energy floods (as suggested by the lack of fine substrata).

Ela3: foothill zone (plane bed)

Ela3 was situated alongside a plane bed and an extensive cobble bar. The sampled bank was wider than at Ela1 or Ela2, although the riparian zone was clearly delineated with no wider floodplain effect. Six assemblages formed into five groups: WE (assemblage 1), CF (2), TS (3 and 4) and OT (5 and 6) (Figure 4.25).

WE was dominated by seedlings, juveniles and adults of *Salix mucronata*, together with less frequent occurrences of *Metrosideros angustifolia* seedlings, the sedge *Juncus effusus*, the restio *Calopsis paniculata*, the shrub *Erica caffra*, and the grass *Pennisetum macrourum* (Table 4.16).

CF also supported seedlings and juveniles of *Salix mucronata* and a high frequency of *Morella serrata* seedlings. *Elegia capensis* made its first appearance and both *Erica caffra* and *Pennisetum macrourum* maintained about the same presence as in WE.

TS encompassed the elevation range 0.43 to 1.38 m, and contained a good variety of Riparian Scrub and Afromontane trees. The former was represented by *Metrosideros angustifolia*, *Brabejum stellatifolium*, *Morella serrata* and *Brachylaena neriifolia*, and the latter by *Halleria lucida*, *Platylophus trifolius* and *Ilex mitis*; most were present as adults and some also as seedlings and juveniles. The ferns *Todea barbara* and *Blechnum capense* were abundant as was *Elegia capensis*. Grasses commonly found at the other sites – *Pennisetum macrourum* and *Ehrharta ramosa* subsp. *ramosa* – were common.

OT occurred from 0.92 to 2.37 m elevation and was a mix of riparian and dry-habitat species. The Afromontane tree species did not appear in this assemblage type although adults and juveniles of the small Riparian Scrub trees were quite common. Still persisting in high cover and frequencies were *Elegia capensis*, *Pennisetum macrourum*, *Calopsis paniculata*, *Ehrharta ramosa* subsp. *ramosa* and *Pteridium aqualinum*. A number of species characteristic of drier habitats were not recorded at earlier sites. The sedge *Epischoenus gracilis* occurred in OT both at this site and at Ela1 or Ela2, along with *Leucadendron salicifolium* and *Pentameris distichophylla*. There was a number of new dry-habitat species only recorded from this site.

The assemblages are logically ordered (Figure 4.26), as at the Rondegat and the Heks Rivers, with the CF and the WE lower down the bank, the TS and the OT occupying approximately the same overall area in the sample plots with one representative assemblage from each assemblage type present in most vegetation blocks. Only WE was absent in one vegetation block, as has been the case on all the sites described so far.

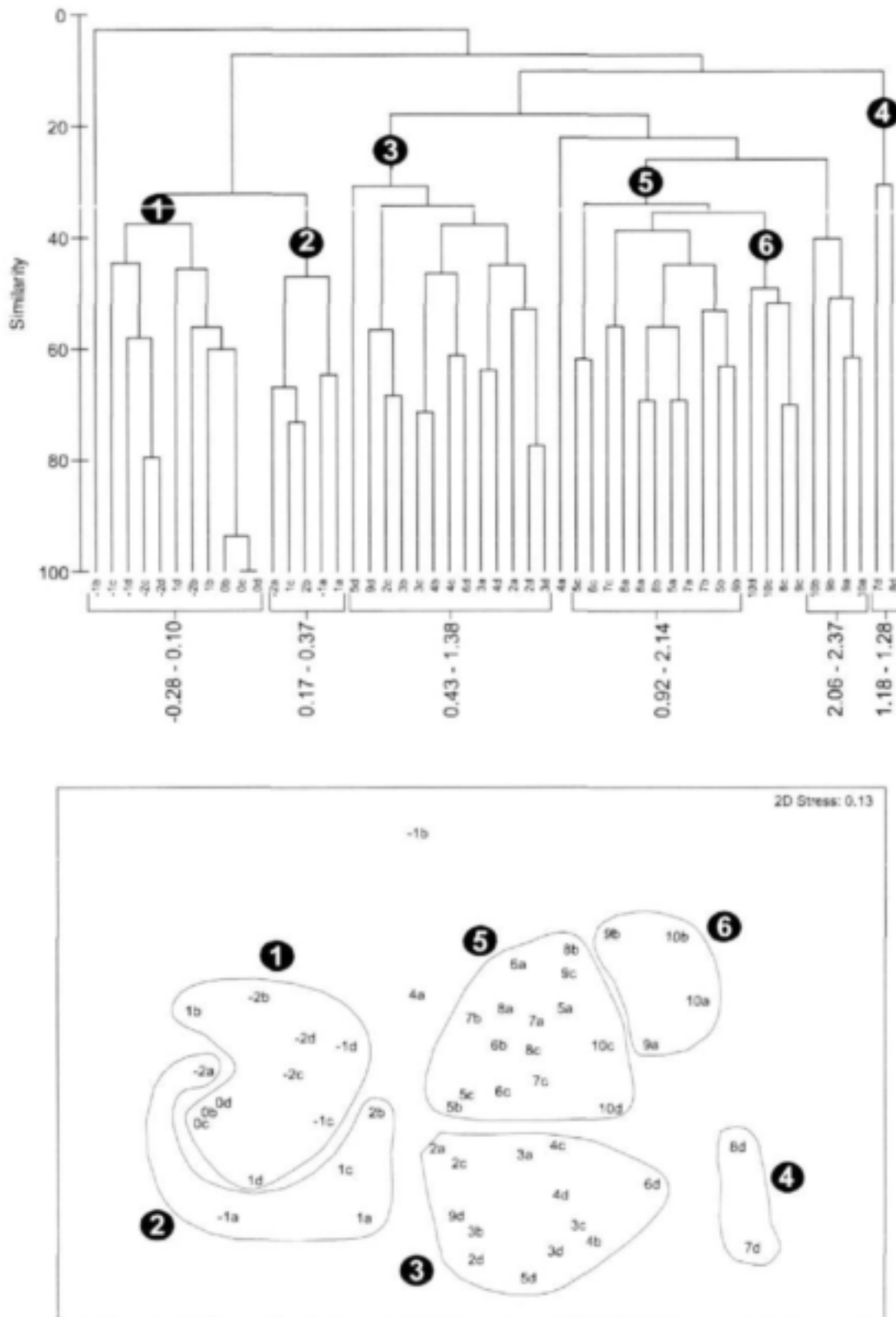


Figure 4.25 CLUSTER analysis and Non-metric MDS ordination for all samples at Ela3 on the Elands River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level, are shown on the dendrogram.

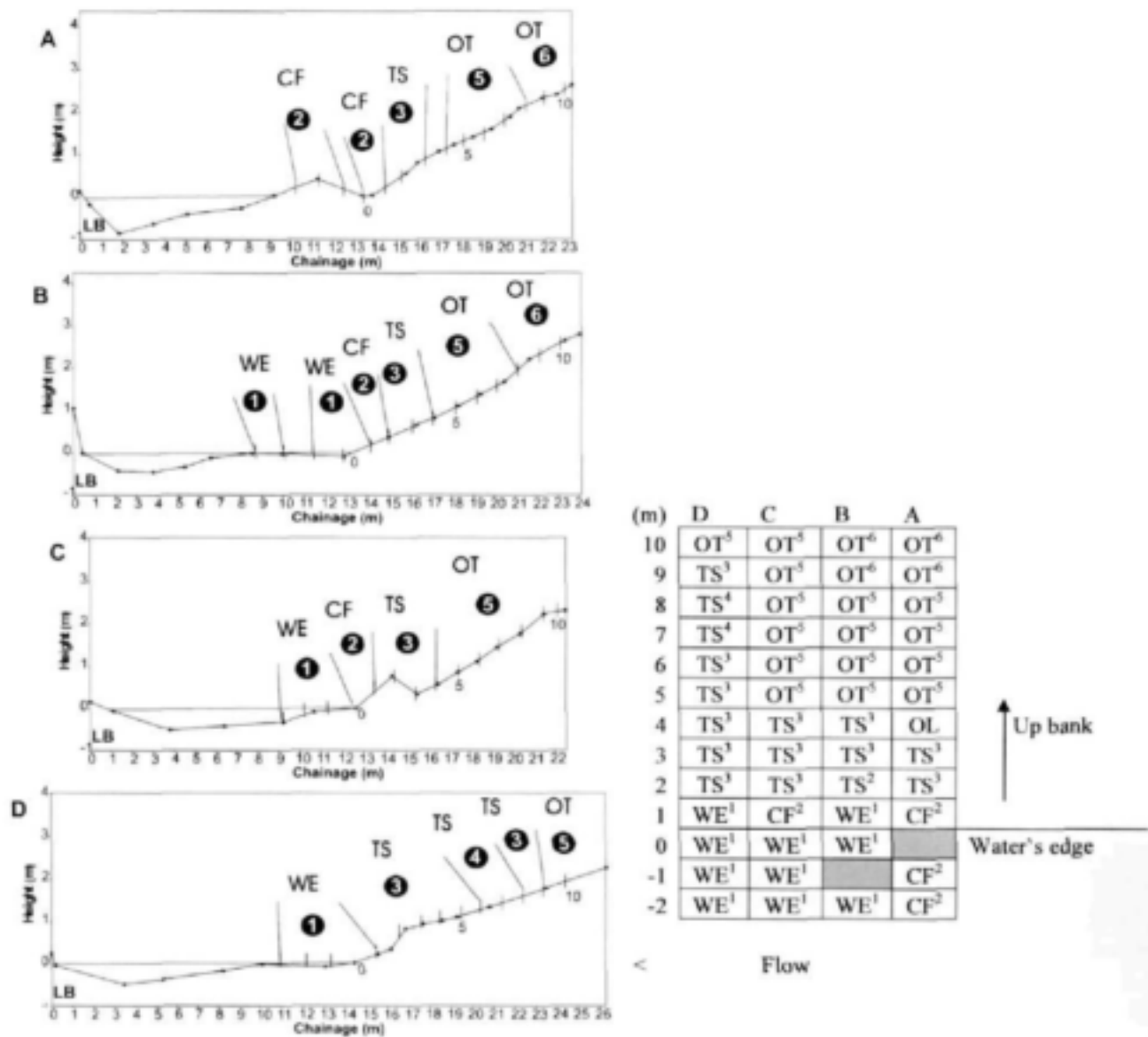


Figure 4.26 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.25 and the assemblage types they represent (Table 4.16) in the four vegetation blocks (A through D) at Ela3 on the Elands River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier, grey box = no sample.

Table 4.16 The percent frequency (F) and the average cover in each assemblage type for all species at Ela3. The assemblage type assigned to the six assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type												
	1 (n=4)		2 (n=6)		3 (n=13)		4 (n=2)		5 (n=15)		6 (n=4)	
	Wet Edge		Channel Fringe		Tree Shrub				Outer Transitional			
% sand	14		14		60		75		96		60	
% rock	87		86		40		25		4		40	
% water	10		6		0		0		0		0	
Elevation above summer low water (m)	-0.28-0.10		0.17-0.37		0.43-1.38		1.18-1.28		0.92-2.14		2.06-2.37	
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover
<i>Salix mucronata</i> (2-5m)	20	0.8										
<i>Metrosideros angustifolia</i> seedling	10	0.1										
<i>Juncus effusus</i>	10	0.3										
<i>Salix mucronata</i> (0.3-2m)	90	5.0	60	1.0								
<i>Salix mucronata</i> seedling	60	0.9	60	0.5								
<i>Erica caffra</i>	10	1.0	20	0.4	31	2.8						
<i>Morella serrata</i> seedling			100	1.2	8	0.2			7	0.1		
<i>Elegia capensis</i>			60	1.0	100	11.8			80	4.2	25	0.1
<i>Pennisetum macrourum</i>	40	4.1	20	0.4	38	3.0			87	19.7		
<i>Calopsis paniculata</i>	10	0.2							47	4.0	25	0.8
<i>Todea babara</i>					31	4.4	50	2.5				
<i>Ilex mitis</i> (2-5m)					15	3.1	50	15.0				
<i>Halleria lucida</i> (2-5m)					8	0.2						
<i>Brachylaena neriifolia</i> (2-5m)					15	2.7						
<i>Pteridium aquilinum</i>					15	0.3						
<i>Platylophus trifolius</i> (2-5m)					8	2.3						
<i>Brabejum stellatifolium</i> seedling					15	0.5			7	0.1		
<i>Podalyria</i> sp.1					8	0.2			40	0.7		

	1 (n=4)	2 (n=6)	3 (n=13)	4 (n=2)	5 (n=15)	6 (n=4)
	Wet Edge	Channel Fringe	Tree Shrub		Outer Transitional	
<i>Cyclopia</i> sp.1				50 2.5	20 1.6	
<i>Metrosideros angustifolia</i> (2-5m)			54 18.5	50 7.5		50 5.0
<i>Blechnum capense</i>			8 1.2	100 17.5	13 0.3	25 0.3
<i>Ehrharta ramosa</i> subsp. <i>ramosa</i>				50 2.5	47 4.3	100 5.8
<i>Diospyros glabra</i>			23 1.2		7 0.7	25 0.5
<i>Brabejum stellatifolium</i> (2-5m)			15 1.2		13 4.0	25 10.0
<i>Morella serrata</i> (0.3-2m)			8 0.2		20 0.7	25 0.8
<i>Brabejum stellatifolium</i> (0.3-2m)			15 0.3			25 6.3
<i>Aristea capitata</i>					40 1.5	100 5.5
<i>Pentameris distichophylla</i>					27 2.3	
<i>Leucadendron salicifolium</i>					20 0.4	
<i>Ursinia abrotanifolia</i>					13 0.1	
Species 16					7 0.1	
Rubiaceae sp.1					67 11.9	75 15.0
<i>Pteridium aquilinum</i>					53 2.9	100 3.8
<i>Epischoenus gracilis</i>					27 3.3	25 2.0
<i>Elegia asperiflora</i>					20 0.6	75 2.0
<i>Tetraria</i> c.f. <i>flexuosa</i>					13 2.3	50 3.8
<i>Morella serrata</i> (2-5m)					13 0.8	25 0.5
Cyperaceae sp.1					13 0.5	25 0.8
<i>Cullumia ciliaris</i>					7 0.3	75 3.0
<i>Ischyrolepis fraternal</i>					7 0.1	50 1.5
<i>Osteospermum ciliatum</i>						100 8.8
<i>Metrosideros angustifolia</i> (0.3-2m)						50 3.8
<i>Restio multiflorus</i>						25 0.8
<i>Asparagus africanus</i>						25 0.8
<i>Othonna quinquidentata</i>						25 0.8
<i>Cliffortia</i> sp.1						25 0.5
<i>Helichrysum odoratissimum</i>						25 0.3
<i>Stoebe spiralis</i>						25 0.3

Ela4: foothill zone (pool)

Ela4 was situated downstream of Ela3 alongside a pool with the bank dropping into the pool. The valley shape and riparian vegetation structure was much the same as Ela3. Seven assemblages formed into three assemblage types: CF (assemblage 1), TS (2-6) and OT (7) (Figure 4.27 and Table 4.17).

CF consisted exclusively of *Elegia capensis*, which was common and with high cover.

TS encompassed the majority of the samples plots and was the most rich in species. Juveniles and adults of *Morella serrata*, *Brabejum stellatifolium* and *Metrosideros angustifolia* were common, as were adults of two forest species *Maytenus acuminata* and *Hartogiella schinoides*. Afromontane tree species *Cunonia capensis* and *Ilex mitis* were rarer. Common species listed elsewhere and also present here were *Calopsis paniculata*, *Elegia capensis*, *Pennisetum macrourum*, and *Diospyros glabra*.

OT was dominated by *Erica pinea*, a fynbos species, followed by the grass found at all three sites upstream in OT and TS, *Pentameris distichophylla*. Again a number of species not found at the other sites occurred in OT, mostly characteristic of drier habitats.

The distribution of the assemblages across the site (Figure 4.28) followed the same pattern as recorded at the other sites on the Rondegat and the Heks Rivers of a steady progression from the wetter assemblages through TS to the drier OT higher up the bank. The height range over which these assemblage types were distributed matched that recorded in the Olifants system.

Summary of Elands sites

The sites in the two zones - the mountain stream and mountain stream (transitional) - differed in that no CF assemblages were assigned to Ela2 in the mountain stream and no WE assemblages to Ela4 in the foothill; each of the other two sites had four of the five assemblage types: no NR assemblage types were assigned. TS and OT were equally prominent at Ela2 and Ela3 while TS was more abundant at Ela1 and Ela4. WE was found at the three uppermost sites and absent from the pool in the foothill where the channel bank dropped sharply into the channel.

Generally the four sites had the same species and none of the sites were obviously different in terms of species dominance. A number of new species were recorded, including *Pseudobaeckia africana*, *Pentameris distichophylla* and the forest species *Ilex mitis*, *Cunonia capensis*, *Platylophus trifolius* and *Maytenus acuminata*. At all sites, other than at Ela2 (discussed below), there was the recognised progression of assemblage types up the bank. Ela2 differed in that WE and CF were absent over half its area and in their place TS was located down to the channel edge. This was the only site of the 12 where this was recorded.

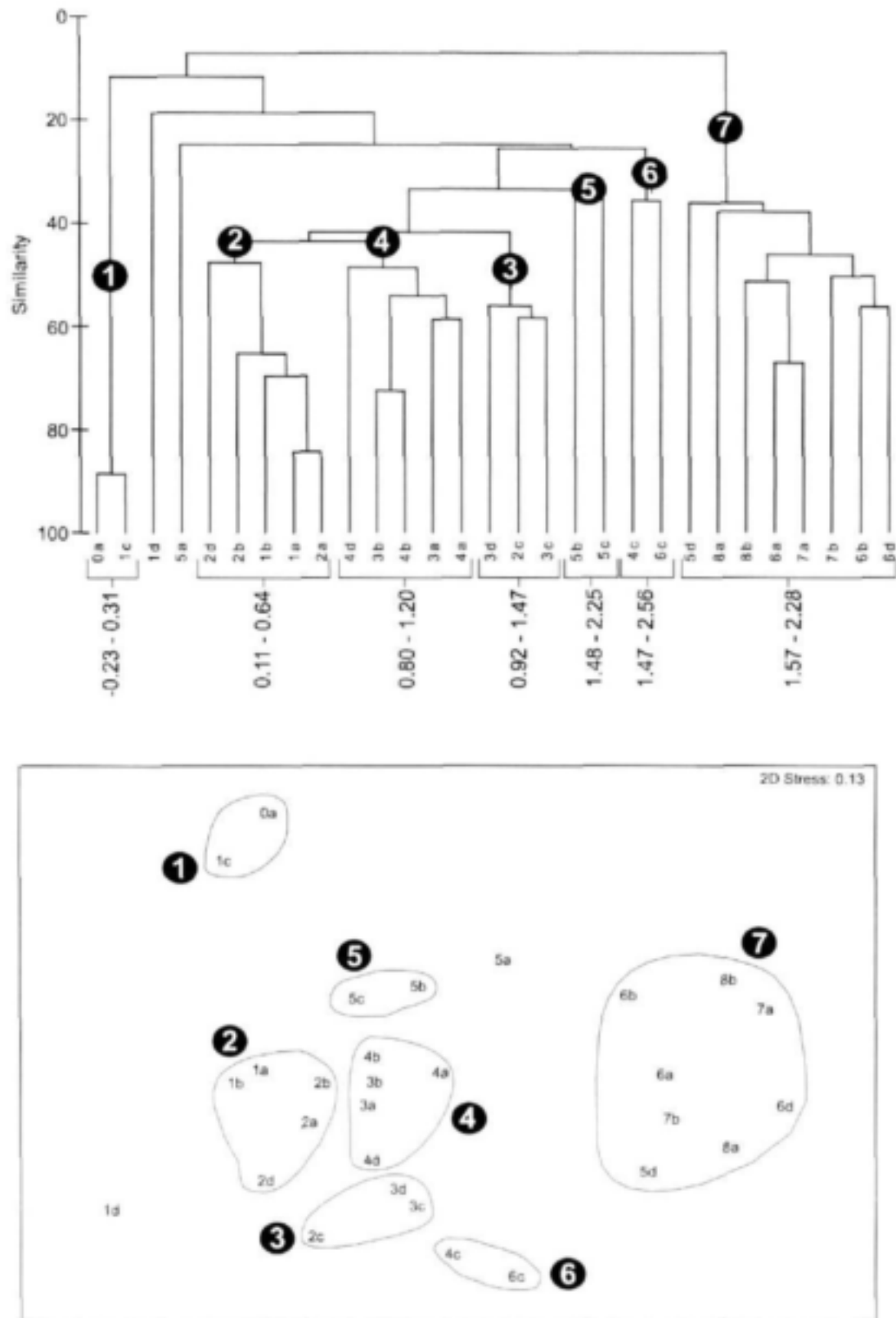


Figure 4.27 CLUSTER analysis and Non-metric MDS ordination for all samples at Ela4 on the Elands River. The vegetation assemblages are numbered in black circles. The range of elevations in metres above summer water level, are shown on the dendrogram.

Table 4.17 The percent frequency (F) and the average cover in each assemblage type for all species at Ela4. The assemblage type assigned to the seven assemblages is shown along with the physical variables recorded for each assemblage. (n) = number of sample plots.

Vegetation assemblage number and type																
	1 (n=2)		2 (n=5)		3 (n=3)		4 (n=5)		5 (n=2)		6 (n=2)		7 (n=8)			
	Channel Fringe		Tree Shrub												Outer Transitional	
% sand	10		20		57		48		30		38		28			
% rock	90		80		43		50		70		63		72			
% water	60		21		17		0		0		0		0			
Elevation above summer low water (m)	-0.23-0.31		0.11-0.64		0.92-1.47		0.80-1.20		1.48-2.25		1.46-2.56		1.57-2.28			
Species	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover	F	Cover		
<i>Canonia capensis</i> (0.3-2m)			20	0.6												
<i>Salix mucronata</i> seedling			20	0.1												
<i>Morella serrata</i> (0.3-2m)					67	12.7	20	0.4								
<i>Brachylaena neriifolia</i> (0.3-2m)					67	5.0	60	4.8								
<i>Cyclopia</i> sp.1							60	4.0								
<i>Blechnum capense</i>							40	1.2								
Species 13							20	0.4								
<i>Metrosideros angustifolia</i> (0.3-2m)							20	0.6								
<i>Elegia asperiflora</i>							20	0.4								
<i>Morella serrata</i> seedling							20	0.2								
<i>Stoebe spiralis</i>							20	0.2								
<i>Ilex mitis</i> (2-5m)							20	0.4	50	12.5						
<i>Brachylaena neriifolia</i> (2-5m)					33	4.7			50	5.0						
<i>Erica caffra</i>			60	14.0	33	1.7	80	8.6	50	1.0						
<i>Clusia</i> sp.1			100	21.0	100	13.7	100	9.6								
<i>Calopsis paniculata</i>			100	9.4	100	26.7	80	6.6	100	3.0	50	2.5				
<i>Elegia capensis</i>	100	3.5	80	9.0			80	6.6	100	2.0			13	0.4		
<i>Pennisetum macrourum</i>			40	2.6	33	8.3	80	10.2	100	6.5	100	2.0	13	0.3		
<i>Morella serrata</i> (2-5m)			20	2.2	100	19.3	60	6.0			100	7.5	25	5.0		
<i>Diospyros glabra</i>			20	0.6			80	4.4	50	0.5			25	1.0		

	1 (n=2)	2 (n=5)	3 (n=3)	4 (n=5)	5 (n=2)	6 (n=2)	7 (n=8)
	Channel Fringe	Tree Shrub					Outer Transitional
<i>Cliffortia ruscifolia</i>			33 0.3			50 1.0	63 6.3
<i>Brabejum stellatifolium</i> (2-5m)			67 4.7	20 3.0		50 15.0	25 1.9
<i>Brabejum stellatifolium</i> (0.3-2m)			33 2.0	20 0.6		100 3.5	13 0.4
<i>Metrosideros angustifolia</i> (2-5m)			33 1.7	100 30.0	50 10.0	50 12.0	
<i>Podalyria</i> sp.1				20 0.4		50 1.0	13 0.1
<i>Todea babara</i>					50 1.0		
<i>Maytenus acuminata</i> seedling					50 0.5		
<i>Hartogiella schinoides</i> (2-5m)						50 7.5	
<i>Maytenus acuminata</i> (2-5m)						50 7.5	
<i>Cannomois virgata</i>				20 2.0			38 1.1
<i>Protea laurifolia</i> (2-5m)				20 0.6			13 0.4
<i>Pentameris distichophylla</i>					50 2.5		88 13.0
<i>Erica pinea</i>							100 14.1
<i>Ischyrolepis fraterna</i>							63 3.8
<i>Brabejum stellatifolium</i> seedling							38 0.4
<i>Aristea capitata</i>							25 0.8
<i>Pentameris thurarii</i>							25 0.4
<i>Hartogiella schinoides</i> (0.3-2m)							13 1.9
<i>Stoebe plumosa</i>							13 1.3
<i>Rubiaceae</i> sp.1							13 0.6
<i>Thamnochortus lucens</i>							13 0.6
Species 16							13 0.4
<i>Osteospermum ciliatum</i>							13 0.3
<i>Othonna quinquidentata</i>							13 0.3

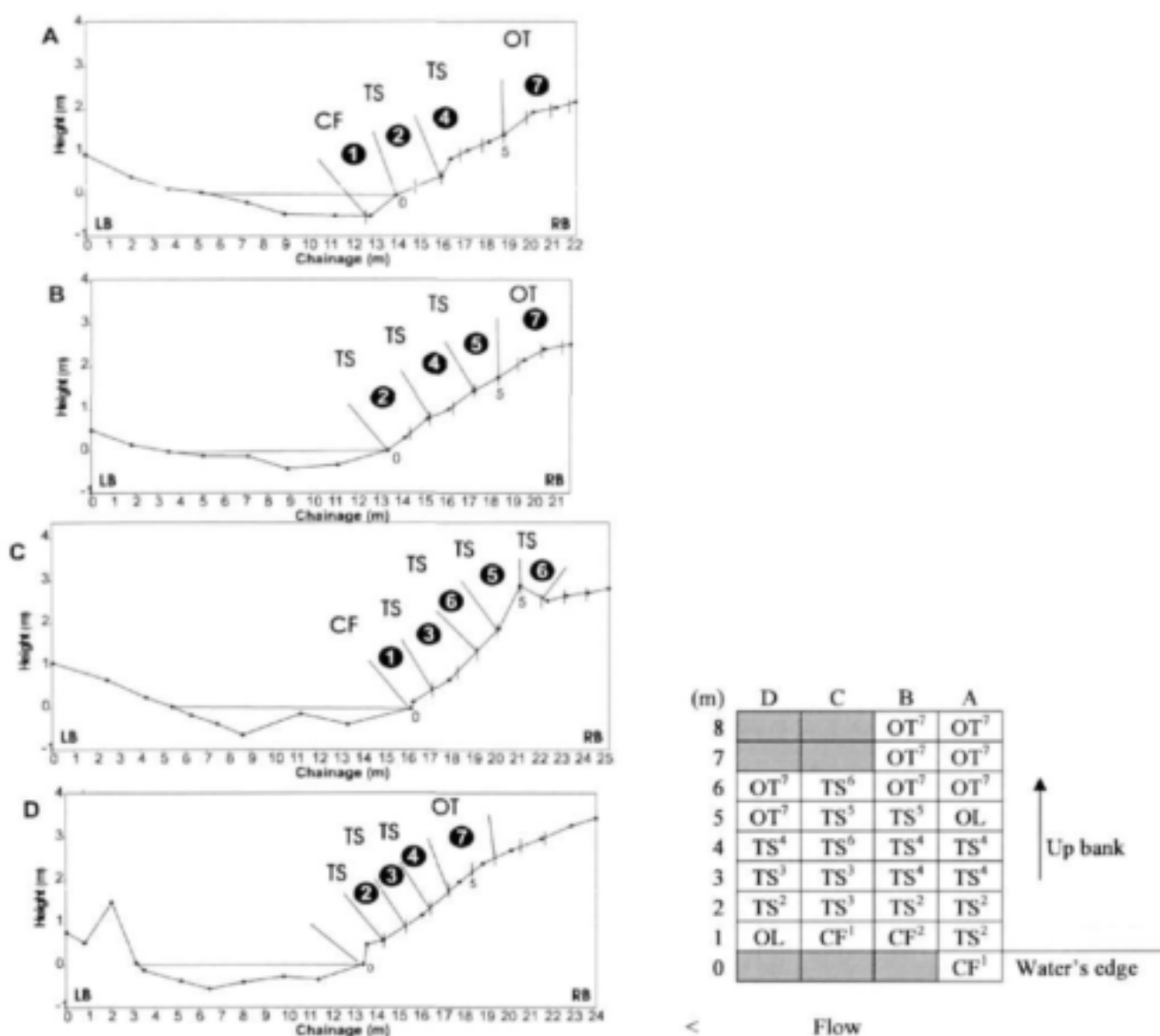


Figure 4.28 Surveyed cross-sections showing the position of vegetation assemblages recognised in Figure 4.27 and the assemblage types they represent (Table 4.17) in the four vegetation blocks (A through D) at Ela4 on the Elands River. A bird's eye view of the distribution of vegetation assemblages in the complete sample grid is shown at the bottom right of the figure. OL = outlier, grey box = no sample.

A plot of the elevation above and distance from the low flow water's edge, for every sample taken from the four sites on the Elands River (Figure 4.29a) showed a disjointed pattern at the two upper sites, where the valley was narrow and the channel rocky (figure 4.29a) and a progression from WE and CF, through TS to OT where the valley was wider and the bank gradient less steep (Figure 4.29b). WE, as on the other two rivers, was restricted to the channel margin. CF occurred between 1.0 and 2.4 m elevation and 1.0 to 2.0 m distance at the upper two sites and overlapped with WE below 0.5 m elevation on the channel margin at the lower two sites.

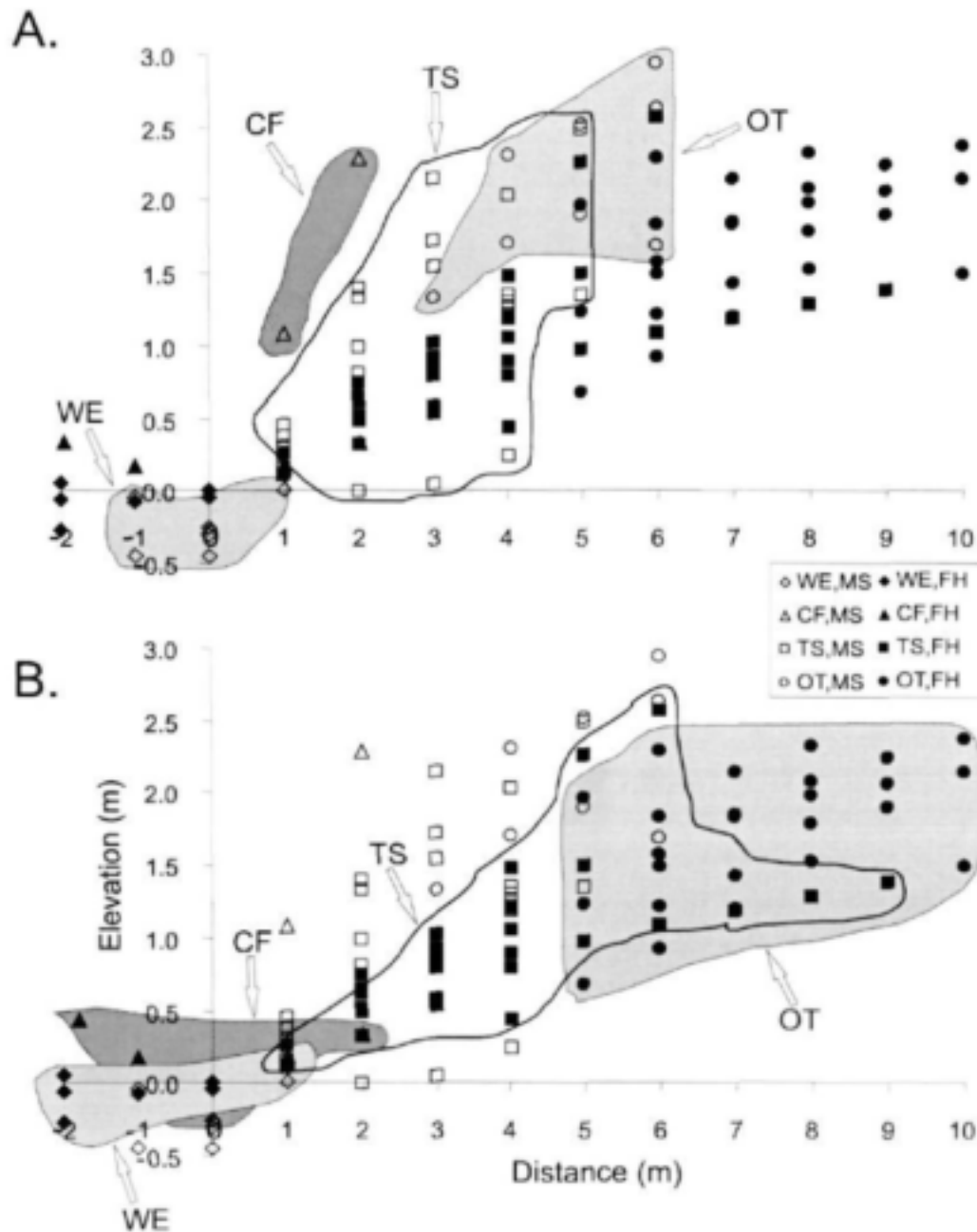


Figure 4.29 Elevation and distance from low flow water's edge for all sample plots at the four Elands River sites. Outline (A) are sample plots at Ela1 & Ela2 in the mountain stream [MS] and outline (B) are sample plots at Ela3 and Ela4 in the foothill [FH] zones respectively. Four of the five assemblage types are shown: WE = Water's Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

The progression described for the two other rivers, from WE through CF to OT and overlaid to varying extents by TS, was not apparent for the Elands sites. The ranges for WE, CF and OT were restricted in favour of TS that overlapped less than previously described with the three other assemblage types. TS occurred from the channel edge to an elevation of 2.5 m and distance of 1.0 to 5.0 m (mountain stream) and for a further 4.0 m distance at the two lower foothill sites. OT was situated over much the same range as on the other two rivers of elevation 1.3 m to 2.8 m and distance 3.0 to 6.0m (mountain stream) or 0.7 m to 2.5 m elevation and distance 1.0 m to 10.0 m distance (foothill).

No NR was assigned but would have occurred if the sample plots had extended into the adjacent fynbos.

4.4 USING THE 12 SITES TO OBTAIN A FIRST DEFINITION OF THE REFERENCE CONDITION

The purpose of the above intense exercise to define the reference condition was to ultimately allow an assessment of how alien invasive plants could impact riparian plant communities. Before that could be achieved, certain additional analyses were required. The full sequence of steps was:

- 1 Use 12 undisturbed sites to recognise and describe vegetation assemblage types that are typical of Western Cape headwater riparian zones (completed above);
- 2 describe where these were located in undisturbed sites and correlate this, if possible, with some easily measured physical variables (partially completed above);
- 3 describe the biological characteristics of the vegetation assemblage types or of the sample grids as a whole;
- 4 derive from steps 2-3 a first tentative description of the reference condition;
- 5 test this using similar data from six more undisturbed sites;
- 6 use the physical variables defined in the reference condition to locate the areas where the various assemblage types should be located in invaded or cleared sites (Chapter 5);
- 7 assess how the biotic characteristics of the assemblage-type areas have changed in invaded or cleared sites (Chapter 5).

The following Sections 4.4.1-4.4.2 address steps 2 and 3, whilst the tentative derivation of reference condition (step 4) appears in Section 4.4.3.

4.4.1 Physical variables correlated with the distribution of assemblage types in undisturbed sites

The graphics of distance from water versus elevation above water for the 12 undisturbed sites (Figures 4.11, 4.20 and 4.29) revealed a trend of assemblage types changing from the water's edge through to the outer riparian zone. There was considerable overlap of the assemblage types, however, particularly of TS with either CF or OT. As each of these graphics was a composite drawn from two sites, the overlaps may have been due to differences in the bank shape at the sites. To investigate this,

the plots were redrawn site by site (Figures 4.30 to 4.32). This revealed much less overlap between assemblage types, although TS and OT still overlapped noticeably at sites where the upper bank flattened out (e.g. Figure 4.31: Hek3 and Hek4). The two variables used thus appeared to be potentially useful for predicting where a specified assemblage type should occur. This was investigated further in Section 4.4.4.

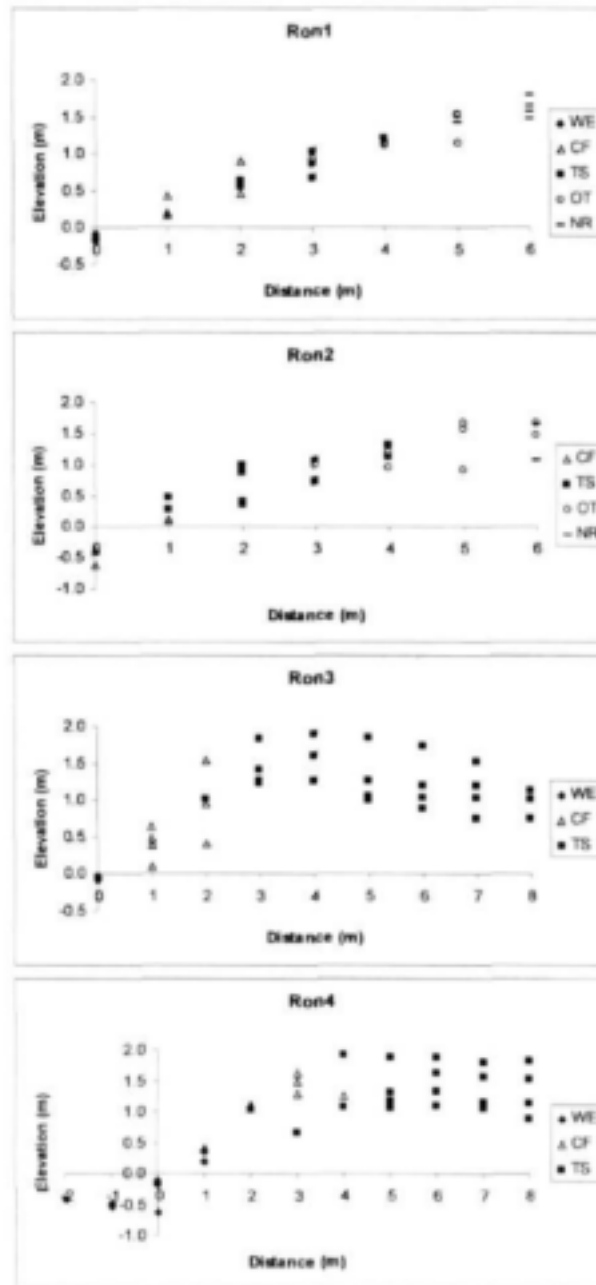


Figure 4.30 Elevation and distance from low flow water's edge for all sample plots at the four Rondegat River sites. The five assemblage types are shown: WE = Water's Edge, CF = Channel Fringe, TS = Tree Shrub, OT = Outer Transitional and NR = Non Riparian.

4.4.2 Biotic characteristics of assemblage types in undisturbed sites

Step 3, the biological characterisation of each assemblage type, further defined the reference condition through four main variables. These are addressed below.

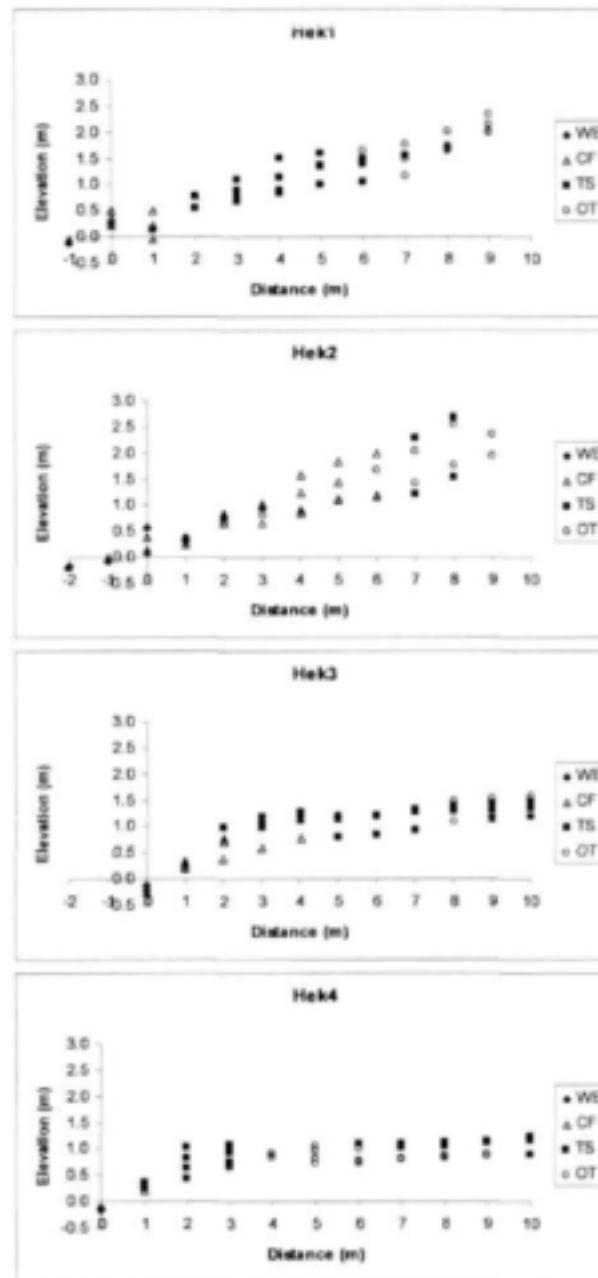


Figure 4.31 Elevation and distance from low flow water's edge for all sample plots at the four Heks River sites. The five assemblage types are shown: WE = Water's Edge, CF = Channel Fringe, TS = Tree Shrub, OT = Outer Transitional and NR = Non Riparian.

Species richness of the assemblage types

Species richness was calculated by averaging the number of species per 5 m² sample plots (Table 4.18). Overall the OT assemblage type showed the greatest species richness, with an average 19.9 species per sample plot, usually because of the presence of a large number of non-riparian species from the neighbouring fynbos communities. Though there was often a high number of species present, generally no one species dominated.

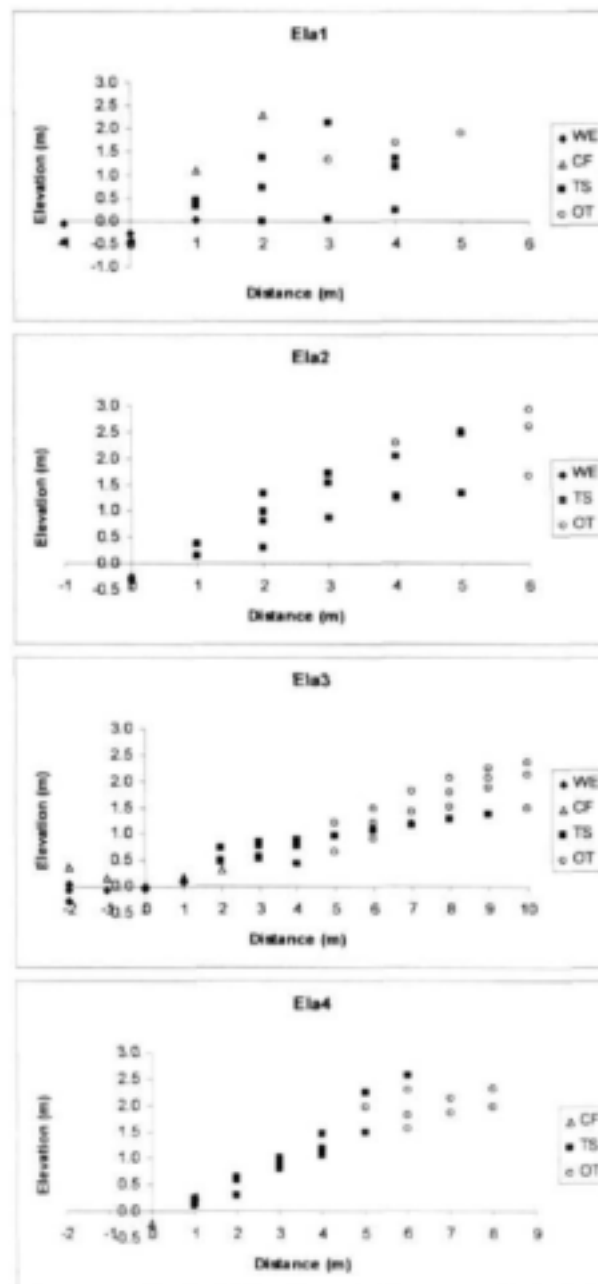


Figure 4.32 Elevation and distance from low flow water's edge for all sample plots at the four Elands River sites. The five assemblage types are shown: WE = Water's Edge, CF = Channel Fringe, TS = Tree Shrub, OT = Outer Transitional and NR = Non Riparian.

Table 4.18 Species richness (5 m² sample plot) in each assemblage type at each of the reference sites on the Rondegat, Elands and Heks Rivers.

Site code	Ron1	Ron2	Ron3	Ron4	Hek1	Hek2	Hek3	Hek4	Ela1	Ela2	Ela3	Ela4	AVE	SD
Zone	MS		MStr		MStr		FH		MS		FH			
WE	4	-	5	14	6	12	3	1	8	2	6	-	6.1	4.2
CF	12	5	21	15	12	2	10	8	9	-	5	1	9.1	5.9
TS	4	6	10	5	10	11	8	10	13	8	8	13	8.8	2.9
OT	19	15	-	-	21	23	6	19	12	32	31	21	19.9	7.9

TS and CF had approximately the same species richness at 8.8 and 9.1 species per sample plot respectively, but the variability about the mean was much lower in TS. WE was the most species-poor assemblage type (6.1 species per sample plot) and also generally less frequently encountered. From site to site the most species rich assemblage type differed although, in most cases where it was present, OT scored highest.

Growth forms of the assemblage types

The occurrence of ten growth forms (definitions as per Table 3.3, Section 3.4.1) in each of the assemblage types for the 12 reference sites is shown in Figure 4.33. WE consisted mainly of sedges, restios and shrubs, in decreasing order. CF contained more restios than WE, fewer sedges and shrubs, and more seedling, juvenile and adult small trees; and forbs. Rushes were only present in WE and CF. TS and OT were similar in their low frequency of sedges, restios and shrubs, and contained similar proportions. Large trees were only found in TS and OT, but these two assemblage types differed in that TS contained the highest frequency of adult small trees and only OT contained small shrubs. Of all the assemblage types, OT had the most even and overall lowest frequencies of occurrence of the ten growth forms.

Measures of biodiversity in 50 m² sample plots

Ten adjacent sample plots, of 5 m² each, were chosen at random from each sample grid to create a larger sample plot totaling 50 m² so that the results could be compared to those from other riparian studies (Chapter 6). A data set was compiled of presence-absence data for all species within the larger sample plot. The species richness at this scale showed some variation between sites (Table 4.19), both within the same zone on the same river (for example between Ron1 and Ron2) and between the same zones on different rivers (for example between Ron3/Ron4 and Hek1/Hek2), but all were within the range 16 to 31. Both the Shannon-Weiner function (equitability: H, Zar 1996) and relative diversity (evenness: J, Pielou 1966) were relatively constant. The high values of J indicate that the species cover is well distributed amongst the species recorded in each sample plot. Lower values would indicate a dominance of one or two species with low cover values in the majority of species categories.

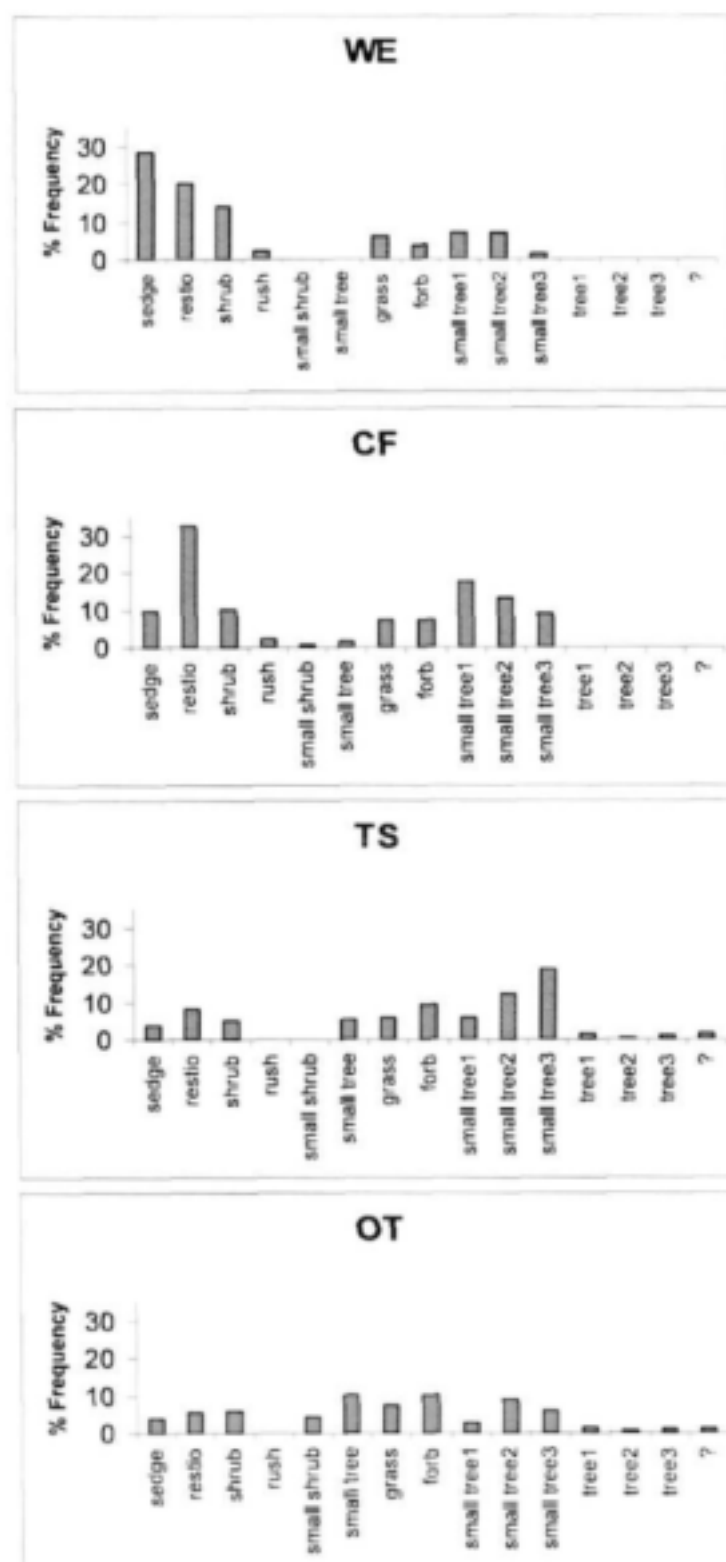


Figure 4.33 Distribution of growth forms (definitions as per Table 3.3) in the four assemblage types on the Rondegat, Elands and Heks Rivers. WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional. 1 = seedling, 2 = juvenile and 3 = adult.

Table 4.19 Measures of diversity calculated for the twelve pristine study sites: species richness (per 50 m² plot). Shannon-Weiner function (equitability: H) and Pielou's relative diversity (J). MS = mountain stream, MStr = mountain stream (transitional) and FH = foothill. Ron(1-4) = 4 sites on Rondegat River, Hek = Heks River and Ela = Elands River.

	Zone	Sp./50m ²	H	J
Ron1	MS	31	2.48	0.72
Ron2	MS	19	2.23	0.76
Ron3	MStr	30	2.53	0.74
Ron4	MStr	16	2.04	0.72
Hek1	MStr	17	2.38	0.84
Hek2	MStr	16	2.19	0.79
Hek3	FH	18	2.00	0.69
Hek4	FH	28	2.57	0.77
Ela1	MS	27	2.79	0.84
Ela2	MS	18	2.51	0.87
Ela3	FH	26	2.34	0.72
Ela4	FH	26	2.51	0.77

Sites from any one river were not noticeably more similar to one another than to sites from the other two rivers nor were sites in the same zone, from the same river, also markedly more similar (Table 4.20). In some cases a particular site, for example Ela1, was more similar to a site on another river in a different river system, Ron1! On the Elands River, the two mountain stream sites (Ela1 and Ela2) showed only a 36% similarity. Both these mountain stream sites were more similar to the mountain stream (transitional) sites (Ela3 and Ela4). Overall the four Heks River sites show the highest similarity to one another, greater in all cases than the similarities between the Elands and the Rondegat sites.

