ASSESSING THE ECOLOGICAL RELEVANCE OF A SPATIALLY-NESTED GEOMORPHOLOGICAL HIERARCHY FOR RIVER MANAGEMENT

by

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EXECUTIVE SUMMARY

Introduction

Rivers are at the centre of our landscapes and lives. In South Africa, they are the source of almost all freshwater which, arguably, is the most limited of the country's resources. Despite this, they are manipulated and used in many ways not conducive to sustainable use of this resource. As the end point of drainage in catchments, they are highly vulnerable to change from land-use and other human activities. Their flow is manipulated, to provide water supplies; barriers are built across and along them for flood control; gabions, walls and canalisation are used to counteract erosion; and the river channels are used as conduits for delivering irrigation water and disposing of wastes. These practices have brought many benefits to society but they have also resulted in widespread degradation of the actual river ecosystems.

Healthy, efficiently functioning rivers provide a wealth of reliable benefits to people, from good-quality water, to resources such as fish and reeds, to recreational pleasure. Poorly functioning rivers gradually lose their valued attributes, require continual expensive remedial actions, or are costly to the nation in other ways, such as through collapsing banks, sediment-filled dams and water-quality problems. Such costs are largely unquantified at a national level but undoubtedly are very high. A reasonable objective might therefore be to maximise benefits from them for society whilst minimising disturbances to them. This is the basis of sustainable use, and requires pro-active management.

Such management of rivers requires a new approach, based on an understanding of their nature and how they function as living systems. The data upon which to develop this understanding is sparse, and generalisations will have to be made for management purposes, at least in the short term.

One generalisation often made for management purposes is that the physical and chemical (non-living; abiotic) attributes of rivers are good surrogates for their biological (living; biotic) attributes. By implication, the plants and animals (biota) that occur in one river with a given slope, altitude, aspect, geology, channel form, and water chemistry, should be present in a similar stretch of all the other rivers in the region. If the first river is undisturbed, then the degree to which the other rivers have not got similar biotas is a measure of the degree to which they are degraded. The underlying assumption is that all the rivers with the same abiotic features will have the same biota, unless they are degraded. This assumption, which is the foundation of river health biomonitoring programmes in South Africa and many other countries, is thus based on using abiotic attributes to infer ecological attributes.

Such inference is useful, not least because abiotic attributes are often more easily measured. Rivers and stretches of rivers could be grouped, and management practices and decisions streamlined, based perhaps on physical attributes gleaned from maps. We could say, for instance, that all stretches of river within the Fynbos Biome of the Western Cape that have a slope of X and are at an a altitude of Y should be ecologically similar, so as long as one has been studied, we know all we need to know to make management decisions about any of them.

But how well do such physical attributes truly reflect the ecological nature of the river systems? If they reflect them accurately, then generalising on river ecosystems based on physical data is a valid and useful management tool. If they do not, then such generalisations could represent a misleading "black-box" approach that is insensitive to the living system, and could guide management decisions that are highly detrimental to it. Clearly, abiotic surrogates should not be a long-term management option until their ecological relevance is well understood.

To aid generalisations of the physical attributes of rivers, fluvial geomorphologists have suggested an hierarchical classification system for them. The system provides a way of grouping (classifying) similar rivers or parts of rivers, based on their physical features. The hierarchy operates over a range of spatial and temporal scales. The *catchment* occupies the coarsest spatial level of the hierarchy, and changes to it occur over the longest time spans. Successively smaller-scale levels are the *zone/segment*; the *reach*; the *morphological unit*; and the *hydraulic biotope*. The hydraulic biotope occupies the smallest-scale level and changes to it occur over the shortest time spans. Each level nests in the one above and is restricted by its characteristics. As an example, fynbos plants typically found on the banks of mountain streams will not be found along a mountain-stream *zone*, if that zone does not occur within a *catchment* in the Fynbos Biome.

The objective of the project reported on here was to assess the ecological relevance of this geomorphological hierarchy. The question we set out to answer was:

Is the geomorphological character of a river a useful guide to its ecological character?

We aimed to ascertain how well the hierarchy aids ecological study of rivers; how sensitive it is to the living parts of rivers; and to what extent it could be used to generalise about rivers for management purposes. The research was carried out using Western Cape fynbos rivers, as their distinctive character and high degree of similarity should minimise "noise" in the collected data.

Project objectives

The project objectives, as agreed in the original contract between the University of Cape Town and the Water Research Commission, and amended at the first steering committee meeting, are summarised below.

1. Assess the extent to which abiotic and biotic river data are collected in ways that limit their use by others.

2. Assess the ecological relevance of the geomorphological hierarchical classification system for rivers.

3. Liaise with similar programmes in other countries, particularly in Australia and Great Britain.

Objective 1 was achieved through a preliminary exercise, designed to ascertain how well scientific data already collected could become part of a linked, geomorphological-biological approach to data collection and management. The report on this investigation is given in Appendix E1.

Objective 3 was the subject of ongoing liaison activities, which were reported upon in each progress report for the steering committee. There was close liaison with Prof. Rowntree and other geomorphologists at Rhodes University throughout the project, culminating in her writing Chapter 6 of this report. Both authors worked with the Abiotic-biotic links team in the Kruger National Park Rivers Research Programme (Appendix E2), and the first author made input to the South African, British and Australian River Health Programmes.

Objective 2 was addressed through a comprehensive research programme that is the subject of this report. Chapters 1-9 provide background information, aims and methods of the research. Chapters 10-15 detail the research results. Chapters 16-19 illustrate additional uses for the methods developed and data collected, and Chapter 20 provides a summary of conclusions and recommendations.

General approach (Chapters 3-9)

The research focused on a site in each of 28 headwater streams in the Western Cape. These were all in the mountain and foothill zones of perennial rivers, in order to standardise study sites as much as possible. Sites were designated "mountain" or "foothill" based on prior biological knowledge of which they were likely to be. All fieldwork was done during summer low flows, when flow and other physical conditions are most stable and the rivers most comparable in hydraulic terms. Eighteen of the rivers had minimal disturbance, and were used to detect underlying trends in physical-biotic links. The remaining ten had specific disturbances, and were used to assess how disturbance affected the trends.

At each of the sites, up to 12 biological samples were collected from the widest possible range of physical conditions, and these conditions were measured in detail. The sites, which ranged from 30-100 m in length, were mapped using eight categories of substrata and 14 categories of flow type, and the location of every biological sample shown (Tables E1 and E2). Aquatic invertebrates were used to provide the biological input to the study, as different species are known to seek different kinds of flow or substrata and by this selectivity should illustrate clear physical-biotic links.

The sampling programme as a whole was designed to assess the ecological relevance of all levels of the hierarchy. Details of the research for each level follow.

Assessment at the level of catchment and zone (Chapter 10)

Catchments and zones were combined in one assessment, using the 13 mountain and five foothill undisturbed sites. An initial assumption was that the invertebrate samples would group by zone: those invertebrates from all 13 mountain sites would be so similar that these rivers would group together, whilst the foothill sites would form a second group. We further assumed that, within each group, there might be sub-groups that would reflect geological or geomorphological differences at the catchment level. In other words, we thought that the main difference in headwater river sites across the region was their position along the