Table 4.20 Sorenson's index of community similarity (Clarke and Warwick 2001). Data are percentage similarities for the Elands (e1-4), Heks (h1-4) and the Rondegat (r1-4) Rivers are shown.

	e1	e2	e3	e4	h1	h2	h3	h4	r1	r2	r3	r4
e1												
e2	35.6											
e3	45.3	45.5										
e4	45.3	40.9	53.8									
h1	40.9	22.9	41.9	46.5								
h2	27.9	17.6	33.3	38.1	72.7							
h3	44.4	22.2	45.5	45.5	57.1	52.9						
h4	40.0	26.1	37.0	37.0	57.8	54.5	60.9					
r1	55.2	44.9	52.6	45.6	37.5	34.0	44.9	47.5				
r2	43.5	32.4	48.9	48.9	33.3	28.6	43.2	34.0	56.0			
r3	35.1	33.3	42.9	32.1	29.8	30.4	41.7	41.4	45.9	40.8		
r4	54.5	40.0	46.5	37.2	52.9	36.4	51.4	48.9	54.2	50.0	51.1	

Indicator species

No species occurred exclusively in any one assemblage type. The most frequently occurring species in WE was the sedge *Isolepis prolifer*, occurring in 54% of WE sample plots (Figure 4.34). In CF the probability of finding this species halved (27%) while it was present in only 5% of TS sample plots and none of those designated OT. The only other species virtually restricted to WE was the shrub *Prionium serratum*, which occurred in 24% of WE (and 4 and 2% of CF and TS respectively). As with the sedge, this species was not found in OT. Two restios were common on all three rivers and were found in all of the four assemblage types: *Calopsis paniculata* was more frequent in WE than was *Elegia capensis* (34% and 6 % respectively), but the two species were equally frequent in CF (49 and 47%), TS (35 and 46%) and OT (6 and 5%). *Pennisetum macrourum* occurred in all assemblage types but was not dominant. *Erica caffra*, *Todea barbara* and *Pteridium aquilinum* were found on the Rondegat and the Elands (and not the Heks) Rivers, with the two former being quite common in all but OT. *Pteridium aquilinum* occurred in all four assemblage types but was more common in TS and most common in OT. *Rhus angustifolia*, only recorded in the samples from the Elands River though it was observed to be present at other locations in the general area of the other river sites, was not found in any WE sample plots and occurred with increasing frequency further up the bank, being most frequently found in OT (10%). Another species restricted in distribution up the bank was the shrub *Diospyros glabra* found in 2% of CF, 26% of TS and 44% of OT.

In terms of potential indicator species, none was restricted to one assemblage type and so none were perfect indicators. Assemblage types were distinguished more by shifts in proportions of various species than by presences and absences. *Isolepis prolifer* and *Diospyros glabra*, however, did show opposing trends in distribution that could help delineate some boundaries: *Isolepis prolifer* could be used to identify the position where the riparian zone begins at the water's edge (WE) and *Diospyros glabra* the outer limits of the riparian zone (OT) where species from adjacent drier habitats take over. An increasing presence of the fern *Pteridium aquilinum* and the shrub *Rhus angustifolia* would also confirm the likely presence of OT. CF and TS are most difficult to distinguish. Both have a high frequency of the restios *Calopsis paniculata* and *Elegia capensis*, which helped distinguish them from WE and OT. In addition, CF may be distinguished from TS by its higher frequency of *Isolepis prolifer* and lower frequency of *Diospyros glabra*.

Common small Riparian Scrub trees

In addition to any potential indicator species mentioned above, the potential as indicators of the four common Riparian Scrub small trees (Figure 4.35) was assessed. The four species generally occurred in all four assemblage types, with all life stages low in frequency in WE, and frequencies tapering off again in the upper bank in OT. Although seedlings were scattered throughout the assemblage types, juveniles and adults were most common in TS, with the most common species and life stage being adult *Metrosideros angustifolia* (63% of TS sample plots). No juvenile or adult *Brabejum stellatifolium* or adult *Brachylaena neriifolia* were found in WE. No seedlings of *Brachylaena neriifolia* and *Metrosideros angustifolia* were found in OT.

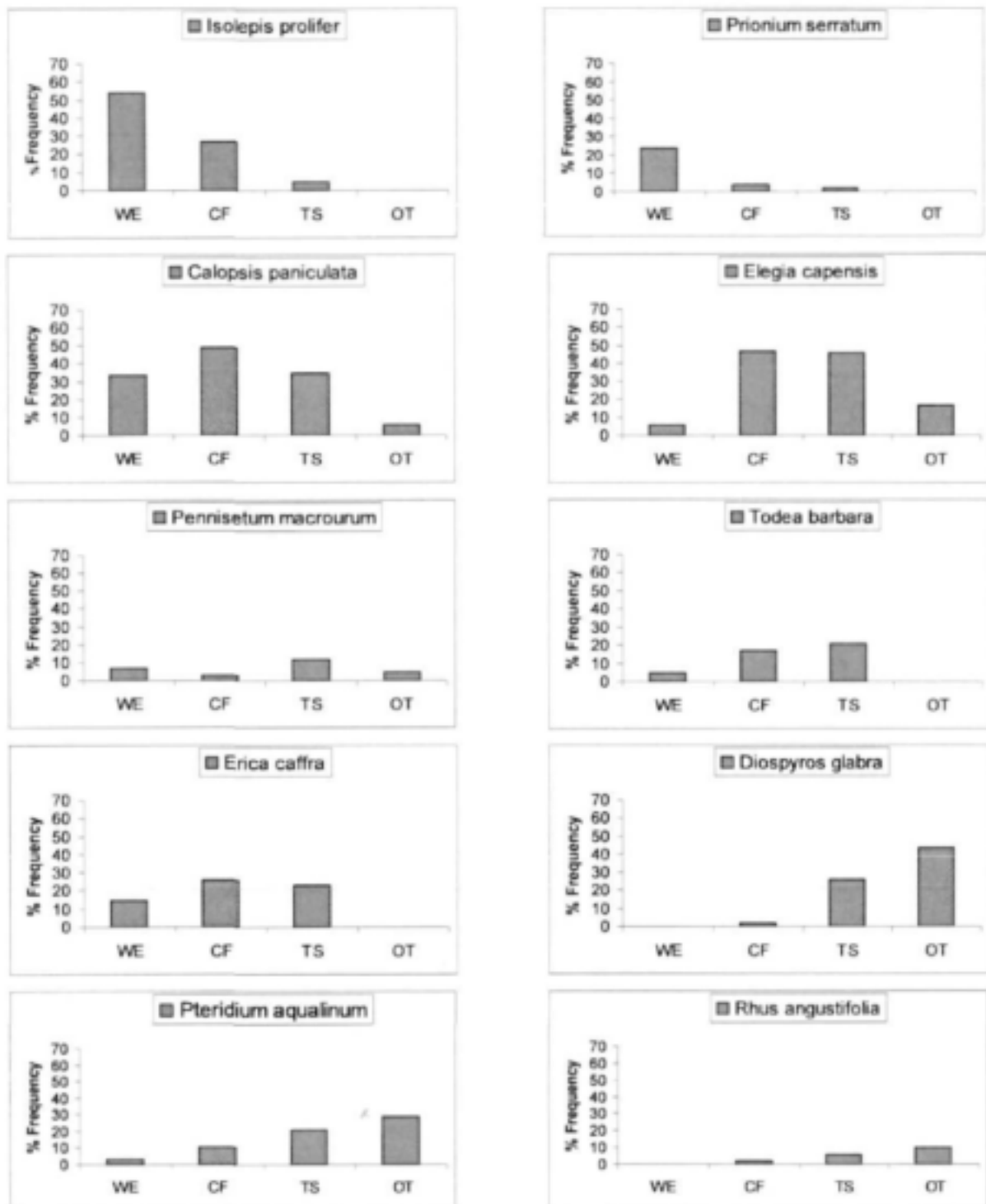


Figure 4.34 Distribution of ten common riparian species among the four assemblage types. WE = wet edge, CF = channel fringe, TS = tree shrub and OT = outer transitional.

The presence of any of these four species would indicate the position of the riparian area in general but none were ideal indicators for any one assemblage type. For all of these species there was a higher probability of finding adults, and either a higher or approximately equal chance of finding juveniles, in

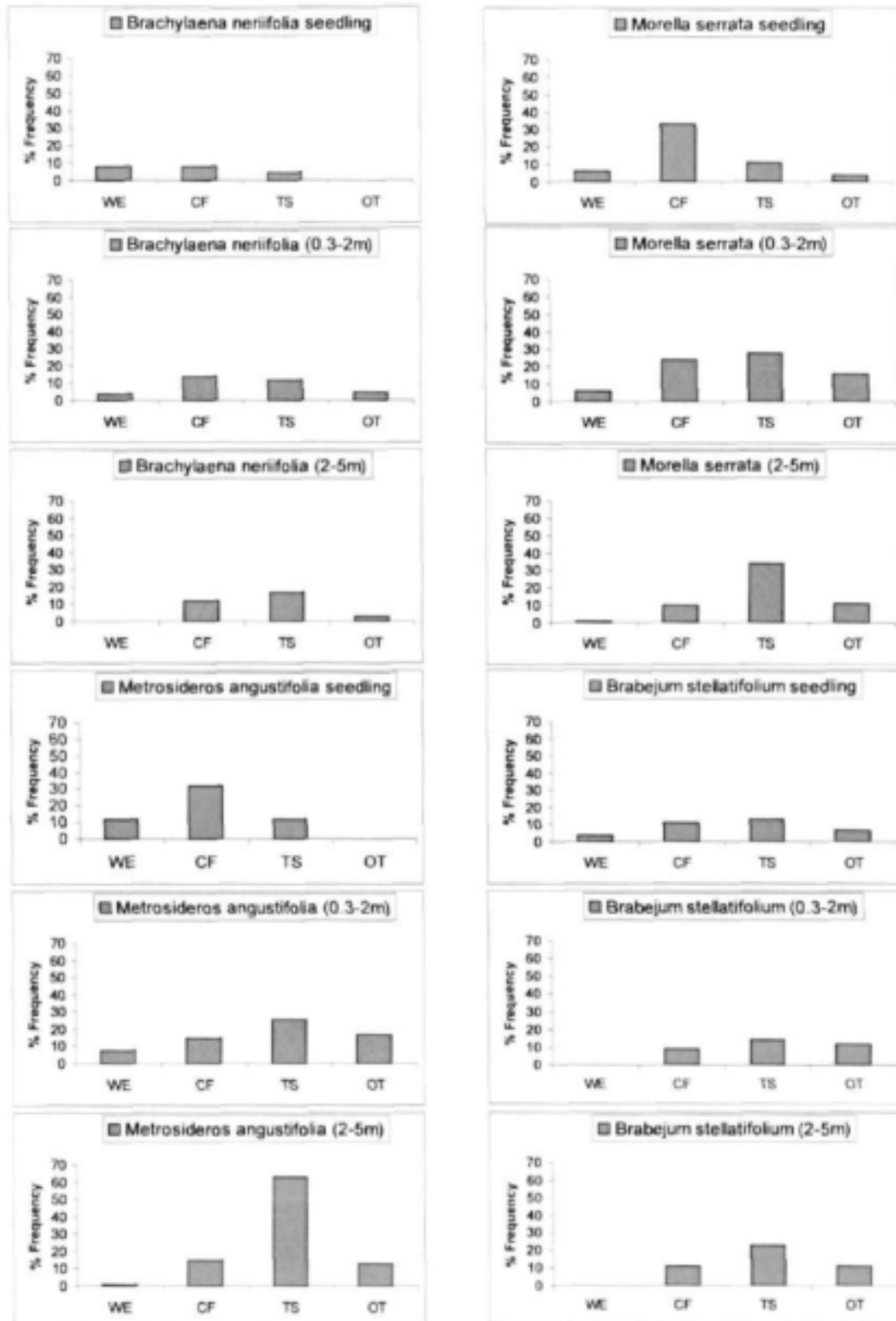


Figure 4.35 Life stage distribution of the four common Riparian Scrub species. Data are percent frequencies in each of four assemblage types, WE = wet edge, CF = channel fringe, TS = tree shrub and OT = outer transitional.

TS than in CF and OT. In most cases their lowest probability of occurrence, in all life stages, was in WE.

4.4.3 Defining a tentative reference condition

Step 4 (Section 4.4) is the derivation of a tentative reference condition. This can be done by using the data from the 12 undisturbed sites to construct rules of two aspects of the riparian zone:

- *a physical reference condition*: physical measures of where specific assemblage types generally occur;
- *a biological reference condition*: biological attributes of the various assemblage types.

Physical reference condition

The description of a physical reference condition was constructed with the aid of a Classification and Regression Tree (CART) model (Breiman et al., 1984). The goal of the technique is to predict membership of cases of a dependent categorised variable from their links with continuous or categorised data of predictor variables. In the data sets for the 12 sites, the categorised dependent variable was the assemblage type to which each sample plot had been allocated.

Twelve physical variables dealing with bank shapes and slopes, the proximity to water and the rockiness of sample plots, and the zone type were entered into the CART model. It then searched through all available combinations for the one with the best goodness of fit (accuracy of predictions) to the categorised variables. Of the 12 physical variables tested the following three best predicted assemblage type:

- elevation from water;
- distance from water;
- gradient of the outer edge of the riparian zone.

The results were summarised in a classification tree (Figure 4.36), allowing derivation of four simple rules of physical measurement that provided a high degree of certainty of locating a specific assemblage type (Table 4.21).

The grey box in Figure 4.36 was pruned, or disregarded, as the rule based on percent cover of water does not discriminate CF and TS effectively. From the rules derived by the tree CF is the assemblage type most likely to be wrongly located. This is probably because CF is sensitive to ground water conditions and thus to localised differences in bank gradient that were not picked up in our data.

Biological reference condition

As with the physical reference condition, no set of biological attributes uniquely distinguished each assemblage type. Some values and guidelines were drawn from Section 4.4.2, however, for comparison with those from disturbed sites in order to assess the degree of impact that had occurred

(Table 4.22). Some values were available per assemblage type (e.g. species richness – Table 4.18) and others per 50 m² plot (e.g. species diversity – Table 4.19).

Table 4.21 Tentative physical rules for locating assemblage types in undisturbed vegetation on the banks of the upper reaches of Western Cape rivers.

Assemblage type	Physical rule	Probability of locating correct assemblage type (%)
WE	Less than 1.5 m distance from summer low-flow water's edge, and less than 0.1 m above the water	82
CF	Less than 1.5 m distance from summer low-flow water's edge, and greater than 0.1 m above the water	39
TS	Between 1.5-4.5 m distance from summer low-flow water's edge	84
TS	Greater than 4.5 m distance from summer low-flow water's edge, where the outer edge gradient is less than 0.2	
OT	Greater than 4.5 m distance from summer low-flow water's edge, where the outer edge gradient is greater than 0.2	62

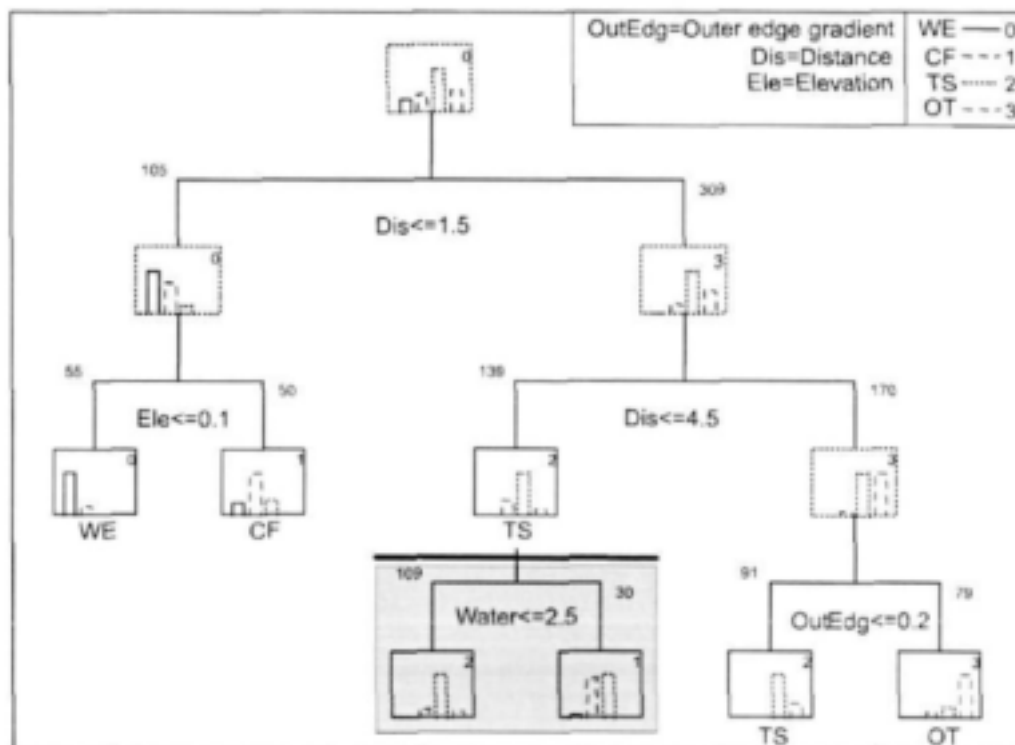


Figure 4.36 Classification tree of physical variable predictors for riparian assemblage types. WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional. Grey box = pruned branch of tree to be disregarded.

Table 4.22 Tentative guidelines for the biological reference condition of undisturbed vegetation on the banks of the upper reaches of Western Cape rivers. Data are averages values for the 12 reference sites on the Rondegat, Heks and Elands Rivers.

Attribute	Vegetation assemblage type			
	WE	CF	TS	OT
Species richness	per 5m ² plot: 6.1 ± 4.2	per 5m ² plot: 9.1 ± 5.9	per 5m ² plot: 8.8 ± 2.9	per 5m ² plot: 19.9 ± 7.9
Equitability (H)	per 50 m ² plot: 2.38 ± 0.23			
Relative diversity (J)	per 50 m ² plot: 0.77 ± 0.06			
Growth form	• Sedges most common • Restios common • Rushes present but very rare • Adult Riparian Scrub trees very rare • No large tree species	• Restios most common • Sedges and shrubs rare • Rushes present but rare • All life stages of Riparian Scrub trees rare • No large tree species	• Sedges, restios and shrubs very rare • Rushes absent • Adult Riparian Scrub trees common • Large tree species very rare	• Most growth forms present at low frequency • Rushes absent • Small shrubs most common to this assemblage type • Riparian Scrub trees less common • Large tree species rare
Possible indicator species	<i>Isolepis prolifer</i> prolific <i>Prionium serratum</i> common <i>Calopsis paniculata</i> very common <i>Elegia capensis</i> very rare	<i>Calopsis paniculata</i> very common <i>Elegia capensis</i> very common <i>Erica caffra</i> common <i>Isolepis prolifer</i> common <i>Diospyros glabra</i> very rare <i>Morella serrata</i> and <i>Metrosideros angustifolia</i> seedlings common <i>Morella serrata</i> juveniles common	<i>Calopsis paniculata</i> very common <i>Elegia capensis</i> very common <i>Erica caffra</i> common <i>Isolepis prolifer</i> very rare <i>Diospyros glabra</i> common <i>Metrosideros angustifolia</i> adults prolific; juveniles common <i>Brabejum stellatifolium</i> adults common <i>Morella serrata</i> adults and juveniles common	<i>Elegia capensis</i> and <i>Calopsis paniculata</i> rare <i>Erica caffra</i> , <i>Prionium serratum</i> , and <i>Isolepis prolifer</i> absent <i>Diospyros glabra</i> very common <i>Pteridium aquilinum</i> common <i>Rhus angustifolia</i> rare but most common to this assemblage type All life stages of <i>Morella serrata</i> , <i>Metrosideros angustifolia</i> , <i>Brabejum stellatifolium</i> and <i>Brachylaena neriifolia</i> rare

Note: Prolific = > 50 % frequency of occurrence (f), very common = 35 % < f < 50 %, common = <20 % < f < 35% , rare = 10 % < f < 20 % and very rare = f < 10 %.

4.4.4 Testing the tentative reference condition

The tentative definitions of physical and biological reference condition were tested on a further six undisturbed sites from three rivers, the Disa River (Plate 4A) in Hout Bay, the Eerste River (Plate 4B) near Stellenbosch and the Witte River (Plate 5) in Bainskloof (data presented in 4.3).

Physical reference condition

Each sample plot on the six rivers was allocated to an assemblage type, following the same procedure as for the earlier twelve undisturbed sites (Section 4.3.2). The physical rules listed in Table 4.21 were then applied to each sample plot to assess how accurately they predicted the observed assemblage type.

The results (Table 4.23) indicated a high success rate for five of the six sites: for Disa 2, Eerste 1 and 2 and Witte 1 and 2, 60 to 89 % of the sample plots were predicted correctly. Addressing these five sites first, overall 68 out of 220 sample plots were predicted incorrectly (30 %). Of these, and assuming the sequence WE to CF to TS to OT, only twelve sample plots were predicted more than one assemblage types from their observed one. Nine of these twelve were at one site: Wit2. Irrespective of the degree of misidentification, most cases occurred around the 4.0 m mark where localised depressions in the bank possibly created ground water conditions that allowed CF to expand beyond the 1.5 m distance specified in the rule. Most mis-identifications thus involved CF.

The poorly-performing site, Disa 1 (Table 4.23) supported Afromontane Forest in a deep narrow gorge. The forest extended up the sides of the gorge, far removed from the river channel, with no typical non-riparian (drier) species taking over. TS did not transform into OT within the confines of this site, and the physical cut-off distance for this transformation, given as 4.5 m by the model, was not valid. OT was thus incorrectly predicted through three of the four vegetation blocks.

Biological reference condition

The species data were summarised for each assemblage type, following the same procedure as the twelve earlier undisturbed sites. The assemblage types from each site were examined against the biological reference condition guidelines (Table 4.22). In each case the presence of at least some of the possible indicator species, listed in the table, matched those present. The distributions of the growth forms were also similar to those described. Though the species richness for the different assemblage types was higher than the average reported (Table 4.22) the trend of increasing species richness from WE through to OT remained. Five of the six sites had values of H and J (Table 4.24) comparable to those reported for the reference condition; only those for Witte 2 fell outside of the range expected. At this site the 50 m² sample plot over which this was measured did not capture any TS or OT assemblage types and so was relatively species poor.

Table 4.23 Classification model results from six undisturbed sites on three rivers. Results are presented in the full sample grid for each site (as per Sections 4.3.3, 4.3.4 and 4.3.5). Tables WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Disa 1 < Flow Accuracy 26 %

	D	C	B	A
15			OT TS	TS TS
14		OT TS	OT TS	TS TS
13	OT TS	OT TS	OT TS	TS TS
12	OT TS	OT TS	OT TS	TS TS
11	OT TS	OT TS	OT TS	TS TS
10	OT TS	OT TS	OT TS	TS TS
9	OT TS	OT TS	OT TS	TS TS
8	OT TS	OT TS	OT TS	TS TS
7	OT TS	OT TS	OT TS	TS TS
6	OT TS	OT TS	OT TS	TS TS
5	OT TS	OT CF	OT CF	TS TS
4	TS TS	TS CF	TS CF	
3	TS CF	TS CF	TS CF	
2	TS CF	TS CF	TS CF	TS CF
1		CF CF		CF CF

Disa 2 Flow > Accuracy 60 %

	A	B	C	D
13		TS TS		TS TS
12	TS TS	TS TS	TS TS	TS TS
11		TS TS	TS TS	TS TS
10		TS TS	TS TS	TS TS
9	TS TS	TS TS	TS TS	TS TS
8	TS TS	TS TS	TS TS	TS TS
7	TS TS	TS TS	TS TS	TS TS
6	TS TS	TS TS	TS CF	TS CF
5	TS CF	TS CF	TS CF	TS CF
4	TS WE	TS CF	TS CF	TS CF
3	TS WE	TS CF	TS CF	TS CF
2		TS CF	TS CF	TS CF
1		CF CF	CF CF	WE CF

Left Predicted from model
Right Observed (allocation)
No record (outlier/rock)
Correct

Eerste 1 < Flow Accuracy 75 %

	D	C	B	A
5	OT OT	OT OT	OT OT	OT OT
4		TS OT	TS OT	TS OT
3	TS TS	TS TS	TS TS	TS TS
2		TS TS	TS TS	TS TS
1	CF TS			CF CF

Eerste 2 Flow > Accuracy 89 %

	A	B	C	D
10	OT OT	OT OT	OT OT	OT OT
9	OT OT	OT OT	OT OT	OT OT
8	OT OT	OT OT		OT OT
7	OT OT	OT OT	OT OT	OT OT
6		OT OT	OT OT	OT OT
5	OT OT	OT OT	OT OT	OT OT
4	TS TS	TS OT	TS OT	TS OT
3	TS TS	TS TS	TS TS	TS TS
2	TS TS	TS TS	TS TS	TS TS
1	CF TS	CF CF	CF CF	CF CF

Witte 1	< Flow				Accuracy		72 %	
	D		C		B		A	
13	OT	OT	OT	OT	OT	OT	OT	OT
12	OT	OT	OT	OT	OT	OT	OT	OT
11	OT	OT	OT	OT	OT	OT	OT	OT
10			OT	OT	OT	OT	OT	OT
9	OT	OT	OT	OT	OT	OT	OT	OT
8	OT	OT	OT	OT	OT	OT	OT	OT
7	OT	OT	OT	TS	OT	OT	OT	TS
6	OT	TS	OT	TS	OT	TS	OT	TS
5	OT	TS	OT	TS	OT	TS	OT	TS
4	TS	TS			TS	CF	TS	CF
3	TS	CF			TS	CF	TS	CF
2	TS	CF	TS	WE	TS	CF	TS	CF
1	CF	CF	CF	CF	CF	CF	CF	CF
0	WE	WE	WE	WE	CF	WE	WE	WE
-1	WE	WE	WE	WE	WE	WE	WE	WE
-2	WE	WE	WE	WE				
-3	WE	WE	WE	WE				
-4	WE	WE						

Witte 2	< Flow				Accuracy		66 %	
	D		C		B		A	
13	OT	OT	OT	OT	OT	OT	OT	OT
12	OT	OT	OT	OT	OT	OT	OT	O
11	OT	OT	OT	OT	OT	OT	OT	OT
10	OT	OT	OT	OT	OT	OT	OT	OT
9	OT	OT	OT	OT	OT	OT		
8	OT	OT	OT	OT	OT	OT	OT	TS
7	OT	OT	OT	OT	OT	OT	OT	TS
6	OT	CF	OT	CF	OT	CF	OT	TS
5	OT	CF	OT	CF	OT	CF	OT	TS
4	TS	CF	TS	CF	TS	CF	TS	CF
3	TS	CF	TS	WE	TS	CF	TS	CF
2	TS	CF	TS	WE	TS	WE	TS	CF
1	CF	CF	CF	WE	CF	WE	CF	CF
0	WE	WE			WE	WE	WE	WE
-1	WE	WE	WE	WE	WE	WE	WE	WE
-2	WE	WE	WE	WE	WE	WE		
-3	WE	WE	WE	WE				
-4			WE	WE				

Left Model prediction
 Right Assigned assemblage
 No record (outlier/rock)
 Correct

Table 4.24 Shannon-Weiner function (equitability: H) and relative diversity (J) for the six undisturbed test sites.

	Disa 1	Disa 2	Eerste 1	Eerste 2	Witte 1	Witte 2
H	2.46	2.07	2.85	2.94	2.48	0.69
J	0.76	0.61	0.80	0.84	0.73	0.36

4.4.5 Summary of reference condition

The preceding sections have defined and tested a reference condition for riparian vegetation that shows good potential for guiding studies of disturbed sites. The physical predictors performed worst for the CF assemblage type, and for the riparian zone in deep, narrow headwater gorges; both of these areas need further research to better define physical predictor variables. The biological reference condition matched the results of the test satisfactorily. The predicted assemblage types all contained the expected species and range of growth forms and five of the six sites had comparable biodiversity measures (H and J). An attempt was made to tighten the biological descriptors beyond the general descriptions given (Table 4.22).

Further refinement of the reference condition is beyond the scope of this project. For the purpose of this assessment of the impact of aliens on riparian zones the reference condition as described and tested above is accepted as being sufficiently robust to guide a useful analysis of disturbed sites. This follows in Chapter 5.

5. INVADED AND CLEARED RIPARIAN ZONES

5.1 INTRODUCTION

In this chapter, the impact of alien tree species on the riparian vegetation of river ecosystems is assessed, through a study of the nature and status of invaded and cleared riparian zones.

First, the 17 disturbed sites (Table 3.3) are described in the context of their general riparian character and their relationship with the 18 undisturbed sites (Section 5.2). Then, the uncleared, heavily invaded sites are described individually (Section 5.3.3) at the site scale, followed by a similar section on the cleared and recovering sites (Section 5.3.4). Section 5.4 summarises the trends from the individual site analyses and compares the disturbed sites to the reference condition.

5.2 CATCHMENT-SCALE PATTERNS

The 35 study sites in this project Table (3.2) were located on rivers draining five adjacent mountain ranges and included undisturbed (Chapter 4) and disturbed sites. An initial assessment of the nature of the riparian zones of the 35 sites (Section 4.2.1) revealed that the disturbed and undisturbed sites were clearly distinguishable from one another based on simple presence and absence data of riparian vegetation species (Figures 4.1 and 4.2). Further, within these two broad groupings, undisturbed sites grouped by catchment and then by river. This section investigates how the disturbed sites fitted into this pattern.

5.2.1 Catchment groupings

A presence/absence list of riparian vegetation species was collated for each disturbed site, following the same procedure used for the undisturbed sites, and analysed to produce a CLUSTER analysis and a Multi-Dimensional Scaling (MDS) ordination (Figure 5.1). The disturbed sites displayed a pattern of catchment groupings in much the same way as had the full set of 35 sites (Figure 4.1).

There were four main groups in the disturbed-sites data set (Figure 5.1):

1. heavily invaded and cleared sites from the Cedarberg and Hawequas mountain ranges (group B);
2. cleared sites on the Molenaars River in the Hawequas mountain range (group C);
3. cleared sites in the Hottentots Holland and Table Mountain ranges (group D);
4. cleared sites in the Hottentots Holland mountain range on the Assegaaibos River (group E).

The group letters were assigned as in Figure 4.1, with Group A missing in Figure 5.1 because it consisted of undisturbed sites. Additionally in Figure 5.1 there were two outlier sites: Cecelia Ravine (Cec1) on Table Mountain, which was heavily invaded with the grey poplar *Populus x canescens*; and the Sir Lowry's Pass River (SLP3) in the Hottentots Holland mountains, which was heavily invaded with *Eucalyptus leucoxylon*. These were the only two disturbed sites that did not contain *Acacia*, all

of the others containing *Acacia mearnsii*, other *Acacia*, or *Acacia mearnsii* mixed with other *Acacia* or other species (Table 4.1). The two outlier sites are not discussed further in this section but their characteristics are summarised later in the site-level descriptions (Section 5.3.3).

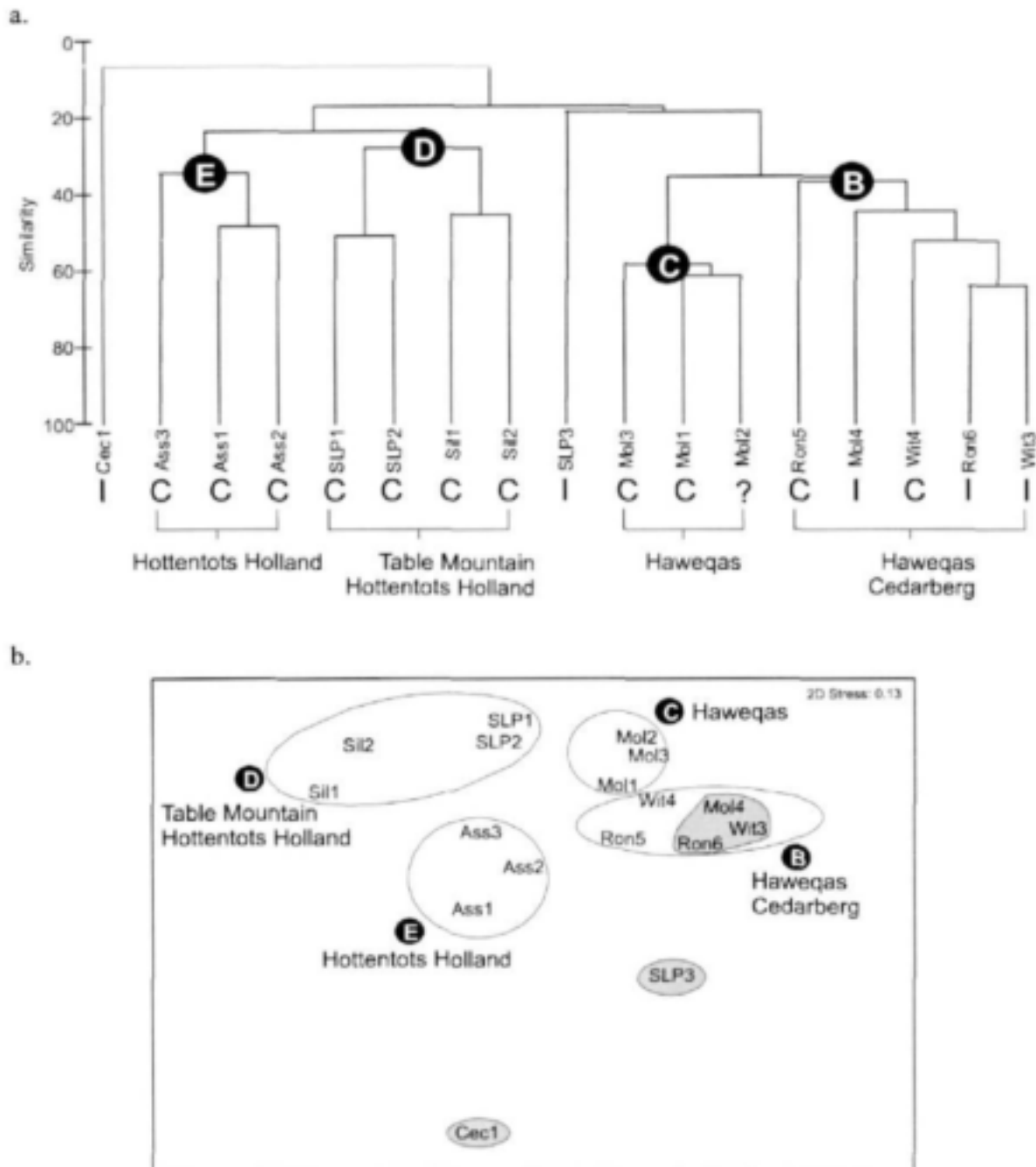


Figure 5.1 CLUSTER analysis (a) and Multi-Dimensional Scaling (MDS) ordination (b) of Bray Curtis similarities between all 17 disturbed sites. Multiple sites on river are numbered 1 through 3, site codes as per Table 3.2. I = invaded and C = cleared. Group A, the undisturbed sites (Figure 4.1) is excluded from these figures. Grey shading in figure 5.1b indicates the five invaded sites.

Groups B and C and groups D and E formed two larger groups within the similarity matrix (Figure 5.1b). Groups B and C sites were located in the Hawequas and Cedarberg mountain ranges and groups D and E in the Hottentots Holland and Table Mountain mountain ranges. Thus there was a similar identification of sites by catchment and river to that described in the larger analysis in Chapter 4.

5.2.2 Within-group characteristics

Apart from the two outliers, all the heavily invaded sites (Mol4, Wit3, Ron6) were in group B. Mol4 and Wit3 were invaded with *Acacia mearnsii* while Ron6 had a mixed invasion of *Acacia mearnsii*, *Acacia longifolia* and *Eucalyptus* spp. The other two sites in group B (Ron5, Wit4) were cleared seven and eight years before this study in the years 1998 and 1997 respectively, were within 100 m of the heavily invaded areas (Ron6 and Wit3 respectively) and though subject to post-clearing clean-ups this was not done at annual intervals as was the case for many of the other disturbed sites (Table 4.1, section 4.2).

Group C contained two cleared sites (Mol1 and Mol3) and the anomalous site Mol2 (Section 4.2.1) on the Molenaars River. Mol1 was first cleared in 1994 and Mol3 in 1997; the adult *Acacia* trees were felled and the cut stumps treated with herbicide. At the time of sampling the vegetation was ten and seven years old respectively. These sites had been subject to follow-up clearing operations; recruiting *Rubus* spp. and *Acacia* seedlings were treated with herbicide foliar spray.

Despite the invasions and clearances, all the sites within groups B and C retained their greater catchment identity as part of a Cedarberg-Hawequas grouping, as had the undisturbed sites. Nevertheless, there was poorer distinction than in the undisturbed sites at the river level, suggesting that the finer details of their identities had been lost.

Group D contained only cleared sites: two on the Sir Lowry's Pass River (SLP1 and SLP2) in the Hottentots Holland mountains and two on the Silvermine River (Sil1 and Sil2) on the Table Mountain range. The two Sir Lowry's sites had supported mixed invasions of *Acacia mearnsii*, *Acacia longifolia*, *Acacia saligna* and *Pinus pinaster*, whilst the uppermost site on the Silvermine River (Sil1) had been infested with *Pinus pinaster* and the lower one (Sil2) with *Acacia saligna* and some *Acacia longifolia*. The recovering vegetation at these four sites was between three and thirteen years post-clearing age when this project started, and all were receiving intensive follow-up clearance. At the time of sampling (Table 3.4) very few individuals of the relevant alien species were present.

Group E contained three cleared sites on the Assegaaibos River in the Hottentots Holland mountains. Ass3, Ass1 and Ass2 were one, two and four years post-clearing age respectively at the time of this study. The entire catchment around these three sites supported pine plantation that was being clear-felled during the study. Ass2 was subject to a secondary invasion of *Acacia longifolia* and *Acacia*

meurnsii, the individuals being between two and four metres in height. This was subjected to follow up clearance immediately after sampling and re-sampled one year later as Ass3.

The MDS ordination revealed the same pattern of four groups and the two outliers. The stress value of 0.13 in the ordination (Figure 5.1b) indicated a small chance of the 2-d relationship portrayed being misleading or inaccurate (Clarke & Warwick 2001).

In summary the trends were as follows.

- Cleared sites from a catchment group were more similar to one another than to uncleared sites within the same catchment group.
- The main catchment groupings identified for the undisturbed sites (Chapter 4.2.1) were still discernable in the disturbed sites but finer definition at the level of river was weak, particularly for invaded (uncleared) sites.
- The heavily invaded site with the gum *Eucalyptus leucoxylon* (SLP3), and possibly that with the grey poplar *Populus X canescens* (Cec1), appeared most affected in that they no longer grouped by catchment. This might be interpretable as a severe loss of catchment identity. Heavily invaded sites with *Acacia* (Mol4, Ron6 and Wit3) appeared somewhat less impacted as they remained within their catchment groupings.

5.2.3 Comparison of growth forms at disturbed sites

As with the undisturbed sites (Section 4.2.2), the total cover of each species at each disturbed site was summed and reduced to a percentage of the total cover per growth form per site. These percentage covers were averaged across all sites present in each of the four catchment groups to give the mean percent cover for each of the ten growth form categories (Table 3.5) in each catchment group (Table 5.1). The two outliers, Cec1 and SLP3, are not included here in discussions on characteristics of the disturbed groups; individual site discussions are presented in Section 5.3.3 for all disturbed sites.

Large trees were generally well represented in all of the four catchment groups due to the overwhelming presence of alien trees at various life stages at most sites. Notable differences between the four groups were as follows:

- The uncleared and heavily invaded Hawequas/Cedarberg group differed to the cleared groups in that it contained the lowest proportion of forbs as well as a high proportion of shrubs;
- the cleared Hawequas group on the Molenaars River contained a similar proportion of small trees to the uncleared group, which was much higher than in the two Hottentots Holland groups;
- this Hawequas Molenaars River group also differed from all the other groups in its high proportion of restios;
- the two Hottentots Holland groups differed in their higher proportion of small shrubs when compared to the heavily invaded Hawequas Cedarberg group ($p < 0.05$);
- the combined Hottentots Holland/Peninsula group contained the most sedges and grasses of any of the groups;
- the Hottentots Holland group on the Assegaaibos River had the highest proportion of rushes and the lowest of shrubs;

- geophytes were generally poorly represented, as they were at the undisturbed sites.

Table 5.1 The mean (and standard deviation) percentage cover of each growth form in each of the four catchment groups (disturbed sites only). Growth form categories as per Table 3.5. *n* = the number of sites in each group. *N* = the number of sites in which the growth form occurred in each group. From the Kruskal Wallis ANOVA, * against two groups denotes a significant difference between them ($p < 0.05$). ^ Denotes a large difference that was not significant ($0.05 < P < 0.10$).

Growth form	Forb	Geophyte	Rush	Sedge	Grass	Restio	Small shrub	Shrub	Small tree	Large tree	Un-identified
B Hawequas/Cedarberg (uncleared and cleared 7-8 yrs)											
<i>n</i> =5			*	^			*				
Mean	3.25	0.00	0.72	2.48	8.23	6.48	0.05	28.31	24.32	25.71	0.50
SD	4.1	0.0	1.2	2.5	11.4	6.1	0.1	14.9	21.4	18.5	0.7
N	5	5	4	5	4	3	5	1	5		2
C Hawequas (Molenaars; cleared 7-10 yrs)											
<i>n</i> =3									^		
Mean	11.10	0.10	1.86	6.51	7.98	11.72	0.43	14.54	27.58	16.60	1.57
SD	10.7	0.2	0.3	4.2	4.2	11.0	0.2	4.1	12.2	12.0	0.2
N	3	1	3	3	3	3	3	3	3	3	3
D Hottentots Holland/Table Mountain (cleared 3 - 15 yrs)											
<i>n</i> =4				^			*		^		
Mean	15.81	0.02	2.36	14.55	23.64	2.45	3.47	18.35	1.59	16.59	1.17
SD	5.7	0.0	1.0	12.4	11.5	1.6	4.0	10.2	0.9	13.6	1.4
N	4	1	4	4	4	4	4	4	4	4	2
E Hottentots Holland (Assegaaibos; cleared 1-4 yrs)											
<i>n</i> =3			*				*				
Mean	13.67	0.06	16.01	8.26	14.44	5.11	2.50	8.08	3.25	24.64	3.98
SD	5.1	0.1	10.3	1.3	4.8	2.4	2.0	6.1	2.9	19.1	2.5
N	3	2	3	3	3	3	3	3	3	3	3

5.2.4 Families and species

The total cover recorded for each species at each site was summed and reduced to a percentage of the total cover per family per site. These percentage covers were averaged across all the sites present in each of the four catchment groups (B through E) to give the mean percent cover for each of the families represented in each catchment group. The total list of families was sorted per group, and the dominant ones by percent cover and frequency of occurrence were selected for further analysis (Table 5.2). The families were arranged in the table in the same way as for the undisturbed sites (Table 4.3) so that comparisons could be made between those prominently found at the undisturbed and the disturbed sites. The dominant families for disturbed sites fell into four main groups: cosmopolitan families, those affiliated with Riparian Scrub communities, those affiliated with Forest communities and those prominent at disturbed sites. The four catchment groups of disturbed sites, B to E, were compared with the reference condition, by comparing each disturbed catchment group (B through E) with the general range of reference conditions encompassed by the Hawequas, Cedarberg

Table 5.2 Mean percentage cover for each family in each catchment group of disturbed sites. (n) = the number of sites in each catchment group. B through E are the four catchment groups as per Figure 5.1. (N) = the number of sites in which the growth form occurred. From the Mann-Whitney U test, * denotes a significant difference ($p < 0.05$) between the family and the set of reference condition data (16 Riparian Scrub sites, Table 4.3, section 4.2.3).

	B Hawequas Cedarberg (n=5) Cleared/uncleared			C Hawequas (Molenaars, n=3) Cleared			D Hottentots Holland Table Mountain (n=4) Cleared			E Hottentots Holland (Assegaaibos, n=3) Cleared		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
1. Cosmopolitan families												
Poaceae	7.7	11.7	5	6.4	3.1	3	* 21.0	11.5	4	14.4	4.8	3
Cyperaceae	2.6	2.8	4	6.5	4.2	3	13.5	12.4	4	8.3	1.3	3
Dennstaedtiaceae	1.2	2.2	2	10.3	11.1	2	3.4	3.4	4	1.9	2.6	3
Ebenaceae	15.5	16.0	5	3.8	3.5	2	0.4	0.4	2	0.2	0.3	2
Osmundaceae	0.4	0.6	2				1.7	3.4	1			
2. Riparian Scrub affiliation families												
Restionaceae	* 6.4	6.2	4	13.8	13.7	3	* 2.3	1.5	4	* 5.2	2.4	3
Ericaceae				3.2	2.8	3	0.7	0.5	4			
Asteraceae	2.0	2.5	5	5.5	5.6	3	* 13.7	4.8	4	15.3	13.9	3
Myrtaceae	16.0	10.8	5	10.4	5.9	3	0.1	0.1	1	3.6	3.5	3
Myricaceae	* 0.8	0.7	4	4.2	3.9	3						
Proteaceae	9.7	12.7	4	14.1	11.5	3	6.3	8.0	2	1.9	3.2	2
3. Forest affiliation families												
Asparagaceae							0.0	0.1	1			
Blechnaceae	0.0	0.0	1				0.3	0.4	2	0.4	0.3	2
Myrsinaceae												
Juncaceae	1.4	2.6	4	2.1	0.2	3	5.1	4.6	4	* 16.0	10.3	3
Cunoniaceae							2.2	4.4	1	0.0	0.0	2
Fabaceae	* 10.7	6.3	5	3.3	1.0	3	* 10.6	12.6	4	20.2	16.6	3
Rubiaceae				0.2	0.3	1				0.5	0.8	1
Apocynaceae				0.0	0.1	1						
4. Other families prominent at disturbed sites												
Prioniaceae	11.6	11.5	5	3.8	6.2	3	2.5	5.0	1			
Anacardiaceae	0.3	0.7	1	8.9	11.7	3	0.5	0.1	4			
Scrophulariaceae	0.1	0.2	2	* 4.6	3.1	3	0.8	0.8	3	2.9	2.7	3
Campanulaceae	0.2	0.4	1	0.0	0.1	1	0.4	0.5	2	0.1	0.1	1
Podocarpaceae	2.0	3.4	4									
Saliaceae	0.1	0.3	1	1.5	1.1	3						
Bruniaceae	0.0	0.0	2				4.6	3.5	4			
Haloragaceae	0.7	1.5	1	0.1	0.1	1	2.7	3.7	2			
Thymelaceae							2.2	1.4	4	1.2	1.9	2
Pinaceae							1.7	3.5	2			
Aizoaceae							0.6	1.1	1			
Celastraceae							0.6	1.2	2	1.0	1.7	1
Phytolacaceae										1.4	0.9	3
Polypodiaceae										1.1	1.0	2

and Hottentots Holland mountain ranges (Table 4.3). The Table Mountain sites were excluded on the basis that they were Forest and not Riparian Scrub. A Mann-Whitney U test was used to test significance between any large differences noted (differences reported where $p < 0.05$).

Group B

Group B, containing five heavily invaded⁵ or recently cleared sites from the Hawequas/Cedarberg mountain ranges, deviated from the average covers defined for the reference condition (Table 4.3). In the cosmopolitan group of families (1) there was a disproportionate cover of *Diospyros glabra* (Ebenaceae) - more so than in any of the undisturbed or other disturbed groups. The high standard deviation is due to high covers of this species at the three Hawequas sites (Mol4, Wit 3 and Wit4) and much lower covers at the two Cedarberg sites (Ron5 and Ron6) (Appendices 5.6 & 5.7). Perhaps invasion by *Acacia mearnsii* favours the proliferation of this species in some way; this is an area needing research.

Two of the Riparian Scrub families (group 2) were noticeably more sparsely distributed beneath the alien canopy than in the reference condition, namely *Morella serrata* (Myricaceae, $p < 0.05$) and the dominant riparian restios *Calopsis paniculata*, *Cannamois virgata* and *Elegia capensis* ($p < 0.05$). Where present, these species tended to occur only at the water's edge in contrast to their wider distribution at undisturbed sites. The common, dominant species *Erica caffra* (Ericaceae) in the reference condition was completely absent from group B, as it was also from group E. The dearth of *Erica caffra* at these heavily invaded sites cannot necessarily be attributed to the presence of alien species as it was also absent from the undisturbed Heks River sites.

The comparatively high cover of Fabaceae ($p < 0.05$) in the Forest-affiliated group of families (group 3) was mainly due to the alien species *Acacia mearnsii* and *Acacia melanoxylon*. Some species of *Psoralea* were also recorded here but were not dominant.

Among the final group, that of families prominent at disturbed sites, the Podocarpaceae showed a noticeable increase in occurrence and abundance due to the presence of *Podocarpus elongatus*. Perhaps this forest species was favoured by the closed canopy created by the presence of the dominant *Acacia mearnsii*.

Group C

Group C contained three sites on the Molenaars River in the Hawequas mountain range. Two of these were heavily invaded with *Acacia mearnsii* but were cleared in 1994 and 1997; the status of the third site is anomalous at this stage. This group is most similar to the undisturbed sites in that only three families deviate from the reference condition described in Table 4.3. The fern *Todea barbara* (Osmundaceae) was absent, as for group E (the recently cleared sites on the Assegaaibos River). The abundances of the Riparian Scrub and Forest families were similar to those described for the undisturbed sites. Two families appeared to be more prominent than at undisturbed sites: the Anacardiaceae, represented by *Rhus angustifolia* and, to a lesser extent, by *Rhus crenata*; and the

Scrophulariaceae ($p < 0.05$), represented by *Freylinia lanceolata* and *Halleria elliptica*. *Oftia africana*, another member of this family, was also present but to a lesser extent. All were present at some other disturbed and undisturbed sites, but in lower abundances.

Group D

Group D consisted of two sites each in the Hottentots Holland and Table Mountain mountain ranges. The two Hottentots Holland sites supported mixed invasions (*Pinus radiata*, *Acacia mearnsii*, *Acacia saligna* and *Acacia longifolia*) while the Table Mountain sites were invaded with *Pinus radiata* or *Acacia saligna*. The two Hottentots Holland sites were clear felled in 2000 and 2002 and the alien debris was burnt in stacks (J. Manson pers. comm. 2006). The two Table Mountain sites were burnt in a wild fire in January 2000 (K. Reinecke pers. obs. 2000). This group contained the highest recorded presence of Poaceae ($p < 0.05$) among all the disturbed and undisturbed sites. Many species of grass contributed towards this (Table 5.3), the two most dominant being *Ehrharta setacea* and the alien species *Briza maxima*. All of the alien grass species recorded in this group are indicative of disturbance (Goldblatt & Manning 2000). Of the other grass species, the only one normally associated with wet habitats was *Pennisetum macrourum*, and this was recorded at both disturbed and undisturbed sites.

Table 5.3 Grasses (Poaceae) recorded at the disturbed sites on the Sir Lowry's Pass and Silvermine Rivers (disturbance group D). Alien species are bolded. Brackets indicate order of dominance, with 1 being most dominant by cover.

Species favoured by disturbance Goldblatt & Manning (2000)	Species with other habitat requirements (see text)
<i>Briza maxima</i> (2)	<i>Ehrharta setacea</i> (1)
<i>Paspalum urvillei</i> (3)	<i>Pentaschistis barbata</i> (5)
<i>Pennisetum clandestinum</i> (4)	<i>Pentaschistis airoides</i> (6)
<i>Paspalum dilatatum</i> (9)	<i>Pennisetum macrourum</i> (7)
<i>Digitaria debilis</i> (10)	<i>Ehrharta ramosa</i> (8)

All but one of the Riparian Scrub families deviated from that described for the reference sites. The dominant riparian restios were conspicuously reduced in cover, with *Calopsis paniculata* and *Cannamois virgata* still present but *Elegia capensis* completely absent. Other species contributed to the cover of Restionaceae ($p < 0.05$), one of them, *Ischyrolepis subverticillata*, being associated with riverine environments. Though present, *Erica caffra* (Ericaceae) was sparse. *Metrosideros angustifolia* (Myrtaceae) was present at a conspicuously low cover and *Morella serrata* (Myricaceae) absent. Asteraceae ($p < 0.05$) also dominated these four sites; the family was recorded in many of the undisturbed sites but its dominance was much greater in these disturbed sites. Five of the Asteraceae species recorded here occurred at reference sites (*Stoebe plumosa*, *Brachylaena neriifolia*, *Stoebe cinerea*, *Osteospermum ciliatum* and *Taraxacum officinale*, the latter an alien species of disturbed places) two were weedy alien species (*Coryza canadensis* and *Coryza bonariensis*) and the remainder were either disturbance pioneers, or species favouring damp grassy, sandy or rocky slopes.

As with group B, Fabaceae ($p < 0.05$) were prominent members of the Riparian Scrub-affiliated families, due to the presence of *Acacia longifolia*, *Acacia mearnsii* and, to a lesser extent, *Acacia melanoxylon*. Prominent non-alien members of the Fabaceae were *Psoralea pinnata*, *Virgilia oroboides* and *Indigofera filifolia*.

Three families appeared more prominently in group D than in any other disturbed group. *Berzelia lanuginosa* was solely responsible for the cover of Bruniaceae, occurring at a similar cover as in some undisturbed sites from the Hawequas mountain range, although it co-occurred with *Pseudobaeckia africana* in the undisturbed sites. Both these members of the Bruniaceae are typically associated with riparian or wetland habitats. Another species often at very low cover at undisturbed sites, *Laurembergia repens* (Haloragaceae), reached its highest cover in group D.

Group E

Group E was similar to C in that *Todea barbara* (Osmundaceae) was absent from the cosmopolitan family group, similar to B in the absence of *Erica caffra* (Ericaceae) from the Riparian Scrub affiliation, and similar to D in the absence of *Morella serrata* (Myricaceae) and the low cover of *Metrosideros angustifolia* (Myrtaceae), both from the Riparian Scrub group. Asteraceae, as in group D, appeared to proliferate in the disturbed conditions at these three sites. As at the undisturbed areas, there was a number of species contributing towards the total asteraceous cover but the average was much greater than that recorded for any of the reference conditions. Only three species of Asteraceae were recorded at any of the reference sites; *Helichrysum odoratissimum*, *Stoebe plumosa* and *Metalsia densa*. Of the other species, two were weedy alien species. The first, *Conyza canadensis*, was the most prominent herbaceous perennial present in this group. The second, *Inula graveolens*, was much less prominent. All the others were either pioneer species, or species favouring damp grassy or sandy slopes or rocky slopes. Since none of these species are specifically riparian they are not considered further here.

Of the species affiliated with Forest communities, two main differences from the reference condition occurred. First, the Fabaceae, already mentioned for the other disturbed groups, was the dominant family in this group. The two main species responsible were *Acacia longifolia* and *Virgilia oroboides*; *Acacia mearnsii* and two *Podalyria* species were also present but less abundant. Second, there was a high cover of Juncaceae ($p < 0.05$) due to four species: *Juncus lomatophyllus*, *Juncus capensis*, *Juncus effusus* and *Juncus exsertus*, listed in order of abundance. The latter species was not recorded at any other site.

5.2.5 Summary of catchment-wide community patterns

Four main groups of disturbed sites were apparent, with many similarities but also with unique features. Group B, the most heavily disturbed, and group C, the least disturbed, were shown to be most different from the other two groups. Group B had the lowest cover of forbs, rushes, sedges and small shrubs, whilst group C had the highest cover of small trees due to the presence of generally

abundant Riparian Scrub species. The other two groups were similar in their abundance of grasses and small shrubs but differed in that group D had a high cover of sedges while group E had a high cover of rushes.

The super-groups BC and DE were from different catchments and had different invading species; it is not clear which of these, if either, was the over-riding influence in causing the super-groups. There are few studies of riparian recovery in the Western Cape. One recent study by Galatowitsch and Richardson (2005) found that areas cleared of dense invasions that were between three and six years in age had a diminished extent of trees in the canopy, an increased importance of shrubs or re-invading trees, reduced species richness, reduced occupancy of one third of common Riparian Scrub species and reduced incidence of indigenous tree regeneration (Table 4.5). Our data corroborate this finding in that super-group DE (all sites < 6 years of age other than SLP1) contained a higher proportion of small shrubs and reduced cover of Riparian Scrub species, particularly tree species (small trees in this report). Super-group BC (all sites > 7 years of age other than the anomalous Mol2) had a higher cover of Riparian Scrub species (small trees).

Families and species typically cosmopolitan at the undisturbed sites were generally present, other than the Osmundaceae, absent from groups C and E (Table 5.2). Families generally more abundant in one of the disturbed groups were Poaceae (grasses) in groups D and E, Cyperaceae (sedges) in group D, Dennstaedtiaceae (the fern *Pteridium aquilinum*) in group C and Ebenaceae (the shrub *Diospyros glabra*) in group B.

The abundances of the undisturbed Riparian Scrub families (Group 2, Table 4.3) most closely resembled those of disturbance group C (Table 5.2), while the other three disturbed groups differed largely in reduced covers of Restionaceae and Ericaceae. Further, groups D and E differed from the undisturbed Riparian Scrub group in having reduced covers of Myrtaceae (*Metrosideros angustifolia*), an absence of Myricaceae (*Morella serrata*) and an increase in the cover of Asteraceae (many species). The other two notable increases in cover were for the Juncaceae (four species, one new) in group E and Fabaceae, largely due to the presence of alien *Acacia* in groups B, D and E; again group C was most closely aligned with the undisturbed sites in this regard.

5.3 SITE-SCALE PATTERNS

To assess the impact on riparian vegetation of invasive alien plants, the detailed structure and characteristics of disturbed sites were investigated through sampling of disturbed sites in the same way as had been done for undisturbed sites (Section 3.3). No *a priori* assumptions were made about the nature and location of different vegetation assemblages and instead the collected data were used to define these, guided by the model developed for the reference condition (Section 4.4). This was done through the following steps (the bolded text refers to the steps taken in this chapter):

1. Use data from 12 undisturbed sites to recognise and describe vegetation assemblage types that are typical of Western Cape headwater riparian zones (section 4.3);
2. describe where these assemblage types were located in undisturbed sites and correlate this, if possible, with some easily measured physical variables (section 4.4.1);
3. describe the biological characteristics of the vegetation assemblage types or of the site plots as a whole (section 4.4.2);
4. derive from steps 2-3 a first tentative description of the reference condition (section 4.4.3);
5. test this using similar data from six more undisturbed sites (section 4.4.4);
6. **use the physical variables defined in the reference condition to locate areas where the various assemblage types should be in invaded (Section 5.2.3) or cleared (Section 5.2.4) sites;**
7. **assess how the biotic characteristics of the assemblage-type areas differ from the reference condition in invaded (Section 5.2.3) or cleared sites (Section 5.2.4).**

5.3.1 Preliminary data management

The vegetation data collected at the disturbed sites were prepared and analysed in the same manner as done for the undisturbed sites: species-level cover data from all the sample plots at each study site were 4th root transformed and analysed using a non-metric Multi-dimensional Scaling ordination and a CLUSTER analysis. Groups of sample plots with a natural coherence were recognized as a possible vegetation assemblage and allocated a number, with 1 being closest to the water's edge and numbers increasing with physical distance from the water's edge. Each assemblage so identified was assessed in terms of its species composition and, in cases of two assemblages with an overall 50-60% similarity and no substantial difference in the composition or abundance of species, the groups were merged. The full data set for all the disturbed sites appears as Appendix 5.

When searching for dominant or typical species of each assemblage, species-cover data were ranked per assemblage by frequency of occurrence with additional consideration of cover. Ranking by frequency allows assemblages to be defined primarily by species that are generally or always present rather than by species that contribute the most cover, thus allowing smaller, common species to contribute towards the identity of the assemblage.

5.3.2 Assigning assemblages to an assemblage type

Because natural vegetation distribution patterns were disrupted by the alien trees, the CART model (Section 4.4.3) was used to assign each sample plot to an assemblage type (step 6 above). The model used the physical characteristics of distance from summer water's edge and height above summer water's edge to allocate each sample plot to one of WE, CF, TS or OT assemblage types (Table 4.21; Figure 4.36). The abundance and frequency of species present in the delineated area for an assemblage type were then compared to the biological reference condition for that assemblage type (Table 4.22), as step 7 of the above sequence.

The results are presented below for each of the 17 sites, starting with the heavily invaded sites. For each site the distribution of assemblage types, as determined using the CART model is shown.

5.3.3 Heavily invaded, un-cleared sites

Three of the five invaded sites were infested with *Acacia mearnsii*, with two also supporting some *Acacia melanoxylon* individuals and one of these additionally containing a few *Eucalyptus* spp. adults. One of the remaining two invaded sites was infested with *Populus X canescens*, and the other with *Eucalyptus leucoxylon* together with scattered *Acacia longifolia* and *Acacia mearnsii*.

Sir Lowry's Pass River, site 3, mountain stream (transitional) infested with Eucalyptus leucoxylon

The Sir Lowry's Pass River (Plate 6 & Appendix 5.1) arises in the Hottentots Holland mountain range near the town of Somerset West, and flows to False Bay. The site was the most disturbed of all studied, with only seven species present and no evidence of any clearing activities. Using the CART model rules (Table 4.21) five sample plots were assigned to WE, three to CF, 21 to TS and three to OT (Table 5.4). The resulting measures of biodiversity were very low, with all assemblage types scoring well below the values obtained for the reference condition (Table 5.5). The average species richness (5 m²) of 0.9 was far below the reference condition average of 9.7. The species richness of the complete sample grid (50 m²) was 3.00, far less than the reference condition average of 22.70. The depauperate state of the flora at this site was best illustrated by the relative diversity (J) value of 0.00, indicating the lowest possible species diversity based on the unevenly distributed vegetation present. The low value for Shannon-Weiner Equitability (H) of 0.02 when compared to 2.38 for the reference condition further illustrated the poor condition of the site.

Table 5.4 Distribution of assemblage types at SLP3 as predicted by the CART model.

	Flow →			
	A	B	C	D
7	TS	OT	TS	TS
6	TS	OT	TS	TS
5	TS	OT	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	WE	WE	CF
0	CF	WE	WE	WE

It consisted almost entirely of adult (>10m and 2-5m) *Eucalyptus leucoxylon* with some adult (2-5m) *Acacia mearnsii* and *Acacia longifolia*. *Isolepis prolifer* was found in small patches on the water's edge (Table 5.6) as well as a single, small individual each of *Diospyros glabra*, *Kiggelaria africana* and *Maytenus acuminata*.

Cecelia Ravine, site 1, mountain stream infested with Populus X canescens

Cecelia Ravine (Plate 7B & Appendix 5.2) flows through the Cecelia pine plantation on the eastern flanks of the Table Mountain range. Its riparian zones had been infested with grey poplars *Populus x canescens*. Some clearance had taken place, and most remaining large adult poplars had been ring-barked but were still living.

Table 5.5 Measures of biodiversity for the reference condition and for SLP3. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Condition	SLP 3
50 m ²			
	Equitability (H)	2.38 ± 0.23	0.02
	Relative Diversity (J)	0.77 ± 0.06	0.00
	Species Richness	22.70 ± 5.80	3.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	1.0 ± 0.8
	CF	9.1 ± 5.9	1.3 ± 1.0
	TS	8.8 ± 2.9	0.9 ± 0.6
	OT	19.9 ± 7.9	0.3 ± 0.6
	Average	9.7 ± 7.7	0.9 ± 0.7

Table 5.6 Dominant species frequencies at SLP3 per assemblage type designated using the CART model. Tree life stage: seedling < 0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=5)			
Tree	Sapling	<i>Acacia longifolia</i>	33
Tree	2-5m Adult	<i>Eucalyptus leucoxylon</i>	33
Sedge		<i>Isolepis prolifer</i>	33
CF (n=3)			
Tree	2-5m Adult	<i>Acacia mearnsii</i>	33
Tree	2-5m Adult	<i>Eucalyptus leucoxylon</i>	33
Tree	5-10m Adult	<i>Eucalyptus leucoxylon</i>	33
Sedge		<i>Isolepis prolifer</i>	33
Tree	Sapling	<i>Acacia mearnsii</i>	33
Tree	Sapling	<i>Acacia longifolia</i>	33
TS (n=21)			
Tree	5-10m Adult	<i>Eucalyptus leucoxylon</i>	46
Tree	2-5m Adult	<i>Eucalyptus leucoxylon</i>	46
Tree	Sapling	<i>Eucalyptus leucoxylon</i>	6
Shrub		<i>Diospyros glabra</i>	6
Tree	0.3-2m Adult	<i>Kiggelaria africana</i>	6
Tree	0.3-2m Adult	<i>Maytenus acuminata</i>	6
OT (n=3)			
Tree	5-10m Adult	<i>Eucalyptus leucoxylon</i>	46
Tree	2-5m Adult	<i>Eucalyptus leucoxylon</i>	46

Using the CART model, four sample plots were assigned to WE, four to CF, 20 to TS and none to OT (Table 5.7). The species richness of CF and TS sample plots were similar to that of the reference condition (Table 5.8) as were species richness (50 m²), Equitability (H) and Relative diversity (J). The

location of WE, as predicted by the model, occurred in rocky or submerged sample plots with no vegetation and thus the species richness for WE was zero.

Table 5.7 Distribution of assemblage types at Cec1 as predicted by the CART model.

	← Flow			
	D	C	B	A
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	WE	WE	WE	WE

Table 5.8 Measures of biodiversity for the reference condition and for Cec1. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Condition	Cec 1
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.49
	Relative Diversity (J)	0.77 ± 0.06	0.73
	Species Richness	22.70 ± 5.80	17.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	0.0 ± 0.0
	CF	9.1 ± 5.9	3.5 ± 7.0
	TS	8.8 ± 2.9	10.5 ± 2.7
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	8.0 ± 5.3

Adult *Populus X canescens* dominated the overhead canopy cover while many smaller poplars were present in the understorey, along with many small healthy individuals of indigenous forest species (Table 5.9).

Witte River, site 3, foothill infested with Acacia mearnsii

The Witte River (Plate 5 & Appendix 5.3) is a large tributary of the Breede River, flowing through Bainskloof Pass in the Hawequas mountain range. At this point the river is wide (5-10 m) with considerable floodplain development on the left bank. The right bank of the river is heavily infested with medium to large (5-10 m) *Acacia mearnsii* trees. The floodplain on the left bank was cleared of aliens some time ago, but there was no evidence that the right bank had ever been cleared.

Using the CART model), eight sample plots were assigned to WE, four to CF, 19 to TS and 22 to OT (Table 5.10). Overall the species richness (50 m²) was low - 8.00 compared to 22.70 for the reference condition (Table 5.11) - with both Equitability (H) and Relative diversity (J) falling short of the reference condition but far less severely than at SLP3, the *Eucalyptus* site - 1.71 compared to 2.38 and 0.67 compared to 0.77 respectively. Species richness values (5 m²) for the two wet-bank assemblage

types (WE and CF) were at or just below the bottom end of the range for reference condition, whilst those for the two dry-bank assemblage types (TS and OT) were much lower. This was probably attributable to the healthy fringe of Riparian Scrub persisting beneath the edges of the alien canopy along the water's edge. The presence of *Acacia mearnsii* mainly suppressed the growth of indigenous species higher up the bank where the alien canopy was more closed.

Table 5.9 Dominant species frequencies at Cec1 per assemblage type designated using the CART model. Tree life stage: seedling < 0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=4)			
CF (n=4)			
Sedge		<i>Cyperus glomerata</i>	25
Tree	Sapling	<i>Canthium capensis</i>	25
Tree	Seedling	<i>Kiggelaria africana</i>	25
Tree	Seedling	<i>Populus x canescens</i>	25
Forb		<i>Asparagus scandens</i>	25
Forb		<i>Todea barbara</i>	25
Geophyte		<i>Zantedeschia aethiopica</i>	25
TS (n=20)			
Forb		<i>Asparagus scandens</i>	100
Grass		<i>Ehrharta erecta</i>	100
Shrub		<i>Diospyros glabra</i>	89
Forb		<i>Blechnum australe</i>	78
Tree	Seedling	<i>Diospyros whyteana</i>	78
Tree	Seedling	<i>Populus x canescens</i>	72
Tree	Seedling	<i>Kiggelaria africana</i>	56
Tree	Seedling	<i>Afrocarpus falcatus</i>	50
Forb		<i>Achyranthes sicala</i>	33
Tree	2-5m Adult	<i>Afrocarpus falcatus</i>	28
Tree	2-5m Adult	<i>Canthium ventosum</i>	28

Table 5.10 Distribution of assemblage types at Wit3 as predicted by the CART model.

	← Flow			
	D	C	B	A
11	TS	OT	OT	OT
10	TS	OT	OT	OT
9	TS	OT	OT	OT
8	TS	OT	OT	OT
7	TS	OT	OT	OT
6	TS	OT	OT	OT
5	TS	OT	OT	OT
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	WE	WE	WE	WE
-1	WE	WE	WE	WE

Table 5.11 Measures of biodiversity for the reference condition and for Wit3. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Wit 3
50 m ²			
	Equitability (H)	2.38 ± 0.23	1.71
	Relative Diversity (J)	0.77 ± 0.06	0.67
	Species Richness	22.70 ± 5.80	8.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	2.1 ± 1.4
	CF	9.1 ± 5.9	3.3 ± 2.1
	TS	8.8 ± 2.9	3.2 ± 1.1
	OT	19.9 ± 7.9	3.4 ± 1.2
	Average	9.7 ± 7.7	3.1 ± 1.4

Acacia mearnsii was generally dominant, but there were also many indigenous riparian and forest species (Table 5.12). *Prionium serratum* and *Cannamois virgata* were present in both WE and CF, together with the small Riparian Scrub trees *Metrosideros angustifolia*, *Morella serrata* and *Brachylaena neriifolia*. *Diospyros glabra*, present in all four assemblage types, was most prominent higher on the bank in TS and OT with the small Riparian Scrub trees *Metrosideros angustifolia* and *Brabejum stellatifolium* and another tree species *Podocarpus elongatus*. The presence of the indigenous trees beneath the alien canopy suggests that once cleared of aliens the natural riparian vegetation would recover quickly.

Molenaars River, site 4, foothill infested with Acacia mearnsii

Both banks of the Molenaars River (Plate 8 & Appendix 5.4) were heavily infested with *Acacia mearnsii* for a river length of about 2 km around this site. Additionally, the river's floodplain, which was 300 m wide on the right bank was also heavily infested. This was the most downstream reach of the Molenaars River with a relatively natural channel and flow, as downstream the floodplain was intensively cultivated and water was abstracted in and around the town of Rawsonville. At the site, the channel was wide (15-20 m), with *Acacia mearnsii* canopy reaching over but not covering the water. There was no evidence of any clearing activities at the site, although there had been extensive clearing 2.5 km upstream.

Using the CART model, no sample plots were assigned to WE, eight to CF, 52 to TS and none to OT (Table 5.13). Overall the species richness (50 m²) was poor with only seven species (Table 5.14) and the Equitability and Relative diversity coefficients were low. Species richness (5 m²) of the two assemblage types predicted to occur by the model were lower than the reference condition for TS but not for CF.

The site was dominated by large *Acacia mearnsii* trees, some large individuals of *Brabejum stellatifolium* and some other riparian shrubs scattered beneath the alien canopy (Table 5.15). Indigenous riparian and forest species were less prominent than at Wit3, and the alien *Acacia*

Table 5.12 Dominant species frequencies at Wit3 as per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=8)			
Shrub		<i>Prionium serratum</i>	86
Restio		<i>Cannamois virgata</i>	57
Shrub		<i>Diospyros glabra</i>	29
Small tree	Sapling	<i>Morella serrata</i>	29
Forb		<i>Todea barbara</i>	14
Small tree	Sapling	<i>Brachylaena neriifolia</i>	14
CF (n=4)			
Shrub		<i>Prionium serratum</i>	100
Restio		<i>Cannamois virgata</i>	50
Shrub		<i>Diospyros glabra</i>	50
Small tree	2-5m Adult	<i>Metrosideros angustifolia</i>	25
Small tree	2-5m Adult	<i>Morella serrata</i>	25
Tree	2-5m Adult	<i>Acacia mearnsii</i>	25
TS (n=19)			
Shrub		<i>Diospyros glabra</i>	94
Small tree	2-5m Adult	<i>Metrosideros angustifolia</i>	58
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	35
Restio		<i>Cannamois virgata</i>	35
Tree	Sapling	<i>Podocarpus elongatus</i>	24
Shrub		<i>Prionium serratum</i>	18
Small tree	Sapling	<i>Metrosideros angustifolia</i>	12
OT (n=22)			
Shrub		<i>Diospyros glabra</i>	81
Small tree	2-5m Adult	<i>Metrosideros angustifolia</i>	76
Tree	5-10m Adult	<i>Acacia mearnsii</i>	38
Restio		<i>Cannamois virgata</i>	24
Tree	Seedling	<i>Acacia mearnsii</i>	24
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	14
Shrub		<i>Prionium serratum</i>	14

Table 5.13 Distribution of assemblage types at Mol4 as predicted by the CART model.

← Flow				
	D	C	B	A
14	TS	TS	TS	TS
13	TS	TS	TS	TS
12	TS	TS	TS	TS
11	TS	TS	TS	TS
10	TS	TS	TS	TS
9	TS	TS	TS	TS
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	CF	CF	CF	CF

were much larger. The site was the second most depauperate one in terms of species after SLP3, probably due to a combination of the presence of large, mature alien trees and the magnitude of the invasion. The lower bank was dominated by a herbaceous alien weed, *Persicaria lapathifolia*, and the sedge *Isolepis prolifer*. Some alien and non-alien seedlings were present, along with smaller occurrences of the forest shrub *Diospyros glabra* (Table 5.15).

Table 5.14 Measures of biodiversity for the reference condition and for Mol4. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Mol 4
50 m ²			
	Equitability (H)	2.38 ± 0.23	0.10
	Relative Diversity (J)	0.77 ± 0.06	0.05
	Species Richness	22.70 ± 5.80	7.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	-
	CF	9.1 ± 5.9	2.6 ± 3.7
	TS	8.8 ± 2.9	1.3 ± 1.1
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	1.5 ± 1.7

Table 5.15 Dominant species frequencies at Mol4 per assemblage type designated using the CART model. Tree life stage: seedling < 0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
CF (n=8)			
Forb		<i>Persicaria lapathifolia</i>	100
Sedge		<i>Isolepis prolifer</i>	67
Rush		<i>Juncus effusus</i>	33
Forb		<i>Xanthium strumarium</i>	33
Shrub		<i>Diospyros glabra</i>	33
Tree	Seedling	<i>Acacia mearnsii</i>	33
Small tree	Seedling	<i>Salix mucronata</i>	33
TS (n=52)			
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	51
Tree	5-10m Adult	<i>Acacia mearnsii</i>	35
Shrub		<i>Prionium serratum</i>	19
Small tree	Sapling	<i>Brabejum stellatifolium</i>	19
Shrub		<i>Diospyros glabra</i>	16
Small tree	5-10m Adult	<i>Brabejum stellatifolium</i>	14
Tree	2-5m Adult	<i>Acacia mearnsii</i>	8
Tree	5-10m Adult	<i>Podocarpus elongatus</i>	3

Rondegat River, site 6, mountain stream (transitional) infested with *Acacia mearnsii* and *Acacia melanoxylon*

The Rondegat River is a tributary of the Olifants River upstream of the Clanwilliam reservoir. This small channel, 5 m in width, (Plate 9A & Appendix 5.5) was heavily infested on both banks for a large

portion of its length, mainly with *Acacia mearnsii* and *Acacia melanoxylon*. The site was 800 m downstream of Ron5, where clearing had already taken place (Section 5.3.4).

Using the CART model no sample plots were assigned to WE, eight to CF, 40 to TS and none to OT (Table 5.16). Overall species richness (50 m²) was low - 8.00 compared to 22.70 for the reference condition (Table 5.17). Equitability (H) and Relative diversity (J) both fell outside of the reference condition range though this site was not as depauperate as SLP3 and Mol4. Species richness (5 m²) of CF and TS were both lower then that described for the reference condition.

Table 5.16 Distribution of assemblage types at Ron6 as predicted by the CART model.

← Flow				
	D	C	B	A
11	TS	TS	TS	TS
10	TS	TS	TS	TS
9	TS	TS	TS	TS
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	CF	CF	CF	CF

Table 5.17 Measures of biodiversity for the reference condition and for Ron6. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Ron 6
50 m ²			
	Equitability (H)	2.38 ± 0.23	1.60
	Relative Diversity (J)	0.77 ± 0.06	0.59
	Species Richness	22.70 ± 5.80	8.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	-
	CF	9.1 ± 5.9	0.9 ± 1.5
	TS	8.8 ± 2.9	2.3 ± 1.4
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	2.1 ± 1.5

Despite the density of the alien canopy the presence of the riparian scrub species overall bode well for the restoration of this area should clearing commence in the future. The sparsely vegetated bank was best reflected in the low species richness for the wet and dry bank (5 m²) sample plots. The presence of a healthy and densely vegetated riparian scrub community 7 km upstream (Section 4.3.3) will supply propagules for the natural re-colonisation of the riparian community here. Seedlings of two riparian scrub species, *Brabejum stellatifolium* and *Brachylaena neriifolia*, were found on the wet bank with the shrub *Prionium serratum* persisting beneath the alien canopy (Table 5.18). The bank

was patchily vegetated with adult *Metrosideros angustifolia* and *Brabejum stellatifolium*, *Ehrharta ramosa*, *Pteridium aquilinum* and *Diospyros glabra* occurring interspersed amongst the aliens. The non-alien species, though patchily distributed, bode well to initiate recovery should clearing commence here in the future.

Table 5.18 Dominant species frequencies at Ron6 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
CF (n=8)			
Small tree	Seedling	<i>Brabejum stellatifolium</i>	100
Shrub		<i>Prionium serratum</i>	100
Small tree	Seedling	<i>Brachylaena neriifolia</i>	100
Tree	Seedling	<i>Acacia mearnsii</i>	100
TS (n=40)			
Small tree	2-5m Adult	<i>Metrosideros angustifolia</i>	53
Grass		<i>Ehrharta ramosa</i> ssp. <i>ramosa</i>	33
Forb		<i>Pteridium aquilinum</i>	31
Tree	Seedling	<i>Acacia mearnsii</i>	19
Tree	Sapling	<i>Acacia mearnsii</i>	14
Tree	2-5m Adult	<i>Acacia melanoxylon</i>	11
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	8
Shrub		<i>Prionium serratum</i>	8
Shrub		<i>Diospyros glabra</i>	6
Tree	5-10m Adult	<i>Acacia mearnsii</i>	6

5.3.4 Cleared and recovering sites

The pattern of recovery is discussed in two parts following the similarity relationship between the sites as shown in the four catchment groups B through D in Figure 5.1. The two outlier and the three heavily invaded sites from group B have been discussed in section 5.3.3. First the two other sites in group B, both which have been cleared at some stage, are presented followed by those in group C, the three on the Molenaars River. This completes the site specific discussions for the Hawequas and Cedarberg mountain ranges. Then sites in group D from the Table Mountain and Hottentots Holland mountain ranges are discussed followed by the three in group E on the Assegaaibos River (Hottentots Holland range). All of these areas have different histories and are different post-clearing ages (Table 4.1).

Group B

*Rondegat River, site 5, mountain stream (transitional) first cleared of *Acacia mearnsii* and *Acacia melanoxylon* in 1998*

This section of the Rondegat River (Plate 9A & Appendix 5.6) is situated 800 m upstream of Ron6 (section 5.3.3) and 6 km downstream of the undisturbed sites (Section 4.3.3). It has been assumed that this section of river was infested to the same degree as recorded at Ron6, before clearing began in

1998. The adult trees were hacked and the smaller wood and twigs stacked; some of these stacks were burnt though this was not part of the clearing operation. There have been two follow up clearings since then, the last in 2002, three years before the vegetation was sampled.

Using the CART model rules (Table 4.21) nine sample plots were assigned to WE, three to CF, 36 to TS and none to OT (Table 5.19). The vegetation was noticeably young with most tree and shrub individuals, including alien species less than 3 m in height. There was an abundance of new growth, with all measures of biodiversity falling within or above the ranges described for the reference condition (Table 5.20).

Table 5.19 Distribution of assemblage types at Ron5 as predicted by the CART model.

	← Flow			
	D	C	B	A
10	TS	TS	TS	TS
9	TS	TS	TS	TS
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	WE	CF	CF
0	WE	WE	WE	WE
-1	WE	WE	WE	WE

Table 5.20 Measures of biodiversity for the reference condition and for Ron5. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Ron 5
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.84
	Relative Diversity (J)	0.77 ± 0.06	0.86
	Species Richness	22.70 ± 5.80	25.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	8.0 ± 4.1
	CF	9.1 ± 5.9	12.0 ± 1.0
	TS	8.8 ± 2.9	4.8 ± 1.6
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	5.9 ± 3.0

Many of the species found upstream at the reference sites on this river (Ron1-4, Section 4.3.3) were present. Species not found downstream at the uncleared site (Ron6, Section 5.2.1) include a number of small herbaceous 'wet' species such as *Isolepis digitata*, *Laurembergia repens*, *Vellereophyton dealbatum*, *Juncus lomatophyllus* and *Wimmerella arabidea*. All were found in both WE and CF positions as at the reference sites upstream (Table 5.21). Both common riparian restios, *Calopsis paniculata* (WE and CF) and *Elegia capensis* (CF and TS), were present, in contrast to the heavily

invaded sites where *Elegia capensis* was absent. The riparian shrub *Prionium serratum* occupied a large portion of this site both adjacent to and some distance away from the water's edge. Only one of the four riparian small tree species, *Metrosideros angustifolia*, was present. There was recruitment of both *Acacia melanoxylon* and *Acacia mearnsii* in CF and TS. The other species commonly occurring in TS sample plots, though not specifically riparian, were *Ehrharta ramosa* ssp. *ramosa* and *Pteridium aquilinum*.

Table 5.21 Dominant species frequencies at Ron5 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=9)			
Sedge		<i>Isolepis digitata</i>	88
Grass		<i>Paspalum urvillei</i>	88
Restio		<i>Calopsis paniculata</i>	75
Forb		<i>Lauremburgia repens</i>	75
Small tree	Seedling	<i>Metrosideros angustifolia</i>	75
Shrub		<i>Prionium serratum</i>	75
Forb		<i>Vellereophyton dealbatum</i>	75
Rush		<i>Juncus tomatophyllus</i>	63
Forb		<i>Wimmerella arabidea</i>	63
CF (n=3)			
Restio		<i>Calopsis paniculata</i>	100
Grass		<i>Paspalum urvillei</i>	100
Sedge		<i>Isolepis digitata</i>	100
Small tree	Seedling	<i>Metrosideros angustifolia</i>	100
Forb		<i>Lauremburgia repens</i>	100
Tree	Sapling	<i>Acacia melanoxylon</i>	100
Forb		<i>Vellereophyton dealbatum</i>	100
Shrub		<i>Prionium serratum</i>	67
Tree	2-5m Adult	<i>Acacia mearnsii</i>	67
Rush		<i>Juncus tomatophyllus</i>	67
Tree	Seedling	<i>Acacia mearnsii</i>	67
Forb		<i>Wimmerella arabidea</i>	67
Small tree	Sapling	<i>Metrosideros angustifolia</i>	33
Restio		<i>Elegia capensis</i>	33
TS (n=36)			
Small tree	Sapling	<i>Metrosideros angustifolia</i>	66
Grass		<i>Ehrharta ramosa</i> ssp. <i>ramosa</i>	66
Shrub		<i>Pteridium aquilinum</i>	48
Tree	2-5m Adult	<i>Acacia mearnsii</i>	34
		<i>Elegia capensis</i>	21

There had been successful recruitment of many of the typical riparian species, though a number of common species were still missing: notably the shrub *Erica caffra*, the small trees *Brabejum stellatifolium*, *Brachylaena neriifolia* and *Morella serrata*, and the shrub *Diospyros glabra*. The vegetation was seven years old. It is not known how destructive the initial clearing and follow ups were to any indigenous species present at the time of clearing. If this section of river had once had similar vegetation communities to Ron6, the invaded section downstream, *Brabejum stellatifolium*, *Brachylaena neriifolia* and *Diospyros glabra* would have been present and *Elegia capensis* absent.

Their absence in the post-clearing stand suggests they may have been destroyed during the felling operation.

Witte River, site 4, foothill first cleared of Acacia mearnsii 1997

This site (Plate 5 & Appendix 5.7) was situated immediately downstream of the uncleared Wit3 (Section 5.3.4) so pre-clearing conditions were assumed to be similar. Wit4 was first cleared in 1997 with four follow up clearances and a wild fire in 2001. It is not known if the vegetation in the sample grid was burnt in the fire. Photographs of the floodplain in 1998 (S. Steytler pers. com. 2006), after the initial clearing, show many *Brabejum stellatifolium* adults coppicing after being felled during the felling of the *Acacia mearnsii*. There were a number of mature riparian small trees present at the time of sampling that must either have re-sprouted after the fire in 2001 or not been burnt. Age of the vegetation was thus taken to be between four and eight years, between the time of the first clearing activities and the fire.

Using the CART model rules (Table 4.21) eight sample plots were assigned to WE, four to CF, 32 to TS and none to OT (Table 5.22). Overall the biodiversity measures were similar to those recorded for the reference condition. Species richness (50 m²) of 10.00 and (5 m²) for TS of 4.13, as opposed to 22.70 and 8.8 respectively (Table 5.23), were lower than the reference condition data; other measures fell within the expected range. Though no woody alien species were present it seems inevitable that this cleared patch will revert back to an invaded state should follow up clearing in the vicinity around this site not take place again. The other areas of the floodplain adjoining this site had some scattered *Acacia mearnsii* saplings 1-2 m in height amongst the other riparian species.

Table 5.22 **Distribution of assemblage types at Wit4 as predicted by the CART model.**

	Flow →			
	A	B	C	D
9	TS	TS	TS	TS
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	WE	WE	WE	WE
-1	WE	WE	WE	WE

Apart from the high number and cover afforded by the expected species (Table 5.24) a number of grasses (Poaceae) were prominent. *Merxmeullera cincta*, recorded at one of the control sites (Wit2) upstream, was particularly abundant. *Pentameris distichophylla*, recorded at the four Elands River reference sites and all four Witte River sites (both in the Hawequas mountain range) was also present, with another alien grass *Briza maxima* common in disturbed areas. It is unusual for grasses to dominate to this extent in undisturbed riparian zones. As at Ron5 *Calopsis paniculata* and *Diospyros*

glabra were abundant with another common riparian restio, *Cannamois virgata* and both *Elegia capensis* and *Erica caffra* were absent. Three of the four small Riparian Scrub trees were present; only *Morella serrata* was missing. There was no recruitment of *Acacia* from upstream or post-fire from the seed bank even though individuals were present both up and downstream on both banks of this cleared area.

Table 5.23 Measures of biodiversity for the reference condition and for Wit4. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Wit 4
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.00
	Relative Diversity (J)	0.77 ± 0.06	0.72
	Species Richness	22.70 ± 5.80	10.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	3.3 ± 1.8
	CF	9.1 ± 5.9	4.5 ± 2.1
	TS	8.8 ± 2.9	4.1 ± 1.8
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	4.0 ± 1.8

Table 5.24 Dominant species frequencies at Wit4 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=8)			
Restio		<i>Cannamois virgata</i>	57
Shrub		<i>Prionium serratum</i>	43
Grass		<i>Merxmüllera cincta</i>	29
Shrub		<i>Diospyros glabra</i>	14
Forb		<i>Todea barbara</i>	14
Restio		<i>Calopsis paniculata</i>	14
Rush		<i>Juncus lomatophyllus</i>	14
Small tree	Seedling	<i>Metrosideros angustifolia</i>	14
CF (n=4)			
Small tree	Sapling	<i>Metrosideros angustifolia</i>	75
Shrub		<i>Diospyros glabra</i>	50
Restio		<i>Cannamois virgata</i>	50
Grass		<i>Merxmüllera cincta</i>	50
Restio		<i>Calopsis paniculata</i>	25
Forb		<i>Todea barbara</i>	25
Small tree	2-5m Adult	<i>Metrosideros angustifolia</i>	25
Small tree	Seedling	<i>Brachylaena neriifolia</i>	25
TS (n=32)			
Shrub		<i>Diospyros glabra</i>	90
Grass		<i>Merxmüllera cincta</i>	63
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	30
Small tree	2-5m Adult	<i>Metrosideros angustifolia</i>	27
Restio		<i>Cannamois virgata</i>	27
Grass		<i>Pentameris distichophylla</i>	23
Grass		<i>Pentaschistis pallida</i>	20
Grass		<i>Briza maxima</i>	20

Group C

Molenaars River, site 1, foothill first cleared of Acacia mearnsii in 1994

This is the first of three cleared sites on the Molenaars River (Mol 1-3, Table 3.3). Mol2 was designated undisturbed but grouped with these disturbed sites in the MDS ordination and CLUSTER analyses unexpectedly (Figure 5.1) and so is considered here. The fourth Molenaars River site, Mol4, was uncleared and discussed in Section 5.3.3. There were thus four foothill sites (Plate 8) on the same river at different stages of invasion or recovery. Mol1 (Appendix 5.8) was first cleared in 1994 and has had regular follow up clearing (Table 4.1), the last being in October 2004 six months after sampling was completed in April 2004 (Table 3.4). *Acacia mearnsii* stumps were cut and treated with herbicide. Foliar spray of herbicide was applied to a secondary invasion of *Rubus* spp. (reported to be *R. fruticosus* in the clearing history but this could not be confirmed by the herbarium) and *Acacia mearnsii* seedlings. The age of the vegetation at the time of sampling was 10 years.

Using the CART model rules (Table 4.21) no samples plots were assigned to WE, eight to CF, 32 to TS and none to OT (Table 5.25). Overall this area scored within the reference condition limits for all measures of biodiversity (Table 5.26). Based on the species present and the calculated biodiversity measures it could be said that this area had recovered successfully following the clearing of *Acacia mearnsii*. Though species present appear to be distributed normally and in sufficient numbers to generate measures of biodiversity in line with the averages calculated for the reference conditions, the maturity, density and height of the vegetation was not comparable to that seen at undisturbed areas suggesting that ten years had been insufficient time for the vegetation to return to reference condition. Further, the persistent presence of recruiting *Acacia mearnsii* individuals indicated that sustained removal efforts were still needed. This was the disturbed site with the second oldest vegetation, the oldest being SLP2 which first cleared in 1992 (discussed below in group D).

Table 5.25 **Distribution of assemblage types at Mol1 as predicted by the CART model.**

	← Flow			
	D	C	B	A
9	TS	TS	TS	TS
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	CF	CF	CF	CF

CF contained *Isolepis prolifer* and *Pennisetum macrourum* found at reference sites in the same position (Table 5.27). *Pennisetum macrourum* and *Platycaulos callistachyus* were both not present at the other disturbed sites discussed thus far. TS contained a mixture of typically Riparian Scrub and

Afromontane Forest species with some scattered adult *Acacia mearnsii* trees. *Erica caffra* and *Halleria elliptica*, two species not found at the other disturbed sites thus far, were present. *Morella serrata* was absent though the other three small riparian tree species were present.

Table 5.26 Measures of biodiversity for the reference condition and for Mol1. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Mol 1
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.73
	Relative Diversity (J)	0.77 ± 0.06	0.78
	Species Richness	22.70 ± 5.80	31.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	-
	CF	9.1 ± 5.9	4.4 ± 4.9
	TS	8.8 ± 2.9	7.5 ± 4.2
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	6.9 ± 4.5

Table 5.27 Dominant species frequencies at Mol1 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage		F
WE (n=0)			
-			
CF (n=8)			
Grass		<i>Pennisetum macrourum</i>	100
Sedge		<i>Isolepis prolifer</i>	100
TS (n=32)			
Forb		<i>Pteridium aquilinum</i>	48
Restio		<i>Calopsis paniculata</i>	45
Small tree	Sapling	<i>Metrosideros angustifolia</i>	41
Shrub		<i>Diospyros glabra</i>	40
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	35
Shrub		<i>Erica caffra</i>	35
Shrub		<i>Halleria elliptica</i>	28
Restio		<i>Platycaulos callistachyus</i>	28
Grass		<i>Pennisetum macrourum</i>	28
Tree	2-5m Adult	<i>Acacia mearnsii</i>	24
Small tree	2-5m Adult	<i>Metrosideros angustifolia</i>	24
Small tree	Seedling	<i>Metrosideros angustifolia</i>	25
Small tree	Sapling	<i>Brabejum stellatifolium</i>	21
Small tree	Seedling	<i>Brabejum stellatifolium</i>	21

Molenaars River, site 2, foothill designated as undisturbed, history unknown

This site (Plate 8 & Appendix 5.9) was situated just upstream of the confluence with the Klip River tributary in an area purported to be pristine by Boucher (1998). There was no evidence of previous invasion (cut or burnt stumps) and few invader species were present.

Using the CART model rules four sample plots were assigned to WE, four to CF, 23 to TS and 17 to OT (Table 5.28). Measures of biodiversity all fell within the range expected of a reference condition with only OT species richness (5 m^2) of 4.1 falling outside of the expected 19.9 (Table 5.29). With the exception of the few small invading species, this site showed few signs of disturbance, and had vegetation that was noticeably more mature and dense than that at Mol1 and more similar to that of undisturbed sites.

Table 5.28 Distribution of assemblage types at Mol2 as predicted by the CART model.

	Flow →			
	A	B	C	D
11	OT	OT	TS	OT
10	OT	OT	TS	OT
9	OT	OT	TS	OT
8	OT	OT	TS	OT
7	OT	OT	TS	OT
6	OT	OT	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	WE	WE	WE	WE

Table 5.29 Measures of biodiversity for the reference condition and for Mol2. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Mol 2
50 m^2			
	Equitability (H)	2.38 ± 0.23	2.68
	Relative Diversity (J)	0.77 ± 0.06	0.76
	Species Richness	22.70 ± 5.80	28.00
5 m^2			
Species richness:	WE	6.1 ± 4.2	1.5 ± 1.0
	CF	9.1 ± 5.9	9.8 ± 2.2
	TS	8.8 ± 2.9	6.0 ± 4.8
	OT	19.9 ± 7.9	4.1 ± 2.5
	Average	9.7 ± 7.7	5.2 ± 4.1

OT contained very few species and was dominated by *Pteridium aquilinum* and *Rhus angustifolia*, interspersed between mature *Brabejum stellatifolium* trees. WE was typically a fringe of *Isolepis prolifer* with seedlings of *Brabejum stellatifolium* (Table 5.30) and another riparian invader not yet encountered; *Paraserianthes lophantha* (stinkbean). CF was dense and mostly contained *Isolepis prolifer*, *Pennisetum macrourum* and *Juncus lomatophyllus* with seedling and sapling *Morella serrata* and *Salix mucronata* and the small riparian tree *Freylinia lanceolata*, all not encountered at any of the disturbed sites discussed thus far. Seedling *Acacia mearnsii* were present as well as some *Persicaria lapathifolia*, both alien species, as well as the common riparian shrub *Prionium serratum*. TS contained a mixture of all the species found in both CF and OT though some individuals of the small

riparian trees were larger, along with two restios *Calopsis paniculata* and *Platycaulos callistachyus* and the shrub *Diospyros glabra*. *Morella serrata* was present in three life stages (seedling, sapling and 2-5m adults) but the shrub *Erica caffra* was not recorded. *Salix mucronata* and *Freylinia lanceolata*, both present on the Heks and Elands reference-condition rivers, were present.

Table 5.30 Dominant species frequencies at Mol2 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=4)			
Sedge	Seedling	<i>Isolepis prolifer</i>	100
Small tree		<i>Brabejum stellatifolium</i>	25
Forb		<i>Paraserianthes lophantha</i>	25
CF (n=4)			
Sedge		<i>Isolepis prolifer</i>	100
Grass		<i>Pennisetum macrourum</i>	100
Rush		<i>Juncus lomatophyllus</i>	100
Small tree	Sapling	<i>Morella serrata</i>	75
Small tree	Sapling	<i>Salix mucronata</i>	75
Tree	Seedling	<i>Acacia mearnsii</i>	75
Small tree	Seedling	<i>Morella serrata</i>	75
Small tree	2-5m Adult	<i>Freylinia lanceolata</i>	50
Forb		<i>Persicaria lapathifolia</i>	50
Shrub		<i>Prionium serratum</i>	50
Small tree	Seedling	<i>Salix mucronata</i>	50
TS (n=23)			
Small tree	Sapling	<i>Morella serrata</i>	57
Small tree	Sapling	<i>Metrosideros angustifolia</i>	57
Rush		<i>Juncus lomatophyllus</i>	57
Small tree	2-5m Adult	<i>Rhus angustifolia</i>	50
Grass		<i>Pennisetum macrourum</i>	50
Forb		<i>Pteridium aquilinum</i>	43
Restio		<i>Calopsis paniculata</i>	43
Restio		<i>Platycaulos callistachyus</i>	29
Small tree	Sapling	<i>Salix mucronata</i>	29
Tree	Seedling	<i>Acacia mearnsii</i>	29
Small tree	2-5 Adult	<i>Morella serrata</i>	21
Shrub		<i>Diospyros glabra</i>	21
OT (n=17)			
Forb		<i>Pteridium aquilinum</i>	100
Small tree	2-5m Adult	<i>Rhus angustifolia</i>	94
Shrub		<i>Diospyros glabra</i>	41
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	18

*Molenaars River, site 3, foothill first cleared of *Acacia mearnsii* in 1997*

This site (Plate 8) is located between the anomalous Mol2 and the disturbed site Mol4. Clearing of *Acacia mearnsii* first took place in 1997 with regular follow ups, the last in December 2004. The age of the vegetation at the time of sampling was seven years. Alien trees were felled and cut stumps were treated with herbicide while a foliar spray of herbicide was applied to recruiting alien seedlings. At the time of sampling in April 2004 (Table 3.4) many of the re-sprouting small riparian tree stumps had been felled during follow-up treatments and herbicide applied to the cut stumps. The felled

indigenous wood was stacked with the *Acacia mearnsii* litter. There was evidence of stack burning (large open spaces of sandy substrata with little vegetative growth and scattered burnt blackened stumps) and generally the greater riparian area was disturbed, either burnt or covered in a stack of hacked material.

Using the CART model rules (Table 4.21) six sample plots were assigned to WE, two to CF, 45 to TS and 11 to OT (Table 5.31). Surprisingly, the biodiversity measures fell within the ranges described for the reference conditions (Table 5.32), other than for the lower OT species richness of 2.1 as opposed to 19.9 for the reference condition. The wetbank, particularly CF, was well vegetated and contained many species recorded at a low frequency and therefore not shown in Table 5.32, which boosted the measures of biodiversity. The dry bank (TS and OT) was less species rich and more disturbed due to the clearing that had taken place. Despite the high scores for biodiversity this area remained disturbed and requires sustained follow-up clearing by teams able to distinguish indigenous from alien species.

Table 5.31 Distribution of assemblage types at Mol3 as predicted by the CART model.

	← Flow			
	D	C	B	A
..15	OT	TS	TS	TS
12..	OT	TS	TS	TS
11	OT	TS	TS	TS
10	OT	TS	TS	TS
9	OT	TS	TS	TS
8	OT	TS	TS	TS
7	OT	TS	TS	TS
6	OT	TS	TS	TS
5	OT	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	WE	WE
0	WE	WE	WE	WE

Due to the damaged nature and patchy distribution of the riparian plants many of the sample plots contained few if any species. WE and CF (Table 5.33) were densely vegetated and contained many of the species encountered upstream. *Prionium serratum* was more prominent than at the two upstream sites and there were many seedlings of *Salix mucronata*. *Juncus effusus*, another rush not yet encountered at any of the disturbed sites but quite common at some of the undisturbed areas, was also found in WE. Not all the species present are shown in the table, many more were scattered infrequently amongst the sample plots (Appendix 5.10). The main species present in TS and OT were the common small riparian trees *Brabejum stellatifolium*, *Metrosideros angustifolia*, *Brachylaena neriifolia* and *Morella serrata*, all present in all three life stages (seedling, sapling and 2-5m adults, though not shown as such in Table 5.31). There were many seedling *Acacia mearnsii* recruiting from the seedbank in TS and OT. Outside of the sample grid, further onto the right bank and into the floodplain there were dense stands of *Acacia mearnsii* seedlings recruiting *en masse*.

Table 5.32 Measures of biodiversity for the reference condition and for Mol3. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Mol 3
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.66
	Relative Diversity (J)	0.77 ± 0.06	0.79
	Species Richness	22.70 ± 5.80	24.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	4.3 ± 3.8
	CF	9.1 ± 5.9	13.5 ± 3.5
	TS	8.8 ± 2.9	3.6 ± 2.8
	OT	19.9 ± 7.9	2.1 ± 1.6
	Average	9.7 ± 7.7	3.7 ± 3.3

Table 5.33 Dominant species frequencies at Mol3 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage types	F
WE (n=6)			
Small tree	Seedling	<i>Salix mucronata</i>	86
Shrub		<i>Prionium serratum</i>	71
Sedge		<i>Isolepis prolifer</i>	57
Rush		<i>Juncus effusus</i>	57
Small tree	Sapling	<i>Salix mucronata</i>	53
Restio		<i>Calopsis paniculata</i>	53
CF (n=2)			
Sedge		<i>Isolepis prolifer</i>	100
Small tree	Sapling	<i>Morella serrata</i>	100
Shrub		<i>Prionium serratum</i>	100
Rush		<i>Juncus effusus</i>	100
Rush		<i>Juncus lomatophyllus</i>	100
Small tree	Sapling	<i>Metrosideros angustifolia</i>	100
Grass		<i>Pennisetum macrourum</i>	100
TS (n=45)			
Tree	Seedling	<i>Acacia meurnsii</i>	54
Small tree	Sapling	<i>Brabejum stellatifolium</i>	41
Small tree	Sapling	<i>Metrosideros angustifolia</i>	33
Small tree	Sapling	<i>Morella serrata</i>	33
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	21
Small tree	Sapling	<i>Brachylaena neriifolia</i>	15
OT (n=11)			
Tree	Seedling	<i>Acacia meurnsii</i>	63
Small tree	Sapling	<i>Brabejum stellatifolium</i>	50
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	25
Small tree	Sapling	<i>Brachylaena neriifolia</i>	25
Small tree	Sapling	<i>Metrosideros angustifolia</i>	25

Group D

Sir Lowry's Pass River, site 1, mountain stream first cleared of *Acacia mearnsii*, *Acacia longifolia* and *Acacia saligna* in 1992.

The two cleared sites on the Sir Lowry's Pass River (Plate 6, SLP1 and SLP2) are situated 2 km upstream of the invaded SLP3 discussed in Section 5.3.3: both are mountain stream sites whereas SLP3 was located in the mountain stream (transitional) zone. Clearing first took place at SLP1 (Appendix 5.11) in 1992 when woody aliens were felled, stacked and burnt, and stumps were treated with herbicide. Annual follow-up clearances, where seedlings are hand pulled, have taken place every year since. The age of the sampled vegetation was 13 years.

Using the CART model rules (Table 4.21) four sample plots were assigned to WE, four to CF, 12 to TS and 12 to OT (Table 5.34). The resulting biodiversity measures were higher than recorded for the reference conditions except for the species richness (5 m²) of OT and the average across the four assemblage types, which both still fell within the range defining the reference condition (Table 5.35). Amongst the riparian species, there were many patches of drier or rocky-habitat species that are normally associated with other fynbos habitats. The river was heavily invaded upstream of this uppermost site so a propagule supply was presumably limited.

Table 5.34 Distribution of assemblage types at SLP1 as predicted by the CART model.

	Flow →			
	A	B	C	D
7	OT	OT	OT	OT
6	OT	OT	OT	OT
5	OT	OT	OT	OT
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	WE	WE	WE	WE

Table 5.35 Measures of biodiversity for the reference condition and for SLP1. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	SLP 1
50 m ²			
	Equitability (H)	2.38 ± 0.23	3.02
	Relative Diversity (J)	0.77 ± 0.06	0.80
	Species Richness	22.70 ± 5.80	41.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	9.5 ± 2.9
	CF	9.1 ± 5.9	16.3 ± 5.7
	TS	8.8 ± 2.9	11.3 ± 2.6
	OT	19.9 ± 7.9	8.0 ± 2.0
	Average	9.7 ± 7.7	10.5 ± 3.9

The wet bank (WE and CF) contained many of the expected sedges and shrubs found at many of the undisturbed sites. Two alien species, the grass *Paspalum urvillei* and the forb *Taraxacum officinale* were found in WE and CF respectively at a higher occurrence than recorded for the reference sites (Table 5.36). A new species of sedge *Neesenbeckia punctoria* was recorded, while there were few small riparian tree species other than the less common *Freylinia lanceolata*. The two woody elements of the dry bank were the small riparian tree *Brabejum stellatifolium* and *Acacia longifolia*, the latter

Table 5.36 Dominant species frequencies at SLPI per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=4)			
Shrub		<i>Prionium serratum</i>	100
Sedge		<i>Neesenbeckia punctoria</i>	67
Sedge		<i>Isolepis prolifer</i>	67
Sedge		<i>Cyperus glomerata</i>	67
Shrub		<i>Oftia africana</i>	67
Shrub		<i>Helichrysum cymosum</i>	67
Grass		<i>Paspalum urvillei</i>	67
Shrub		<i>Berzelia lanuginosa</i>	67
Rush		<i>Juncus capensis</i>	67
CF (n=4)			
Shrub		<i>Prionium serratum</i>	100
Sedge		<i>Cyperus glomerata</i>	100
Shrub		<i>Berzelia lanuginosa</i>	75
Sedge		<i>Neesenbeckia punctoria</i>	75
Small shrub	Sapling	<i>Freylinia lanceolata</i>	75
Shrub		<i>Helichrysum cymosum</i>	75
Forb		<i>Taraxacum officinale</i>	75
TS (n=12)			
Forb		<i>Pteridium aquilinum</i>	82
Grass		<i>Ehrharta setacea</i>	73
Small tree	Sapling	<i>Brabejum stellatifolium</i>	64
Forb		<i>Taraxacum officinale</i>	64
Shrub		<i>Berzelia lanuginosa</i>	55
Sedge		<i>Ficinia nigrescens</i>	45
Shrub		<i>Prionium serratum</i>	45
Restio		<i>Ischyrolepis subverticillata</i>	45
Tree	Sapling	<i>Acacia longifolia</i>	45
OT (n=12)			
Forb		<i>Pteridium aquilinum</i>	100
Forb		<i>Taraxacum officinale</i>	80
Small tree	2-5m Adult	<i>Brabejum stellatifolium</i>	50
Grass		<i>Ehrharta ramosa</i>	50
Restio		<i>Ischyrolepis subverticillata</i>	40
Tree	Sapling	<i>Acacia longifolia</i>	40

only present as seedlings or saplings. Apart from these, the riparian flora remained generally herbaceous and shrubby, more like that associated with seepage vegetation than riparian zones. The forbs *Pteridium aquilinum* and *Taraxacum officinale* (an alien species) dominated TS and OT with two other grass species *Ehrharta setacea* and *Ehrharta ramosa*.

Full restoration towards a reference condition state is unlikely to occur soon in the absence of a re-vegetation strategy or seeding programme. The neighbouring two rivers, the Lourens and the Eerste, which arise from the same source region and have pristine mountain stream reaches, present the best opportunity for reference condition data and a source of seed for a re-vegetation programme.

Sir Lowry's Pass River, site 2, mountain stream first cleared of Acacia mearnsii, Acacia longifolia and Acacia saligna in 2002

SLP2 (Plate 6 & Appendix 5.12) was situated 10.0m downstream of SLP1 and was first cleared ten years later than SLP1, so was three years post-clearing recovery at the time of sampling.

Using the CART model (Table 4.21) four sample plots were assigned WE, four CF, 12 TS and OT (Table 5.37). All biodiversity measures fell within the ranges defining the reference condition except for OT species richness (5m²) of 7.6 as opposed to 19.9 (Table 5.38). Though these measures of biodiversity indicate a speciose riparian area the species present were not indicative of natural riparian vegetation as there were many more terrestrial species present and few Riparian Scrub indicator species (Table 4.5). Presumably in seven years time the vegetation will resemble that of upstream with less fynbos and more Riparian Scrub elements present.

Table 5.37 Distribution of assemblage types at SLP2 as predicted by the CART model.

	Flow →			
	A	B	C	D
7	OT	OT	OT	OT
6	OT	OT	OT	OT
5	OT	OT	OT	OT
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	WE	WE	WE	WE

Many of the same species recorded upstream at SLP1 were also found here. Noticeably different was the lower frequency of small Riparian Scrub trees, present only as seedlings in WE and saplings in TS, the absence of *Prionium serratum* from the wet bank WE and CF, and the lack of dominance by *Pteridium aquilinum* in TS and OT: two alien species, *Taraxacum officinale* and *Briza maxima* were recorded in its place (Table 5.39). Generally terrestrial fynbos shrubs, grasses and forbs dominated the area with recruitment of *Acacia mearnsii* and *Acacia longifolia* seedlings taking place in TS and OT respectively. The dry bank was distinctly fynbos in character and did not appear to resemble Riparian Scrub apart from a few scattered individuals of *Calopsis paniculata*, *Carpha glomerata* and *Brabejum stellatifolium*.

Silvermine River, site 1, mountain stream first cleared of Pinus radiata in 2000

The Silvermine River is a small river that arises on the Steenberg plateau on Table Mountain, flows alongside Ou Kaapse Weg and empties into False Bay at Fish Hoek. Sill (Plate 9B & Appendix 5.13) was located in the mountain stream in an area previously afforested with *Pinus radiata* until a wild fire.

Table 5.38 Measures of biodiversity for the reference condition and for SLP2. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	SLP 2
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.78
	Relative Diversity (J)	0.77 ± 0.06	0.81
	Species Richness	22.70 ± 5.80	29.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	5.8 ± 2.9
	CF	9.1 ± 5.9	8.3 ± 3.0
	TS	8.8 ± 2.9	9.3 ± 2.5
	OT	19.9 ± 7.9	7.6 ± 2.3
	Average	9.7 ± 7.7	8.1 ± 2.7

Table 5.39 Dominant species frequencies at SLP2 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=4)			
Sedge	Seedling	<i>Isolepis prolifer</i>	100
Rush		<i>Juncus capensis</i>	100
Forb		<i>Taraxacum officinale</i>	75
Restio		<i>Platycaulus compressus</i>	50
Small tree		<i>Brabejum stellatifolium</i>	50
CF (n=4)			
Shrub		<i>Berzelia lanuginosa</i>	100
Sedge		<i>Cyperus glomerata</i>	75
Sedge		<i>Isolepis prolifer</i>	75
Forb		<i>Taraxacum officinale</i>	75
Restio		<i>Calopsis paniculata</i>	75
Shrub		<i>Stoebe plumosa</i>	50
Rush		<i>Juncus capensis</i>	50
Grass		<i>Pentstemon barbata</i>	50
Forb		<i>Blechnum capense</i>	50
TS (n=12)			
Forb		<i>Taraxacum officinale</i>	83
Grass		<i>Briza maxima</i>	75
Grass		<i>Ehrharta setacea</i>	67
Grass		<i>Pentstemon barbata</i>	67
Shrub		<i>Stoebe plumosa</i>	67
Restio		<i>Calopsis paniculata</i>	50
Small tree	Sapling	<i>Brabejum stellatifolium</i>	42
Sedge		<i>Cyperus glomerata</i>	42
Tree	Seedling	<i>Acacia mearnsii</i>	42
OT(n=12)			
Forb		<i>Taraxacum officinale</i>	100
Grass		<i>Briza maxima</i>	82
Grass		<i>Pentstemon barbata</i>	73
Shrub		<i>Athanasia trifurcata</i>	64
Shrub		<i>Asparagus rubicundus</i>	55
Grass		<i>Paspalum urvillei</i>	46
Tree		Seedling	<i>Acacia longifolia</i>

burnt most of the vegetation in 2000. The few remaining pines were felled and removed and recruiting seedlings were hand-pulled in successive follow-up treatments. The vegetation was five years old at the time of sampling.

Using the CART model rules (Table 4.21) five sample plots were assigned to WE, three to CF, 36 to TS and none to OT (Table 5.40). The measures of biodiversity measured at the 50 m² scale (Table 5.41) all fell within or were slightly higher than the reference condition data. Species richness (5 m²) for WE was below the reference condition, whereas the other assemblage types fell within the reference range. This area appeared to have recovered well from the fire and the subsequent alien removal. Without any intervention other than alien clearance the site was on a trajectory towards a forest canopy beneath which forest-adapted understorey species were already present. Though not present in the sample grid, one or two isolated *Pinus radiata* seedlings were present in the general vicinity.

Table 5.40 Distribution of assemblage types at Sill as predicted by the CART model.

	Flow →			
	A	B	C	D
10	TS	TS	TS	TS
9	TS	TS	TS	TS
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	WE
0	WE	WE	WE	WE

Table 5.41 Measures of biodiversity: reference condition and recorded for Sill. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Sill
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.86
	Relative Diversity (J)	0.77 ± 0.06	0.87
	Species Richness	22.70 ± 5.80	24.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	1.3 ± 1.0
	CF	9.1 ± 5.9	5.0 ± 3.2
	TS	8.8 ± 2.9	7.4 ± 2.5
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	6.7 ± 3.1

There were few alien species present although two, the forb *Taraxacum officinale* and the grass *Briza maxima*, dominated TS (Table 5.42). WE and CF were similar in that they had high occurrences of

the riparian forb *Todea barbara* and the sedge *Isolepis prolifer*. Seedling *Cunonia capensis*, a riparian forest species, was also found in CF in all life stages, as were two common rushes *Juncus capensis* and *Juncus effusus*. Another riparian forb *Histiopteris incisa* and the grass *Ehrharta setacea* were less common in the wet bank. *Virgilia oroboides* dominated the canopy of TS as well as being abundantly present as seedlings, along with *Cunonia capensis* and another forest species *Maytenus acuminata*.

Table 5.42 Dominant species frequencies at Sill per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=5)			
Forb		<i>Todea barbara</i>	100
Sedge		<i>Isolepis prolifer</i>	75
Forb		<i>Laurembergia repens</i>	25
Forb		<i>Histiopteris incisa</i>	25
Rush		<i>Juncus effusus</i>	25
Rush		<i>Juncus capensis</i>	25
Tree	Seedling	<i>Cunonia capensis</i>	25
CF (n=3)			
Forb		<i>Todea barbara</i>	67
Sedge		<i>Isolepis prolifer</i>	67
Shrub		<i>Berzelia lamuginosa</i>	67
Tree	2-5m Adult	<i>Cunonia capensis</i>	33
Rush		<i>Juncus effusus</i>	33
Grass		<i>Ehrharta setacea</i>	33
Forb		<i>Histiopteris incisa</i>	33
Tree	Sapling	<i>Cunonia capensis</i>	33
Tree	Seedling	<i>Cunonia capensis</i>	33
Small tree	Seedling	<i>Maytenus acuminata</i>	
TS (n=36)			
Forb		<i>Taraxacum officinale</i>	85
Grass		<i>Briza maxima</i>	82
Tree	Seedling	<i>Cunonia capensis</i>	45
Tree	Seedling	<i>Virgilia oroboides</i>	42
Tree	2-5m Adult	<i>Virgilia oroboides</i>	39
Tree	5-10m Adult	<i>Virgilia oroboides</i>	39
Shrub		<i>Indigofera fillifolia</i>	33
Small tree	Seedling	<i>Maytenus acuminata</i>	33
Sedge		<i>Isolepis ludwigii</i>	30

*Silvermine River, site 2, first cleared of *Acacia saligna*, in 2000*

Sil2 (Plate 9B & Appendix 5.14) was situated 2.5 km downstream of Sill1 in the mountain stream (transitional) zone of the river. It was in a wider valley infested with large and dense *Acacia saligna* that was also burnt to the ground in the wild fire of 2000. The vegetation was five years old at the time of sampling and was quite different to that found upstream at Sill1.

Using the CART model rules (Table 4.21) one sample plot was assigned to WE, three to CF, 12 to TS and 48 to OT (Table 5.43). The resulting measures of biodiversity (Table 5.44) were equivalent to the reference condition data for those at the 50 m² level and for all measures of species richness at 5 m² excepting that for OT which was lower – 5.9 as opposed to 19.9.

Table 5.43 Distribution of assemblage types at Sil2 as predicted by the CART model.

	Flow →			
	A	B	C	D
16	OT	OT	OT	OT
15	OT	OT	OT	OT
14	OT	OT	OT	OT
13	OT	OT	OT	OT
12	OT	OT	OT	OT
11	OT	OT	OT	OT
10	OT	OT	OT	OT
9	OT	OT	OT	OT
8	OT	OT	OT	OT
7	OT	OT	OT	OT
6	OT	OT	OT	OT
5	OT	OT	OT	OT
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	WE

Table 5.44 Measures of biodiversity for the reference condition and for Sil2. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Sil 2
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.39
	Relative Diversity (J)	0.77 ± 0.06	0.78
	Species Richness	22.70 ± 5.80	21.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	5.0 ± 0.0
	CF	9.1 ± 5.9	7.7 ± 0.6
	TS	8.8 ± 2.9	8.7 ± 2.5
	OT	19.9 ± 7.9	5.9 ± 3.3
	Average	9.7 ± 7.7	6.5 ± 3.2

Many typically riparian species of sedges, forbs and shrubs were present mixed in with other fynbos shrubs and grasses (Table 5.45). Common riparian species included *Laurembergia repens* and *Isolepis prolifer*, more prominent in the wet bank (WE and CF), and larger species such as *Psoralea pinnata*, *Carpha glomerata* and *Berzelia lanuginosa*, more prominent in TS. The latter two species were also prominent in OT. Other dominants not typically riparian were the alien *Paspalum dilatatum* and non-alien *Ehrharta setacea* grasses, dominant in CF and OT, and *Erharta ramosa* subsp. *aphylla* and *Ehrharta setacea* both dominant in TS. Noticeably lacking were the forest trees or small Riparian Scrub trees, either of which normally constitute a large proportion of the wet and dry banks.

Though the measures of biodiversity (Table 5.44) appear to indicate a healthy riparian zone they are misleading. Though speciose, this riparian zone is missing vital elements of the upper canopy, the small tree and other tree species, as well as the larger restios and riparian shrubs (Table 4.22). This section of river, which once ran through a farm with livestock on non-indigenous pasture, would

benefit from a revegetation strategy in order to re-establish the shrub and small tree/forest species. It is not certain which species would be most appropriate for the site as there were no Afromontane Forest of Riparian Scrub species present to indicate its likely former nature. Though forest species occur upstream, this does not necessarily mean they would have naturally occurred at this site.

Table 5.45 Dominant species frequencies at Sil2 as per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=1)			
Sedge		<i>Isolepis prolifer</i>	100
Forb		<i>Laurembergia repens</i>	100
Sedge		<i>Juncus capensis</i>	100
Shrub		<i>Psoralea pinnata</i>	100
Sedge		<i>Cyperus glomerata</i>	100
CF (n=3)			
Forb		<i>Laurembergia repens</i>	100
Grass		<i>Ehrharta setacea</i>	100
Shrub		<i>Psoralea pinnata</i>	100
Forb		<i>Histioglossa incisa</i>	100
Grass		<i>Paspalum dilatatum</i>	100
Sedge		<i>Cyperus glomerata</i>	50
Sedge		<i>Isolepis prolifer</i>	50
Shrub		<i>Helichrysum cymosum</i>	50
Shrub		<i>Berzelia lanuginosa</i>	50
Restio		<i>Platycaulus compressus</i>	50
TS (n=12)			
Sedge		<i>Cyperus glomerata</i>	100
Grass		<i>Ehrharta setacea</i>	92
Shrub		<i>Psoralea pinnata</i>	92
Shrub		<i>Berzelia lanuginosa</i>	67
Sedge		<i>Fuirena hirsuta</i>	58
Shrub		<i>Helichrysum cymosum</i>	50
Grass		<i>Ehrharta ramosa</i> subsp. <i>aphylla</i>	50
OT (n=48)			
Sedge		<i>Cyperus glomerata</i>	69
Shrub		<i>Helichrysum cymosum</i>	66
Grass		<i>Ehrharta setacea</i>	51
Shrub		<i>Berzelia lanuginosa</i>	43
Forb		<i>Laurembergia repens</i>	43
Grass		<i>Paspalum dilatatum</i>	43

Assegaaibos River, site 1, mountain stream (transitional) first cleared of Pinus radiata in 2002

The Assegaaibos River (Plate 7A) is one of the source tributaries of the Berg River, arising on the Franschoekberge. The entire surrounding catchment was afforested with *Pinus radiata* but subsequently cleared. Ass1 (Appendix 5.15) was the upper most of three sites on this short section of river. It was first cleared in 2002, with the woody aliens felled and removed; the area was not burnt.

Using the CART model rules (Table 4.21) two sample plots were assigned to WE, six to CF, 28 to TS and none to OT (Table 5.46). The resulting biodiversity measures (Table 5.47) at the 50 m² scale were

all larger than the defining reference condition data as was species richness (5 m^2) for TS while that for CF was within the defining limits.

Table 5.46 Distribution of assemblage types at Ass1 as predicted by the CART model.

	Flow →			
	A	B	C	D
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	CF	CF
0	CF	WE	WE	CF

Table 5.47 Measures of biodiversity for the reference condition and for Ass1. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Ass 1
50 m^2			
	Equitability (H)	2.38 ± 0.23	3.91
	Relative Diversity (J)	0.77 ± 0.06	0.84
	Species Richness	22.70 ± 5.80	47.00
5 m^2			
Species richness:	WE	6.1 ± 4.2	0.0 ± 0.0
	CF	9.1 ± 5.9	6.4 ± 4.7
	TS	8.8 ± 2.9	10.9 ± 4.1
	OT	19.9 ± 7.9	-

This site was well vegetated generally with a mix of both forest and scrub species (Table 5.48). The sedge *Isolepis prolifer*, rush *Juncus effusus* and alien grass *Paspalum urvillei* dominated CF. There were smaller occurrences of the alien forb *Taraxacum officinale* and the non-riparian grass *Agrostis lachnantha* and shrub *Helichrysum odoratissimum*. *Brabejum stellatifolium* sapling and adult small riparian trees were present, as were sapling *Acacia longifolia* in the wet bank as a result of a secondary invasion by this species. TS had the same three alien species as CF but no sedges and rushes.

As at the Silvermine River sites (discussed above) there were adult and sapling *Virgilia oroboides*. In addition there were sapling *Rapanea melanophloeos* (forest), *Brabejum stellatifolium* (scrub) and *Acacia longifolia* (woody alien). This abundance of species presents a confusing picture as many of the species present are not specifically riparian. This was similar to that found at Sil2, on the Silvermine River in the area cleared of *Acacia saligna*, where a mix of forest, fynbos and riparian species were found all together.

Table 5.48 Dominant species frequencies at Ass1 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=2)			
CF (n=6)			
Sedge		<i>Isolepis prolifer</i>	67
Grass		<i>Paspalum urvillei</i>	50
Forb		<i>Taraxacum officinale</i>	50
Rush		<i>Juncus effusus</i>	50
Sedge		<i>Juncus lomatophyllus</i>	33
Grass		<i>Agrostis lachnantha</i>	33
Shrub		<i>Helichrysum odoratissimum</i>	33
Tree	Sapling	<i>Acacia longifolia</i>	33
TS (n=28)			
Forb		<i>Taraxacum officinale</i>	68
Tree	2-5m Adult	<i>Virgilia oroboides</i>	56
Tree	Sapling	<i>Rapanea melanophloeos</i>	52
Grass		<i>Paspalum urvillei</i>	48
Tree	Sapling	<i>Virgilia oroboides</i>	44
Restio		<i>Ischyrolepis subverticillata</i>	40
Tree	Sapling	<i>Acacia longifolia</i>	40
Small tree	Sapling	<i>Brabejum stellatifolium</i>	36
Shrub		<i>Helichrysum cymosum</i>	36

Assegaaibos River, site 2, mountain stream (transitional) first cleared of Pinus radiata 2000

Ass2 (Plate 7A & Appendix 5.16) was situated 200 m downstream of Ass1, also in an area formerly afforested with *Pinus radiata*. The pines were felled in 2000 and removed, with no burning taking place. There were no subsequent follow-up clearing activities and as a result there was a secondary invasion by *Acacia mearnsii* and *Acacia longifolia*. At the time of sampling the vegetation was four years old.

Using the CART model rules (Table 4.21) one sample plot was assigned to WE, three to CF, 36 to TS and none to OT (Table 5.49). The measures of biodiversity (Table 5.50) generally fell within the range expected for most indices. Relative diversity was slightly lower than expected – 0.67 compared to 0.77 and species richness (50 m²) was slightly higher: 29.00 species as opposed to 22.70.

There was a densely vegetated WE and CF mainly consisting of the sedge *Isolepis prolifer*; the rushes *Juncus lomatophyllus*, *Juncus capensis*, *Juncus effusus* and *Juncus exsertus*; the small shrub *Helichrysum odoratissimum*; the grass *Agrostis lachnantha* and the two alien species found at the Silvermine River and Sir Lowry's Pass River sites: *Taraxacum officinale*, a forb, and *Paspalum urvillei*, a grass (Table 5.51). There were also sapling *Acacia longifolia* in CF with seedling *Cunonia capensis*. TS contained the three alien species already mentioned as well as the forest trees *Virgilia oroboides* and *Rapanea melanophloeos* and the small Riparian Scrub tree *Brabejum stellatifolium*. Though the alien species were a prominent part of the canopy, the other riparian and forest species were still flourishing. Non-woody species were also abundant and only two alien herbaceous species

were present. This area was cleared soon after the sampling visit and the same sample grid was sampled one year later as Ass3.

Table 5.49 Distribution of assemblage types at Ass2 as predicted by the CART model.

	Flow →			
	A	B	C	D
10	TS	TS	TS	TS
9	TS	TS	TS	TS
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	WE	CF

Table 5.50 Measures of biodiversity for the reference condition and for Ass2. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Ass 2
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.24
	Relative Diversity (J)	0.77 ± 0.06	0.67
	Species Richness	22.70 ± 5.80	29.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	9.0 ± 0.0
	CF	9.1 ± 5.9	9.0 ± 3.0
	TS	8.8 ± 2.9	7.1 ± 3.0
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	7.3 ± 3.0

Assegaaibos River, site 3, mountain stream (transitional) first cleared of Acacia longifolia and Acacia mearnsii 2004

Ass3 (Plate 7A & Appendix 5.17) and Ass2 represent the only BACI (Before-After, Control-Impact; Stewart-Oaten et al., 1986) set of sample grids successfully employed during this project. Ass2 (discussed above) was cleared of *Acacia mearnsii* and *Acacia longifolia* one year before it was re-sampled as Ass3. The woody aliens were felled, stacked and burnt in 2004.

Using the CART model rules (Table 4.21) five sample plots were assigned to WE, three to CF, 36 to TS and none to OT (Table 5.52). Additional samples were collected closer to the channel in this second survey as new wet bank vegetation extended into the channel (sample plots 0A-0D, Table 5.52). The resulting biodiversity measures were either within the limits defining the reference conditions or were higher (Table 5.53). Measures that were higher were species richness (50 m²) - 36.00 as opposed to 22.70 and TS species richness (5 m²) - 17.0 as opposed to 8.8. Similar high

measures of species richness were recorded at Ass1 on this river and at the two cleared sites on the Sir Lowry's Pass River.

Table 5.51 Dominant species frequencies at Ass2 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=1)			
Sedge		<i>Isolepis prolifer</i>	100
Rush		<i>Juncus lomatophyllus</i>	100
Forb		<i>Taraxacum officinale</i>	100
Grass		<i>Paspalum urvillei</i>	100
Rush		<i>Juncus capensis</i>	100
Grass		<i>Agrostis lachnantha</i>	100
Shrub		<i>Helichrysum odoratissimum</i>	100
Rush		<i>Juncus exsertus</i>	100
Grass		<i>Digitaria debilis</i>	100
CF (n=3)			
Grass		<i>Paspalum urvillei</i>	100
Rush		<i>Juncus lomatophyllus</i>	100
Forb		<i>Taraxacum officinale</i>	100
Grass		<i>Agrostis lachnantha</i>	100
Sedge		<i>Isolepis prolifer</i>	100
Shrub		<i>Helichrysum odoratissimum</i>	100
Tree	Sapling	<i>Acacia longifolia</i>	100
Rush		<i>Juncus effusus</i>	100
Rush		<i>Juncus capensis</i>	50
Rush		<i>Juncus exsertus</i>	50
Forb		<i>Solanum nigrum</i>	50
Sedge		<i>Cyperus glomerata</i>	50
Tree	Seedling	<i>Cunonia capensis</i>	50
TS (n=36)			
Forb		<i>Taraxacum officinale</i>	68
Tree	2-5m Adult	<i>Virgilia oroboides</i>	56
Tree	Sapling	<i>Rapanea melanophloeos</i>	52
Grass		<i>Paspalum urvillei</i>	48
Tree	Sapling	<i>Virgilia oroboides</i>	44
Restio		<i>Ischyrolepis subverticillata</i>	40
Tree	Sapling	<i>Acacia longifolia</i>	40
Small tree	Sapling	<i>Brabejum stellatifolium</i>	36
Shrub		<i>Helichrysum cymosum</i>	36

Many of the same species persisted in WE and CF after the fire, presumably regenerating from the seed bank. The most notable changes took place in TS where the forest and Riparian Scrub species were either killed in the fire or were felled and removed along with the woody aliens. The only tree species to regenerate after the fire was *Acacia longifolia* (Table 5.54). Many new species not present before the fire included the shrubs *Stoebe cinerea*, *Ursinia paleacea*, *Hippia frutescens*; the forbs *Nemesia diffusa*, *Pseudognaphalium undulatum*, *Conyza canadensis*, *Phytolacca americana*, the latter two being alien species; and the grass *Ehrharta ramosa* and the riparian restio *Calopsis paniculata*.

The presence of these alien and non-riparian species might be typical of riparia in the first year following clearing, or some other disturbance event such as flooding or fire. Presumably successful recruitment of typically riparian species follows this initial 'pioneer' phase.

Table 5.52 Distribution of assemblage types at Ass3 as predicted by the CART model.

	Flow →			
	A	B	C	D
10	TS	TS	TS	TS
9	TS	TS	TS	TS
8	TS	TS	TS	TS
7	TS	TS	TS	TS
6	TS	TS	TS	TS
5	TS	TS	TS	TS
4	TS	TS	TS	TS
3	TS	TS	TS	TS
2	TS	TS	TS	TS
1	CF	CF	WE	CF
0	WE	WE	WE	WE

Table 5.53 Measures of biodiversity for the reference condition and for Ass3. Assemblage types: WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub and OT = Outer Transitional.

Attribute		Reference Conditions	Ass 3
50 m ²			
	Equitability (H)	2.38 ± 0.23	2.71
	Relative Diversity (J)	0.77 ± 0.06	0.76
	Species Richness	22.70 ± 5.80	36.00
5 m ²			
Species richness:	WE	6.1 ± 4.2	4.4 ± 1.5
	CF	9.1 ± 5.9	6.3 ± 2.5
	TS	8.8 ± 2.9	17.0 ± 4.8
	OT	19.9 ± 7.9	-
	Average	9.7 ± 7.7	14.8 ± 6.4

5.4 SUMMARY OF THE IMPACTS OF INVADING ALIEN TREES

The data presented above were used to summarise the impact of woody alien plants on natural riparian vegetation communities. In all analyses presented, the study sites were grouped according to the patterns shown by the CLUSTER analysis (Figure 4.1) and MDS ordinations (Figure 4.2). The status of the groups/sites may be summarised as:

First super group – Riparian Scrub sites

1. Reference sites (Group A): close to natural riparian communities, with no known history of alien invasion and clearance;
2. Group B sites: presently uncleared and heavily invaded with *Acacia mearnsii* (3 sites) or invaded with *Acacia mearnsii* and cleared seven to eight years ago (2 sites);

3. Group C sites: previously invaded with *Acacia mearnsii* and cleared seven to ten years ago (2 sites), plus an anomalous site with unknown invasion history;
4. Group D sites: previously invaded with *Acacia mearnsii*, *Acacia saligna*, *Acacia longifolia* and *Pinus pinaster* and cleared three or 13 years ago (2 sites), plus previously invaded with *Pinus pinaster* or *Acacia saligna* and cleared five years ago (2 sites);
5. Group E sites: previously invaded with *Pinus pinaster* (2 sites), or *Acacia longifolia* and *Acacia mearnsii* (1 site); all cleared one to four years ago.
6. SLP3: a single outlier to groups A through E, this site was heavily invaded with the yellow gum *Eucalyptus leucoxylon*;

Second super-group – Afromontane sites on Table Mountain

7. Group 3 sites: close to natural Afromontane Forest communities approximately 60 years old (2 sites: Dis1 and Dis2), plus an outlier, Cec1, heavily invaded with the grey poplar *Populus X canescens*.

Table 5.54 Dominant species frequencies at Ass3 per assemblage type designated using the CART model. Tree life stage: seedling <0.3m, sapling = 0.3-2m. n = number of sample plots. F = percent frequency of occurrence in sample plots assigned to that assemblage type. Bold = alien species.

Growth form	Life stage	Assemblage type	F
WE (n=5)			
Sedge		<i>Isolepis prolifer</i>	100
Rush		<i>Juncus lomatophyllus</i>	100
Forb		<i>Taraxacum officinale</i>	80
Rush		<i>Juncus exsertus</i>	60
Grass		<i>Paspalum urvillei</i>	40
Rush		<i>Juncus capensis</i>	20
Grass		<i>Agrostis lachnantha</i>	20
Forb		<i>Vellereophyton dealbatum</i>	20
CF (n=3)			
Rush		<i>Juncus lomatophyllus</i>	100
Sedge		<i>Isolepis prolifer</i>	100
Grass		<i>Paspalum urvillei</i>	100
Rush		<i>Juncus exsertus</i>	67
Forb		<i>Taraxacum officinale</i>	67
TS (n=36)			
Grass		<i>Paspalum urvillei</i>	100
Shrub		<i>Stoebe cinerea</i>	86
Forb		<i>Conyza canadensis</i>	86
Forb		<i>Nemesia diffusa</i>	83
Rush		<i>Juncus capensis</i>	77
Grass		<i>Digitaria sanguinalis</i>	74
Forb		<i>Pseudognaphalium undulatum</i>	74
Shrub		<i>Ursinia paleacea</i>	66
Shrub		<i>Hippia frutescens</i>	60
Forb		<i>Phytolacca americana</i>	57
Grass		<i>Ehrharta ramosa</i>	54
Rush		<i>Juncus effusus</i>	51
Restio		<i>Calopsis paniculata</i>	46
Tree	Seedling	<i>Acacia longifolia</i>	46
Rush		<i>Juncus lomatophyllus</i>	40

Most of the sites in the study (Groups A through E) supported Riparian Scrub communities (Table 4.5) and thus these were the focus of this report. Two sites supported near-natural Afromontane Forest communities, as shown by the presence of different indicator species (Table 4.5), and could be used to provide a first definition of the reference condition against which the only other Afromontane site, the invaded Cec1, was compared. Findings for this small group are summarised first, followed by those for the Riparian Scrub sites.

5.4.1 Afromontane Forest communities (Group 3)

Since there were only three Afromontane sites the full suite of analyses seemed premature, and instead the three main biological attributes assessed for the Riparian Scrub sites are briefly summarised in this section. The three sites are also listed in the summary tables at the end of this chapter, but are not referred to again.

Growth forms

As previously, the Riparian Scrub small tree species (Figure 4.33) were represented by the three growth forms 'small tree1 to small tree3'. The other category of 'small tree' was for other species not specifically restricted to Riparian Scrub (Appendix 3.2). Large tree species were indicated by 'tree1 to tree3'.

No small Riparian Scrub tree species were recorded at these three sites (Figure 5.2). Seedlings of large forest trees were present in the undisturbed WE but were absent at the disturbed site. The CF of both reference and disturbed sites contained a similar distribution of sedges, shrubs, forbs, seedlings and saplings, but the disturbed sites lacked rushes, grasses and adult trees.

The TS assemblage type differed most between undisturbed and disturbed sites. The latter had a far higher frequency of sedges, shrubs, grasses, forbs and all life stages of large trees, and lacked the rushes, restios and small shrubs of the reference sites. Whilst the large trees present at the reference sites were all indigenous Afromontane species those at the disturbed site were not. Instead, the alien *Populus X canescens* provided mature trees and the forest canopy, with a mixture of alien and indigenous seedlings and saplings in the understorey.

The CART model did not recognize an OT assemblage type at the disturbed site (Table 5.7), and so there were no data to compare with the reference growth forms.

Indicator species

The disturbed and undisturbed areas shared six indigenous dominant species (Table 5.55).

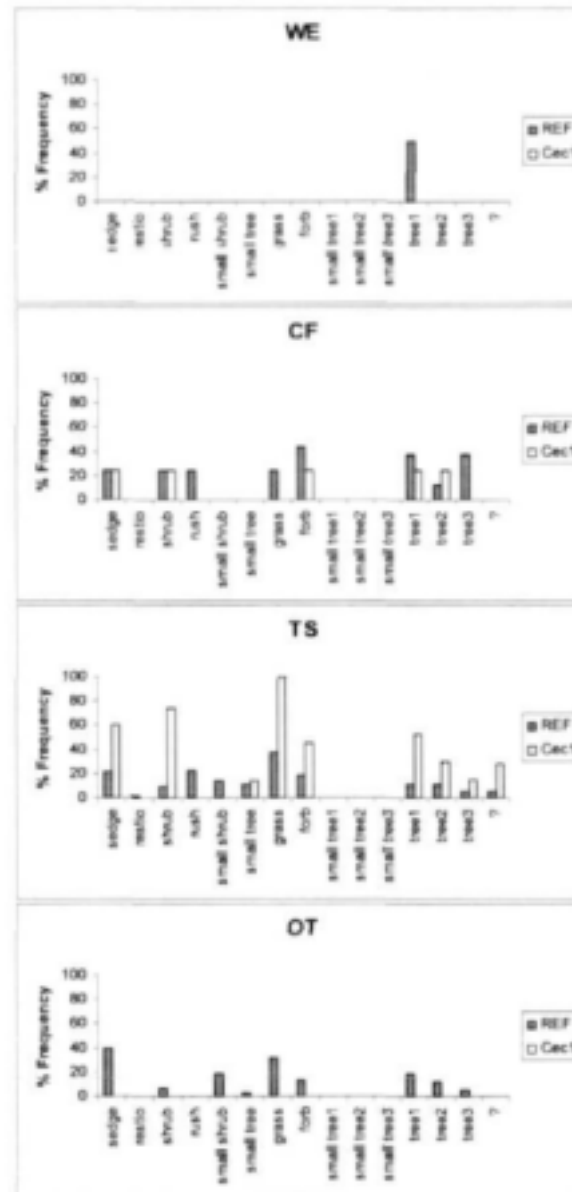


Figure 5.2 Distribution of growth forms in all four assemblage types for the disturbed and reference Afromontane Forest sites. REF = two Disa River sites (Dis1 & Dis2, site codes as per Table 3.2).

Though there was an overwhelming presence of *Populus X canescens* at Cec1, this did not show up well in the analysis as only trees rooted in the sample plots were scored. Fewer typically Afromontane species (Table 4.5) were dominant members of the canopy at Cec1, when compared to the two Disa River sites: three compared to nine. Perhaps the six species that were missing from the *Populus X canescens* invaded site (Cec1; *Virgilia oroboides*, *Ilex mitis*, *Halleria lucida*, *Podocarpus* sp., *Secamone alpinii* and *Maytenus acuminata*) are more sensitive to the presence of *Populus X canescens* than the other three species also present at both undisturbed forest sites (Dis1 and 2; *Kiggelaria africana*, *Canonia capensis* and *Rapanea melanophloeos*). With so few replicate forest sites it was not possible to test this hypothesis further.

Table 5.55 Dominant species at two undisturbed and one disturbed Afromontane Forest sites. Asterisk (*) species are typically Afromontane (Taylor 1978, Campbell 1987). Bolded species indicate cosmopolitan families (Table 4.3). Shaded species are present in both undisturbed and disturbed groups.

Disa River (n=2)		F	Cecelia River (n=1)		F
Asparagaceae	<i>Asparagus scandens</i>	100	Podocarpaceae	<i>Afrocarpus falcatus</i>	100
Blechnaceae	<i>Blechnum capense</i>	100	Asparagaceae	<i>Asparagus scandens</i>	100
Poaceae	<i>Ehrharta erecta</i>	100	Blechnaceae	<i>Blechnum capense</i>	100
Myrsinaceae	<i>Rapanea melanophloeos</i> *	100	Cyperaceae	<i>Carpha glomerata</i>	100
Juncaceae	<i>Juncus effusus</i>	100	Ebenaceae	<i>Diospyros glabra</i>	100
Dennstaedtiaceae	<i>Histiopteris incisa</i>	100	Salicaceae	<i>Populus X canescens</i>	100
Cunoniaceae	<i>Canonia capensis</i> *	100	Kiggelariaceae	<i>Kiggelaria africana</i> *	100
Osmundaceae	<i>Todea barbara</i>	100	Rubiaceae	<i>Canthium ventosum</i>	100
Rubiaceae	<i>Canthium ventosum</i>	100	Ebenaceae	<i>Diospyros whyteana</i>	100
Blechnaceae	<i>Blechnum punctulatum</i>	100	Amaranthaceae	<i>Achyranthes sicula</i>	100
Ebenaceae	<i>Diospyros whyteana</i>	100	Celastraceae	<i>Cassine peragua</i>	100
Fabaceae	<i>Virgilia oroboides</i> *	100	Fabaceae	<i>Acacia melanoxylon</i>	100
Kiggelariaceae	<i>Kiggelaria africana</i> *	100	Cunoniaceae	<i>Canonia capensis</i> *	100
Aquifoliaceae	<i>Ilex mitis</i> *	100	Myrsinaceae	<i>Rapanea melanophloeos</i> *	100
Scrophulariaceae	<i>Halleria lucida</i> *	100	Osmundaceae	<i>Todea barbara</i>	100
Podocarpaceae	<i>Podocarpus sp.</i> *	50	Polypodiaceae	<i>Pleopeltis macrocarpa</i>	100
Apocynaceae	<i>Secamone alpinii</i> *	50	Flacourtiaceae	<i>Scolopia mundii</i>	100
Dennstaedtiaceae	<i>Pteridium aquilinum</i>	50	Aspleniaceae	<i>Asplenium aethiopicum</i>	100
Celastraceae	<i>Maytenus acuminata</i> *	50	Araceae	<i>Zantedeschia aethiopica</i>	100

Biodiversity indices

Although the measures of biodiversity were not appreciably different between the undisturbed and disturbed sites, the latter did support fewer species (Table 5.56). The values shown are in line with those described for the Riparian Scrub reference condition below.

Table 5.56 Measures of biodiversity (50 m²) for two undisturbed and one disturbed Afromontane Forest sites. Sites codes as per Table 3.1. MS = mountain stream zone. H = Equitability, J = relative diversity.

	Zone	Sp./50 m ²	H	J
Dis1	MS	21	2.46	0.76
Dis2	MS	26	2.07	0.61
Cec1	MS	17	2.49	0.73

5.4.2 Riparian Scrub communities (Groups A through E)

Because of the greater number of sites in this super group it was possible to summarise more comprehensively the impacts of alien invasives in terms of growth forms, indicator species, presence of the four common Riparian Scrub small tree species and presence of two of the more common riparian woody alien species. Biotic indices are addressed later (Section 5.4.4).

Growth forms

The occurrence of the ten growth forms (Table 3.5) for the six Riparian Scrub groups is shown in Figure 5.3 for the wet bank (WE and CF) and Figure 5.4 for the dry bank (TS and OT) assemblage types. Each assemblage type is compared to the reference condition and discussed in turn. In all of the disturbed groups, the 'trees' present were generally alien species.

Wet Edge assemblage type

The most heavily disturbed site sampled during this study, SLP3, had only four indigenous species present (Table 5.6). Of these the sedge *Isolepis prolifer* was present in WE. Adult *Eucalyptus leucoxylon* and seedling, sapling and adult *Acacia longifolia* were present in the tree category. There was one indigenous tree present here, a sapling (0.3-2m) *Kiggelaria africana*, that barely contributed towards the canopy cover. E had more sedges, rushes, small shrubs, grasses and forbs than the reference group and no other growth forms. Group D also showed higher than reference levels of these five growth forms, but also supported small trees, restios and shrubs in about the same frequency as reference sites. The spread of growth forms in both Groups B and C was closer to reference condition, but with Group C having higher levels of sedges and Group B having alien trees in both seedling, sapling and adult form. Interestingly, Group B, with its three heavily invaded sites, retained a WE that was comparable to the reference sites, albeit it with large alien trees scattered throughout it, but crucially also with a sparse scattering of the indigenous species characteristic of this assemblage type.

There is an incomplete knowledge of the fire history of these sites and of their original indigenous vegetation but, accepting these uncertainties a tentative trajectory of recovery can be hypothesised. Within the first year or so after clearance, a flush of new growth occurred in WE in the form of sedges, rushes, forbs, grasses and small shrubs. The three former tended to be species more closely allied with wet environments while the grasses and small shrubs were more typical of drier environments (Appendix 3.2). By about five years after clearance the occurrence of these growth forms had declined and restios, shrubs and seedlings and saplings of riparian scrub trees had appeared in about the same proportion as at reference sites. By seven to ten years after clearance, the distribution of growth forms was approaching the reference condition, with a further decline in sedges, the disappearance of small shrubs, a persistent low level of grasses and forbs and, in some cases, the re-appearance of alien trees as seedlings and saplings.

Channel Fringe assemblage type

The most noticeable differences between disturbed and reference condition of all four assemblage types were in CF. There were no indigenous species recorded at the outlying SLP3; only adult *Eucalyptus leucoxylon* and sapling *Acacia mearnsii* and *Acacia longifolia*. All the other four groups of disturbed sites had many trees – mostly alien – compared to none in the reference sites, and also higher occurrences of sedges, rushes, grasses, forbs. Other growths forms varied in their response:

some, such as restios were most abundant in the reference condition, whilst other, such as shrubs, had their highest frequencies in the older recovering groups. Again, Group B appeared most similar to the reference condition and Group E least similar.

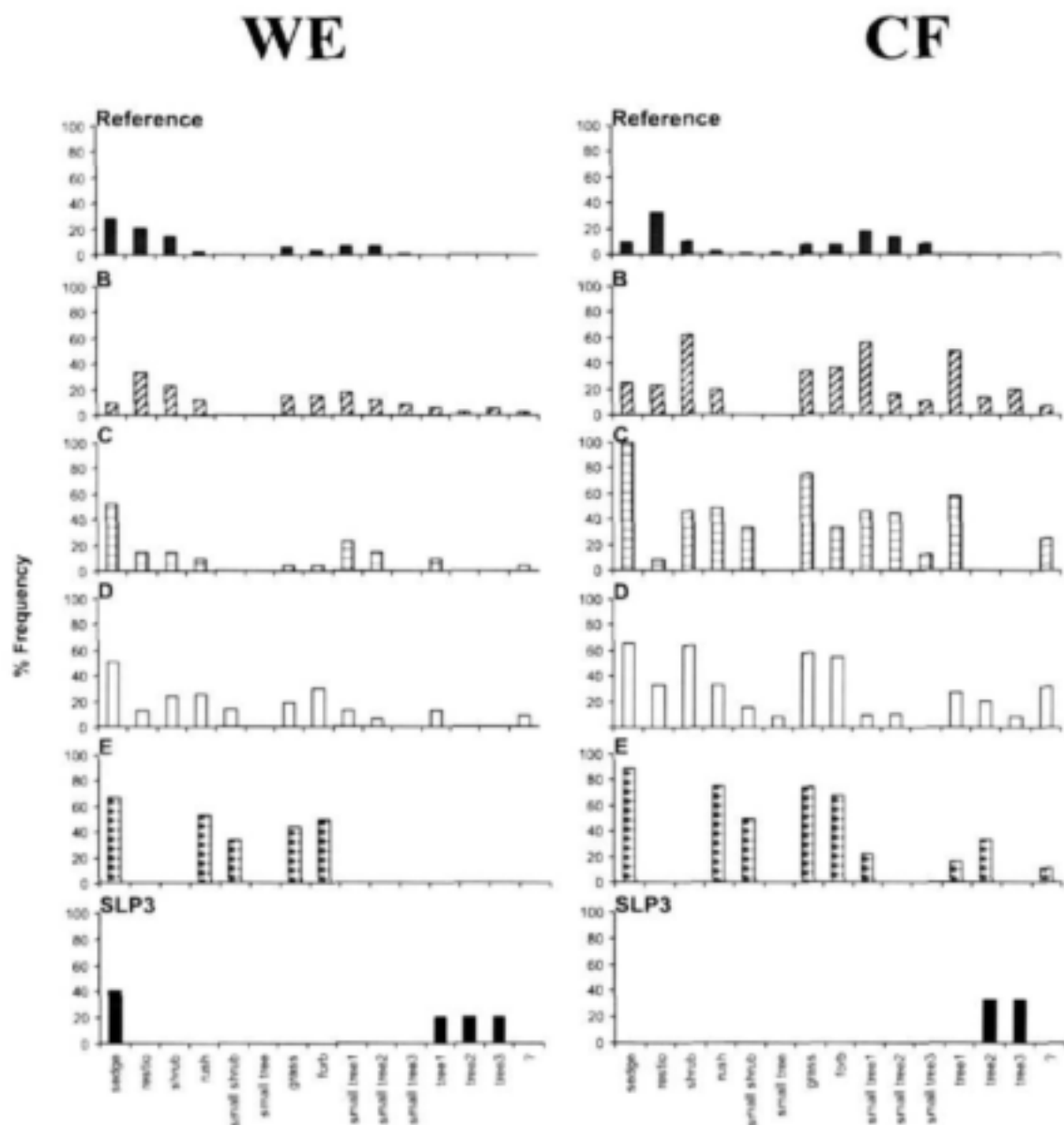


Figure 5.3 Distribution of growth forms in the two wet bank assemblage types; WE (wet edge) and CF (channel fringe). B = Hawequas/Cedarberg, C = Hawequas, D = Hottentots Holland/Table Mountain, E = Hottentots Holland and SLP3 = Sir Lowry's Pass River site 3 invaded with *Eucalyptus leucoxylon*.

Using the trends suggested by the groups, the trajectory of recovery may be hypothesised as follows. An initial flush of herbaceous growth (sedges, rushes, grasses, forbs) occurs, much as in WE, but with these growth forms persisting at high levels for several years into the recovery period and still being higher than those of reference sites up to ten years after clearance. Small shrubs also establish themselves in this assemblage type, but decline after 5-10 years, whereas restios show the opposite

trend by increasing in frequency with time. Small Riparian Scrub tree species, almost absent from heavily degraded sites, gradually colonise the area, mostly as seedling and saplings, with the numbers of their seedlings, in particular, higher than reference condition up to ten years after clearance. This trend is mirrored by shrubs. Alien trees reappear, first as seedlings and saplings but with adult trees becoming obvious after about five years. In contrast to WE, sites with recovering vegetation up to ten years old were still obviously different from the reference condition although moving toward it, probably because the initial recruiting species had not yet thinned out. Thus, ten years appears not to be a sufficient time span for recovery of CF vegetation after alien clearance.

Tree/Shrub assemblage type

TS at the disturbed sites was less obviously different to the reference condition than were wetbank assemblage types, as a wider range of growth forms was present in all cases except the heavily invaded SLP3. The three indigenous species persisting at SLP3 under a canopy that was almost exclusively *Eucalyptus leucoxylon* were represented by single individuals of *Diospyros glabra*, *Maytenus acuminata* and *Kiggelaria africana*.

The four cleared groups of sites tended to have more growth forms than did the reference group. The most recently cleared sites had a slightly higher proportion of sedges, rushes, grasses and forbs than reference sites, as has already been described for WE and CF, but also contained a greater proportion of restios. Seedlings, saplings and adult small trees were present at all sites, indicating that the recruitment of indigenous Riparian Scrub species had occurred soon after clearing and had persisted. This was in contrast to the wetbank situation where they only began to establish themselves in the older stands of vegetation.

The hypothesised trajectory of recovery is an initial growth flush of herbaceous flora that persists at higher than reference frequency levels for up to ten years although there is some decline during that time. Restios, shrubs and small shrubs mirror this pattern. Small Riparian Scrub trees establish themselves within the first one to four years and maintain their presence through sapling and early adult phases. Their earlier presence in TS than in WE or CF may be because the trees require an already established cover of herbaceous vegetation for successful germination, and this happens sooner in TS due to less disturbance from floods – about once in two years in the lower TS as opposed to approximately yearly in CF and WE. The same microclimate and flooding conditions that allow the indigenous trees to become established are also favourable for alien tree species. Thus, these also establish themselves early and persist through all phases of recovery.

Outer Transitional assemblage type

The invading species appeared to have the greatest effect on recovery in this assemblage type. Perhaps at this position on the bank the alien canopy and other influences of the invading species (Chapter 7) might be more pronounced.

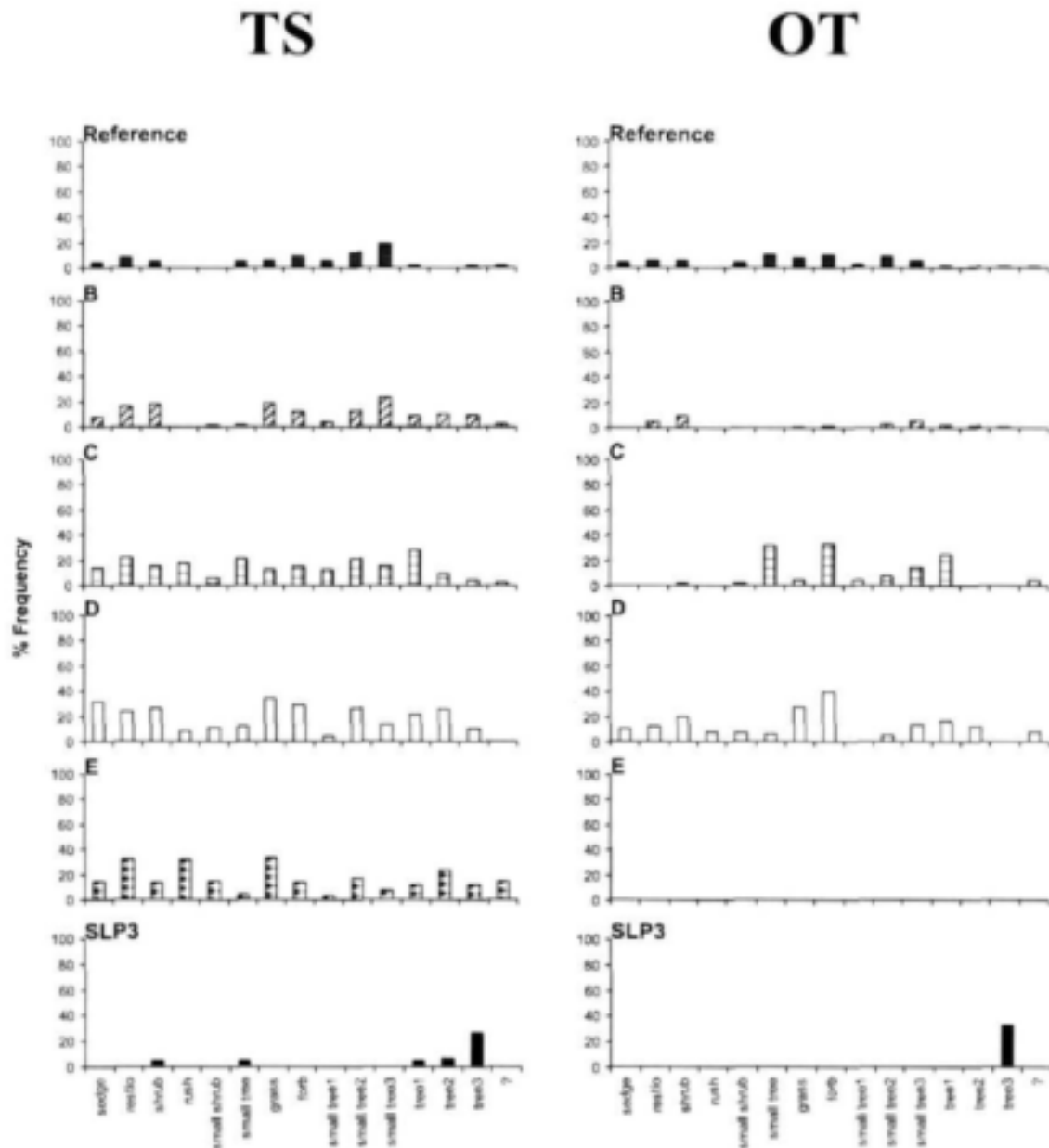


Figure 5.4 Distribution of growth forms in the two dry bank assemblage types; TS (tree shrub) and OT (outer transitional). B = Hawequas/Cedarberg, C = Hawequas, D = Hottentots Holland/Table Mountain, E = Hottentots Holland and SLP3 = Sir Lowry's Pass River site 3 invaded with *Eucalyptus leucoxylon*.

At the heavily invaded sites SLP3 there was only one species present –adults of the alien *Eucalyptus leucoxylon*.

Group E did not have an OT assemblage type assigned and so there were no data for comparison.

Of the remaining disturbed sites, group D displayed the most variety of growth forms, closely resembling that in TS. The four herbaceous forms and restios were dominant and there was recruitment of small Riparian Scrub trees. Group C had a smaller variety of growth forms, with no

sedges, restios or rushes and a reduced frequency of grasses and small trees. As with Group D the frequency of forbs was high.

Group B, containing some invaded sites and some that had been cleared for some time, had the most depauperate OT of any of the cleared groups. It is not known why this should be so as invading woody species were not concentrated in this assemblage type (Section 5.4.3).

Perhaps successful recruitment of propagules and germination of seed banks was limited by the drier conditions in this highest part of the riparian zone and a lack of other germination cues (e.g. fire) appropriate for recruitment of the non-riparian vegetation elements associated with this assemblage type. The flush of herbaceous vegetation growth shown on the wet bank may result from downstream propagule dispersal during low flow periods (spring and summer). Perhaps vegetative recovery of Riparian Scrub species higher up the bank is only possible once vegetative cover has established lower down.

Indicator species

The occurrence of the ten indicator species (Figure 4.34) in the disturbed and reference groups of sites is illustrated in Figure 5.5. All were missing from SLP3 except where mentioned below.

The sedge *Isolepis prolifer* was almost completely absent from group B sites and was present as one small clump in the WE of SLP3. In the other disturbed groups its levels of occurrence were higher than in the reference condition. This species naturally occurs in the main channel on exposed boulders, bordering mid-channel bars, or further up the bank on damp, sandy or stony deposits. It appeared to be one of the first to take advantage of cleared areas, perhaps because of an apparent ability to establish itself quickly in a variety of naturally-disturbed habitats.

The riparian forb *Todea barbara* was common in both Afriomontane and Riparian Scrub reference sites, more often on the wet bank than dry bank. It was generally absent or less frequent in the disturbed groups in WE, CF and TS. Though easy to identify and generally present sometimes to dominance, its overall occurrence was not sufficiently high to detect recovery trends with any confidence.

The shrub *Erica caffra* was generally abundant in most reference sites, in WE, CF or TS. It was not present at invaded sites and recovered slowly after clearance. Mostly individuals were adult, even at reference sites, suggesting very low fecundity. If this is the case, it would explain the slow recovery rate.

The shrub *Prionium serratum* was noticeably more abundant in WE, CF and TS of disturbed groups B, C and D than in the reference sites, although it did not occur in the mostly recently cleared sites (group E). Its higher frequencies at the disturbed sites suggests the modified conditions provided by alien

trees, perhaps including trapped sand deposits, favour proliferation of the species in WE and CF (Boucher 1998).

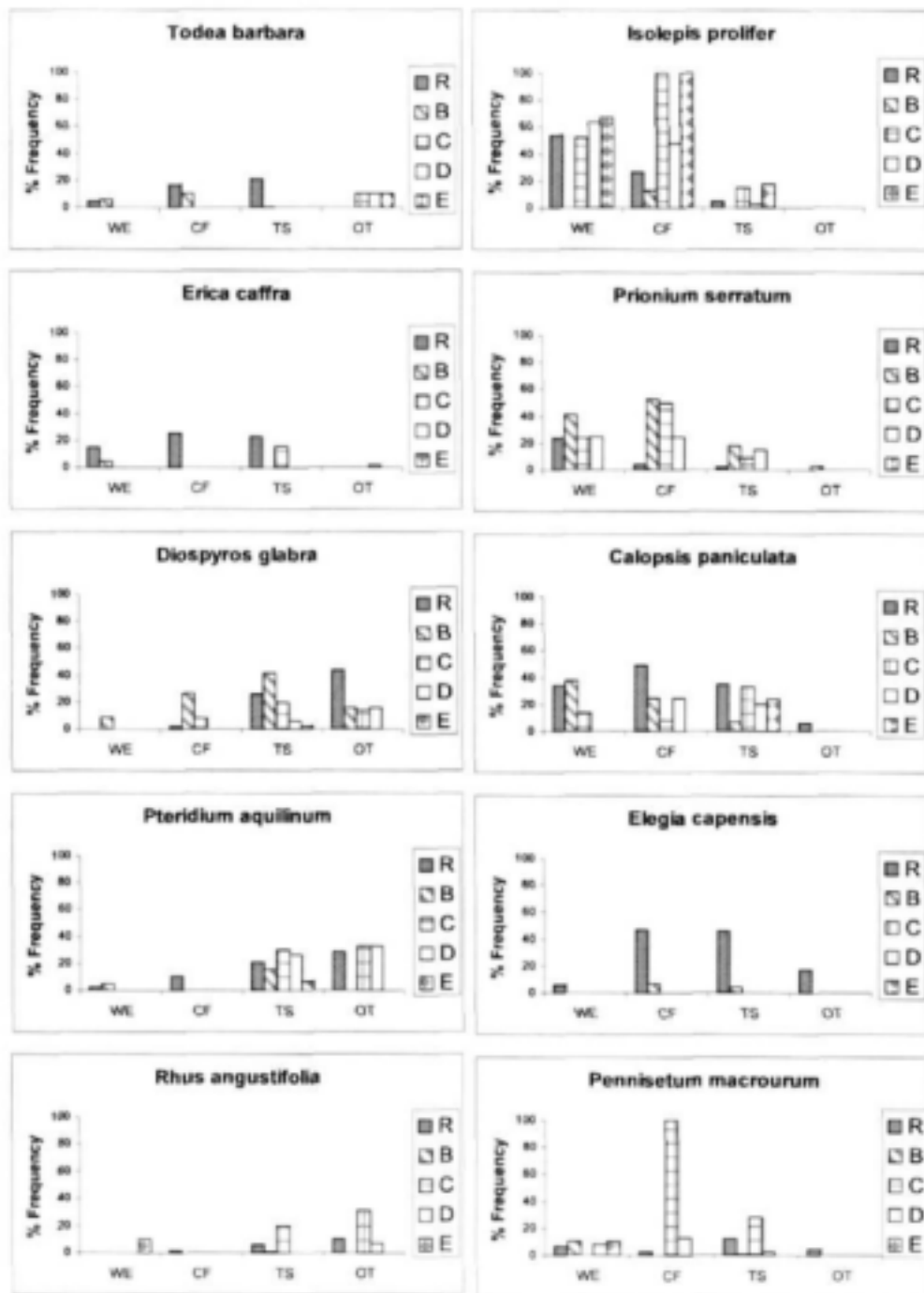


Figure 5.5 Distribution of ten indicator species among the four assemblage types of all 17 disturbed sites. WE = wet edge, CF = channel fringe, TS = tree shrub and OT = outer transitional. Site SLP3 has too few occurrences to register on the graphic – see text.

Diospyros glabra was one of the last indigenous species to persist under severe invasion. It occurred as a single individual in SLP3, was rare in the youngest vegetation group (E) and was most common in the oldest cleared vegetation group (C).

The riparian restio *Calopsis paniculata* was less frequent in disturbed sites than in reference sites, and was less common at the recovering sites with the youngest vegetation. It was generally present except at the most heavily invaded and most recently cleared sites, appearing between four and seven years after clearance.

The forb *Pteridium aquilinum* is not restricted to riparian areas, occurring widely over the landscape. It was found in both disturbed and undisturbed sites, generally on the dry bank, and sometimes acted as a pioneer species, being one of the first to appear and one of the most abundant after clearance. It appeared to reach a reference-level frequency of occurrence in TS and OT quite soon after clearance and maintain that level through the next few years of recovery.

The riparian restio *Elegia capensis* was abundant, mainly in CF and TS, of the reference sites. It appeared to be one of the most heavily impacted and to recover very poorly from invasion and/or clearance, still being absent at cleared sites with vegetation up to 13 years old even when upstream propagules sources were abundant. Of the ten indicator species, this was the one least likely to recruit into cleared areas.

Rhus angustifolia is a small tree that was more common in the dry bank, although it only occurred at some reference sites. When present, it was a useful indicator for OT. In disturbed sites, it was most common at the sites with older vegetation, often reaching higher than reference-condition frequencies.

The grass *Pennisetum macrourum* occurred at some reference sites, where it was characteristically found in CF. It reached slightly higher to very much higher frequencies in recovering sites, but in no discernable recovery pattern.

Comparing distributions of four small Riparian Scrub species in disturbed and reference sites

The distribution of three life stages (seedling, sapling, adult) of the four common small Riparian Scrub trees is shown in Figures 5.6 and 5.7. Generally *Brachylaena neriifolia* and *Morella serrata* (Figure 5.6) were either missing or occurred at lower frequencies than recorded at the reference sites. These two species were not recorded on the Assegaaibos River (disturbance group E) and were rare in disturbance group D (the Sir Lowry's Pass and Silvermine River sites). The exception to this general pattern was the higher occurrences of *Brachylaena neriifolia* seedlings in CF of group B and of *Morella serrata* saplings in CF of group C. As adults, *Morella serrata* was the rarest of the four Riparian Scrub species at disturbed sites, which explain why its seedlings and saplings were only present in the older recovering sites (group C).

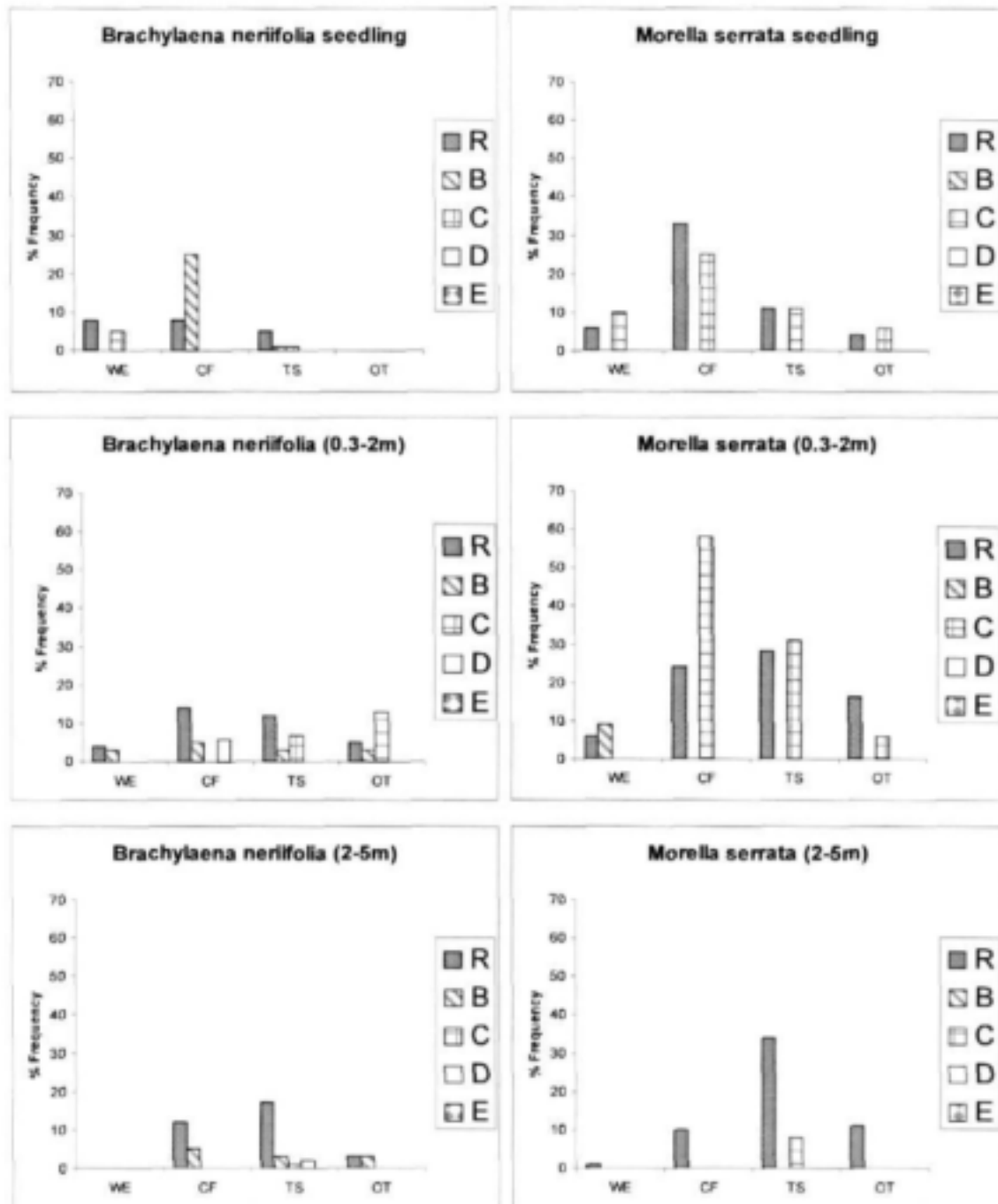


Figure 5.6 Life stage distributions of the common Riparian Scrub species *Brachylaena nerifolia* and *Morella serrata*. Data are percent frequencies in each of four assemblage types, WE = wet edge, CF = channel fringe, TS = tree shrub and OT = outer transitional. R = reference, B-E = invaded & cleared supergroups.

Metrosideros angustifolia and *Brabejum stellatifolium* (Figure 5.7) were generally more abundant than *Brachylaena nerifolia* and *Morella serrata* in recovering sites. Adults, recruiting seedlings and persisting saplings of *Metrosideros angustifolia* were quite common in all the disturbance groups, other than for group D, the Sir Lowry's Pass and Silvermine River sites.

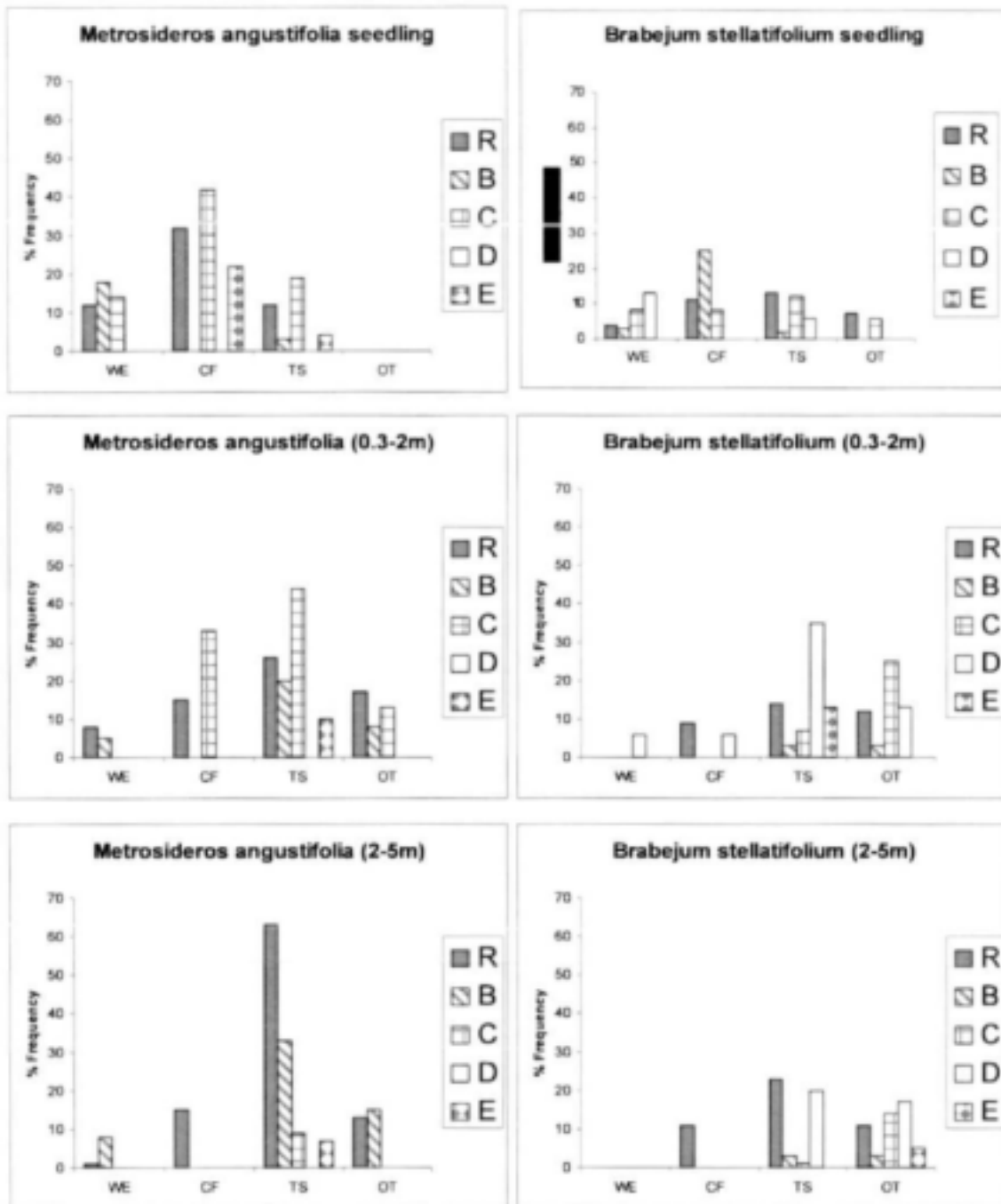


Figure 5.7 Life stage distributions of the common Riparian Scrub species *Metrosideros angustifolia* and *Brabejum stellatifolium*. Data are percent frequencies in each of four assemblage types, WE = wet edge, CF = channel fringe, TS = tree shrub and OT = outer transitional. R = reference, B-E = invaded & cleared supergroups.

No individuals were recorded on these rivers although it was the most common Riparian Scrub species present at all of the reference sites and all the other disturbed sites. *Brabejum stellatifolium* adults were generally abundant in OT, while saplings were common in OT and TS of all four disturbance groups. In many cases for both of these species, seedlings and saplings had higher frequencies in

disturbed sites than in reference sites but this was reversed for adult individuals, where reference sites had the highest levels.

Following the same comparative trajectory from the younger disturbance super group DE towards the older super group BC, the following recovery pattern is suggested:

- *Morella serrata* is only present in group C, the oldest in terms of vegetation age since clearing. This species might be the most sensitive to invasion pressure and the least likely of the four to recruit into a newly cleared area. An alternative explanation is that this species, similar in appearance to alien species such as *Acacia longifolia*, may have been cleared with the alien species.
- *Brachylaena neriifolia*, though generally sparsely distributed, persisted at some of the heavily invaded sites (group B) and recruited slowly in the cleared environment if adults were present.
- *Metrosideros angustifolia*, the most common species recorded during our surveys, was missing from the youngest of the cleared groups (group E), but produced relatively high numbers of seedlings and saplings in all three lower assemblage types (WE, CF, TS) although adults persisted mostly in TS.
- *Brabejum stellatifolium* persisted as a few individuals under heavy invasion and was present at sites at all ages post-clearance, though sometimes sparsely or only as seedlings or saplings. Although seedlings, in particular, were scattered in many parts of the bank, adults tended to occur in TS or OT.

If adults of these four species are present, recruitment into the post-clearing environment will probably occur. In many sites studied, however, they were hacked and cleared together with alien trees. On the Molenaars River in 2002 or 2003, particularly downstream of the Klip confluence, almost all adults were felled and the stumps treated with herbicide; on the Witte River many were felled and burnt. Such activities will confuse the picture of recovery, retard recovery and possibly exacerbate further invasion by creating an unnecessary and greater disturbance.

5.4.3 The distribution of *Acacia mearnsii* and *Acacia longifolia* in the four assemblage types

The distributions of *Acacia mearnsii* and *Acacia longifolia*, two common riparian invading woody species, are compared in Figure 5.8. *Acacia mearnsii* was by far the more common, with seedlings in all assemblage types but most abundant in CF, followed by TS and then OT. Saplings and adults were less common and occurred mostly in CF, with a noticeable presence also in TS.

Acacia longifolia seedlings also occurred in all assemblage types and, along with adult individuals, were most abundant in TS although many saplings were found in CF. There was possibly a trend of highest frequencies in newly cleared sites with declining numbers as the vegetation aged – possibly due to repeat clearances or the presence of a biocontrol agent for a longer period of time, when compared to *Acacia mearnsii*.

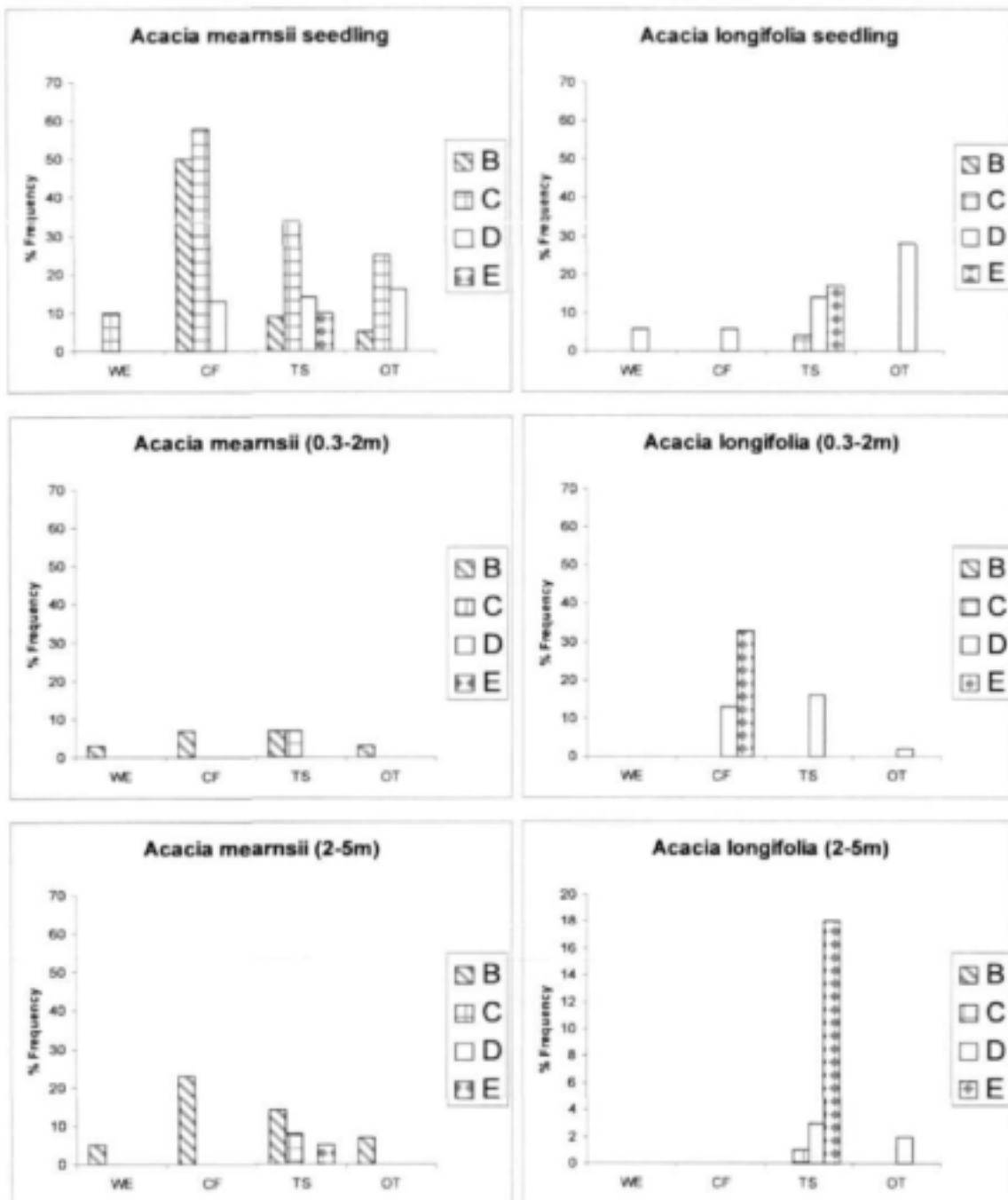


Figure 5.8 Life stage distributions of two common woody alien invaders of riparian zones species. Data are percent frequencies in each of four vegetation assemblage types, WE = wet edge, CF = channel fringe, TS = tree shrub and OT = outer transitional. B-E = invaded & cleared supergroups.

Thus, both species recruit seedlings into all four assemblage types, but the trend suggested by the study sites is that they persist as adults mostly in CF (*Acacia mearnsii*) or in TS (*Acacia longifolia*). Unlike Riparian Scrub species, which showed recruitment only in the presence of adults, *Acacia mearnsii* seedlings appeared in the absence of adults, for example in disturbance group D. Perhaps the Riparian Scrub seedbanks become diminished or lost after a lengthy invasion, or other variables

influence germination such as dispersal distance and increased sand deposition around alien trees. These aspects were not studied in this project.

5.4.4 Assessment of the CART model

The CART model was used to predict the assemblage type that would have occurred in each sample plot of each disturbed site if alien invasives had not been present. To do this, it used simple rules of physical attributes derived from the reference sites (Table 4.21). The assemblage type it identified for each sample plot was compared to that derived from the groupings of plots shown in the cluster analyses for the same sites, using the rules shown in Section 3.4.2.

The comparison was produced as a table of comparative percent ratings of accuracy (Table 5.57). The model predicted the location of WE and OT most accurately, with perfect scores (100%) for some assemblage types at some sites, and averages over all sites of 52% (WE) and 47% (OT). CF and TS were predicted accurately less often, perhaps because they share many species and are most similar.

Table 5.57 Percentage of sample plots at disturbed sites assigned to the same assemblage type by the CART model as by the cluster-analysis approach. Site codes as per Table 3.1.

	WE	CF	TS	OT
SLP3	40%	0%	14%	0%
Cec1	0%	0%	90%	-
Wit3	0%	50%	78%	38%
Mol4	-	37%	46%	-
Ron6	-	0.0%	52%	-
Ron5	22%	100%	47%	-
Wit4	0%	50%	37%	-
Mol1	-	0%	43%	-
Mol2	100%	100%	0%	100%
Mol3	33%	100%	71%	0%
SLP1	0%	100%	41%	91%
SLP2	100%	25%	16%	91%
Sil1	80%	33%	50%	-
Sil2	100%	66%	0%	56%
Ass1	50%	0%	64%	-
Ass2	100%	0%	0%	-
Ass3	100%	0%	0%	0%
Average	52%	39%	38%	47%

The inaccurate predictions could have been caused by assignment of a group of sample plots in the cluster analysis to an inappropriate assemblage type, or by an inadequate set of rules in the model. Each of these is discussed below.

Mis-identification between physical and floral groups in the cluster analysis

In many cases it was difficult to assign a cluster of sample plots to one of the four assemblage types for three main reasons:

- some clusters, though speciose, might have contained species not encountered at the undisturbed sites;
- heavily invaded sites often had sample plots that were species poor or contained no plants;
- terrestrial species often occurred far lower down the bank than in the reference condition, and the rules assigned these sample plots to OT even though they were physically in an area that might naturally have been inhabited by TS, CF or WE assemblages.

In the first two situations, there were insufficient data of the kind used to create the reference condition to allocate a cluster accurately. In the third situation dry-bank species were in locations shown in the reference sites to be wet-bank areas (and thus identified as such by the CART model). In any of these three circumstances, the CART outputs could have disagreed with the cluster analysis allocation without it necessarily having been an inadequacy of the model.

Inadequate rules in the model

The physical rules are based upon the commonest condition derived from the reference sites, namely, that the bank slopes up fairly evenly from the water's edge to the outer riparian zone. Some sites were different however. A few had noticeably convex-shaped banks that rose sharply from the water and then flattened out. Others had concave shapes including a few – particularly lower down the systems – that had small floodplains, and so the bank nearest the water was very flat and the outer limit of the riparian zone was too distant to be covered by the sampling method. The simple physical rules in the model worked less well for such sites, mis-identifying the location of assemblage types, although usually only by one category: WE might be identified as CF, which was next up the bank, and so on. Modification of the model to incorporate these and other kinds of bank shapes would improve its accuracy. This will be addressed in Mr Reinecke's post-graduate thesis.

Though data collection was labour intensive using the method described in this project, it provided the benefit of being able to predict the natural plant assemblages that could be expected to occur in a section of river bank invaded by alien trees. This is of great potential use in restoration projects where indicator species are absent and where assemblages are to be planted out. Locally, this might be prohibitively expensive however. Moreover, since many persons tasked with restoration may not be professional botanists, and thus may not be able to recognise some of the indicator species used to determine the position of the assemblage types mentioned in this report, a simple model based on easy-to-measure physical characteristics is valuable and warrants further development.

5.4.5 Summarising the impacts of aliens on biodiversity indices

The measures of biodiversity for all seventeen disturbed sites are shown in Table 5.58. All of the measures, both at the scale of 50 m² and 5 m², fell outside of the reference condition range for all of the sites still heavily invaded (SLP3, Wit3, Mol4 and Ron6). Cec1, which had been partially cleared, had lower values for species richness for the wet bank assemblage types (WE and CF), with all other measures within the reference condition ranges. Wit4, four to eight years since clearance and with no follow-up clearances, had lower equitability (H), relative diversity (J), species richness (50 m²) and TS species richness (5 m²). Of the remaining sites, all of which had been cleared, all but two had higher equitability and half of them higher relative diversity than the reference condition. Several of these sites also had a higher number of species than the reference condition, with few examples of species numbers being lower. The only disturbed site where all the measures fell within the expected reference condition range was Sil2. Without a full detailed history it is difficult to speculate why this may be so. There are lottery effects in community assembly so there will always be a large amount of variability.

Table 5.58 Comparison of biodiversity indices for the reference condition and disturbed sites. Bolded figures are lower than reference condition ranges, italicised figures are higher. Site codes as per Table 3.1. H = Equitability, J = relative diversity. WE = Wet Edge, CF = Channel Fringe, TS = Tree Shrub, OT = Outer Transitional. Disturbance groups as per Figure 5.1.

Disturbance group	Site code	50 m ²			Species richness (5 m ²)				Average
		H	J	Species richness	WE	CF	TS	OT	
	Reference	2.38±0.23	0.77±0.06	22.7±5.80	6.1±4.2	9.1±5.9	8.8±2.9	19.9±7.9	9.7±7.7
-	SLP3	0.02	0.00	3	1.0	1.3	0.9	0.3	0.9
B	Wit3	1.71	0.67	8	2.1	3.3	3.2	3.4	3.1
B	Mol4	0.10	0.05	7	-	2.6	1.3	-	1.5
B	Ron6	1.60	0.59	8	-	0.9	2.3	-	2.1
-	Cec1	2.49	0.73	17	0.0	3.5	10.5	-	8.0
B	Wit4	2.00	0.72	10	3.3	4.5	4.1	-	4.0
B	Ron5	2.84	0.86	25	8.0	12.0	4.8	-	5.9
C	Mol1	2.73	0.78	31	-	4.4	7.5	-	6.9
C	Mol2	2.68	0.76	28	1.5	9.8	6.0	4.1	5.2
C	Mol3	2.66	0.79	24	4.3	13.5	3.6	2.1	3.7
D	SLP1	3.02	0.80	41	9.5	16.3	11.3	8.0	10.5
D	SLP2	2.78	0.81	29	5.8	8.3	9.3	7.6	8.1
D	Sil1	2.86	0.87	24	1.3	5.0	7.4	-	6.7
D	Sil2	2.39	0.78	21	5.0	7.7	8.7	5.9	6.5
E	Ass1	3.91	0.84	47	0.0	6.4	10.9	-	9.3
E	Ass2	2.24	0.67	29	9.0	9.0	7.1	-	7.3
E	Ass3	2.71	0.76	36	4.4	6.3	17.0	-	14.8

These indices appear to reasonably reflect biodiversity changes that occur through the process of invasion and recovery. Biodiversity was seen to plummet in heavily invaded stands of riparian vegetation stands. After clearance there was a flush of new growth that often led to species (alien and

indigenous) numbers initially being higher than the reference condition. Some of these species may not necessarily have been naturally associated with the riparian zone but could be seen as pioneers: forbs, rushes and sedges that appeared low on the bank, and fast-growing grasses and small shrubs higher up. Many of these species would gradually decline in numbers as recovery proceeded, to be replaced over a decade or more by a more typical and balanced riparian community.

The indices provide useful signposts to recovery, but do not present the full picture. They should be used in parallel with other information such as on growth forms and the presence of indicator species. The absence of certain common growth forms might indicate the absence of certain basic riparian habitat requirements, for example recently deposited fluvial sands. The presence of certain of the indicator species, apart from helping to locate the position of the assemblage types, also indicate favourable recovery: the absence of these species might indicate a protracted state of recovery and the presence of a threshold barrier to full and naturally functioning recovery (section 2.3.3).

6. THE EFFECTS OF ALIEN-CLEARING METHODS ON RECOVERY OF RIPARIAN VEGETATION

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6.1 INTRODUCTION

Considerable effort is being expended on the removal of invasive alien plants from South African indigenous ecosystems. A national initiative charged with this task is the Working for Water programme of the Department of Water Affairs and Forestry (DWAF), but the effects of its numerous clearing projects have yet to be assessed. In this chapter the methods used by the Working for Water teams are addressed and their impacts on the recovery of indigenous riparian vegetation evaluated. This evaluation forms part of a larger Working for Water initiative entitled: "Targets for ecosystem repair in riparian vegetation in Fynbos, Grassland & Savannah biomes". It aims to provide baseline information on the impacts of alien plant invasions and clearing on riparian vegetation recovery. The data collected will help assessment of the progress of alien-clearing operations in terms of rehabilitation of riparian ecosystems, and make input into improved management tools.

Classified as a semi-arid country, South Africa receives an average 500 mm rainfall per annum, which is not evenly distributed (Hoffman & Ashwell 2001). Owing to the large variation in climate and other environmental factors, South Africa has many different vegetation types and is known worldwide for its high levels of plant endemism and diversity (Cowling & Hilton-Taylor 1994). The Cape Floristic Region (CFR), which lies primarily in the Western Cape Province, is one of the world's botanical hotspots and recently has been declared a World Heritage Site. The western part of the CFR experiences a winter rainfall climate with hot, dry summers that may lead to water shortages (Deacon et al., 1992).

South African river systems are important to the economy as they provide much of the water for industrial, irrigation and drinking water requirements. Invasive alien plants have major impacts on these ecosystems, infesting river channels and using more water than comparable indigenous species (Le Maitre et al., 2000). Trees and shrubs are the most important alien invaders in the CFR (Nel et al., 2004), and have been shown to reduce water run-off and affect hydrological processes in mountain catchments (Dye & Poulter 1995; Higgins et al., 2000). Increased evapo-transpiration from them may also affect the overall water balance within a river system (Weins 2002).

Alien species used in commercial forestry, such as *Pinus* and *Eucalyptus* species, prompted whole-catchment experiments as early as the 1930s to ascertain their effects on water yield (Macdonald 2004). The removal of invasive alien vegetation was highlighted in 1995 with the inception of DWAF's Working for Water (WfW) programme. The main aims of WfW are threefold: to promote biodiversity by removing invasive alien species; to increase surface-water runoff; and to provide poverty relief through job creation (van Wilgen et al., 1998). The focus is on both terrestrial and

riparian habitats. Methods used for removal of the invasive vegetation fall into three categories: mechanical, chemical and biological control.

Mechanical methods of control are labour-intensive and include hand pulling, brush cutting, hacking and ring-barking. Burning may also be used as a tool to kill non-resprouting aliens, or to remove excessive above-ground biomass (slash) and initiate vegetation recovery, in fire-prone ecosystems such as fynbos shrublands in the CFR. Chemical methods include the use of herbicide applied either as a foliar spray if the plants are below knee height, or to stumps after cutting or via stem injection (frilling). Biological control is a more long-term method for controlling an alien species. Its efficacy will depend on how easily the vector is able to spread and how efficient it is in reducing fecundity of the targeted species. South African biological control researchers have contributed much in terms of successful controlling agents and ecological information needed in understanding invasions (van Wilgen 2004; Zimmermann et al., 2004).

Guidelines for promoting the restoration of indigenous vegetation following invasion by alien plants were prepared for WfW in December 2000 (Anon 2000). They included protocols on the removal of alien vegetation for initial, follow-up and maintenance clearance (Table 6.1). Treatments are integrated for effective control (Richardson 1998). As an example, by using both mechanical and chemical methods on re-sprouting aliens, plant biomass is reduced while also killing the plant effectively. Integrated control measures should be species-specific, thus knowledge of the biology of invading species is vital. The follow-up treatments are an important part of alien control as they normally bring the infestations under control, largely by reducing the amount of seed input by new recruits.

Table 6.1 Alien control methods designed to promote recovery of indigenous vegetation (Anon 2000).

Major Groups	Species	Initial (preferred)	Follow-up
Serotinous non-sprouters	Hakeas & pines	Fell & burn	Hand pull or fell older plants before they reach maturity
Thicket resprouters	Wattles, mesquite & gums	Fell close to ground and treat stump with herbicide; or frilling	Hand pull while still small or spot spray herbicide
Thicket non-resprouters	<i>Acacia cyclops</i> (Rooikrans)	Fell & leave slash; fell & burn; or burn standing	Hand pull or fell before maturity
Subtropical resprouters and scramblers	<i>Lantana</i> , <i>Pereskia aculeata</i> , <i>Caesalpinia</i> spp.	Dig out with hand pick; where lagers use a bulldozer; fell close to ground & treat stump with herbicide.	Hand pull

All lowland rivers have been transformed to a greater or lesser extent (Brown 1998) because the rich alluvial soils and available water provide suitable conditions for a number of farming activities.

Higher up the systems, many foothill and some mountain-stream river segments have natural riparian vegetation, but in many cases this has been densely invaded by invasive alien plants. These invasions, followed by their clearance, have changed the species composition of riparian plant communities in many CFR headwater systems. The composition has shifted from one dominated by riparian scrub with tall trees to one dominated by small shrubs, emerging aliens and herbaceous vegetation (Galatowitsch & Richardson 2005). These changes have in turn impacted the downstream supply of riparian tree propagules from upland areas. It is important to restore the indigenous riparian communities as they play a vital role in the regulation of stream flow and stabilisation of riverbanks (Sieben 2002).

6.2 OBJECTIVES OF THE STUDY

In the Western Cape, alien clearing has been implemented for several decades to remove both dense and emerging stands of invasive alien vegetation. Little monitoring of past clearing projects has taken place, particularly in riparian zones, to assess the impacts of the methods used on natural vegetation recovery. In this chapter, investigations of the main initial clearing treatments applied in riparian zones during the past ten years in the Western Cape are outlined, namely: felling (with or without the removal of slash), and treatments using burning after felling. To date, insufficient stands have been killed standing (by ring-barking or frilling) to investigate the impacts of this method. Owing to large-scale transformations in lowland river systems, and the lack of reference systems there, this study focused on mountain stream and foothill segments where dense alien invasions and reference vegetation stands both occur.

The aim of this study was to investigate which alien clearing methods best facilitate the recovery of natural riparian vegetation, through the following questions:

1. Is there a significant difference in floristic or growth form composition between reference vegetation and cleared vegetation?
2. Is there a significant difference in floristic or growth form composition among the recovering vegetation stands following different clearing treatments?
3. Which of the more commonly used clearing methods best facilitates vegetation recovery in the riparian zone?

In order to answer these questions previously cleared sampled plots were compared to reference plots with no records of invasion or clearing. The latter provide a description of the reference condition to which the cleared plots can be compared, in order to assess which, if any, species or growth forms are missing and whether their absence could be related to a particular clearing method. To minimise the effects of catchment differences, reference plots were sampled on as many rivers as possible.

6.3 METHODS

6.3.1 Study area and site selection

Sample plots were located based on invasion densities and previous management histories. Sites of moderate to dense alien infestation (25-75% canopy cover) generally had sufficient indigenous

vegetation remaining to facilitate recovery, thus the focus of this study was on the closed alien stands (>75% canopy cover) where recovery may be protracted. These areas would be most affected by bad management since the regeneration of indigenous vegetation was already severely impaired by the presence of invasive alien species. Possible sites were located using the WfW database and then confirmed by discussions with CapeNature and DWAF's WfW project managers. Management histories were collected from records kept within each department. The records obtained from WfW offices comprised the contracts issued to the contractors used to remove alien vegetation, and included initial clearing methods, alien plant species and densities, dates of initial clearance, follow-up methods and dates. To confirm burning as part of the initial treatment other databases were consulted, as the contractor was not responsible for burning and therefore it would not be recorded in the WfW database.

Only sites cleared at least two years previously were chosen, to allow sufficient time for some post-clearance recovery. Twenty-seven plots on seven rivers were sampled (Table 6.2), with multiple plots on any one river being at least 200 m apart to provide some independence (Galatowitsch & Richardson 2005). Three initial clearing treatments were identified (Fell Only, Fell & Remove slash, and Fell & Burn slash).

Table 6.2 Locations of study plots for each of the three clearing treatments and reference plots along Western Cape rivers. ^ = reference data taken from Prins et al. (2004), * = additional reference plots sampled in this study.

Clearing Treatment (total plots)	River Name	No. of recovering plots	Reference plots (28)	Locality range(decimal degrees)	Altitude (masl)
Fell & Remove (12)	Sir Lowry	4	1*	S34.1004-E18.9342	268
	Molenaars	4	8^	S33.7115-E19.1965	300-500
	Waterval	2		S33.3603-E19.1024	220-240
	Titus	2		S33.2530-E19.1614	300
Fell only (8)	Witte	3	8^	S33.5606-E19.1486	240-600
	Assegaaibos	2	1*	S33.5502-E19.0452	300
	Palmiet	3	9^	S34.270883- E19.022083	40-500
Fell & Burn (7)	Jakkals	2		S34.20711-E19.15918	261
	Hocks	2	1*	S33.99774-E19.83792	259
	Houtbaai	3			251

6.3.2 Vegetation sampling

Vegetation survey plots measuring 10 x 5 m, which is the commonly used size for phytosociological studies in fynbos shrubland vegetation (Boucher 1977), were set up in the riparian zone with the long edge parallel to the river. Although different lateral riparian zones up the banks have been identified in fynbos rivers (Boucher 2002), this study focused on sample plots chosen in the major (dry bank) zone, that is, the area that may be flooded at times during the wet season. This zone is dominated by riparian scrub (shrubs and small trees) and may incorporate some elements of neighbouring fynbos

communities. The wet bank zone closer to the river is seasonally inundated and is often very narrow or, in mountain streams, may be almost non-existent.

Within each plot, the total indigenous vegetation cover was visually estimated as a percentage of the entire plot (50 m²), while vegetation composition was estimated as a percentage of the projected canopy-cover values for individual perennial plant species (indigenous and alien) present within the plot. Indigenous species richness was recorded in three 1 m² quadrats within the plot, as well as for the entire 50 m² plot. The 1 m² measurement of richness is a surrogate for heterogeneity and indicates the diversity found at a smaller scale in the plot.

The species richness data were gathered by recording all recognizable species in the field and taking specimens of unknown species for later identification. Species' identifications were done in the Guthrie and Bolus herbaria at the University of Cape Town.

A useful way to measure the success of vegetation recovery is by comparing the trajectory of different variables with reference sites (Ruiz-Jaen & Aide 2005). Data on reference sites and target vegetation were obtained from Prins et al. (2004), who determined reference characteristics for riparian vegetation along six rivers in the Western Cape in areas with no previous history of invasion and <25% presence of alien vegetation. That study included the Witte, Molenaars and Palmiet Rivers, all of which were sampled in the current study. For rivers included in this study but with no such reference data, new reference plots were created (Table 6.2). Invaded and cleared sites were located downstream of reference sites, with the exception of the Palmiet River where the only pristine vegetation is in the Kogelberg Nature Reserve at the downstream end of the system (Prins et al. 2004).

6.3.3 Data Analysis

The effects of the three different clearing treatments were assessed in terms of the variables total indigenous cover, indigenous species richness and diversity, and alien cover. Values for each cleared site were compared to those for the appropriate reference plots using a one-way analysis of variance (ANOVA). In order to determine any differences between treatments the data were first assessed to see if they met the criteria of normality as required for ANOVA analysis. Levene's test was used to test for homogeneity between samples and the Kolmogorov-Smirnov test was used to test for normality in data. Percentages and proportions were transformed using arcsine transformation where required. Where normality was not achieved the nonparametric Kruskal-Wallis (H) test was used to determine significance. Where ANOVAs were significant, a Tukey's Multiple Range Test (TMRT) was used to test for differences among the groups. Significance for all statistical tests was determined at $P \leq 0.05$ using Statistica 7 (Statsoft 2004).

Diversity per 50 m² plot was assessed using cover values per species as a proportion of the total vegetation cover calculated for the Shannon Weiner (H') index and Evenness using "Pielou's J " (Zar 1984).

$$H' = -\sum_{i=1}^k p_i \cdot \ln p_i$$

where k = number of species and p_i = the proportion of species found in plot i .

$$J = \frac{H'}{H_{\max}} \quad \text{and} \quad H_{\max} = \log k$$

Indigenous species were assigned to one of four growth-form classes: tree, shrub, graminoid or forb, and the average growth-form structure of the vegetation following each clearing treatment was calculated by summing the cover values in each growth-form. Contingency table analyses, applying the Pearson's Chi-square statistic, were used to compare growth-form structure in each treatment separately with that of the reference data (Statistica 7; Statsoft 2004).

Ordinations

According to Ruiz-Jaen & Aide (2005), who conducted a survey of popular methods used in describing recovery success, the use of ordination techniques were mostly used in determining the recovery of diversity. Firstly, plots were clustered according to species composition based on presence/absence values, using the Bray Curtis distance measure and flexible beta group linkage method. The same matrix was plotted in ordination space. Ordinations have proven useful in community ecology in seeking and describing patterns in species composition (McCune & Grace 2002). By plotting species data in ordination space it can be assessed whether cleared sites are on a trajectory towards reference status. Species data were analysed using Detrended Correspondence Analysis (DCA), to assess shifts in floristic and growth form composition in relation to various clearing methods and time since initial clearance. As part of the options, rare species were down-weighted and the axes were rescaled. Ordinations and cluster analysis were carried out in PC-Ord (version 4, MjM Software design, 2002). Table 6.3 summarises the various analytical approaches used.

Table 6.3 Summary of the statistical analyses performed. * indicates which tests and graphic the variable 'Alien cover' is linked to.

Variable	Test	Tab. & Fig.
1 Species richness, Growth forms, Diversity, Evenness, Indigenous vegetation cover, Alien cover*	Levenes test, Kolmogorov-Smirnov test, ANOVA or Kruskal-Wallis*	Tab. 6.4 & 6.5
2 Growth form	Chi square*	Fig. 6.1* & 6.2
3 Plots are analysed based on species percentage cover and grouped by clearing methods and age since clearing	Cluster analysis	Fig. 6.3
4 Plots are graphed based on species percentage cover and grouped by clearing methods and age since clearing	Detrended Correspondence Analysis	Fig. 6.4
5 Plots are graphed based on percentage growth form cover	Detrended Correspondence Analysis	Fig. 6.5

6.4 RESULTS

6.4.1 Analyses of vegetal cover, diversity and richness

A total of 235 indigenous perennial species was recorded in the cleared and reference sites, although only 95 species occurred in more than 10% of the plots. The highest species count (23) was found in a site with Fell & Remove treatment and the lowest species count (3) in a site with Fell & Burn treatment.

The vegetation variables monitored showed some variability among the plots, which became more apparent when plots were grouped by clearing treatment. Indigenous vegetation cover was significantly different between the reference plots and cleared plots (ANOVA, $P < 0.05$; Table 6.4), with the reference plots having significantly higher cover than those that had been cleared. There was no significant difference in indigenous vegetation cover between cleared plots.

Table 6.4 ANOVA results indicating the effect of clearing on vegetation variables
d.f. = degrees of freedom. MSS = mean sum of squares. F = test statistic. P = significance level. *: $n=3$ for 1 m² reference plots instead of 28

Vegetation variable	Effect MS (df)	Error MS (df)	F	P
Indigenous vegetation cover	4820.8(3)	296.3 (51)	16.3	<0.0001
Diversity (H')	0.24 (3)	0.16 (51)	1.52	0.22
Evenness (J)	0.08 (3)	0.91 (51)	0.90	0.44
Species richness: 50 m ²	82.2 (3)	20.3 (51)	4.03	0.01
*1 m ²	6.79 (3)	1.90 (26)	3.57	0.027

At the 50 m² plot scale, plant species richness differed among treatments (ANOVA, $P < 0.05$; Table 6.3). The Fell & Remove treatment had significantly higher species richness than the Fell & Burn treatment (TMRT $P < 0.05$; Table 6.5). Species richness at the 1 m² scale differed significantly among treatments (ANOVA, $P < 0.05$; Table 6.4). The Reference plots had significantly higher point richness than the Fell Only and Fell & Burn plots (TMRT $P < 0.05$; Table 6.5). There was no difference in diversity (H') and evenness (J) between Reference and cleared plots nor among the different clearing treatments (Tables 6.4 & 6.5).

Table 6.5 Summary statistics (means $\pm$ SD) for vegetation variables. *: $n=3$ for 1 m² reference plots instead of 28.

Vegetation variable	Reference	Fell	Fell & Remove	Fell & Burn
N	28	8	12	7
Indigenous vegetation cover (% of total plot)	75.1 $\pm$ 13.4 *	42.2 $\pm$ 20.5 ^b	47.2 $\pm$ 19.7 ^b	37.1 $\pm$ 22.7 ^b
Diversity (H')	1.72 $\pm$ 0.38	1.66 $\pm$ 0.35	1.75 $\pm$ 0.45	1.38 $\pm$ 0.45
Evenness (J)	1.65 $\pm$ 0.25	1.57 $\pm$ 0.20	1.49 $\pm$ 0.32	1.59 $\pm$ 0.49
Species richness:				
50 m ²	11.6 $\pm$ 4.30 ^{ab}	12.7 $\pm$ 4.9 ^{ab}	15.7 $\pm$ 5.2*	8.70 $\pm$ 3.8 ^b
1 m ²	5.00 $\pm$ 1.70	2.25 $\pm$ 1.2 ^b	2.60 $\pm$ 1.6 ^{ab}	2.00 $\pm$ 0.9 ^b
Alien cover (% of total plot)	4.10 $\pm$ 6.13*	21.5 $\pm$ 23.9 ^b	30.8 $\pm$ 22.4 ^b	17.8 $\pm$ 18.9 ^{ab}

Alien cover distribution was not normal even after arcsine transformation. The Kruskal-Wallis nonparametric (H) showed that alien cover was significantly different among treatments ($H_{(3, 55)} = 21.9, p=0.0001$). Differences occurred between Reference plots, Fell Only and Fell & Remove treatments, with Reference plots having the least alien cover. Of the clearing treatments, Fell & Burn had the least alien cover but was not significantly different to the other treatments.

Different letter superscripts indicate a significant difference between clearing treatments within a particular vegetation variable (TMRT, $P<0.05$). Alien cover tested using nonparametric Kruskal-Wallis test.

In summary:

- reference plots had significantly higher indigenous vegetation cover than all cleared plots;
- cleared plots had similar levels of indigenous vegetation cover;
- there was no significant difference between Reference and cleared plots in terms of diversity and evenness;
- species richness was highest in cleared plots for Fell & Remove plots at the 50 m² plot scale;
- Fell & Burn treatments had the lowest species richness and vegetation cover of all treatments;
- invasive alien plants were still present after clearing had taken place.

6.4.2 Growth form distribution

Growth-form distribution differed significantly between all treatments and the Reference condition (Figure 6.1), at least partly because of the lower cover of trees and shrubs in cleared plots.

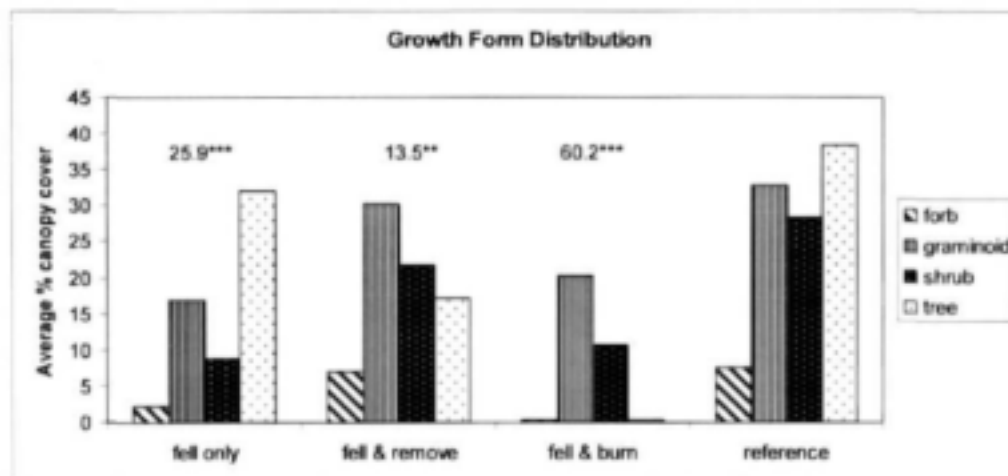


Figure 6.1 Growth form distribution following each treatment plotted as average percentage canopy cover. χ^2 values for contingency table analysis (above bars) compare each treatment separately with reference plots: ** $P<0.01$; *** $P<0.001$.

Sites cleared more than five years ago appeared more structurally similar to Reference plots than those that were recently cleared (Figure 6.2). The older plots had a higher cover of trees and shrubs than did the younger plots and also supported a greater overall indigenous canopy cover.

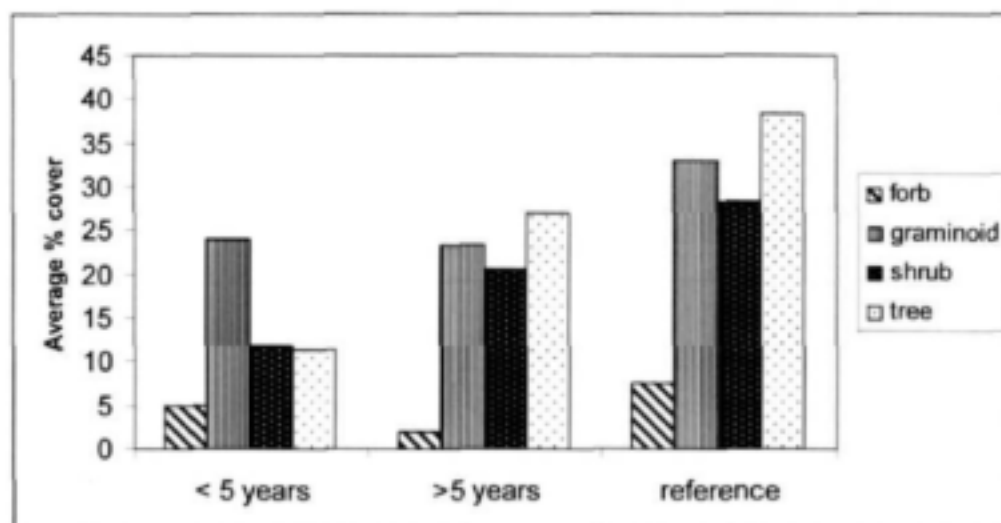


Figure 6.2 A comparison of growth form distribution for reference sites and those cleared more or less than five years ago.

Diospyros glabra was the only species found in all the treatments at high concentrations (Table 6.6). Other species common to all treatments included *Metrosideros angustifolia*, *Calopsis paniculata* and *Stoebe plumosa*, whereas *Berzelia lanuginosa*, *Elegia capensis* and *Cannomois virgata* were only found in reference conditions.

Burning riparian zones appears to remove, or prevent early recolonization by, common species such as *Brabejum stellatifolium*, *Prionium serratum*, *Pteridium aquilinum* and *Rhus angustifolia*.

6.4.3 Ordinations

At the species level, overall similarity among plots in the cluster analysis was low (Figure 6.3). Two groups were apparent: a cleared group and a reference group, with some anomalies. Most cleared plots that fell in the reference group had been cleared longer than five years ago (Figure 6.4); exceptions were Assegaaibos 3, Sir Lowry Pass 5, Molenaars 2 and Molenaars 4, which were all cleared less than five years ago. Although some cleared plots clustered with reference plots (e.g. Molenaars 4 and Titus 2) none of the Fell & Burn plots did.

The reference plots grouped mainly according to river, suggesting the presence of river signatures, as has been noted in other Western Cape river studies (Schael & King, 2005; Reinecke & King, Chapters 4 & 5).

Table 6.6 Top ten species recorded after each type of treatment. * = the species is present in at least one of the relevant plots.

Reference	Fell & Remove	Fell Only	Fell & Burn
<i>Diospyros glabra</i>	<i>Diospyros glabra</i>	<i>Diospyros glabra</i>	<i>Diospyros glabra</i>
<i>Metrosideros angustifolia</i>	<i>Metrosideros angustifolia</i>	<i>Metrosideros angustifolia</i>	*
<i>Brabejum stellatifolium</i>	<i>Brabejum stellatifolium</i>	<i>Brabejum stellatifolium</i>	
<i>Brachylaena neriifolia</i>	<i>Brachylaena neriifolia</i>	<i>Brachylaena neriifolia</i>	
<i>Prionium serratum</i>	<i>Prionium serratum</i>	<i>Prionium serratum</i>	
<i>Pteridium aquilinum</i>	<i>Pteridium aquilinum</i>	*	
<i>Rhus angustifolia</i>	*	<i>Rhus angustifolia</i>	
<i>Berzelia lanuginosa</i>			
<i>Elegia capensis</i>			
<i>Cannomois virgata</i>		*	
*	<i>Calopsis paniculatus</i>	<i>Calopsis paniculatus</i>	*
*	<i>Passerina vulgaris</i>	<i>Passerina vulgaris</i>	
	<i>Ehrhata ramosa</i>	*	<i>Ehrhata ramosa</i>
*	<i>Stoebe plumosa</i>	*	*
*	*	<i>Stoebe cinerea</i>	
*	*	<i>Erica caffra</i>	
*		*	<i>Cliffortia strobilifera</i>
			<i>Athanasia trifurcata</i>
			<i>Ehrhata thunbergii</i>
	*		<i>Isolepis prolifer</i>
	*		<i>Carpobrotus edulis</i>
	*		<i>Chrysanthemoides monilifera</i>
	*		<i>Juncus lomatophyllus</i>
			<i>Cyperus sphaenopermus</i>

Figure 6.4a is a graphic representation of the plots as represented in ordination space. The Eigenvalues for the first and second axis were 0.72 and 0.63 respectively, but the percentage variation explained was low for both axes combined ($R^2=0.12$). The DCA analysis separated the Fell & Burn treatment from Fell Only and Fell & Remove, with the latter treatments more similar to the Reference plots. Burning in the riparian zones appeared to have an effect on the species composition in a way that sets the Fell & Burn group apart from the others. The overlap of the Fell Only and Fell & Remove treatments with the Reference plots indicated a similar species composition, although the older plots were more similar to the Reference plots than were the younger plots (Figure 6.4b). Plots burnt more than five years previously had not recovered sufficiently to overlap with the Reference plots.

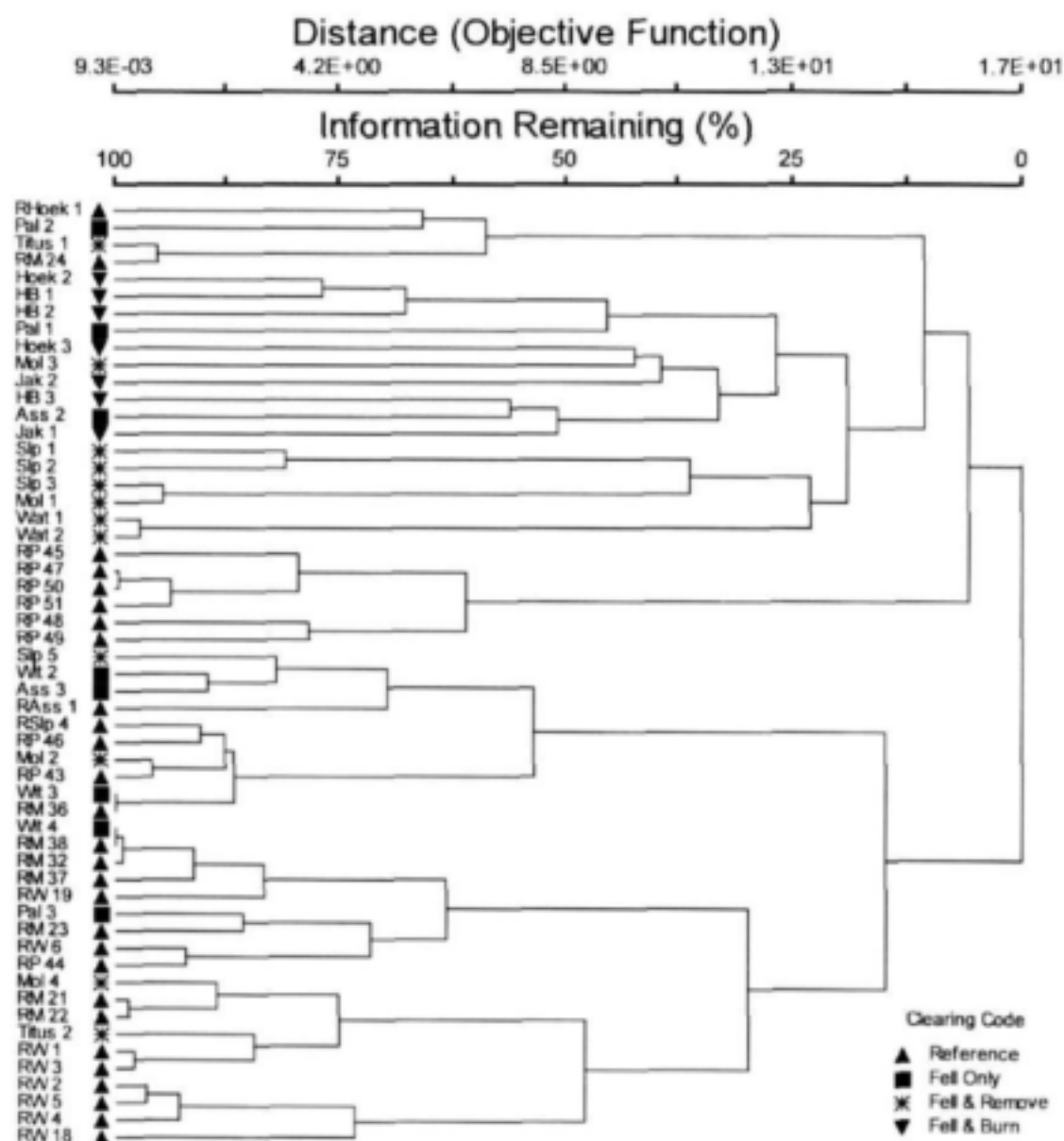


Figure 6.3 Cluster analysis for all indigenous perennial species found in both cleared and reference plots, grouped by clearing treatment. '*' indicates plots older than five years. Reference plots have 'R' preceding the location.

6.4.4 Growth forms

The DCA ordination of growth forms varied to that of species composition (Figure 6.5). The results showed no clear aggregations of clearing treatments. The spread of reference plots indicated the variability in natural patterns and cleared plots mirrored this trend.

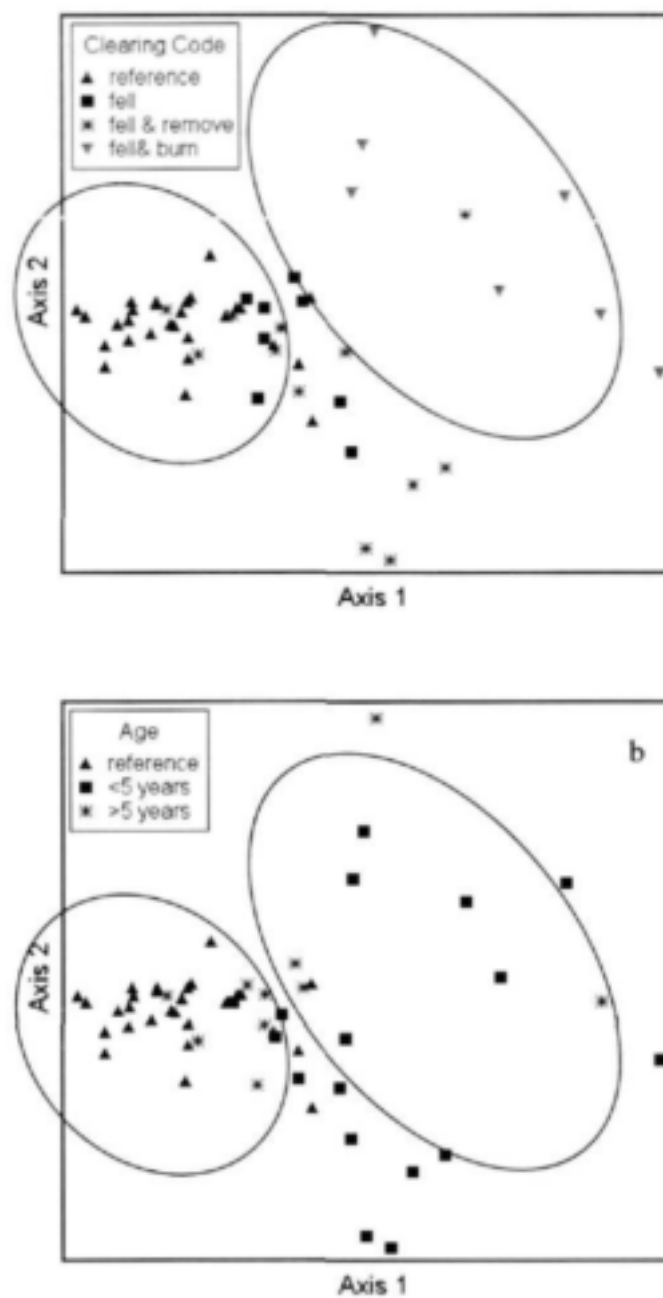


Figure 6.4 a) DCA ordination for all indigenous perennial species found in both cleared and reference plots grouped by clearing treatment. Ellipses are drawn around the two distinctive groups: Reference and Fell & Burn plots.
b) The same ordination for all indigenous perennial species found in both cleared and reference plots grouped by age since clearing.

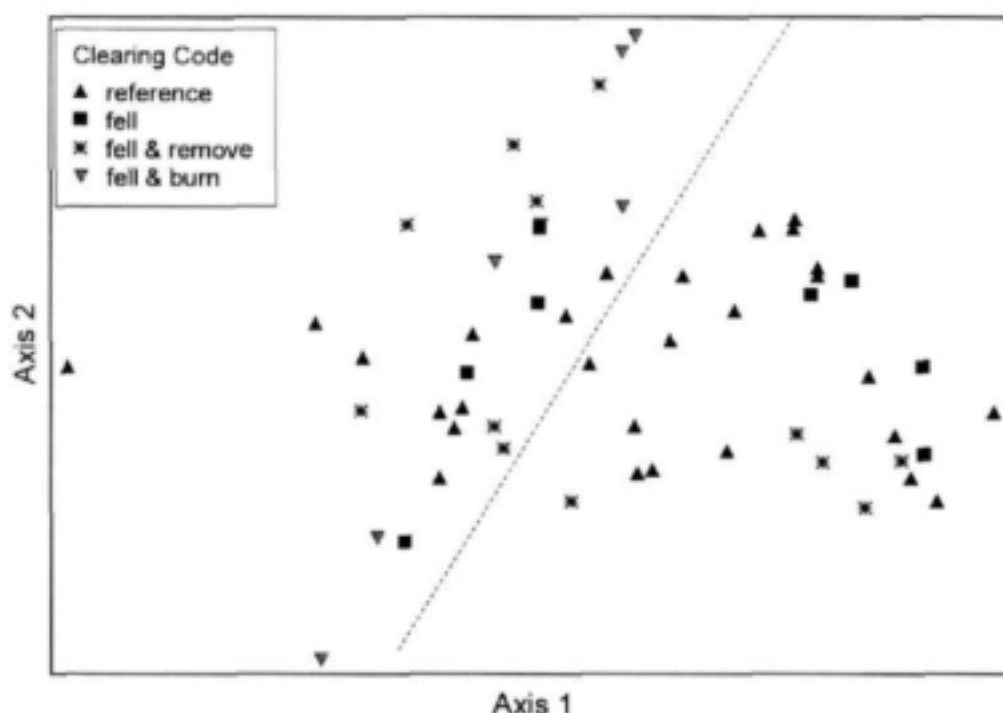


Figure 6.5 DCA ordination for cover values of the growth forms (forb, graminoid, shrub, tree) found in each plot, grouped according to clearing treatment. The dashed lines illustrates that none of the burnt plots are spread along axis 1, which is correlated with trees (Pearsons and Kendall = 0.612).

The Eigenvalues for the first and second axis were 0.35 and 0.14 respectively (Figure 6.5). Whilst this was low, the percentage variation explained by both axes was high ($R^2=0.85$). Testing Pearsons and Kendall correlation coefficient, axis 1 was correlated with trees (0.612) and axis 2 with graminoids (0.48). The spread of Reference plots indicated the variability in natural patterns, and cleared plots mirrored this trend although their greater spread indicated more graminoid cover than in Reference plots. All the Fell & Burn plots fall on the left side of the inserted dotted line (Figure 6.5), as there were fewer riparian trees species present. Table 6.6 indicates which species are likely to be absent from Fell and Burnt plots.

6.5 DISCUSSION

Major questions in restoration ecology relate to how long an ecosystem takes to recover and what the goals of recovery should be (Ruiz-Jaen & Aide 2005). Reference sites have often been used in rehabilitation and restoration efforts to provide recovery goals (e.g. Buijse et al., 2002). In this study, natural rates of recovery were assessed for various methods of alien clearing and by comparing the floral community with that of Reference sites. This showed that the method of removal of alien trees does have an impact on the recovery of indigenous riparian vegetation.

6.5.1 What is the difference in floristic and growth form composition between reference vegetation and cleared vegetation?

Areas that have not been invaded and cleared had higher vegetation cover, and generally higher species richness than cleared plots. An anomaly was the highest species count, which was found in a Fell and Remove plot. The study by Prins et al. (2004) revealed various indigenous riparian communities. Although many structural components were present, the lack of overlap in species composition for cleared plots indicated a change in riparian communities.

Figure 6.4 indicates a similarity between some cleared plots and the Reference plots, and the overlap in ordination space of particularly the Fell & Remove treatment plots with the Reference plots suggests that vegetation recovery is on a positive trajectory where burning is not involved. A depiction of the plots based on time since clearance further supports the contention that recovery is moving in the direction of the reference condition, and that given sufficient time indigenous riparian communities will become re-established. This may also be true for the Fell & Burn treatment plots, although the much slower recovery rate there suggests that after fire active re-introductions could substantially accelerate recovery.

Results from the analyses of growth-form distributions and species composition mirrored those of the other vegetation variables tested. In all cases, plots receiving the Fell & Burn treatment were least similar to the Reference plots, owing to their very different species composition and a dearth of trees. Galatowitsch & Richardson (2005) indicated that riparian scrub species colonized only stable banks and rock fractures, suggesting that open, fire-prone environments are likely to be unfavourable for their recruitment. Colonization by these riparian scrub species may only take place once an initial pioneer herbaceous and shrub cover has sufficiently stabilized the river banks and insulated the soil surface from extreme conditions.

The same study showed that some tree and shrub species (e.g. *Brabejum stellatifolium*, *Metrosideros angustifolia*, *Rhus angustifolia* and *Prionium serratum*) have been classified as ubiquitous. The absence of these species in the Fell & Burn plots may be an indication of an above-normal disturbance regime.

In summary, the vegetation of cleared plots was different to that of Reference plots by having reduced cover and species richness, and an altered growth-form structure.

6.5.2 Are there differences between plots cleared using different methods?

The Fell & Burn initial clearing treatment was more detrimental to vegetation recovery in the short-term than the Fell Only and Fell & Remove treatments. Fell & Burn resulted in the lowest indigenous vegetation cover, diversity and richness at point and plot scales. This finding requires consideration by managers, as fire is a preferred tool to reduce above-ground biomass after alien clearing has taken place.

Natural fires do burn riparian scrub vegetation, and the vegetation has a natural resilience to this through the resprouting capability of species from epicormic or basal stem buds. Fires of unnatural intensity and severity, however, may kill riparian scrub species and set the succession back to a stage requiring initial colonization by pioneer plant species. Such high-intensity fires may happen after clearing if the felled, dried biomass is not removed from the site.

In fynbos systems hotter fires linked to felled alien species have been held responsible for a loss of species and a reduction in seedling density (Euston Brown et al., 2002). This occurs because such a disturbance window provides the opportunity for secondary invaders, particularly fast-growing herbaceous species, to colonize. Similar effects have been reported from Ponderosa pine plantations, where slash piles are accumulated and burnt (Korb et al., 2004). Soil chemistry may also be altered and seed viability decreased (Korb et al., 2004), suggesting that fires should be avoided where unnaturally high fuel loads are present (Breytenbach 1989). Instead, biomass should be removed from the river corridor and, perhaps, sold as firewood to offset some of the costs. Where this is not feasible, stacks of unwanted biomass could be burnt on exposed sandbars during low flow periods or on existing roads (Korb et al., 2004), thereby avoiding the negative impacts of fire on any surviving indigenous vegetation.

In this study, burning was shown to reduce the amount of alien cover after clearing (Table 6.5), but the burned plots retained the least similarity to the Reference plots.

6.5.3 Which clearing method best facilitates indigenous vegetation recovery?

Compared to the reference condition, the Fell & Remove treatment performed slightly better than all other assessed clearing methods in all the measured variables though not significantly more so than the Fell Only method. It is unlikely that propagule pressure (either from soil-stored seed banks or dispersing propagules) differed between these two treatments, so the most likely explanation for its marginally better performance is that biomass removal promoted the growth of establishing species and possibly provided a larger number of establishment niches. The differences between the two treatments may not be of sufficient magnitude to justify the cost of biomass removal. If biomass levels are unnaturally high, however, the risk of a severe wild fire may also be high with a potentially negative impact on vegetation recovery. For this reason, biomass removal (of especially the larger pieces) is recommended.

6.5.4 The way forward

This study revealed the importance of long-term monitoring in restoration experiments or ecosystem repair projects, as it provided insights into a definite trend for species composition and growth form structure in cleared plots to more closely resemble the reference condition with time. Thus, provided that invasive aliens are controlled appropriately, time may be the prime criterion for ecosystem recovery and in many cases active revegetation programmes may not significantly improve recovery rates. There may be subcatchment areas that are too degraded to supply indigenous propagules for

riparian vegetation recovery, however, and in such cases a revegetation programme to re-introduce key riparian scrub species should be considered.

Further studies are required to investigate the impacts of different follow-up treatments and secondary alien invasions on indigenous vegetation recovery. Where alien grasses such as kikuyu (*Pennisetum clandestinum*) invade following alien tree clearance, for instance, the regeneration niche may be usurped, further delaying vegetation recovery. The influence of the surrounding landscape in supplying propagules is also likely to be important in influencing recovery rate. In un-invaded rivers, flooding increases plant species richness through the delivery of propagules (Jansson et al., 2005), but if the upstream catchment is degraded no propagules may be supplied to promote vegetation recovery post-clearance.

The results reported here are preliminary and based on a limited number of sample plots. It is anticipated that vegetation patterns in response to different alien clearing treatments will become clearer once a larger number of plots have been sampled. A larger data set will also allow other factors influencing vegetation composition, such as biogeography (i.e. catchment) and environment (especially geology and soil type; Prins et al., 2004) to be taken into account when interpreting the effects of clearing treatment.

6.6 CONCLUSION

All clearing treatments produced significantly different results to the reference condition for some of the following variables: indigenous cover, species richness and growth form structure. An overlap in species composition between the unburnt treatment plots and the Reference plot, however, indicated that vegetation recovery following those clearing treatments was moving toward natural. The Fell & Burn treatment showed the poorest recovery relative to the reference condition and it is recommended that fires of unnaturally high severity be avoided in the riparian zone by removing some of the felled and dried alien biomass. Of the treatments tested, Fell & Remove appeared to best promote vegetation recovery in the short-term.

Further results and discussion on this topic are presented in Mr Blanchard's M.Sc thesis:

Blanchard, R. (in press). To what extent are the alien plant clearing methods currently used in the Western Cape resulting in riparian vegetation recovery. M.Sc thesis, Institute for Plant Conservation, Botany Department, University of Cape Town.

7. INVESTIGATION INTO THE ALLELOPATHIC POTENTIAL OF ALIEN TREES

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7.1 INTRODUCTION

7.1.1 Background to the project

It was originally envisaged that the allelopathy section of the project would form a student thesis or dissertation. Despite an extensive search for a suitable and interested student no such candidate could be found. The work was then finally taken on by Dr Heather Malan and started in July 2005. The limited length of time left to carry out the work (six months) imposed several constraints on the type of experiments that could be conducted (for example no field trials) and the extent to which definitive answers could be obtained. Because of these limitations one of the major products of this study is a road map of suggested future research.

The following approach was used in this study:

- Appropriate objectives were set for the study (Section 7.2)
- A review of the literature was carried out (Section 7.3).
- The experimental methods to achieve the project objectives were planned.
- Suitable target plants were identified and cultivated (Section 7.4).
- Field trips were carried out in order to obtain soil, plants and leaf litter.
- The various experiments were conducted (Section 7.5).
- The results were analysed and reported.
- A road map of future research was drawn-up (7.8).

7.1.2 Rationale

The phenomenon of allelopathy is concerned with the effect that chemicals (termed allelochemicals) of plant or microbial origin have on the growth, development and distribution of other plants and micro-organisms in natural communities or agricultural systems (Einhellig 1993a). Both inhibitory and stimulatory effects of allochemicals produced by a source plant on a target plant have been observed. It has long been recognized that the invasive nature of many alien species, including those of interest to this project (eucalypts, wattle, poplar and pine) may, to some extent, be a result of the production and action of allelochemicals. Thus the typical bare areas, devoid of plant growth, under some invasive tree species may often (although not necessarily) be a result of allelochemicals inhibiting germination or seedling establishment of indigenous plants (Inderjit and Callaway 2003). In South Africa, bare areas around and/or under invasive tree species such as *Eucalyptus* are a common sight both within, and as these species increasingly escape cultivation and infest natural areas, outside

of plantations. Considerable research has been carried out into this topic worldwide, but the relevance of the research findings to the South African situation is not clear.

In the realm of allelopathic research it is useful to refer to a plant species with suspected or confirmed allelopathic potential as the "source" (or donor) plant. The term "target" (or receptor) plant is used for the plant species that is affected by the allelopathic compounds released by the donor plant (Foy 1999). This convention has also been used in this chapter.

7.2 AIMS AND CHALLENGES OF THE PROJECT

7.2.1 Aims

Overall, the project aims to carry out simple, preliminary experiments to investigate potential allelopathic effects of the alien trees under consideration, and to consider whether the invasive success of these trees in the riparian area is due to this phenomenon. The work includes identifying indigenous plants that can be used as "target plants," recommending future research avenues that could be pursued in order to gain a fuller insight into allelopathy and finally, using the knowledge gained in advising future management activities. In particular, the aims of this study are to answer the following questions:

1. Do young saplings of the invasive alien trees under consideration exert an interference effect on indigenous colonizing plants growing nearby?
2. What is the effect of incorporation of invasive species litter (leaves, twigs, bark) on the germination and growth of indigenous colonizing species?
3. What are the implications of the above for the management of alien-infested lands and for clearing programmes?
4. What is the way forward?

7.2.2 Challenges

There are several challenges that faced this project and these are discussed below. Some of the challenges are general to the field of allelopathic research and others are peculiar to working with fynbos vegetation.

The complexity of allelopathic interactions

Most allelopathic effects appear to involve a complex of chemicals rather than just one chemical that is phytotoxic (Foy 1999) and this makes investigations into allelopathy difficult. In addition, several hundred allelochemicals have been identified and a given plant species is likely to produce more than one type of allelochemical. Furthermore, frequently the source of a compound that is exerting an allelopathic effect is not obvious. A further complication is that the same chemical compound may have different effects on different target plants and be present in the soil in minute amounts (Einhellig

1993a). The above factors make investigations into potential allelopathic effects particularly challenging and are discussed in more detail in the literature review (Section 7.3).

Distinguishing between allelopathy and resource competition

Another aspect that contributes to the challenge in this field of research is the difficulty in distinguishing between resource competition and allelopathy. A considerable number of papers investigate the allelopathic potential of various species of *Eucalyptus*, *Acacia*, *Pinus* and *Populus* (del Moral, Willis and Ashton 1978; Schumann, Little and Eccles 1995; Bernhard-Reversat 1999; Kohli, Daizy, Singh and Batish 1996), and it is well established that species of these alien trees interfere with other plant species that try to establish themselves as an under-storey level (see the literature review, Section 7.3.9). Furthermore, allelochemicals have been extracted from many of the above-named alien trees. It is extremely difficult, however, to differentiate between different forms of interference and in particular between allelopathy and competition for resources. This difficulty has been widely acknowledged in the literature (Inderjit and del Moral 1997; Reinhardt, Khalil and Bezuidenhout 1999a). For example, it has been postulated that the lack of vegetation under mature *Eucalyptus* trees may be due to release of allelochemicals, to the trees taking up large proportions of nutrients and water, to shading, or to a combination of these and other effects (Tshivandekano 1989). Consequently, whilst it is recognized in South Africa that in the field, indigenous, and other plants struggle to establish under mature eucalypts, acacias, pines and to a lesser extent poplars, the exact reason for this is not clear.

From a management perspective, and at this early stage in the investigation, whether the failure of indigenous under-storey plants to thrive is a result of allelopathy or of resource competition is not of critical importance. What is important, however, is determining whether after clearing infestations of these aliens there is a lasting effect in the soil. Would this effect be alleviated by removing the litter? How long does this effect last? At what age do the invasive alien seedlings start to produce allelochemicals? Therefore the research in this short-term project is directed towards potential allelopathic effects noted after clearing efforts, rather than the effects induced in established stands of the alien trees. The focus is thus on the practical implications for management of infested riparian land rather than the mechanism of interference *per se*.

Ultimately, in order to obtain a deeper understanding of the effect of these invasive species on indigenous vegetation, it will be necessary to distinguish between resource competition and potential allelochemical inhibition. For example, the action of fire may remove allelochemicals (Keeley, Morton, Pedrosa and Trotter 1985) but would not necessarily affect competition for water or nutrients. This in turn would influence the management actions that would be most effective. Unfortunately, due to the short duration of this project it will not be possible to pursue such detailed investigations. This type of approach should, however, be considered for future work (Section 7.8).

Ecological relevance

Allied to the difficulties in distinguishing between resource competition and allelopathic effect is the need to establish the ecological relevance of experimental results. Many studies are reported in the literature, in which organs of putative allelopathic species have been macerated or extracted with organic solvents. The phytotoxic properties of these extracts have then been tested, often on plant species that would not occur in the natural situation. As far as possible, the experiments carried out in this study mimicked the situation in the field.

Time constraints

As mentioned in the introduction there were constraints with regard to the time available to carry out the experimental work. Many indigenous species are extremely slow (and notoriously difficult) to germinate. Because of this, several potential species could not be used, either because seed was not available during the period of the study or, if available, the seed could not be germinated (Section 7.4.2).

An obvious question that needs to be answered but that is not listed under the aims to this project is "Do *mature* trees of the alien species under consideration exert an interfering effect on the soil around them, and does this then inhibit the establishment of colonizing species"? This question is best answered using field-trials. Because of the constraints of time within the present project, it was decided that field experiments were not feasible. Consequently field trials occupy a prominent position in the suggested road map for future research (Section 7.8).

7.3 LITERATURE REVIEW

The phenomenon of allelopathy has been recognized for over 2000 years and has been studied intensively for the last few decades or so (Dakshini, Foy and Inderjit 1999; Macias 1993). As a result, there is a relatively large body of literature covering this topic. Thus, although a discussion of allelopathy in terms of definition, manifestations and causes is presented in this report, this discussion is not exhaustive and the reader is directed to several comprehensive reviews of the subject (e.g. Indejit, Dakshini and Einhellig 1993; Indejit, Dakshini and Foy 1999; Hierro, and Callaway 2003). The focus of this review is directed towards allelopathy in the context of the overall project. In other words, how this phenomenon relates to the invasion of alien plant species and allelopathy in arid environments (the prevailing condition over a large part of South Africa). Of the four alien invasive trees that were studied in the broader project, two (*Eucalyptus* and *Acacia*) are discussed in detail because these are considered to possess the greatest allelopathic potential (Coder 1999) and the most has been written about allelopathy in these species. Factors that may influence allelopathic effects in fynbos and riparian areas are also highlighted.

7.3.1 What is allelopathy?

Mollisch (1937 – cited by Reinhardt, Mphephu and Bezuidenhout 1999b) coined one of the early definitions of allelopathy stating that “allelopathy ...involves both growth-stimulating and growth-inhibiting plant responses to chemicals released from other plants into the environment.” This definition has been extended over the years to emphasize that the term “plants” includes micro-organisms such as fungi and bacteria. As understanding of the complexity of chemical signaling developed it was realized that plant-animal interactions also occurred, for example, in plant defense responses to insect predation (Einhellig 1993a). In this project, however, as in most studies in this field, allelopathy is understood to include plant-plant interactions, and is defined as:

Allelopathy, a subset within the broader scope of chemical ecology, is concerned with effects that chemicals of plant or microbial origin have on growth, development and distribution of other plants and micro-organisms in natural communities or agricultural systems.” (Einhellig 1993a).

Several hundred organic chemicals, known to have an effect on the growth or functioning of target species, are released from plants and microbes. These compounds cover a wide range of chemical forms (Macias 1993). It should be remembered, however, that in addition to allelochemicals, many other organic compounds are also released by plants - either from living tissue or during decomposition (Bertin, Yang and Weston 2003). These may have no apparent impacts (either positive or negative) on other plants, or possibly some of them do, but these have not yet been recognized. When investigating and establishing evidence for an allelopathic effect it is necessary to show that the donor plant is capable of accumulating allelochemicals in the environment at phytotoxic levels and that the observed patterns of vegetation distribution are not solely explained by physical (e.g. resource) or biotic (e.g. herbivore) factors (Blum 1999).

7.3.2 Some case-studies of allelopathic effects

Three case-studies of allelopathic interactions are presented below in order to demonstrate different aspects of this phenomenon.

A classical case of allelopathy is exemplified by the effect of juglone, a chemical produced by black walnut (*Juglans nigra* L.) as discussed in Bertin, Yang and Weston (2003). Established walnut trees generally cause wilting, browning of vascular tissue and eventual necrosis and death of sensitive plant species growing near them. Plants susceptible to damage include tomato, potato, pea, pear, apple, corn, barley as well as some ornamental species. The toxic effect is due to the production of juglone (5-hydroxy-1,4-naphthoquinone) by the walnut trees. In living tissues, juglone is generally found in a reduced, non-toxic form but when exposed to air it becomes oxidized and toxic (Rietveld et al., 1983 cited by Bertin, Yang and Weston 2003). Since juglone is not particularly water-soluble it is not readily leached from soil and persists underneath the tree canopy where the living roots are located. Consequently, susceptible target plants fail to thrive near these trees. According to Einhellig (1993) this chemical interaction is unusual in the field of allelopathy in that only one chemical (juglone)

appears to be involved. Several allelochemicals are usually responsible for exerting a toxic effect - although it is possible that further research into the allelopathological effect of black walnut will implicate more chemical substances.

Another well-studied example of chemical interaction between two different plant species occurs during nodule formation in leguminous plants, a step that is critical in the process of nitrogen fixation. The initiation of *Rhizobium*-symbiosis involves a complex series of steps in which the bacteria and higher plant influence each other through chemical signaling. *Rhizobium* bacteria are chemotactic towards plant roots and the colonization, growth of roots, and formation of nodules is stimulated by the production of flavonoids (amongst other compounds) produced by leguminous plants. Recent studies show that in turn *Rhizobium* produce chemical compounds that control root growth (Einhellig 1993aa; Bertin, Yang and Weston 2003).

A third interesting case of allelopathy is represented by the areas of bare ground around individual plants, or stands of one type of plant, in the chaparral of southern California. According to Einhellig (1993) studies on the zonation of vegetation in the chaparral (an area with a Mediterranean climate such as the Western Cape) have shown that *Salvia leucophylla*, *Artemisia californica* and other aromatic shrubs release a variety of volatile terpenes. These terpenes solubilize into the leaf cuticle of other plant species growing nearby. They also adsorb onto soil particles from which they may later transfer into root tissues of seedlings that try to establish in proximity to the allelopathic shrubs. Water soluble phenolic acids are also leached from leaves of *Salvia* and *Artemisia* and other shrubs, adding to the complex of inhibitory allelochemicals that will be encountered by colonizing herb and grassland vegetation. Annual grasses are sensitive to these allelochemicals and the net result is a border zone of sparse vegetation around stands of *Salvia* and *Artemisia*. The situation is complicated by the action of herbivores making the extent of the allelopathic effect unclear (Inderjit and Callaway 2003).

7.3.3 Direct and indirect effects of allelochemicals

From the above examples it can be seen that a key aspect of allelopathy is the transfer of chemical substances through the environment from a source plant to the target plant. The medium through which the allelochemical travels is usually soil, but may be air or surface water (Cheng 1993; Elakovich and Wooten 1993). A source plant could influence a target plant either directly, or indirectly (Figure 1) via the mediation of micro-organisms such as bacteria or fungi (Inderjit and Nilsen 2003). In the case of the allelopathic effect of black walnut discussed in the previous section, juglone has been found to be directly inhibitory to the growth of other higher plants (Bertin et al., 2003). In some cases the chemical compound produced by a higher plant is not directly toxic, but becomes so only after chemical modification by micro-organisms (for example after partial decomposition of leaf litter). The effect may be even more indirect in that the activity of an allelochemical against a target plant species is through inhibition of the growth of microbial symbionts present in the soil around the roots (the rhizosphere). For example, as noted in the previous section, growth of *Rhizobium* bacteria has been found to be sensitive to various allelochemicals. The presence

of allelopathic plants (or plant residue) can lead to poor growth of the microbial symbiont, which in turn results in sparse nodulation and subsequent reduction in nitrogen available to legumes growing in close proximity. The resultant effect is poor growth of the leguminous plants. Free-living nitrogen fixing bacteria can also be affected by allelochemicals (Einhellig 1993a; Kluson 1993). Suppression of mycorrhizal (fungal-root) colonization can also hinder absorption of water and other nutrients from the soil, slowing growth (Bertin, Yang and Weston 2003).

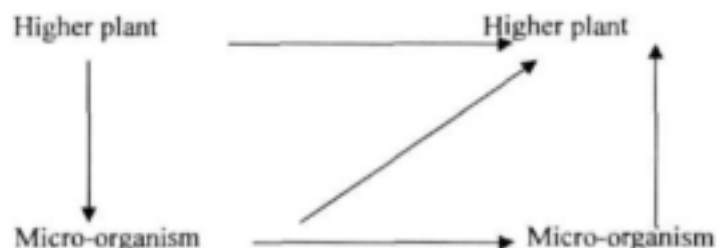


Figure 7.1 The direct and indirect effects of allelochemicals (adapted from Einhellig 1993a).

7.3.4 The chemicals involved

One of the major difficulties in studying allelopathy is the lack of comprehensive knowledge of allelochemicals and root exudate chemistry in general (Cheng 1993). This is partly because such chemicals are usually present in minute quantities, but also because many are labile (Bertin, Yang and Weston 2003) and are thus difficult to isolate and identify. Furthermore, several hundred allelochemicals have been identified with a wide range of chemical structure (Cheng 1993; Marcia 1993). Allelochemicals are organic chemicals that can be released through volatilization, leaching from leaves, degradation of plant residues or root exudation. Root exudates, however, are likely to represent the largest source of allelochemical inputs into the soil environment (Bertin, Yang and Weston 2003). Allelochemicals belong to several different categories of chemical compounds including: phenols, benzoic and cinnamic acid derivatives, flavanoids, coumarone, tannins, terpenoids, alkaloids, and polyacetylenes, of which the phenolics and terpenoids have been the most widely investigated (Inderjit and Dakshini 1995 - citing several different sources).

With few exceptions, allelochemicals have been found to be secondary compounds. Thus, in general they have no central metabolic function, although some allelochemicals do have a recognized role in the source plant. For example, cinnamic acid, ferulic acid and p-coumaric acid are common allelochemicals and are also intermediates in the formation of lignin. Frequently though, no obvious metabolic function can be assigned. Most allelochemicals reported from higher plants originate from either the acetate or shikimate metabolic pathways or from both (Einhellig 1993b) and in general most allelochemicals tend to be water-soluble (Inderjit and Dakshini 1995; Reinhardt, Khalil and Bezuidenhout 1999a).

Bioactivity varies between the different compounds by several orders of magnitude. For example the coumarins, cinnamic and benzoic acid, exert an effect on target plants at concentrations ranging from

100 to 1000 μM . Allelopathic interactions include both inhibitory and stimulatory effects and even for a single chemical compound, low concentrations frequently stimulate growth (possibly due to the fact that this represents a nutrient source). At higher concentrations the same allelochemical is often found to inhibit growth (Reinhardt and Meissner 1996). Analytical techniques that have been employed to quantify these substances include multi-nuclear and 2-D NMR associated with GC-MS which was used to identify the chemical composition of barley and wheat root exudates (Fan et al., 1997b cited by Bertin, Yang and Weston 2003). Various other techniques including HPLC have also been employed depending on the chemical nature of the compound(s) under investigation (Souto, Gonzalez and Reigosa 1994; Inderjit 1996; Inderjit and Nilsen 2003).

In most cases it is not clear whether the release of allelochemicals by a particular source plant is a result of active exudation or passive leakage and the regulation mechanisms of these processes are also generally unknown (Einhellig 1993a). As noted previously, most cases of allelopathic inhibition are due to a combined effect of several compounds acting in a synergistic or additive manner (Einhellig 1993a). The activity of an allelochemical may be altered by the presence of other substances that may act as promoters or inhibitors, and consequently, it may not be very useful to isolate the suspected allelochemical (Inderjit and Nilsen 2003). A common experimental practice is to measure the total concentration of phenolics in the soil, since phenolics are frequently allelopathic.

7.3.5 The scope of allelopathic effects

Allelochemicals can be highly selective influencing the growth of only one organism or exhibit broad activity, influencing the growth of many species (Bertin et al., 2003 - citing several authors). Susceptibility of target plants to the allelochemical effects of a source plant is often species- and even cultivar-dependent (Reinhardt and Meissner 1996). The reason for differential species sensitivity to a given allelochemical is not understood. Not surprisingly, considering that the primary mode of action of allelochemicals is generally unknown. Since an allelopathic effect on a target plant is usually the net result of a combination of chemicals interfering with several physiological processes in the target organism, identifying the primary mechanism(s) of action is extremely difficult. Coumarins and phenolic compounds derived from cinnamic and benzoic acids have been found to exert a deleterious effect on several key plant processes including cell division, mineral uptake, stomatal function, water balance, respiration, photosynthesis, protein and chlorophyll synthesis and the activities of plant hormones (Einhellig 1993b). Despite the uncertainty regarding the underlying mechanisms of impact, one of the primary sites of activity of allelopathic compounds is likely to be at the cell membrane (Foy 1999).

At the organism-level, some allelochemical effects are manifested in reduced seed germination. In other cases, normal germination occurs, but seedling growth is impaired (Inderjit and Dakshini 1995; Reinhardt and Meissner 1996). For example, the effect of aqueous extracts of leaves, roots, litter and soil from the heath plant *Kalmia augustifolia* was tested on spruce seedlings. There was no significant effect on germination, or stem growth, but the growth and development of primary roots was inhibited (Mallik and Zhu 1993). At the ecosystem level, a whole range of effects have been postulated to result

from allelopathy. These include vegetation patterns and associations of plant species, succession, invasion by exotic plants, nitrogen fixation, seed preservation and some of the dynamics of plant disease (Einhellig 1993a; Dakshini, Foy and Inderjit 1999).

7.3.6 Allelopathy and other interference effects

In nature, several plant-plant interference mechanisms, other than allelopathy, are also likely to be in operation. These include resource competition, nutrient immobilization by micro-organisms, and plant/micro-organism interactions. In practice it is extremely difficult to separate these mechanisms since they are generally thought to operate sequentially and/or simultaneously (Dakshini, Foy and Inderjit 1999; Inderjit and del Moral 1997). For example, the reduction in growth of a target plant as a result of allelochemicals simultaneously reduces competition with the source plant for resources. Similarly, Reinhardt et al. (1999a) note that plants growing under conditions of stress (for example due to competition for resources) may frequently produce allelochemicals in response. Stress factors such as shade, drought or nutrient-limitation are known to enhance the production of secondary metabolites (Inderjit and del Moral 1997). Many secondary metabolites such as phenolics and terpenoids have been reported to act as allelochemicals, and are known to complex with inorganic ions and influence the accumulation of soil nutrients. Thus, Inderjit and del Moral (1997) conclude that "separating allelopathy from resource competition is essentially impossible in natural systems. Furthermore, any experimental design to separate allelopathy and resource competition will create conditions that will never occur in nature."

Although the two interference effects of allelopathy and resource competition are closely linked (Inderjit and Callaway 2003), an interesting experimental technique has been used to try to distinguish between them. The approach involves comparing the growth of target species planted at different seedling densities in the presence of a suspected allelopathic source plant. If no allelochemicals are produced by the putative source plant then growth of the target plants will *decrease* with increasing seedling density due to competition for resources. If, on the other hand, an allelochemical is present in the soil, growth should *increase* with increasing density of target seedlings. It is hypothesized that this is due to dilution of the allelochemical effect (due to uptake by many target seedlings). Such an effect was demonstrated by Gentle and Duggin (1997) who examined the growth of two indigenous Australian species after different removal methods for *Lantana camara* thickets.

7.3.7 Extrapolation from laboratory results to the field

Because of the complexity of natural ecosystems and the difficulty in distinguishing resource competition from allelopathic interference, extensive use is made of bioassays in this field of research (Inderjit and Dakshini 1995; Rice 1995; Inderjit and Nilsen 2003). Laboratory bioassays (i.e. measuring responses in living plants) can be carried out under controlled conditions in order to investigate some of the confounding variables that influence allelopathic effects. They are useful approaches for screening plant species for allelopathic potential, and determining the toxicity of crude extracts and fractionated components obtained from various sources (Reinhardt, Khalil and

Bezuidenhout 1999a). Unless careful thought is given to the design of bioassays, however, many will have little or no correspondence with the situation in the field (Inderjit and Dakshini 1995; Hierro and Callaway 2003).

Central to the development of ecologically sensible bioassays is the use of appropriate (i.e. natural) concentrations of allelochemicals (Inderjit and Callaway 2003; Inderjit and Nilsen 2003). As explained previously (Section 7.3.4), allelochemical effects are usually mediated by a range of chemicals, present in very low concentrations, whose profile is likely to change with time. Bioassays provide a means of determining the presence/absence of allelochemicals in a *qualitative* manner. In order for the technique to be used *quantitatively* the allelochemical(s) responsible for the effect need to be isolated, identified and the biologically active concentration determined (Reinhardt et al., 1999a).

Inderjit and Dakshini (1995), Blum (1999), and Inderjit and Nilsen (2003) give guidelines for making bioassays more ecologically relevant. Especial caution is given against the grinding of plant material and the extraction of putative allelochemicals using organic solvents. An often-quoted, but none the less valuable insight is given by Harper (1994 - cited by Inderjit and Nilsen 2003) who notes that "almost all [plant] species can, by appropriate digestion, extraction and concentration be persuaded to yield a product that is toxic to one species or another." Other suggestions for improved bioassays include the use of co-occurring target species - (i.e. species that would naturally be found in an area, rather than artificially sensitive species such as *Lactuca*), the use of soil as a growth medium (and careful examination of microbial involvement), and consideration of different aspects of the growth response in the target plant (Inderjit and Dakshini 1995; Inderjit and Nilsen 2003). A list of parameters that can influence the outcome of allelopathy assays is given in Inderjit and Nilsen (2003). Blum (1999) also gives a list of experimental considerations that must be addressed when carrying out plant debris-soil bioassays (such as the litter experiments in this project - Section 7.5.1). Where possible these guidelines have been followed in the experimental procedure used in this study. Despite the need for caution when designing bioassays to demonstrate potential allelochemical effects, this experimental approach is invaluable. Bioassays offer the advantage of measuring only the phytotoxic portion of an extract. In comparison with chemical analyses, bioassays are often extremely sensitive, economical and simple to perform (Reinhardt et al., 1999a).

7.3.8 Factors that influence allelochemical effects

Plant-related factors

Potential allelochemicals can originate from different plant parts and not all allelopathic plants will produce allelochemicals from all organs (Inderjit and Nilsen 2003). Many allelochemicals originate from decaying plant tissues such as leaf litter (Inderjit, Cheng and Nishimura 1999). It was found, for example, that mature sunflower plants that are cut and left as residue on the soil surface have a beneficial effect on the control of weeds in the next growing season (Reinhardt, Khalil and Bezuidenhout 1999a). There has been considerable interest in the use of plant residues that can act as

alleloherbicides (Chou 1993) since such natural herbicides have the advantage of being unlikely to persist in soil.

The growth stage of the source plant can also affect the production of allelochemicals (Inderjit and Dakshini 1995). For example, Bertin, Yang and Weston (2003) report that the extent of toxicity of juglone produced by black walnut trees is dependent on the age and size of the tree (in addition to soil environmental conditions) which influence toxin production. The highest concentrations of juglone are found around actively growing roots. Reinhardt and Bezuidenhout (2001) found that in *Cyperus esculentus*, maceration of *immature* leaves produced an extract that was more phytotoxic than *mature* leaves. Of interest to this project is the finding that regrowth of *Kochia* plants (an invasive species) may give rise to increased production of allelochemicals (Hierro and Callaway 2003). This effect was demonstrated, however, using laboratory bioassays and it is not clear if similar allelochemical effects occur in the field.

Environmental stress

Allelopathy is tightly coupled with competition for resources and stress from disease, temperature extremes, moisture deficit and herbicidal impacts (Einhellig 1993a). In general, environmental stress usually (although not always) increases the production of allelochemicals (Einhellig 1993a; Reinhardt, Khalil and Bezuidenhout 1999a). Einhellig and Echrich (1984) grew one batch of soybean seedlings at a day temperature of 23°C and another batch at 34°C. The latter value is towards the upper-most limit of the temperature tolerance of these plants, although no difference was exhibited between the biomass of the two batches. If the allelochemical ferulic acid was added to the soil at a concentration of 100 µM, growth of plants held at the lower temperature was not affected, but those grown at 34° C were significantly smaller in size.

Although there is a general lack of understanding of the identity and actions of allelochemicals, enough is known to conclude that both the *synthesis* and the *impacts* of allelochemicals are influenced by stress, although the mechanisms are rarely understood in any detail (Einhellig 1993b).

Soil-related factors

In order for an allelochemical effect to occur, transport of the allelochemical(s) between the source plant and target plant must occur and this is frequently through soil (Cheng 1993). Soil is a complex and dynamic medium and the mobility of organic compounds within soil is dependent on the chemical and physical character of the compound under consideration, as well as that of the soil through which it moves. Environmental factors such as soil moisture and temperature also affect allelochemical mobility (Reinhardt, Khalil and Bezuidenhout 1999a). Phytotoxic substances that leach from plant matter by rainfall or irrigation contribute to the complex interactions between plant residues, the environment and micro-organisms (Kil and Lovett 1999). Once allelochemicals reach the soil they are often altered due to adsorption to soil particles, degradation by micro-organisms, or chemical reactions (Einhellig 1993a). Certain soil types, due to their physical and chemical nature, are able to adsorb

allelochemicals to a greater extent than others. For example, it was found that loamy soils are able to retain a higher proportion of toxic factors than sandy soils (del Moral and Muller 1970).

Quite apart from the abiotic characteristics of soil, the type and distribution of microbial populations within that soil is also important from the point of view of allelopathy. This was discussed in Section 7.3.3.

Allelopathy and invasion of alien plants

Various theories have been put forward to explain the remarkable success of many invasive plants in different parts of the world. One of the most popular of these is the "absence of predators" theory. This theory proposes that in newly-invaded ecosystems, the lack of pathogens and herbivorous predators that would normally keep the population in check in native ecosystems causes the plant to become invasive. There is, however, increasing evidence to suggest that in some cases allelopathy is also an important reason for the invasive success of some species, allowing certain weeds to dominate an ecosystem over time (Gentle and Duggin 1997; Bertin, Yang and Weston 2003; Inderjit and Callaway 2003).

A key debate around the importance of allelopathy in plant invasion is provided in Hierro and Callaway (2003) and much of the discussion below is taken from that source. The effect of *Centaurea diffusa*, an invasive weed in North America, on other plant species both in invaded communities and in its native regions of Eurasia, was examined by Callaway and Aschehoug (2000). The target plants that were chosen were three species of bunchgrass that co-exist with *C. diffusa* in Eurasia and three congeners (or near-congeners) from North America that were similar in morphology and size. Planting trials were conducted with combinations of a grass species and the weed plant grown in sand. *Centaurea diffusa* had a much stronger negative effect on the North American species than on the co-patriot Eurasian species. None of the North American grasses appeared to reduce the biomass of the weed (although the Eurasian grasses did reduce growth of *C. diffusa*). Further planting trials were conducted in which activated carbon (which absorbs organic compounds and thus would ameliorate allelopathic effects) was added to the growth medium. The growth of North American grasses with *C. diffusa* was enhanced in the presence of activated carbon, presumably due to inactivation of the allelochemical compounds. In contrast, the growth of all Eurasian grass species growing in the presence of *C. diffusa* was decreased. One of the major allelochemicals involved in the action of this invasive weed has been identified as ($\pm$)-catechin (Bais et al., 2002).

From experiments such as those described above it has been postulated that native species that come into contact with an allelopathic invasive species from another region may be especially susceptible to the effects of the allelochemicals produced (Willis 1999). They are "naïve," not having previously been exposed to that particular rhizochemical environment, and have not had time to evolve tolerance to potential allelochemicals. Work carried out by Callaway, Ridenour, Laboski, Weir and Vivanco (2005), however, provides initial evidence that indigenous plant species can fairly rapidly adapt to tolerate the allelochemical effects of an exotic plant invader. They conclude that indigenous plant

species can evolve resistance to invaders and that invaded communities may recover some aspects of natural structure and function so that invaders and natives may eventually coexist. Of interest is the finding that an invasive plant often stimulates the germination of its own seeds thus giving it a competitive advantage (Hierro and Callaway 2003). The question of competition for resources versus allelopathy (Section 7.3.6) is also of critical importance when considering the invasion of indigenous communities by alien plants. It has been postulated that allelopathy is especially important in resource-poor plant communities making them prone to invasion (Hierro and Callaway 2003).

Although it is strongly suspected that in some cases of alien plant invasions at least, allelopathy is likely to be involved to a greater or lesser extent, the challenges described previously in trying to isolate allelopathy from other inference effects also hold. As stated by Hierro and Callaway (2003) "there is a great deal of evidence for strong allelopathic effects of exotic invaders on native species, but very little that escapes methodological quandaries." It appears that allelopathic interactions are likely to be very species specific and thus it is important that indigenous species are used to test for an allelochemical effect rather than laboratory test species. Experiments need to be carried out that investigate the allelopathic potential of an alien plant both in its native community and in invaded communities in order to compare the vulnerability of target plants (Inderjit and Nilsen 2003).

Eucalyptus

The genus *Eucalyptus* has been investigated by many researchers from different parts of the world because of its suspected allelopathic potential (Coder 1999; Kil and Lovett 1999). Many eucalypt species are often surrounded by areas of bare ground (Nishimura and Mizutani 1993; Bernhard-Reversat, 1999). Even after felling stands of adult trees, these areas of bare ground can persist for several years until eventually tolerant plant species begin to establish in the bare patches (Tshivandekano 1989; Bernhard-Reversat, 1999). *Eucalyptus* spp. tend to be rich in secondary compounds and several studies have examined the allelochemical nature of these compounds. Volatile terpenoids are characteristic of the genus and various types of this class of chemical have been identified (Wang and Fujimoto 1993 – cited by Kils and Lovett 1999).

Several studies have also been carried out on the allelopathic potential of eucalypts in their native communities (see Kil and Lovett (1999) and Willis (1999) for a summary of this work). Of especial interest is the so-called "auto-toxicity" effect, whereby several species of eucalypts (some of commercial importance) appear to suppress germination and growth of their own seedlings (Bowman and Kirkpatrick 1986; Willis 1999).

The areas of suppressed plant growth under *Eucalyptus* trees have been attributed to different causes by different authors and are listed below. It is important to note though that the genus "*Eucalyptus*" includes many hundreds of species (850 native to Australia alone (Beadle 1981)). Allelopathic interactions operate in combination with other interference effects and allelopathy tends to be species-specific. Thus, although various explanations have been given to explain the reasons for the absence of vegetation below eucalypt species, not all mechanisms are likely to be operating in all situations.

Growth of under-storey plants beneath *Eucalyptus* trees may be prevented by:

1. Allelopathic effects resulting from compounds leached from litter or other plant parts (del Moral, Willis and Ashton 1978; May and Ash (1990); Singh and Kohli (1992); Souto, Gonzalez and Reigosa, 1994; Bernhard-Reversat, 1999).
2. Competition for water (Bowman and Kirkpatrick 1986).
3. Competition for nutrients (Igboanugo 1988 cited by Kil and Lovett 1999).
4. Mobilization of iron from soil by eucalypt litter leachate - which could result in a competitive advantage over other plants (Bernhard-Reversat, 1999).
5. Inhibition of nitrogen fixing bacteria due to allelochemicals (Tshivandekano 1989).
6. Stimulation of microbiological pathogens that adversely influence other plants (Willis 1999).

Tshivandekano (1989) examined areas of non-vegetated ground below *E. cinerea*, on the slopes of Table Mountain, South Africa. He postulated that the difficulty in revegetating previously *Eucalyptus*-dominated areas was due to erosion of topsoil after removal of the trees. This would make the establishment of new vegetation difficult due to the depletion of nutrients, humus and the resultant poor water-holding capacity of the soil. Soil erosion would be accelerated by the lack of vegetation and possibly aided by the observed hydrophobicity of soil in the test area (Tshivandekano 1989).

Bernhard-Reversat (1999) examined the effect of litter leachate from two *Eucalyptus* hybrids on the growth of rice seedlings. It was found that litter leachates obtained from fresh litter (i.e. from recently fallen leaves) decreased root growth of the rice seedlings. However, leachates from litter older than five days did not exhibit any effect. Bernhard-Reversat (1999) opines that because inhibition occurs when fresh litter is used but not old litter, this supports the theory that allelopathy is causing the suppression of growth and that the allelopathic compound is washed out of the litter early in the decomposition process. In *Eucalyptus* plantations litter-fall occurs throughout the year and allelopathic compounds are likely to be leached from fresh litter during the entire rainy season (Molina et al., 1991). Puri and Khara (1991) also studied the effect of leachates from *E. tereticornis* leaves of different ages on the germination and seedling growth of a target plant. They found that seedling growth was decreased in the presence of leachate from green and brown leaves, but not from decayed leaves. In fact growth was often increased in the presence of leachate from decayed leaves. Germination of mung beans, on the other hand was unaffected by leachate from leaves of any age. The authors hypothesized that allelopathic substances present in the *Eucalyptus* litter interferes with the growth of the mycorrhizal fungi present in the root systems and this in turn affects the nutrient uptake and growth of seedlings.

De Moral and Muller (1970) examined the failure of herbaceous plants to grow under or near *E. globulus* and *E. camaldulensis* trees and also attributed it to the allelopathic effect of these trees. They found that fresh leaves of *E. camaldulensis* and *E. globulus* produced large amounts of volatile terpenes that are toxic to plant growth. Insect frass (droppings) falling from *E. globulus* was demonstrated to suppress germination, growth and survival of herb plant species due to the allelopathic nature of the frass (Silander, Trenbath and Fox 1983 - cited by Willis 1999). These

results were contested by other researchers, however, as being non-representative of the natural situation. De Moral, Willis and Ashton (1978) also reported that the suppression of under-storey layers beneath *E. baxteri* was due to the production of allelochemicals rather than to resource competition. They found that topsoil extracts from below *E. baxteri* were inhibitory to the establishment of some seedling species due to the presence of resins and, possibly, terpenoids. On the other hand Lamont (1985 – cited by Willis 1999) demonstrated that under *E. wandoo* – the bare areas were due to the superior ability of these trees to compete for water.

Willis (1999) summarized the research on allelopathy caused by *Eucalyptus* saying that despite many attempts, there has been no unambiguous demonstration of allelopathy in native eucalypt forests in Australia. This is in marked contrast to situations overseas where eucalypts are well known to affect the growth of under-storey species, or in Australia where introduced species may grow poorly underneath eucalypts.

Acacia

Considerably less research has been conducted on the allelopathic potential of *Acacia* compared to *Eucalyptus*. Schumann, Little and Eccles (1995) examined the effect of litter leachate from *Acacia mearnsii* (in addition to that from *Eucalyptus grandis* and *Pinus patula*) on the establishment of weeds. They found that although litter leachate appeared to reduce the biomass of target plants relative to controls, this effect was statistically significant only for *Pinus*. The use of leaf mulch of *A. mearnsii* appeared to have no allelopathic effect on pot-grown wheat and maize (Pieterse 1997).

Gonzalez, Souto and Reigosa (1995) examined phytotoxic compounds formed during the decomposition of *Acacia melanoxylon* decomposition in soil. The process was investigated in different ecosystems, namely an oak wood, a eucalypt stand, and a stand of *Pinus pinata*. Decomposition of *Acacia* residues caused an inhibitory allelopathic effect which was strongest in fresh litter and declined with litter age. However, the soil in which this occurred influenced the extent of toxicity. The authors identified various phenolic compounds and flavanoids from the leachate. They noted that whilst the allelochemical effect is more potent in freshly decomposed leaves, this species sheds litter the whole year round, and thus a toxic effect may be exerted both during the germination and growth periods of under-storey species.

Allelopathy in the fynbos biome

From the foregoing discussion of allelopathy it is clear that many environmental variables including the temperature and pH of the growth medium, the presence of micro-organisms, and soil moisture content are likely to affect allelochemical potential in the field. Consequently, factors characteristic of fynbos ecosystems are also likely to affect allelopathic potential. Fynbos areas, for example, are typically characterized by acidic soils with low nutrient concentrations (Deacon, Jury and Ellis 1992; Cowling and Richardson 1995). According to Hierro and Callaway (2003) allelopathy is of especial importance in resource-poor communities making them more prone to invasion. Micro-organisms in

the form of bacteria in proteoid roots and mycorrhiza play an extremely important role in fynbos ecosystems in extracting nutrients from the soil (Stock and Allsopp 1992; Cowling and Richardson 1995).

At the same time, nutrient limitation has been found to stimulate the production of allelochemicals in many plants (Inderjit and del Moral 1997). Vegetation in the fynbos biome is known to have a high content of secondary compounds – which is believed to be an adaptation to reduce grazing under conditions of low nutrients (Cowling and Richardson 1995). As noted in Section 7.3.4 many secondary plant compounds are also known to be allelopathic and reference was made to the allelopathic nature of species of the chaparral of southern California, an area similar in climate to the Western Cape. Although no information could be found in the literature on recorded allelopathic effects demonstrated by fynbos plants, it is very likely that some indigenous fynbos plants are also allelopathic and that this mechanism is involved in community structuring. Leaching of secondary compounds produced in the leaves of fynbos plants leads, in turn, to a build-up of humic acids in the soil (DWAf 1996). Reinhardt, Khalil and Bezuidenhout (1999a) report that clay minerals and humic acids appear to be involved as catalysts in the inactivation of phenolic compounds through decomposition, mineralization, and adsorption of these chemicals. They conclude that organic compounds bound to humic acids may then be relatively easily broken down by micro-organisms.

The fynbos biome is found in Mediterranean climatic regions, characterized by long hot, dry, summers. May and Ash (1990) examined the allelopathic potential of several *Eucalyptus* species. These authors found that stemflow (i.e. water flowing down the stem) was one of the most potent sources of inhibitors from the eucalypt species examined. From their own studies, and from others, they calculated that the volume of stemflow channeled down this route is typically up to eight times the volume of rainfall for a given area. May and Ash (1990) also noted that evaporative concentration of leachates from *Eucalyptus* species showed an increase in inhibitory action. They found that, in the field, allelopathic chemicals from eucalypts could accumulate in the soil under appropriate conditions but that the allelochemicals involved were water-soluble and therefore prone to leaching from soils. They concluded that allelopathy must therefore be considered in relation to the amount of source material, rainfall and the soil water balance. They calculated that low rainfall events that were insufficient to cause runoff or deep drainage would tend to maximize allelochemical concentrations – especially if followed by hot weather which would allow evaporative concentration of the chemicals. Horsley (1991 – cited by Inderjit and Dakshini 1995) postulated that phenolics are likely to be the primary allelochemicals in temperate ecosystems whilst terpenoids are of greater importance in arid and semi-arid environments. Del Moral and Muller (1970) found that the concentration of allelochemicals in soils under *E. camaldulensis* peaked at the end of the dry Californian summer, declining after the onset of autumn rains. On the other hand, the activity of soil micro-organisms is sensitive to the soil moisture content, and can also be expected to vary with this parameter (Reinhardt, Khalil and Bezuidenhout 1999a).

Finally, fire is an important process in fynbos ecosystems and periodic fires are typical of the region (Stock and Allsopp 1992). Willis (1999) discussed the relevance of fire in the allelopathic activity of

eucalypts and notes that the effects of fire on this phenomenon are very poorly understood. It has been noted that fire can lead to a stimulation of seedlings under potentially allelopathic trees, and this has largely been attributed to the removal of allelochemicals and/or release of nutrients into the soil (Tshivandekano 1989). Renbuss et al. (1972) suggested that the increase in plant growth is due to the removal of soil micro-organisms by the fire. Promotion of seedling growth after fire is by no means a universal effect, however. Everett et al., 1995 found that burning of slash increased both the hydrophobicity and allelopathic potential of the soil below. Part of the confounding results may well be due to different soil environments and fires of different temperatures. Willis (1999) states that whilst numerous investigators have hypothesized that the improved germination/and or growth on burnt soil may be due to the removal of allelopathic inhibitors, hard evidence for this is lacking.

From the above discussion of fynbos vegetation it can be seen that it is difficult to make conclusions concerning the prevalence of allelopathy. Mapping of alien plant species has indicated that the fynbos biome appears to be more severely invaded than other South African biomes (Macdonald 1984; Versfeld, Le Maitre and Chapman 1998). Several theories have been put forward to explain the susceptibility of fynbos vegetation to plant invasion, although no single theory appears to be fully satisfactory (Richardson, Macdonald, Holmes and Cowling 1992). Allelopathy within indigenous fynbos communities may well be an important ecological factor in structuring plant communities. Whether the specific environmental conditions that characterize fynbos soils would enhance the allelopathic potential of alien plants and hence their invasive success is not clear.

Allelopathy in the riparian zone

As reported in Section 7.3.4, most allelochemicals (although not all – see the example of juglone, Section 7.3.2) appear to be water-soluble in nature. Thus rain (and groundwater) flowing down steep river-banks may result in an accumulation of allelochemicals at the base of these banks. At the same time, in riparian zones, areas that are periodically inundated by streamflow are likely to be leached of allelopathic compounds. The persistence of allelochemicals is likely to be dependent on the physico-chemical nature both of the allelochemical and of the substrate, as well as the climate and inundation regime. Little could be found in the literature specifically on allelochemical effects in riparian zones. Xiong and Nilsson (1997) concluded that leaf litter production (a potent source of allelochemicals) is higher in riparian corridors than in upland ecosystems. At the same time, due to high leaching and microbial activity, decomposition of this plant matter is faster than in upland areas. Consequently, they consider that phytotoxins are unlikely to be important in riparian systems due to leaching or dilution by water. Nevertheless, reports of allelopathic inhibition of phytoplankton in pools of standing water (but not running water) were noted by these authors.

It would appear from the above discussion that the accumulation of allelochemicals and possible allelopathic effects along river banks is likely to be extremely site-specific. Allelopathic activity would depend on the source and target plants involved, the physico-chemical nature both of the allelochemical(s) and the substrate, the inundation cycle of the area concerned, environmental factors (such as rainfall) and localized topography. The large number of variables, in addition to the complex

nature of allelopathy would make it very difficult to predict, for a given site, the importance of this phenomenon. With a deeper understanding of the allelochemicals involved and the environmental factors that mediate allelopathic activity it may be possible to model and predict ecosystem response. At this stage, however, this is premature and attention should rather be directed towards optimizing the control of invasive species in riparian belts.

7.4 THE PLANT SPECIES STUDIED

This section of the report discusses which source and target plants were used in the experiments and the methods used in their cultivation. Recommendations are made for target plants that can be used in future experiments.

7.4.1 The source plants

The alien trees (source plants) that were studied for putative allelopathic effects in this study were:

- *Eucalyptus leucoxylon* and
- *Acacia mearnsii* (black wattle).

Due to time constraints, the allelopathic potential of poplar and pine were not investigated. Of the four genera, *Eucalyptus* and *Acacia* are likely to exhibit the most pronounced allelopathic effects (Coder 1999).

Seedlings of *Eucalyptus leucoxylon* were obtained from the Sir Lowry's Pass River (site SLP 3, Tables 3.1, 3.2). *Acacia mearnsii* seedlings were sourced from various areas near to the Molenaars River as well as from the banks of the Sir Lowry's Pass River. Leaf/bark litter from each alien tree species was collected at the same time as the saplings by gathering the litter from areas underneath heavy infestations of the trees.

In preliminary experiments *Virgilia* sp. (either *oroboides* or *divaricata*) saplings were used as control source plants. *Virgilia* saplings were obtained from the banks of the Silvermine River. Litter from an indigenous small tree and shrub (*Meterosideros angustifolia* and *Rhus angustifolia* respectively) was used in some experiments (Section 7.5) and was obtained from the banks of the Molenaars River.

Cultivation of source plants

The saplings of *Eucalyptus leucoxylon*, *Acacia mearnsii* and *Virgilia* sp. (approximately 0.25 – 0.5 m in height) were planted in plastic pots (18 cm in diameter, 3 litre in volume). The soil used was obtained from a riparian area (Orange Grove, Disa River) that had no history of invasion by alien trees. The plants were grown outside at the University of Cape Town, in an area that received morning sun only. They were watered twice per week and supplied with full-strength commercially-available nutrient solution every second week. The plants were placed in a random design and moved each fortnight to minimize the effect of micro-climate. There was a high rate of mortality and the

plants were eventually moved to a greenhouse. Even under these more favourable conditions there was still gradual attrition of saplings. Of the 25 individuals of each genus that was obtained from the field only nine eucalypts, eleven wattles and no *Virgilia* survived after four months. It is suggested that for future work, eucalypts be obtained from a forestry nursery (none were available during the course of this project). Wattle and *Virgilia* should be grown from seed (this was not a feasible option during this project due to time constraints).

7.4.2 The target plants

The use of Lactuca as a standard target plant

The interference effects of the alien trees (source plants) were investigated on target plants including *Lactuca sativa* (cv. Great lakes). *Lactuca* (lettuce) is not an indigenous species and this presents an inherent obstacle in extrapolating results obtained using these plants to the field. Nevertheless, *Lactuca* was used as a target plant for the following reasons:

- This species has been used in a wide range of studies on allelopathy and results from these experiments can therefore be compared with those in the literature. Thus *Lactuca* was used as a "standard" target plant in these experiments.
- In general *Lactuca* has been found to be very sensitive to allelochemicals (Blum 1999).
- The seeds exhibit a rapid, uniform and reliable germination capacity.
- The plants are easy to cultivate.
- The seed is readily available throughout the year.
- Because of the difficulty in germinating and cultivating indigenous plants, the use of *Lactuca* in conjunction with indigenous target systems ensured at least some results were obtained.

Indigenous target plants

Considerable time and effort was directed towards identifying and sourcing suitable indigenous target plants that could be used in the allelopathy experiments. The aim was to identify indigenous species that are commonly found in riparian fynbos areas so that the potential impact of alien trees could be investigated. Dr Patricia Holmes (Cape Ecological Services, Cape Town) was consulted for advice on suitable indigenous candidates and the project team is greatly indebted for her input in this regard.

The choice of suitable fynbos riparian target plants was governed by practical considerations. Availability of sufficient quantities of seed, ease of germination and cultivation were critical factors in identifying suitable candidates. As far as possible, species with large seeds were avoided since it has been found that these are less susceptible to allelochemicals than are small seeds (Reinhardt and Meissner 1996). Some species were found to be more useful than others. Seed from several species that may potentially be useful in future allelopathic experiments could not be obtained in sufficient quantity during the short term of the project, or else took too long to germinate and establish. A brief discussion is given below of all the target plant systems that were investigated. Also given is a list of plants that were not used, but that may offer possibilities in future studies:

- *Virgilia oroboides* ("keurboom") seeds were germinated successfully during the project and healthy seedlings were cultivated. This species was used as an indigenous target plant in the allelopathy experiments (Section 7.5). Germination was found to be reasonably consistent, although there was a difference depending on seed size. Large seeds germinated more readily than small seeds. The latter often remained hard even after the imbibition treatment.
- *Virgilia divaricata* seeds were also germinated successfully and were used as target plants. The two *Virgilia* species are considered by some authorities to hybridise. *Virgilia oroboides* is generally found in the W. Cape and *V. divaricata* in the E. Cape (Palgrave 2002).
- *Ehrharta calycina* (a perennial indigenous grass) was considered to be a potential useful candidate, since this species, unlike many other fynbos plants is tolerant of nitrogen enrichment in the soil and is often a pioneer after the removal of *Acacia* (Dr P. Holmes, Cape Ecological Services, Cape Town, *pers. comm.* August 2005). Seed was unavailable from commercial sources during the project and so stolons of this species were obtained from the field and were cultivated with reasonable success. It was hoped that these plants could be used as target plants. Preliminary trials, however, indicated that there was considerable failure of individual stolons during transplantation. This meant that it was difficult to separate the effect of transplantation shock from possible allelopathic inhibition (for example from litter mulch of a source plant) and thus this plant system was not used in further trials.
- Seeds of *Brachylaena neriifolia* (a small riparian tree) were obtained from an indigenous seed nursery. According to the seed suppliers (Silverhill Seeds, Kenilworth, Cape Town) this species germinates in the field in autumn. Attempts to germinate these seeds either *in vitro* or in the soil were unsuccessful. Variations to the germination protocol that were tried included imbibing seeds in water (for different lengths of time) before planting, altering the temperature and light regime, and submitting the seeds to a stratification (chilling) treatment. Even placing the seeds in a growth cabinet with the temperature and light conditions appropriate to autumnal conditions did not result in germination. It is possible that this batch of seed was non-viable because success in germinating these seeds has been reported by other researchers (Dr P. Holmes, Cape Ecological Services, Cape Town, *pers. comm.* July 2006).

Other indigenous plant systems (from the fynbos region) that may be of use as target plants in allelopathy studies (Dr P. Holmes, Cape Ecological Services, Cape Town, *pers. comm.* August 2005) are listed below. The seed from these species were unavailable from commercial suppliers at the time of this project. An alternative approach in future work would be to obtain seeds from plants growing in the field. The first two species are serotinous, and thus seed is available from mature plants the entire year (Dr P. Holmes, Cape Ecological Services, Cape Town, *pers. comm.* July 2006):

- *Leucadendron salicifolium*,
- *Berzelia* sp.,
- *Erica caffra* and
- Various members of the family Restionaceae e.g. *Elegia capensis*.

It may be possible to use *Salix mucronata* cuttings as target plant systems if they exhibit consistent regeneration. These cuttings root easily in riparian areas and their use has been considered as a possible rehabilitation strategy.

Cultivation of target plants

In the current project *Lactuca* and *Virgilia* sp were used as the target plants. Pilot experiments were conducted to establish the optimum conditions required for germination. Seeds were germinated both in an *in vitro* system and in the soil. The variables that were investigated included temperature, light regime, volume of water added during imbibition, and control of fungal infections. Similar methods were found to be suitable for germinating both *Lactuca* and *Virgilia* seeds and are described below.

Germination in vitro

The method used was adapted from that of Malan (1999):

First *Lactuca* seeds were surfaced-sterilised by immersing in a 0.5% solution of sodium hypochlorite for 10 min to minimize fungal infection. The seeds were then rinsed twice in distilled water and allowed to drain for a few minutes. In the case of *Virgilia* seeds these were first placed in a glass beaker and hot water (approximately 90° C) added. The seeds were left to imbibe in this water for 24 hrs and were then drained and surface-sterilised as described for *Lactuca* seeds.

Then a piece of paper toweling was folded in four and placed in the bottom of a 500ml plastic container that had been surface sterilized with concentrated sodium hypochlorite. Seeds (either 20 *Lactuca* or 10 *Virgilia*) were spread evenly over the surface of the toweling and then covered with another piece of the same.

The toweling was then moistened with 15 ml of distilled water and the germination containers sealed with air-tight lids, wrapped in black plastic to exclude light and placed in a controlled environment chamber (Temp 25/15° C day/night; 12h/12h light/dark; relative humidity 30%). The position of each container in the growth cabinet was changed every day in order to minimize site effects.

The number of seeds that had germinated was recorded each day. Seeds were considered to have germinated when the radicle length was ≥ 2 mm for *Lactuca* and ≥ 4 mm for *Virgilia* (both *divaricata* and *oroboides*). Assessment of germination was terminated after 10 days for *Lactuca* and 14 days for *Virgilia*. Results were expressed in terms of mean daily germination (MDG), the peak value of germination (PV) and the germination value (GV) according to the method of Czabator (1962).

Where MDG represents the *completeness of germination* and is given by:

$$\text{MDG} = \frac{\% \text{ Final germination}}{\text{Total no. of test days}}$$

Where PV represents the *speed of germination* and is given by:

PV = maximum T value

And $T = \frac{\% \text{Cumulative germination on a given day}}{\text{No. days since the beginning of the test}}$

Where GV represents the composite germination value and is given by:

GV = MDG X PV

7.5 EXPERIMENTAL APPROACHES USED AND RESULTS OBTAINED

This section discusses the experimental design used to investigate the allelopathic potential of *Eucalyptus leucoxylon* and *Acacia mearnsii* on *Lactuca* and *Virgilia*. Because of the difficulty in demonstrating allelopathic effects in plant systems, four different approaches were used to answer the questions posed in Section 7.2.1. Namely:

- Tree litter experiments (Section 7.5.1),
- Sapling experiments (Section 7.5.2),
- Soil experiments (Section 7.5.3) and
- Leachate experiments (Section 7.5.4).

For each approach the methods employed and the results obtained are presented, followed by a discussion of the implications of those results. Section 7.6 draws together the overall conclusions from the experiments.

7.5.1 Approach 1: The effect of alien tree *Litter* on target plants

Introduction

Deposits of litter (leaves, twigs, fruits/seeds) are usually found beneath thickets of *Eucalyptus* and wattle covering the soil surface. Such plant litter has been identified in the literature (Section 7.3.8.1) as a common source of allelochemicals, which may potentially affect the germination and establishment of colonizing plants. The aim of this section was to answer the question

"What is the effect of incorporation of invasive species litter in the growth medium on the establishment of colonizing species"?

An answer to this would guide management activities in the field – indicating whether, after removal of infestations of the alien trees, the plant debris remaining on the ground surface should also be collected and removed.

Alien tree litter was added as a mulch layer to pots containing seeds of *Lactuca* or *Virgilia* and the effect on germination and growth examined. Two different control treatments were examined namely; no litter and litter from non-alien trees - termed "indigenous litter" (mainly a mixture of *Metrosideros angustifolia* and *Rhus angustifolia* leaves and twigs obtained from the field - Section 7.4.1).

Method

The following method was used:

- Gravel chips, followed by 190 ml of uncontaminated soil (Section 7.4.1.1) were added to small (270ml) plastic containers.
- Either 3 *Lactuca* or 2 *Virgilia* seeds per container were placed on the soil surface and covered by more soil (to a depth of 10 mm).
- The effect of the alien tree litter on seed germination was examined in one treatment group and the effect on seedling growth in another. In the case of the germination effect group, the litter mulch was placed immediately after planting the seeds. In the second (seedling growth effect) group, seeds were first germinated *in vitro* (Section 7.4.2.3) and were transplanted into the containers five days later. Mulch was placed on the soil surface after the seedlings emerged from the soil, and the cotyledons (in the case of *Virgilia*) or leaves (in the case of *Lactuca*) had grown to just above the rim of the pots (approximately four days after planting).
- All sources of litter were first coarsely macerated by passing through a commercial plant shredder and mixed to ensure homogeneity. It was then air-dried and stored at room temperature prior to use. The litter was dark brown in colour (i.e. not fresh). In both treatment groups, the volume of litter added to the soil surface of each container was approximately 80 ml (a thickness of approximately 20 mm). For the no-litter control 80 ml of soil were used.
- Four different treatments were investigated, namely, addition of i) *Eucalyptus* litter ii) *Acacia mearnsii* litter iii) litter from an indigenous source or iv) no litter (control). There were 8 replicates for each treatment.
- The seedlings were grown in the greenhouse at the Dept. Botany, UCT. Placing of the containers was randomized and changed every week to minimize the effect of micro-habitat on plant growth.
- The experiment was terminated after 6 weeks. The effect of litter on the germination of the target plants was examined by counting the total number of seeds that had germinated per treatment, the effect on germination rate was determined by recording the number of seeds germinated each day.
- The effect of alien tree litter on the growth of the target seedlings was examined by measuring radicle and plumule lengths on harvesting. The seedlings were weighed after drying for 24hrs at 105°C to determine biomass.

Results

The results from these experiments are summarized in Table 7.1. In the case of germination of *Lactuca* seeds, the highest total germination occurred in the control group that had no mulch (although this was not statistically significant). There was no difference in shoot, root length, or shoot to root ratio in any treatment group relative to the controls. A statistically significant difference (ANOVA, $p <$

0.05) was found, however, in seedling biomass. The presence of *any* litter appeared to reduce seedling biomass compared to the (no litter) control (Tukey honest significant difference test for unequal n , $p < 0.05$). The biomass of seedlings grown under *Eucalyptus* litter was found to be significantly lower than the biomass of seedlings under wattle litter, but neither of these differed significantly from the indigenous litter seedling biomass (Figure 7.2).

In the case of germination of *Virgilia* seeds, no statistically significant effects were recorded with regard to the *extent* of germination (Table 7.1). Furthermore no effect was recorded on the *rate* of seed germination for either of the target plant species (results not shown).

With regard to the seedling establishment experiment, there was considerable loss of *Lactuca* seedlings that were germinated *in vitro* and then transplanted to the containers (indicated as “% plants survived” in Table 7.1). This occurred amongst all the litter treatments. In the case of the *Virgilia* seedlings however, these transplanted successfully, and 100% plant survival was obtained. None the less, no significant effects were noted in shoot length, root length, or shoot:root ratio for either *Lactuca* or *Virgilia* in the seedling establishment treatment. *Virgilia* seedling biomass, however, was significantly lower in the presence of *Eucalyptus* litter compared to wattle litter.

Discussion

The results from the above experiments indicate that the presence of litter, whether from *Eucalyptus*, wattle, or an indigenous source, does not appear to have a marked effect on seed germination or seedling establishment. Slight inhibition was exhibited by *Eucalyptus* litter under some circumstances, however.

For example, the biomass of lettuce seedlings that were germinated in the presence of eucalypt mulch was reduced (an effect that was not recorded if seeds were germinated elsewhere). *Eucalyptus* litter also significantly reduced the biomass of *Virgilia* seedlings.

Table 7.1 The effect of plant litter on germination and seedling growth of *Lactuca* and *Virgilia*. Bold = significantly different (Tukey honest significant difference test for unequal n , $p < 0.05$).

Seed germination treatment											
Target plant	Litter treatment	% Seeds germinated	SD	Shoot length (cm)	SD	Total length	SD	Shoot:root	SD	Biomass (dry)	SD
<i>Lactuca</i> seeds	<i>EUCALYPTUS</i>	70.4	42.3	4.8	0.9	19.4	3.3	0.250	0.041	0.058	0.018
	WATTLE	79.2	30.5	6.1	1.9	20.3	4.0	0.300	0.058	0.080	0.042
	INDIGENOUS	75.0	35.0	5.9	0.9	20.3	3.2	0.301	0.086	0.081	0.018
	NO LITTER	100.0	10.0	6.1	1.3	20.4	2.8	0.299	0.051	0.112*	0.031
<i>Virgilia</i> seeds	<i>EUCALYPTUS</i>	92.9	18.9	5.6	1.4	19.4	3.2	0.290	0.037	0.157	0.047
	WATTLE	81.3	37.2	5.3	2.2	17.1	6.7	0.340	0.271	0.147	0.057
	INDIGENOUS	64.3	37.8	4.9	2.2	17.4	6.7	0.253	0.104	0.167	0.075
	NO LITTER	66.7	40.8	4.7	2.0	16.2	6.3	0.259	0.097	0.154	0.078
Seedling establishment treatment											
Target plant	Litter treatment	% Plants survived	SD	Shoot length	SD	Total length	SD	Shoot:root	SD	Biomass (dry)	SD
<i>Lactuca</i> seedlings	<i>EUCALYPTUS</i>	71.4	30.0	6.6	0.9	23.3	5.7	0.282	0.047	0.093	0.024
	WATTLE	66.7	17.8	6.2	2.3	22.2	4.4	0.275	0.082	0.126	0.063
	INDIGENOUS	79.2	24.8	6.9	1.5	22.7	2.8	0.302	0.057	0.120	0.053
	NO LITTER	87.5	17.3	6.2	1.4	20.9	2.0	0.297	0.059	0.097	0.041
<i>Virgilia</i> seedlings	<i>EUCALYPTUS</i>	100		5.1	1.2	19.4	1.9	0.262	0.056	0.190*	0.045
	WATTLE	100		6.9	1.4	21.9	1.5	0.312	0.053	0.280	0.057
	INDIGENOUS	100		5.6	1.0	21.4	2.5	0.260	0.036	0.211	0.037
	NO LITTER	100		5.1	1.7	20.5	2.9	0.247	0.075	0.230	0.069

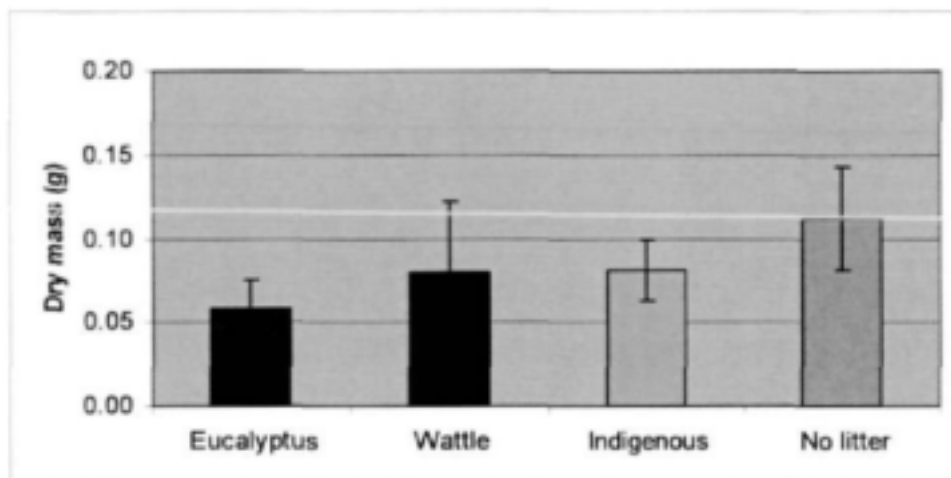


Figure 7.2 The effect of plant litter mulch on *Lactuca* seedling biomass.

There are a number of factors that need to be kept in mind when extrapolating the above results to the field, however. The use of plant mulch to reduce germination of ruderal (weed) plants is an age-old practice and it is therefore not surprising that germination of seeds (*albeit* not statistically significant) was higher in the no-litter treatment. The application of litter to the surface alters the amount (and spectral quality) of the light reaching the seeds, which in turn has an effect on germination. It should be noted that other parameters are also changed, and there are many co-linearities on adding plant debris to soil. Similar inhibition effects may be due to physico-chemical (e.g. nutritional, soil temperature and soil moisture) and biotic (e.g. microbial) modifications associated with increasing plant debris in the soil. For example, as the amount of added debris is increased, soil temperature is likely to decline, soil water content to increase, and many chemicals are likely to be released into the soil including phenolics, nutrients, carbon. Therefore, the potential presence of allelochemicals leached from the litter is not the only factor that differs between the control and treatment groups. According to Blum (1999) allelopathic interactions cannot be definitively proved in litter experiments – and such plant debris experiments are deceptively simple. Nevertheless such experiments do represent a starting point from which to examine the possibility of allelopathic effects.

Of the three types of litter used, *Eucalyptus* plant debris, does seem to exert the most potent effect on plant growth. Seedling biomass was usually the lowest of all the treatments when a layer of *Eucalyptus* mulch had been applied. Litter from wattle and an indigenous source did not greatly affect seedling establishment. Similar results were found by Pieterse (1997) who examined the effect of *A. mearnsii* leaf mulch on pot-grown wheat and maize.

To minimize the differences between the environmental parameters experienced by the source plants in the treatment and controls, some researchers have used washed (inactive) plant debris. In such experiments, litter is first washed several times in water to remove potential allelochemicals (but also

other organic and inorganic substances). This approach was not used in these experiments because it is difficult to ensure that all chemical constituents are removed.

The physical nature of the litter obtained from different tree sources, can also vary. The litter from *Eucalyptus*, for example, is coarser than that from the indigenous shrubs and wattle. This in turn can affect the mechanical resistance experienced by seedlings as they grow through the mulch layer. In addition, from observations made on watering the plants, mulch composed of *Eucalyptus* litter has hydrophobic properties which results in water running off the surface. Although this is not likely to be an important factor in pots (where the water runs to the side of the pot and then under the soil surface) in the field this may be significant and contribute to lowered moisture levels under stands of mature trees. Tshivhandekano (1989) noted a similar effect and attributed it to the presence of hydrophobic aromatic terpenes leached from the leaves.

Leaf litter is heterogeneous and is likely to exude a multitude of complex substances. The chemical profile of this leachate may change depending on the age of the litter. In these experiments only litter that appeared to be aged was used (i.e. it was dark in colour). Fresh litter may well be more toxic (see literature review Section 7.3.9). Further experiments could be carried out in which litter is collected in litter traps in order to examine the effect of litter age on phytotoxicity.

The target plants were grown in small containers with soil that was fairly sandy in nature. Allelochemicals have been demonstrated to persist longer in loamy soils than in sand (del Moral and Muller 1970). In addition, the containers were watered frequently in order to prevent moisture stress inhibiting germination and seedling establishment. Thus allelochemicals released from the litter may have been leached out of the pots.

7.5.2 Approach 2: The effect of alien tree saplings on target plants

Introduction

This experiment investigates the allelopathic potential of root exudates from juvenile invader plants, and is thus directed at the question (Section 7.2.1):

*"Do young saplings of the invasive alien trees under consideration (*Eucalyptus* sp. and *Acacia mearnsii*) exert an interference effect on colonizing plants growing nearby?"*

Studies have shown that allelopathic activity of source plants varies with age (Section 7.3.8). Thus it is possible that the alien species do not exude allelochemicals when still young, in which case no inhibition of target species will be observed. The answer to this question will guide management interventions by indicating whether, in order to encourage recolonisation of natural vegetation, saplings of alien trees in, addition to mature trees need to be removed. This in turn would indicate the need for follow-up activities after clearing.

Method

Young saplings of *Acacia mearnsii* and *Eucalyptus leucoxylon* were obtained from infested riparian sites and cultivated as described in Section 7.4.1. Two control treatments were initially employed in these experiments namely; pots containing the indigenous plant *Virgilia oroboides* and pots containing no sapling tree, only soil. There was, however, gradual attrition of the *Virgilia* saplings, and ultimately there were insufficient saplings left alive to obtain statistically viable results (Section 7.4.2).

To prevent competition for nutrients and water, these were supplied in excess, thus all pots were watered twice per week with tap water and with nutrient solution once every second week. The plants were laid out in a randomized design, and the pots moved every second week to minimize localized habitat effects.

After a period of four months for the saplings to establish, four *Lactuca* seeds per pot were planted. Initial experiments showed that the target plants were prone to under-watering, therefore a 2 cm layer of the appropriate litter mulch was then added to the soil surface. In the case of controls (i.e. no sapling), a layer of plastic beads was added to help retain moisture.

The number of germinated seeds was recorded every third day.

The experiment was terminated four weeks after planting and the following parameters measured:

- Number of seedlings surviving;
- Seedling length (shoot and total);
- Seedling biomass (plant material oven-dried for 24hr at 105°C);
- The above experiment was repeated using the same alien saplings one month later. The mulch layer was removed, as were any *Lactuca* plants. The pots were fertilized and left for a period of two weeks. Three *Virgilia* seeds per pot were planted as the target plants, and a layer of fresh mulch applied to the soil surface;
- At the end of this experiment, all source and target plants were removed. The uppermost layer of mulch was also removed from each pot. The remaining soil was mixed until homogeneous, a sub-sample removed and analysed for pH, resistance, exchangeable cations (Na, K, Ca, Mg), macro-nutrients (N and P) and organic carbon.

Results

Effect on plant growth

The results using firstly *Lactuca* and secondly *Virgilia* as target plants are shown below (Figures 7.3 and 7.4). Neither *Eucalyptus* nor wattle saplings appeared to exert a significant effect and no significant differences were measured between the treatment or control groups with regard to seedling survival. Similarly, no significant differences in seedling length or biomass were recorded (data not shown). In the case of *Lactuca*, maximum seedling survival occurred in the control (no sapling) treatment. In the case of the *Virgilia* seedlings, however, survival was the lowest in the control group.

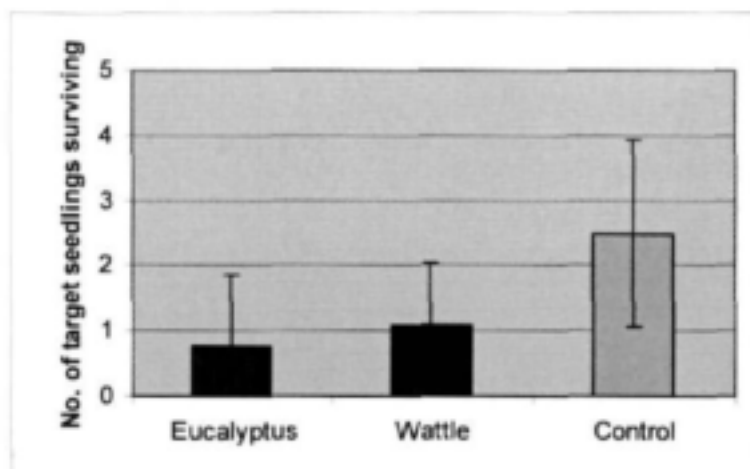


Figure 7.3 The effect of *Eucalyptus* and wattle saplings (and litter) on the survival of *Lactuca* seedlings.

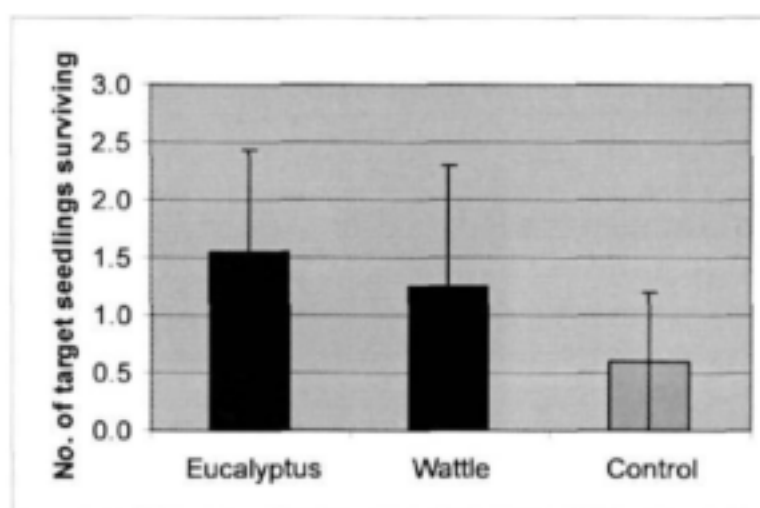


Figure 7.4 The effect of *Eucalyptus* and wattle saplings (and litter) on the survival of *Virgilia* seedlings.

Effect on soil chemical composition

The laboratory results (Table 7.2) for each soil treatment (control, wattle and *Eucalyptus*) were tested for normality within groups and homoscedasticity of variances between groups. They were then compared using either the parametric ANOVA test or the non-parametric Mann-Whitney U test depending on whether or not the assumptions of normality were met. The *post-hoc* Tukey Honest Significant Difference test for unequal sample sizes (Table 7.3) was used to compare individual treatments in the cases where a significant difference between treatments was found.

In order to obtain an overall picture of how similar the soils from each treatment were, multivariate analyses were conducted using only the chemical variable found to differ significantly between samples. The data were normalised and a principle components analysis (PCA) performed on the transformed data. A resemblance matrix based on Euclidean distance was constructed and a 2D multidimensional scaling (MDS) plot constructed.

All treatments were found to have similar (not significantly different) pH, H⁺, Ca, and C values. Only potassium (K) was found to differ significantly between all treatments with the highest concentration of this element in the soil, from the *Eucalyptus leucoxylon* treatment.

The *Eucalyptus* and wattle treatments (i.e. the presence of sapling and litter) significantly decreased resistance and increased the concentrations of K and Na and Mg cations compared to the control (no litter) treatment. Nitrogen concentration was increased slightly compared to the control, but this was only significant in the case of the wattle treatment. Soil concentrations of P (Bray II) were significantly low in the *Eucalyptus* treatment, but wattle treatment had no effect on the concentration of this element.

Table 7.2 Chemical characteristics (means and std dev.) of the soil from the three treatments. * = $p < 0.05$.

Variable	Units	Control		Eucalyptus		Wattle		Sig. Diff
		Mean	SD	Mean	SD	Mean	SD	
pH	-	4.41	0.13	4.47	0.17	4.33	0.16	N
Resist.	Ohm	11986	2269	5664	1053	4978	2696	Y*
H	cmol/kg	0.55	0.05	0.48	0.07	0.53	0.07	N
P Bray II	mg/kg	10.11	1.83	6.11	1.45	10.75	4.56	Y*
Na	cmol(+)/kg	0.02	0.00	0.04	0.01	0.04	0.02	Y*
K	cmol(+)/kg	0.02	0.01	0.06	0.01	0.04	0.01	Y*
Ca	cmol(+)/kg	0.70	0.12	0.68	0.11	0.68	0.13	N
Mg	cmol(+)/kg	0.06	0.02	0.11	0.02	0.13	0.05	Y*
N	%	0.05	0.01	0.06	0.00	0.07	0.01	Y*
C	%	0.47	0.09	0.44	0.08	0.39	0.10	N

Table 7.3 Results of the post-hoc comparisons (Tukey Honest Significant Difference for unequal n) between treatments for the variables found to differ significantly. * = $p < 0.05$.

Variable	p-values		
	Con v Euc	Con v Wat	Euc v Wat
Resist.	0.00*	0.00*	0.79
P Bray II	0.03*	0.90	0.01*
Na	0.00*	0.01*	0.86
K	0.00*	0.01*	0.00*
Mg	0.01*	0.00*	0.47
N	0.35	0.00*	0.08

The first two principle components explained 72.3% of the variation (Table 7.4). The first component is primarily determined by resistance, K, Na and Mg while the second is primarily nutrient (i.e. N and K) based (Table 7.5). The control samples are differentiated from the litter samples along PC1 (i.e. due mainly to differences in resistance, N, Mg and Na) while the eucalypt samples are differentiated from the control and wattle samples along PC2 (i.e. due mainly to K and N, Fig. 7.5).

Table 7.4 Eigenvalues from the principle components analysis

PC	Eigenvalues	%Variation	Cum.%Variation
1	3.42	48.8	48.8
2	1.65	23.5	72.3
3	0.851	12.2	84.5
4	0.614	8.8	93.3
5	0.288	4.1	97.4

Table 7.5 Eigenvectors (coefficients in the linear combinations of variables making up PC's) of the principle components analysis.

Variable	PC1	PC2	PC3	PC4	PC5
Resist.	-0.458	-0.289	-0.117	-0.17	-0.207
P Bray II	-0.191	0.378	0.853	0.011	0.217
K	0.42	-0.435	0.241	-0.192	0.111
Na	0.414	0.051	-0.092	0.767	0.149
Mg	0.41	0.358	0.105	-0.159	-0.805
N	0.289	0.482	-0.339	-0.503	0.47

The multidimensional scaling (MDS) plot of the soil samples shows that the samples from each treatment do separate out from the other treatments (Fig. 7.6). The control and *Eucalyptus* samples form tight groupings while there is more variation amongst the wattle samples.

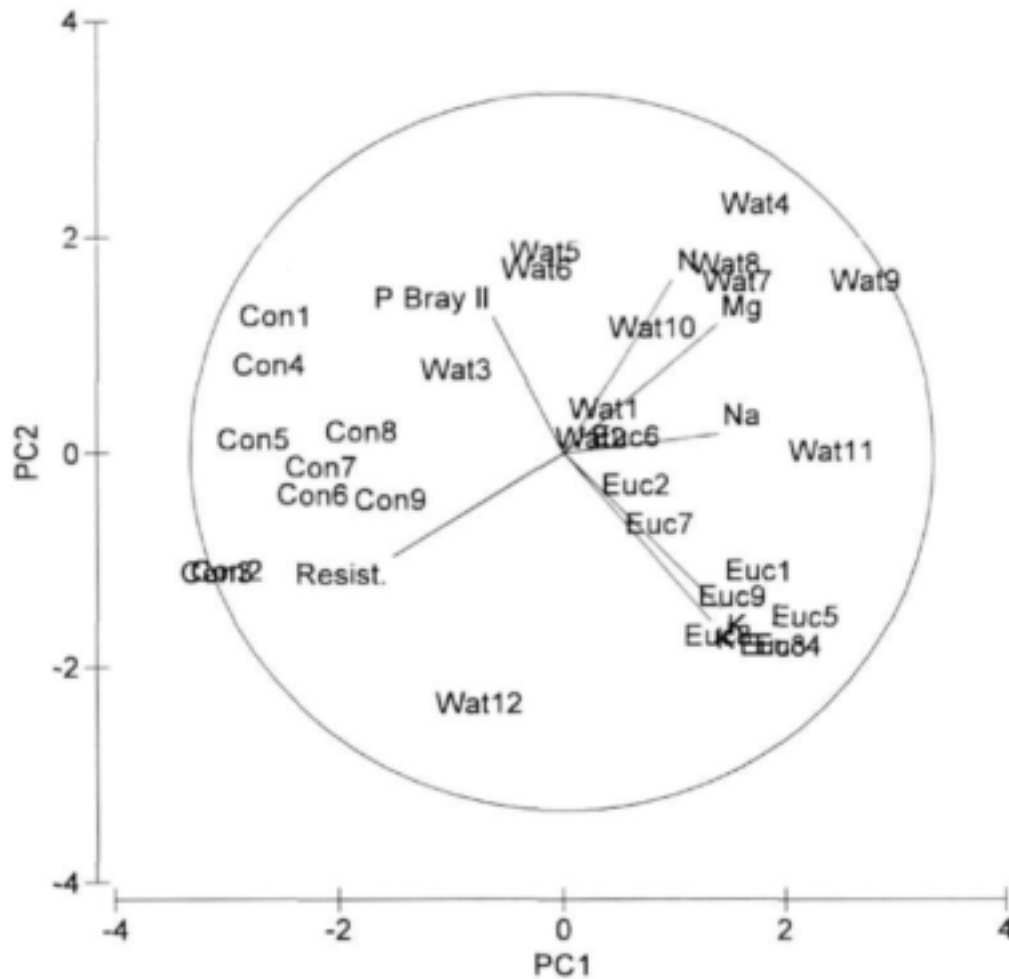


Figure 7.5 The two main principle components.

Discussion

Difficulties were experienced during the course of this experiment with cultivating both source and target plants. As explained in Section 7.4.2 there was a gradual loss of source saplings of all species especially of *Virgilia*. In future work *Virgilia* and wattle saplings should rather be grown from seed as both grow rapidly. *Eucalyptus* saplings should be obtained from a forestry nursery.

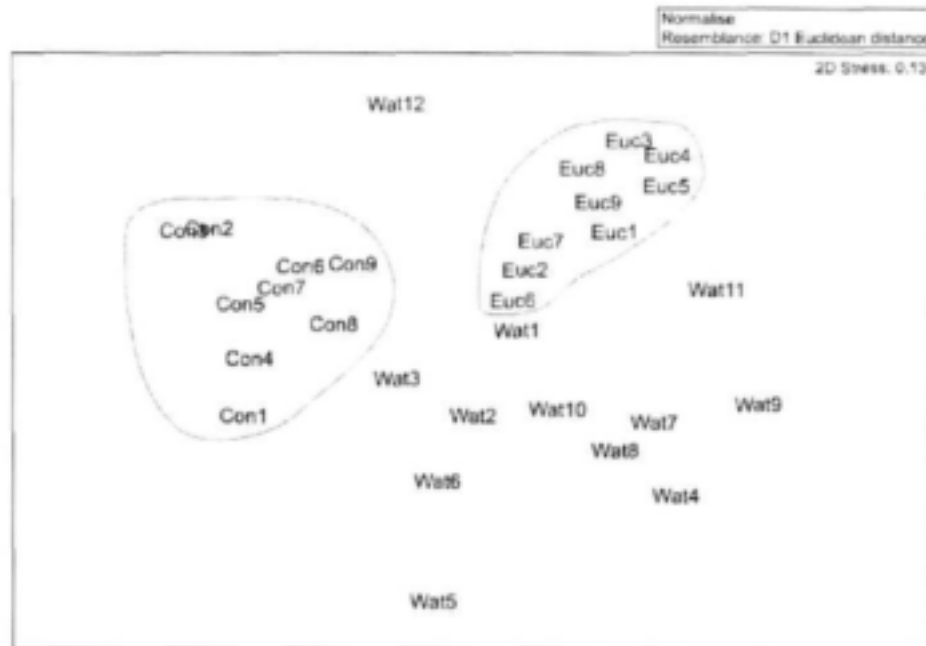


Figure 7.6 Multidimensional scaling (MDS) plot of the soil samples.

There were also difficulties in growing target plants under greenhouse conditions, and loss of seedlings occurred during the hot summer months. Thus the decreased survival of control *Virgilia* plants in the second experiment (carried out in December) compared to control (*Lactuca*) seedlings in the first experiment (carried out in late October/early November) is likely to be due to increased temperature in the case of the *Virgilia* experiment. These results highlight the need to conduct future work under controlled environmental conditions. The initial experimental plan was to omit a mulch layer from the pots in order to examine the role of the saplings as the sole source of potential allelochemicals. Because of the problems with plant moisture stress, the litter mulch was added to promote soil moisture retention. The plastic beads that were used for the controls are considered to be inert with regard to the generation of chemicals, but do help to retain soil moisture. As a consequence, the difference in the physico-chemical attributes of the soil samples may result either from root exudates or leaching of chemicals from the litter, or from both.

No apparent allelopathic effects from the presence of the *Eucalyptus leucoxylon* or wattle saplings or from litter on the soil surface were recorded. This indicates that in the field, young alien trees may not exert an allelopathic effect. This result is also substantiated by the absence of a significant difference in organic carbon levels in the soil samples from the different treatment groups. Caution should be used, however, in extrapolating to the field. Allelochemicals may well have been leached out of the pots due to frequent irrigation (which may not occur in the field). Furthermore, as explained previously, the litter added was not fresh. Further experiments would need to be conducted in the field to examine if there is an increase in the allelopathic potential of *Eucalyptus* or wattle saplings as they mature.

Differences in soil physico-chemical attributes were recorded. Nitrogen levels were significantly

higher in the wattle treatment group, compared to the *Eucalyptus* or control treatments. This is to be expected since *Acacia mearnsii* is a legume and therefore obtains the bulk of this element from nitrogen-fixation. The exchangeable cations (K, Na and Mg) were present in significantly higher concentrations in the *Eucalyptus* and wattle soils compared to the control soil (also reflected in the low resistance for these treatment groups). This may be a consequence of the presence of litter (from either plant source) on the soil surface which gave rise to an overall increase in ions (compared to the inert plastic beads in the control).

One of the most interesting findings was the significantly lower concentration of P in soil from the *Eucalyptus* treatment. Phosphorus is an essential element for plant growth and thus colonizing plants near to *Eucalyptus leucoxylon* stands may suffer P-starvation and fail to establish. Reduced P may possibly be a consequence of the superior ability of *Eucalyptus* saplings to scavenge this element from the soil. This finding requires further study.

Due to the low survival rate of source plant saplings, *Lactuca* seeds were first co-planted with the alien tree saplings, followed by *Virgillia* seeds in the same pots. This is not an ideal experimental protocol since *Lactuca* seedlings may themselves potentially exert an allelochemical effect which could in turn inhibit *Virgillia* seedling establishment. In mitigation of this strategy, no report of allelopathic effects by *Lactuca* could be found in the literature despite the fact that it is commonly used in allelopathic investigations. Nevertheless the slight possibility remains.

7.5.3 Approach 3: The effect of soil from alien saplings on the germination of target plants

Introduction

In the previous approach (Section 7.5.2) to facilitate the establishment of target plant seedlings, pots were well-watered and fertilized. As discussed in the literature review, however, the production of allelochemicals by many plants appears to increase under stressful conditions. To test this hypothesis two *Eucalyptus* and wattle saplings were grown in pots for three months under conditions of low soil moisture and low nutrient levels. The soil was then used as the potting medium for target plants in order to examine whether any allelochemical effect was present in the soil. Thus the aim of this section was to consider the question posed below, with specific reference to the role of environmental stress on allelopathic potential:

"Do young saplings of the invasive alien trees under consideration (Eucalyptus sp and Acacia mearnsii) exert an interference effect on colonizing plants growing nearby?"

Method

- Saplings (obtained as described in Section 7.4.1) of *Eucalyptus* and *Acacia* were grown in the open for 3 months under conditions of low soil moisture and no fertilization. Two saplings from

each group were selected, the soil for each species was combined, mixed well and used as the growth medium in further planting activities.

- Three lettuce seeds per container were planted as described in Section 7.5.1, and a mulch layer (2 cm deep) of the appropriate litter added.
- Control soil was used from a pot that contained no source plant. No mulch was added.
- The containers were watered with the same volume of water each day (and nutrient solution once per week).
- The number of germinated seeds was recorded every three days. Seedling length and biomass were determined on harvesting.

Results

This experiment could only be carried out using *Lactuca* seeds, due to a lack of enough *Virgilia* seeds. Furthermore the experiment with *Lactuca* was terminated early due to the seedlings being infected by a fungal disease. Table 7.6 therefore shows only initial germination results.

Discussion

These initial results indicate that some factor in the soil in which alien saplings had grown inhibited *Lactuca* seed germination or growth. Alternatively, allelochemicals may have been leached from the litter mulch. Furthermore the results suggest that germination was slower in the *Eucalyptus*-contaminated soil than in wattle-contaminated soil. Further experiments are required to substantiate these results.

Table 7.6 Effect of source of soil on *Lactuca* germination.

Soil source	Average number of germinated seeds/container	
	10 days after planting	15 days after planting
Control soil	1.3	1.5
<i>Eucalyptus</i> soil	0.08	0.4
Wattle soil	0.42	0.42

This type of experiment could also be carried using soil obtained from the field (Section 7.8). Soil could be obtained from under alien trees and from a nearby "uncontaminated" site. This approach was considered for the present project, however, there is an inherent difficulty in establishing suitable controls. Soil is notoriously heterogeneous in composition and to ensure that the only difference between the control and treatment soil is the proximity to *Eucalyptus* or wattle stands may be problematical. Nevertheless this approach has merit and should be pursued in the future (Section 7.8).

7.5.4 Approach 4: The effect of litter leachate on the germination of target plants.

Introduction

As noted previously, leaf litter in various stages of decomposition has been reported to inhibit the germination and growth of other plant species. The aim of this section, therefore, was to answer the question:

"What is the effect of incorporation of invasive species litter (leaves, twigs, bark etc.) in the growth medium on the establishment of colonizing species?"

In previous approaches, litter was used as mulch in pots and the effect on seed germination and seedling establishment investigated. In this section, an alternative approach is described in which leachate is prepared from the litter of both alien and indigenous trees and the effect on germination in an *in vitro* system examined. Environmental conditions that may affect this process can be more closely controlled in such bioassays compared to pot or field experiments. The extraction procedure used in the experiments was standardized as far as possible in an attempt to obtain leachate that was reproducible in terms of composition. The following aspects of the extraction procedure were kept constant from one bioassay experiment to the next:

- The mass of litter added per volume of water,
- the length of time litter was left to soak in that water,
- the stirring procedure,
- ambient temperature during the extraction procedure.

Despite these efforts to standardize the extraction protocol it was recognized (and supported by pH and conductivity readings from the leachate) that the chemical composition was likely to vary from one extraction to another. For this reason, careful consideration was given whilst analyzing the results before combining the results from different experiments (see later).

Method

- *Eucalyptus leucoxylon*, *Acacia mearnsii* and "indigenous litter" were used in these experiments (Section 7.4.1). Litter moisture content was determined by oven-drying a sub-sample (in triplicate) for 48hr at 105°C according to the method of Gonzalez, Souto and Reigosa (1995).
- Leachate solutions were prepared as detailed in del Moral and Muller (1970). The well-mixed litter was soaked in distilled water (1:10 mass/mass) for 18hr at room temperature. The litter was stirred for approximately 1 min on adding distilled water and then left to stand overnight.
- The following morning the leachates were filtered through Schleicher and Schuell 602 EH filter paper.
- Three different dilutions, namely 100%; 50% and 10% of each litter leachate were prepared. The pH and conductivity of each leachate solution was measured immediately after preparation using a Hanna HI 9025 pH meter and YSI EC300 conductivity meter respectively.

- *Lactuca* or *Virgilia* seeds were germinated *in vitro* according to the standard protocol described in Section 7.4.2. For the control treatment, 15 ml of distilled water were added to each germination container, whereas for each treatment, 15 ml of the appropriate leachate solution were added. For each treatment, at least three replicates per treatment were prepared.
- The germination containers were placed under constant environmental conditions as described in Section 7.4.2. Each day, the number of germinated seeds was recorded. The standard germination parameters were calculated.
- The first experimental protocol examined the effect of leachate from *Eucalyptus* and indigenous litter (100%, 50% and 10% dilutions) on the germination of both *Lactuca* and *Virgilia*. The experiment was then repeated using leachate prepared from *Acacia* and indigenous litter sources. The results were examined for significant difference using the Mann-Whitney U test in STATISTICA. This is a non-parametric equivalent of the ANOVA test and was used on account of the small sample size.
- In a subsequent experimental, the effect of imbibition in leachate was examined on *Virgilia* seeds. Thus rather than placing the seeds in hot water and leaving them in this liquid overnight (Section 7.4.2.3), the seed coat was scarified by making a small incision with a scalpel blade. The seeds were surface sterilized and then placed in a sample of leachate (either *Eucalyptus*, wattle or indigenous) of a given strength (100%, 50% or 10%) and left overnight at room temperature. The seeds were then again surface-sterilised and germinated according to the standard procedure.

Results

The germination parameters examined were Mean Daily Germination (MDG) which gives an indication of the *extent* of germination and the Germination Value (GV) which gives an indication of the *rate* of germination (Section 7.4.2). In the initial experiments (results not shown) seedling biomass and length was measured. No significant difference was found with regard to these parameters and this aspect was investigated no further.

Lactuca seeds germinated rapidly and consistently under control conditions (i.e. imbibition in water) and an average of 97% germination was usually achieved within 5 -7 days of the start of imbibition. *Virgilia* seeds on the other hand, as expected from a non-cultivated species, exhibited greater variation in the percentage germination under control conditions. From observation, there was a large variation in seed size for this species, and the smaller *Virgilia* seeds often remained hard after the imbibition treatment and did not germinate. *Virgilia* seeds were also slower to germinate compared to *Lactuca* and only reached the maximum percentage germination approximately 12 days after imbibition. As a result of this, and because a smaller number of seeds per container were used, the MDG value (i.e. the total number of seeds germinated divided by the number of days to maximum cumulative germination) was higher for *Lactuca* than for *Virgilia* (Table 3).

The results for the controls from the two different experiments were combined because of the low variability (Table 7.7).

Table 7.7 Comparison of results obtained for the control treatment

	Exp 1	Exp 2	Combined
<i>Lactuca</i>	MDG = 9.67 ± 0.29 GV = 838 ± 53 n = 3	MDG = 9.67 ± 0.58 GV = 873 ± 133 n = 3	MDG = 9.67 ± 0.41 GV = 856 ± 93 n = 6
<i>Virgilia</i>	MDG = 6.67 ± 0.44 GV = 63 ± 12 n = 3	MDG = 6.15 ± 1.09 GV = 58 ± 6 n = 2	MDG = 6.46 ± 0.69 GV = 61 ± 9 n = 5

Two sets of results for the indigenous litter treatments were also obtained (Table 7.8). A greater variation was obtained in these results than for the control treatments above (Table 7.7). This was especially marked in the case of *Virgilia*, and particularly the difference between experiment 1 and 2 using 100% indigenous leachate. Despite this, the values did not appear to be too different and were combined.

After air-drying, and prior to preparation of leachate for the first experiment the moisture content of the litter was determined. The average percentage moisture content of the *Eucalyptus*, wattle and indigenous litter was $28 (\pm 1.8)$; $25 (\pm 2.3)$ and $22 (\pm 3.3)$ respectively and thus did not differ greatly between the different litter sources. Therefore, the mass of litter weighed out to prepare the different leachate solutions was not adjusted to accommodate the difference in moisture content.

Table 7.8 Comparison of results obtained for the indigenous litter treatment.

Seed	Leachate	Exp 1 (n = 3)	Exp 2 (n = 3)	Combined (n = 6)
<i>LACTUCA</i>	100% Indigenous	MDG = 10.00 ± 0.00 GV = 950 ± 50	MDG = 9.50 ± 0.87 GV = 813 ± 160	MDG = 9.75 ± 0.61 GV = 881 ± 130
	50% Indigenous	MDG = 9.50 ± 0.50 GV = 747 ± 143	MDG = 9.83 ± 0.29 GV = 902 ± 48	MDG = 9.67 ± 0.41 GV = 824 ± 127
	10% Indigenous	MDG = 9.67 ± 0.29 GV = 855 ± 126	MDG = 9.83 ± 0.29 GV = 835 ± 77	MDG = 9.75 ± 0.27 GV = 845 ± 94
<i>VIRGILIA</i>	100% Indigenous	MDG = 6.41 ± 0.44 GV = 41 ± 7	MDG = 7.05 ± 1.47 GV = 61 ± 25	MDG = 6.73 ± 1.03 GV = 51 ± 20
	50% Indigenous	MDG = 6.92 ± 0.00 GV = 57 ± 9	MDG = 6.54 ± 0.54 GV = 53 ± 13	MDG = 6.77 ± 0.34 GV = 55 ± 9
	10% Indigenous	MDG = 6.15 ± 0.77 GV = 50 ± 19	MDG = 6.07 ± 0.90 GV = 59 ± 26	MDG = 6.11 ± 0.75 GV = 55 ± 21

Table 7.9 shows the pH and conductivity values for the different leachates. As is to be expected, the specific conductance decreased for each leachate type with increasing dilution. For the most concentrated solutions (100%) *Eucalyptus* leachate exhibited the highest conductivity. All the

leachates were circum-neutral in pH. Some became slightly more acidic with dilution (wattle and indigenous), whereas the *Eucalyptus* became slightly more alkaline on dilution.

The effect of the various litter leachates on the germination parameters for *Lactuca* and *Virgilia* are summarized in Table 7.10.

Table 7.9 The variation in pH and conductivity in different leachate batches.

Leachate	Specific conductance		pH		n
	Mean	SD	Mean	SD	
100% <i>Eucalyptus</i>	173	44	6.04	0.65	2
50% <i>Eucalyptus</i>	93	23	6.28	0.32	2
10% <i>Eucalyptus</i>	23	7	6.36	0.21	2
100% Wattle	139	96	6.25	0.24	2
50% Wattle	74	48	6.17	0.52	2
10% Wattle	18	12	5.90	0.85	2
100% Indigenous	148	80	6.48	0.03	2
50% Indigenous	71	34	6.18	0.3	3
10% Indigenous	24	12	6.09	0.69	3

- For *Lactuca* seeds, there was no significant difference ($p > 0.05$) in MDG compared to the control for any treatment group. Although there was a pattern of increasing MDG with decreasing concentration of *Eucalyptus* leachate, this was not statistically significant. Therefore the extent of germination was not affected by addition of leachate from *Eucalyptus*, wattle or an indigenous source.
- The rate of germination, however, as given by the GV value, was significantly reduced for *Lactuca* seeds imbibed in *Eucalyptus* leachate relative to the control. The effect was most marked for the strongest concentration (100%) of leachate ($U = 0.00$, z adj. = -1.99, $p = 0.05$), less marked though equally significant for the 50% leachate ($U = 0.00$, z adj. = -1.99, $p = 0.05$), and non-significant for the weakest concentration (10%). Consequently, *Lactuca* seeds in the 100% and 50% *Eucalyptus* leachate treatments took a week longer to germinate than the controls or the 10% *Eucalyptus* leachate treatment.
- The rate of germination (GV value) in *Lactuca* was not affected by wattle or indigenous litter leachate of any concentration.
- For *Virgilia* seeds, there was also no significant difference in MDG compared to the control for any treatment group.
- The rate of germination (GV value) for *Virgilia* differed significantly from the controls only for seeds imbibed in 100% indigenous leachate ($U = 0.00$, z adj. = -2.02, $p = 0.04$). This effect was demonstrated only in Experiment 1. For all other treatments the GV value did not differ significantly.

Table 7.10 The effect of litter leachate on various germination parameters for *Lactuca* and *Virgilia* (significantly different results shown in bold). * Results from two separate experiments combined.

Seed	Treatment	No. of replicates	Mean Daily Germination (MDG)	Germination rate (PV)	Germination value (GV)
<i>Lactuca</i>	Control	6*	9.7	88.4	858
	Eucalyptus 100%	3	9.3	21.7	203
	Eucalyptus 50%	3	9.7	37.5	363
	Eucalyptus 10%	3	9.8	91.7	903
	Acacia 100%	3	9.8	81.7	803
	Acacia 50%	3	10.0	85.0	850
	Acacia 10%	3	9.8	85.0	837
	Indigenous 100%	6*	9.7	90.0	873
	Indigenous 50%	6*	9.6	85.2	818
	Indigenous 10%	6*	9.7	86.7	841
<i>Virgilia</i>	Control	6*	6.5	9.4	61
	Eucalyptus 100%	3	6.4	9.7	62
	Eucalyptus 50%	3	6.7	8.7	57
	Eucalyptus 10%	3	7.4	8.3	62
	Acacia 100%	3	6.7	8.7	59
	Acacia 50%	3	6.4	8.3	53
	Acacia 10%	3	6.7	9.6	66
	Indigenous 100%	6*	6.8	7.4	50
	Indigenous 50%	6*	6.7	8.2	55
	Indigenous 100%	6*	6.1	8.7	53

The bioassay experiments in which the seed coats of *Virgilia* were mechanically ruptured rather than imbibing in hot water were not successful. Many of the seeds became infected with a fungus making interpretation of the results unreliable. In addition, many of the seeds that did germinate showed abnormalities in seedling morphology. This approach was therefore not pursued further.

Discussion

Bioassays offer the advantage that variables that may affect seed germination can be more easily controlled than in pot or field experiments. These experiments do suffer from the disadvantage, however, that it is difficult to extrapolate from the laboratory situation to in the field (Reinhardt et al., 1999a). Nevertheless they are useful in yielding some insight into the situation and help to identify substances that are potentially allelopathic. Various authors (Bowman and Kirkpatrick 1986; May and Ash 1990; Inderjit and Dakshini 1994; and others) have used this, or a similar approach. The leachate preparation method of del Moral and Muller (1970) was chosen for use in this study because the original work used *Eucalyptus* litter.

Results from the bioassays indicate that leachate from *Eucalyptus* may well contain a factor that inhibits seed germination. Extrapolating these results to the field, however, is not straight forward.

The *extent* of seed germination was not affected, although the *rate* of germination was reduced. Seeds that germinate more slowly in the field may well be at a competitive disadvantage to those that exhibit rapid germination and this may be manifested as reduced colonization under *Eucalyptus* stands. Further experiments are needed to elucidate these consequences in the field.

Reduction of germination rate was noted only in *Lactuca*, a non-indigenous species that is noted for its sensitivity to allelochemicals (Elakovich 1999). The indigenous *Virgilia* seeds did not exhibit marked inhibition in the presence of leachate from alien trees. It has been documented that large seeds do seem to be less sensitive to allelochemical effects than smaller seeds (Einhellig 1993a; Reinhardt and Meissner 1996). Furthermore *Virgilia* seeds were first imbibed in hot water overnight prior to placing them in leachate. Thus the amount of potentially phytotoxic chemicals entering a *Virgilia* seed in proportion to seed mass is likely to be significantly smaller than for the *Lactuca* seeds (which were imbibed directly in leachate).

In the field, *Virgilia* seeds are likely to imbibe leachate derived from the litter layer. Therefore, in order to reproduce this effect in the laboratory and to increase the proportion of potential allelochemicals entering the seed, the testa was ruptured artificially. This experimental approach was not successful, however, and perhaps other methods for penetrating the testa could be investigated (coupled with more effective sterilization methods). For example, *Virgilia* seeds could be stored in soil for different lengths of time in order to encourage microbially-mediated break-down of the seed coat which would more closely mimic the natural situation.

As noted previously, leachates and compounds released from litter contain a whole range of complex chemicals and this chemical profile is likely to change with time and with the physico-chemical environment. Thus care was taken to standardize the protocol for preparation of the leachate. Nevertheless, there was variation in the pH and conductivity of the various leachate batches, which in turn may have affected the germination parameters that were recorded. In Section 7.5.2 it was reported that the soil nutrient concentrations differed, possibly due to the litter mulch. Thus the leachates may well vary, not only in the concentration of potential allelochemicals, in other physico-chemical properties such as pH, conductivity, osmotic potential, but also in nutrient concentration. Differences in germination parameters may therefore be caused by these factors rather than by the presence of phytotoxic chemicals. It is notable in this regard that the highest reduction in GV was brought about by the leachate solution that exhibited the highest conductivity (100% *Eucalyptus* leachate). Thus the possibility exists that the reduction in the rate of germination of *Lactuca* seeds was brought about not by the presence of allelochemicals in the leachate but because of the high conductivity.

Results from the first experiment indicate that leachate from indigenous litter may exhibit an allelochemical effect. This effect was noted only for *Virgilia*, however, and not for the more sensitive *Lactuca*. In Section 7.3.10 it was reported that fynbos vegetation is well-known for the production of secondary compounds and that such chemicals leach into the surrounding soil. Thus the leaching of potential allelochemicals from indigenous plant debris is not surprising. What is surprising is that

Lactuca seeds were not affected. The *Virgilia* seeds exhibited greater natural variation in germination compared to *Lactuca* and this may have caused an anomalous result. In order to examine this effect more rigorously a larger sample size should be used.

Overall the results from the leachate experiments indicate that leaching of *Eucalyptus* litter may lead to the presence of allelochemicals in underlying soil. Field trials are required to verify this.

7.6 CONCLUSION

Investigations into allelopathy are fraught with experimental difficulties and no single approach is able to demonstrate unequivocally that allelopathy is likely to be taking place. Whilst the use of various bioassays can give indications of potential allelopathic effects, field studies are necessary to confirm if this effect is expressed under natural conditions (Inderjit and Dakshini 1995). Conversely, because of the variability in environmental parameters in the field situation it is difficult to separate potential allelopathic effects from other confounding effects (notably resource competition). Thus a combination of approaches is required.

No definitive proof of an allelochemical effect caused by alien plant debris or by root exudation from saplings was found in this study. Results from *in vitro* bioassays with litter leachate indicated potential phytotoxic effects of *Eucalyptus* on germinating lettuce seed, but not on the indigenous *Virgilia* seeds. At the same time, pot bioassays to which *Eucalyptus* litter had been added showed no definitive phytotoxic effects. Similar disparities have been reported in the literature. Heisey and Delwiche (1985) found leaf extracts of *Trichostema lanceolatum* to be very toxic in petri dish bioassays. But the same leaves when mixed with soil had low allelopathic effects. They concluded that *T. lanceolatum* had low allelopathic potential under natural conditions. Inactivation of phytotoxins in the field compared to *in vitro* experiments may well be due to microbial activity or adsorption to soil colloids (Inderjit and Dakshini 1995).

Considerable difficulty was experienced cultivating both target and source plants – a problem that was exacerbated by the short duration of the project, the difficulty in cultivating many fynbos species, and the lack of controlled environment facilities. This made reproducing experimental results, as well as interpreting the ecological relevance of those results, extremely difficult. Considerable effort should be directed to establishing the routine germination and cultivation of a range of riparian fynbos plants as recommended in Section 7.4.2.2. Furthermore these should exhibit a range of seed sizes, with the emphasis being on small seeds (since they are potentially likely to be more sensitive to allelopathic effects). *Virgilia* seeds are considered to be medium-large in size (P. Holms, Cape Ecological Services, *pers. comm.* July 2006). This may be a reason for the absence of inhibitory effects on *Virgilia* germination and seedling establishment found in this study.

Investigations into the allelopathic potential of *Eucalyptus* and *Acacia mearnsii* in the literature (Section 7.3.9 and 7.3.9) have also yielded conflicting results. This may partly be due to the large number of species (in the case of *Eucalyptus* especially) that occur. It is also likely to be due to the

complex nature of this phenomenon and because in nature allelopathy is likely to operate in conjunction with other interference effects. According to Foy (1999) it may not be possible to prove that allelopathy is operative in a given situation and that it is the *only* responsible factor for the observed pattern.

The results from this study suggest that whilst perhaps *Eucalyptus* at least does show some allelopathic potential this is not an over-riding characteristic. Thus in the field-situation where plant debris and saplings of the alien trees are involved, allelopathy is not considered to be an important factor in prevention of colonization of vegetation. Caution should be employed, however, because the effect of mature trees was not examined in these experiments. There is an urgent need to extend this work to investigate the allelopathic potential of mature trees, especially *Eucalyptus*.

The results from this study indicated that soil P levels may be lowered in the presence of *Eucalyptus leucoxylon* saplings and litter. Thus reduced growth of colonizing plants under stands of *E. leucoxylon* is possibly a consequence of competition for P rather than the presence of allelochemicals. This requires further investigation especially in the context of the fynbos biome which is characterized by low nutrient availability.

7.7 MANAGEMENT IMPLICATIONS

At the beginning of this chapter four questions were posed. The extent to which these questions can be answered is discussed below:

- *Do young saplings of the invasive alien trees under consideration exert an interference effect on colonizing plants growing nearby?*

The results from this project suggest that young saplings probably do not exert an interference effect on establishing seedlings. Field trials are required to confirm this using a range of indigenous target species. The work needs to be extended to examination of the effect of mature alien trees.

- *What is the effect of incorporation of invasive species litter (leaves, twigs, bark etc.) on the germination and growth of colonizing species?*

Results indicate that plant debris from *Eucalyptus* may have some phytotoxic effect on sensitive indigenous species, but that this is not an over-riding effect.

- *What are the implications of the above for the management of alien-infested lands and for clearing programmes?*

Results from the literature review (and from this study) indicate that of the four species examined in the overall project, *Eucalyptus* is likely to exhibit the greatest interference potential.

Allelopathic activity of *Eucalyptus* or *Acacia mearnsii* saplings or litter was not unequivocally demonstrated.

There are indications that *Eucalyptus* may inhibit seed germination and seedling establishment in some situations. The origin of this inhibitory effect is not clear. Although allelopathy cannot be ruled out, this effect may be caused by other processes (for example resource competition).

The establishment of under-storey vegetation may well be improved by removal of *Eucalyptus* litter.

7.8 ROAD MAP FOR FUTURE WORK

In this section a proposed "road-map" for future research into allelopathy is presented. It is divided into three sections:

- Investigative avenues that are considered to be the most important.
- Research approaches that would be useful, should sufficient resources be available.
- Other possible experimental approaches or fields of research.

The road-map has been based on the following premise:

- The most urgent research should not concentrate on demonstrating allelopathic potential of alien trees *per se* but rather be directed towards effective management of these invaders. Any research carried out into allelopathy of alien trees should be in close collaboration with investigation of optimum clearing techniques. This should include field trials and the inclusion of fire – a burn will volatilize the allelopathic chemicals in the litter and promote fynbos recruitment.
- The potential interference effect from alien plant debris and small saplings appears to be low – but this needs to be verified in the field situation.
- The interference potential of mature *Eucalyptus* and *Acacia mearnsii* trees needs to be investigated further.
- Indigenous riparian plants from the fynbos region need to be cultivated and used as target plants in any future allelopathy studies.
- There are many traps for the unwary investigator in the realm of allelopathy. Further investigations should preferably be undertaken by experienced researchers.

Research programme – level 1

- Conduct field trials in which indigenous target plants are planted under infestations of the alien trees. Care should be taken to ensure that the plants receive adequate water and nutrients and that both the treatment and control plots have similar soil. Trenches can be dug lined with plastic so that potential root exudates cannot enter into the soil around the control target plants.
- Repeat the above experiments examining the effect of the presence of plant debris.
- Conduct trials similar to above, except that soil from sites both under alien trees and indigenous trees is removed, taken back to a controlled environment facility and plant trials carried out as outlined in Section 7.5.3. The rate of degradation of allelochemicals in the soil after removal of mature plants also requires investigation. In addition, the hypothesis that the competitive success

of *Eucalyptus* is due to its superior ability to take up P from the soil (Section 7.5.2.4) needs to be examined by conducting soil analyses in conjunction with the above field trials.

- Conduct the above type of experiments in areas that have been cleared by various methods. Include in this work an investigation into the use of fire to remove plant debris. This would involve consideration of different soil types and fire temperature.

Research programme – level 2

The experiments listed above, and in addition:

- An inter-country research thrust in which the allelopathic potential of *Eucalyptus* is investigated both in its native habitat and in South Africa (and possibly in other countries where invasion by this genus is also problematic). A similar approach was used by Hierro and Callaway (2003).
- Pot trials (and *in vitro* leachate experiments) in which a known allelopathic species (e.g. *Salvia* spp) is used. The effect of the alien trees on target plants could then be compared with this.
- In order to enhance the ecological relevance of leachate experiments, seeds could be germinated in soil (both sterilized and non-sterilised) rather than on germination papers. This would enable the effect of soil-related factors on allelopathic responses (including the binding of potential allelochemicals to the soil particles and the effect of soil micro-organisms) to be examined (Reinhardt *pers. comm.* Jan 2006). Different soil types (for example loamy soil versus sandy) could be investigated.
- Root chamber experiments with and without activated carbon to absorb potential allelochemicals.

Suggestions for other experiments

Other possible avenues for research:

- Investigation into the effect of weed tree species on the ecology of soil microbe populations.
- Seedling density experiments such as those carried out by Gentle and Duggin (1997) to distinguish between allelopathy and resource competition (Section 7.3.6).
- An investigation into the allelopathic potential of indigenous fynbos trees.

There are a number of factors that need to be kept in mind when extrapolating these results to the field, however:

- Differences in potential allelopathic effects between terrestrial/upland and riparian areas.
- An investigation into the extent that potential allelochemicals leach into the wetland/river and have an effect on the biota.
- Many allelochemicals, including phenolics, are now commercially available. Based on the allelochemicals that have already been identified from *Eucalyptus* spp and *A. mearnsii* in the literature, it may be possible to obtain these for use as chemical “standards” in experiments. In this way many confusing effects can be avoided. (C. Reinhardt, University of Pretoria, *pers. com.* July 2006).
- Further experiments could be carried out using litter traps in order to examine the effect of litter age on phytotoxicity.

8 CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSIONS

Four objectives were addressed in the research programme. Of these, the first two, constituting the bulk of the research and most of this document, are reported on in Chapters 3, 4 and 5. Two linked minor investigations are reported in Chapters 6 and 7. The findings related to each project objective, and resulting conclusions, are summarised below.

8.1.1 Aim 1: Identify riparian plant communities of undisturbed and invaded riparian zones in Western Cape rivers, and describe their species composition

Two community types were recognised: Riparian Scrub, alternately called 'closed-scrub fynbos', 'hygrophilous mountain fynbos' and 'broad sclerophyllous closed scrub' (Holmes et al., 2005) and Afromontane Forest. It seems likely that these form part of a continuum of riparian communities, linked to age since last major loss of the vegetation and possibly also to altitude and geology (Sieben 2002). The Afromontane Forest sites were all high on the slopes of Table Mountain in gorges that provided some protection from fire and human clearance, whilst the Riparian Scrub sites were mostly in more open landscapes. The Afromontane Forest was at only three sites; this was deemed insufficient to provide a good assessment of reference conditions for this vegetation type or for the impact on it of alien invasion, and so the findings for this group are addressed only briefly. Most of this section focuses on the Riparian Scrub vegetation type.

Riparian Scrub vegetation type

Vegetation data from twelve sites with undisturbed Riparian Scrub vegetation were used to identify four vegetation assemblage types: two on the wet bank, closest to the water (WE = Wet Edge and CF = Channel Fringe) and two on the higher dry bank (TS = Tree Shrub and OT = Outer Transitional) (Section 4.3.2). The reference condition was defined for these, in terms of growth forms, ten indicator species, four small Riparian Scrub tree species and several biological indices: species richness at two scales, relative diversity (J) and equitability (H) (Section 4.4.3; Table 4.22). These characteristics were tested for validity on a further six undisturbed sites, with the conclusion that together they were useful descriptors of the reference condition. The species composition of the assemblage types at all 18 reference sites is provided in Chapter 4 or Appendix 4.3.

In order to identify where the four assemblage types would probably have occurred in invaded or cleared sites, a simple model, the CART model, was developed. This provided physical rules for locating the likely position on the bank of each assemblage type (Table 4.21; Figure 4.36).

The model was used to identify the potential bank location of the same four assemblage types in 17 disturbed sites, and the same character descriptors were developed for each (Table 5.58). The species composition of the assemblage types at all 17 disturbed sites is provided in Appendices 5.1-5.17.

There were considerable differences between the reference condition and the most heavily invaded and most recently cleared sites. For example, comparison of species richness showed that:

- invaded sites generally had lower values than the reference condition (between 3-10 species as opposed to an average 22 at the reference sites);
- sites that had been cleared for five to ten years generally had values that were about the same as those of the reference sites (22.7 ± 5.8);
- sites that had only been cleared within the last one to four years generally had higher values than reference sites, probably reflecting opportunistic invasion of the cleared areas by a range of species, many of which would ultimately disappear again as the riparian community matured (29 to 47 species as opposed to an average 23 at the reference sites).

The other measures of biodiversity - relative diversity (J) and equitability (H) - reflected similar trends.

Species compositions were also different (Section 4.4.2). The wet bank consisted mainly of herbaceous vegetation and graminoids, plus seedlings and saplings of the four typical Riparian Scrub small trees *Metrosideros angustifolia*, *Brabejum stellatifolium*, *Brachylaena neriifolia* and *Morella serrata*. The highest concentration of adults of these small tree species, however, was on the dry bank, suggesting that seedlings might establish themselves indiscriminately but most would be eradicated - perhaps by high flows - before reaching maturity.

A further ten indicator species (Figure 4.34) also characterised the reference sites. None of these occurred exclusively in any one assemblage type, although most were more abundant in one or two. The sedge *Isolepis prolifer* and the shrub *Prionium serratum* were good indicators of the wet bank, and the restios *Calopsis paniculata* and *Elegia capensis* and the shrub *Erica caffra* were common to CF and TS. Three other species *Diospyros glabra*, *Pteridium aquilinum* and *Rhus angustifolia*, were common on the dry bank and most common in OT. *Diospyros glabra* was one of the last indigenous species to persist under heavy invasion.

It was concluded that no one species was an ideal indicator of riparian vegetation as a whole or its component assemblage types. The characteristics described for the reference condition, however, together capture the essence of undisturbed riparian vegetation communities in Western Cape headwaters in the four identified assemblage types.

Identification of the four assemblage types through multivariate analysis was a useful approach for generating some order and generalities out of a considerable body of data. Rules were laid out for how each grouping in the CLUSTER analysis and MDS ordinations was recognised and how it was allocated to an assemblage type. The assemblage types so recognised formed the basis of all subsequent analysis, both of the reference condition and of the impact on it of invasions and clearance. One weakness that emerged from this approach was that catchment signatures were so strong that sites that were not necessarily greatly alike clustered together just because they were in the same catchment.

In the disturbed group B (Figure 5.1), for instance, three heavily invaded sites (Wit3, Mol4 and Ron6) clustered with two cleared sites (Ron5 and Wit4), and so summary statistics of this group masked possible trends in the trajectory of recovery of the cleared sites. Further analysis of individual recovering sites will be done in Mr Reinecke's post-graduate thesis.

The physical location of these assemblage types - through a predictive physical model based on height and distance from the water - was a useful way of addressing the problem of what species should have been at heavily invaded or cleared sites. It worked quite well for most of the sites, but was less effective for sites with floodplain development and not effective at the Afromontane sites because of their steep narrow valley shapes. The model needs further development to work well for a wider range of site types, and a version for the Afromontane sites could only be derived with additional data from more undisturbed Afromontane areas. Further development of the model will be addressed in Mr Reinecke's post-graduate thesis.

Afromontane Forest

Results are tentative because of the small sample size of three sites. The four small Riparian Scrub tree species were missing or in very low numbers at the Afromontane Forest sites. Possible indicator species were suggested from two sites (Table 4.5) and compared to the situation at the one invaded site (Section 5.4.1). Typical growth forms missing from the assemblage types were: tree seedlings from WE; rushes, grasses and adult trees from CF and rushes, restios and small shrubs from TS (Figure 5.2). Of the nine forest species considered to be typically Afromontane, nine were present at the two reference sites and only three, *Rapanea melanophloeos*, *Kiggelaria africana* and *Cunonia capensis*, were present beneath the *Populus X canescens* canopy at the disturbed site (Table 5.55).

8.1.2 Aim 2: Ascertain if each invasive species occurs in one or more lateral riparian vegetation zone

Most disturbed sites had been invaded by, or cleared of, *Acacia mearnsii*, and its typical location within the vegetation can be described with some certainty. Some sites supported other alien species also, but due to their comparative rarity, their typical location is less certain.

Acacia mearnsii (13 sites)

Acacia mearnsii seedlings were present on the wet and dry banks in all assemblage types but were most common in CF, even up to ten years after clearing. Saplings and adults were less common and mostly occurred in CF followed by TS.

Acacia longifolia (9 sites)

Seedlings and adults of *Acacia longifolia* occurred in all four assemblage types. Many saplings were found in CF. Adults were most abundant in TS.

Acacia melanoxylon (6 sites)

No seedlings of this species were recorded at any of the sites. Saplings were most common in CF and adults were equally present in CF and TS.

Acacia saligna (1 site)

In the first year or two after a fire, seedlings of this species recruited *en masse* over the whole macro-channel and floodplain. Five years later after regular annual follow-up clearings, most seedlings had disappeared but a few adults, not cleared, remained at the outer edge of the riparian area in OT.

Pinus pinaster (1 site)

Seedling recruitment took place mainly in TS and OT, following clearing. At the time of sampling a number of uncleared saplings were scattered through TS.

Populus X canescens (1 site)

Seedlings, saplings and adult trees were present throughout TS only.

Eucalyptus leucoxylon (1 site)

Saplings and adult trees were present throughout TS only.

Quercus robur (1 site)

An adult was rooted in WE while seedlings were found in CF.

8.1.3 Aim 3: Begin an exploratory investigation into whether or not allelopathy can be detected in selected common invasive woody alien species, and the possible effects of alien species on common soil variables

The study results suggest that young alien saplings probably do not exert an interference effect on establishing indigenous seedlings. Field trials should be done to confirm this. The work needs to be extended to exam the effect of mature alien trees. With regard to the impact of litter from alien species, the results suggest that litter from *Eucalyptus* may have some phytotoxic effect on sensitive indigenous species, but that this is not an over-riding effect.

In terms of management implications, this study and the general international literature suggest that of the four species examined in the project, *Eucalyptus* probably has the greatest interference potential. *Eucalyptus* may inhibit seed germination and seedling establishment, perhaps through allelopathic influences but possibly also through competition for resources. The establishment of under-storey vegetation would probably be improved by removal of *Eucalyptus* litter.

A proposed road-map for future research into allelopathy, outlined in Chapter 7, has three main thrusts:

- identification of the most important avenues for research;
- suggestions for useful and necessary research;
- other possible experimental or investigatory approaches.

The recommended primary avenue for research is to investigate effective clearing and management of invaders. Any research on allelopathy should be designed to answer questions about clearing techniques. Suggested research topics from the road map are given in Chapter 7.

8.1.4 Aim 4: Monitor the early stages of recovery of indigenous vegetation *in situ* after clearing

In the main study (Chapters 4 and 5), *Calopsis paniculata* was present at a reduced frequency at all disturbed sites. *Elegia capensis* was absent from all invaded areas and only found at the oldest cleared sites despite being present upstream of more recently cleared areas. Similarly, *Erica caffra* was also common to CF and TS but was rare at invaded sites and slow to recover following clearing. The latter two species were the least likely to occur under invasion and during recovery following clearing. *Pteridium aquilinum* was one of the first species to colonise a recently disturbed dry bank and persisted at some of the older cleared sites. *Rhus angustifolia* was most common at cleared sites with older vegetation, and was sometimes more frequent than in undisturbed areas. These and other species specific responses will be explored in more detail in Mr Reinecke's thesis.

From the findings on sites of different post-clearing age, a trajectory of recovery may be hypothesised (Section 5.4.2; Figures 5.3-5.7).

- Phase 1: recruitment of fynbos, scrub and other wet or dry bank species, including aliens and pioneering annuals, takes place in the first year as a flush of new growth.
- Phase 2: herbaceous cover (sedges, rushes, grasses and forbs) establishes between one and four years.
- Phase 3: restios, shrubs and small trees establish in and amongst the herbaceous cover between four and ten years. Woody alien and small Riparian Scrub tree species also establish during this phase.
- Phase 4: long-term recovery occurs that takes longer than a decade because of sensitivity of some species to invasion or clearance, and also due to slow development of a dense canopy cover. *Elegia capensis* and *Erica caffra* are examples of probable sensitive species.

In the secondary study (Chapter 6) sites cleared at least two years previously were investigated to assess how the indigenous vegetation had recovered following three clearing treatments: Fell Only; Fell & Remove slash; and Fell & Burn slash.

All the cleared sites were significantly different to the reference condition for some of the following variables: indigenous cover, species richness and growth form structure. An overlap in species composition between the unburnt treatment plots and the Reference plot indicated that vegetation recovery following those clearing treatments was moving toward natural. The Fell & Burn treatment showed the poorest recovery relative to the reference condition and it is recommended that fires of unnaturally high severity be avoided in the riparian zone by removing some of the felled and dried alien biomass. Of the treatments tested, Fell & Remove appeared to best promote vegetation recovery in the short-term.

8.1.5 Comparing assemblage types to previously reported patterns of lateral zonation

Few studies have described vegetation zonation patterns for Western Cape rivers. Boucher (2002) and Sieben (2002) identified three lateral zones; the aquatic zone, the wet and the dry bank. The wet bank was further sub-divided into the lower sedge and higher shrub sub-zone, while the dry bank had three sub-zones (at increasing elevation); the lower dynamic, the tree/shrub and the back dynamic (Table 8.1). Boucher (2002) described flood-recurrence intervals that maintained each sub-zone for the Breede River and Senqu in Lesotho but did not provide indicator species for these sub-zones. Using Boucher's descriptions, Sieben (2002) sampled species distributions within these sub-zones for a further five rivers near Cape Town on the Hottentots Holland mountain range. In both cases, the sub-zones were chosen *a priori* and subjectively based on species' presence or absence using specialist judgement, whereas in this study the equivalent of the sub-zones – called here assemblage types – were identified and located on the banks objectively through a developed set of rules. As far as can be judged from species information, the two sets of zonation patterns appear to be correlated as per Table 8.1.

Table 8.1 A comparison of lateral vegetation bands on Western Cape river banks.

Bank position	Boucher (2002): sub-zones	This study; assemblage types
Terrestrial	Not addressed	Non Riparian
Dry Bank	Back Dynamic	Outer Transitional
	Tree/Shrub	Tree Shrub
	Lower Dynamic	Channel Fringe
Wet Bank	Shrub/Willow	
	Fringing Sedge	Wet Edge
Aquatic	Rooted Aquatic Macrophyte	Not addressed
	Algae	

Wet Edge and Tree Shrub correlate with Boucher's 'Fringing Sedge' and 'Tree/Shrub' sub-zones respectively. Outer Transitional conforms with his 'Back Dynamic'. Channel Fringe correlates with a combination of his 'Lower Dynamic' and 'Shrub/Willow'. Further work on this and the species present in each will form part of Mr Reinecke's thesis.

8.1.6 Management considerations

Protecting remaining indigenous plants

All the heavily-invaded areas investigated during this study supported a number of Riparian Scrub species beneath the dominant alien canopy. In most cases, except in the most severe states of invasion, the wet bank was abundantly vegetated with indigenous species whilst the dry bank had a few isolated indigenous shrubs and small trees of either *Afromontane* or *Scrub* affiliation. Individuals such as these are important sources of seed in the initial post-clearance recovery. In many areas, most notably on the Molenaars and the Witte Rivers, there was abundant evidence from cleared sites that

clearing programmes had removed indigenous trees as well alien ones. Tree species take far longer to re-establish than do smaller herbaceous species, with the data suggesting that more than a decade is needed to approach natural levels of canopy cover and species composition. Clearing programmes would greatly enhance recovery of the riparian vegetation if all operators could effectively distinguish indigenous from alien species, and protection of indigenous vegetation stocks was a strong priority. This would be more effective on many levels than attempting complex recovery strategies on badly cleared sites.

Re-vegetation strategies

If re-vegetation of cleared areas is attempted, it may be difficult to establish what species should be re-planted. Valuable clues can be gleaned from upstream areas, which would have provided propagules in the past. Failing this, species from neighbouring catchments could be used. As a last resort common riparian species could be planted, and other less common species could be left to colonise the rehabilitated area naturally from the surrounding landscape. A practical manual of concepts and strategies for rehabilitation is needed (Section 8.2).

8.2 RESEARCH RECOMMENDATIONS

Post-clearing recovery patterns of riparian vegetation may differ according to the invading species present, and thus rehabilitation programmes may require different re-vegetation strategies. Several avenues of research could help guide this process.

- Further investigation of the data gathered in this project on possible trends in the trajectory of recovery of cleared sites (Mr Reinecke's thesis).
- Further development of the CART model to capture a wider range of bank shapes and different riparian communities (Mr Reinecke's thesis).
- Further investigation of the data gathered in this project on species-specific responses of indigenous species to invasion and clearance (Mr Reinecke's thesis).
- Further investigation of the data gathered in this project on the characteristics of identified vegetation assemblage types (Mr Reinecke's thesis).
- Data on species distributions and a classification for riparian zones for the Western Cape - and the rest of South Africa. This would allow better selection of appropriate species for rehabilitation in order to protect genetic stocks and catchment identities.
- A practical manual guiding concepts and strategies for riparian rehabilitation.
- Further studies on the impact of fire as a restoration treatment in the riparian zone, especially in relation to fuel loads, season of burn and the interval between felling and burning.
- Further studies on the impacts of different follow-up treatments. For example, manual versus chemical clearing and the impacts of these in relation to initial clearance with and without fire.
- An investigation on the impact of secondary alien invasions by, for instance, kikuyu grass (*Pennisetum clandestinum*) on indigenous vegetation recovery.
- The role of propagules from the surrounding landscape in influencing recovery rate.

Additionally, promising avenues for allopathy research could be as follows.

- Growth trials of indigenous species under alien tree canopies, with and without alien litter, under different soil conditions, and after clearance by a range of methods.
- The rate of degradation of allelopathic chemicals under different conditions.
- Inter-country research on the allelopathic potential of *Eucalyptus*.
- Other research topics as listed in Chapter 7.

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Plate 1 **Four undisturbed site on the Rondegat River.**

Channel

Bank



Ron1



Ron2



Ron3



Ron4



Plate 2

Four undisturbed sites on the Heks River.

Channel

Bank



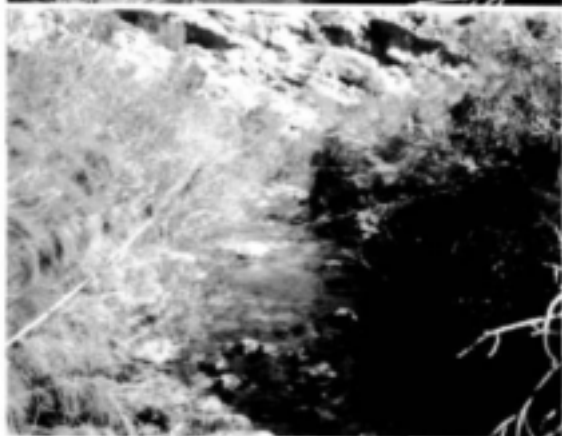
Hek1



Hek2



Hek3



Hek4



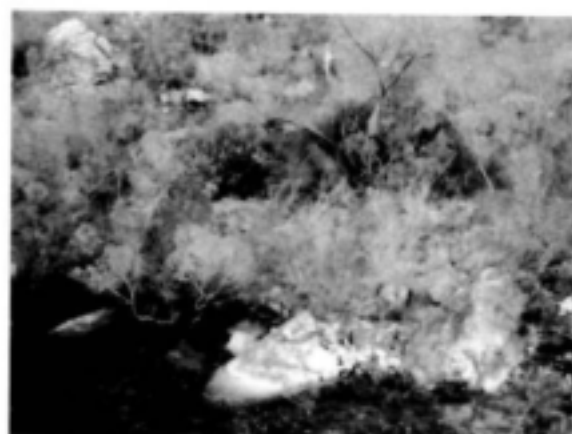
Plate 3 Four undisturbed sites on the Elands River.

Channel

Bank



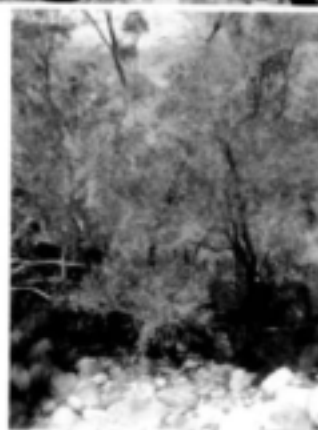
Ela1



Ela2



Ela3



Ela4



Plate 4

A: Two undisturbed sites on the Disa River.
B: Two undisturbed sites on the Eerste River.

Channel

Bank



A



Dis1



Dis2



B



Eer1



Eer2



Plate 5 **Two undisturbed (1 & 2) and two cleared (3 & 4) sites on the Witte River.**

Channel

Bank



Wit1



Wit2



Wit3



Wit4



Plate 6 Two cleared (1 & 2) and one invaded (3) site on the Sir Lowry's Pass River.

Channel

Bank



SLP1



SLP2



SLP3



Plate 7

A: Three cleared sites on the Assegaaibos River.

B: A cleared site on the Cecelia River.

Channel



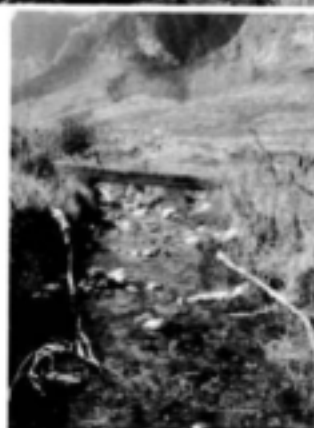
A

Ass1

Bank



Ass2



Ass3



B



Cec1

281



Plate 8 Three cleared (1, 3 & 4) and one anomalous site (2) on the Molenaars River.

Channel

Bank



Mol1



Mol2



Mol3



Mol4



Plate 9

A: Two cleared sites on the Rondegat River.
B: Two cleared sites on the Silvermine River.

Channel

Bank

A



Ron5



Ron 6

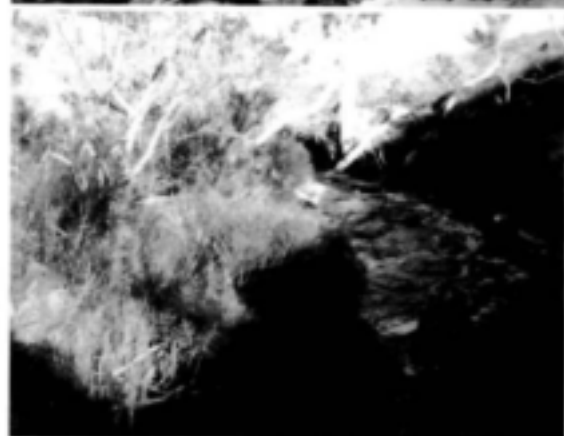


B

Sil 1



Sil 2



APPENDICES

Appendices 3.1, 3.2, 4.1 and 4.2 are located on the CD distributed with this report. Please note that Appendices 4.3 and 5 are in press and will be published by Mr Karl Reinecke as part of his Ph.D thesis. On completion, these will be submitted to the Water Research Commission. WRC Report 1407/1/07, appearing on the WRC web site (www.wrc.org.za), will then be updated with these appendices from where interested parties can download them. Readers may contact the author should they wish to communicate regarding these appendices (karlreinecke@gmail.com).

Other related WRC reports available:

Vol 1: A consultative project to situate, contextualise and plan for a water rehabilitation program in SA, to link this to relevant water-related initiatives; and to trial the Australian procedure for river rehabilitation on a small degraded urban streams

Uys AC

The aims of this project were as follows:

1. Situation/anchoring of river rehabilitation in a South African context and establishment of links with relevant current water initiatives
2. Consultatively developed plan for a long-term program for the development and implementation of river rehabilitation in SA
3. Trialling of Australian river rehabilitation procedures on a small degraded urban river in South Africa.

Aims 1 and 2 are addressed in Volume 1, and Aim 3 is addressed in Volume 2. Volume 1 begins by defining the meaning of river rehabilitation and other related terms to foster the correct general understanding amongst people in the field. This part of the project began with 6 regional workshops which were attended by a total of 150 people. At each of these workshops a number of presentations were made followed by a facilitated discussion. As each of the workshops had a different mix of practitioners, managers, decision makers, consultants and researchers, each of these discussions developed differently. These discussions highlighted a number of areas requiring research, development or application, and these are detailed in the report. In addition, the identified needs were distilled into the terms of reference for a solicited project on the topic.

Volume 2 covers a case study of the rehabilitation of the Ihlanza River, East London. The Ihlanza River runs through the suburbs of East London and discharges into the sea on the city's top surfing beach. It was highly degraded and polluted. Through an extensive process of public participation, funds were mobilized (largely through Buffalo City Metro) to rehabilitate the river. The 12 steps of the process followed are detailed in the report in such a way that they can be followed by others wanting to achieve the same outcome, and include everything from planning and public participation to supervision, monitoring and maintenance on the ground.

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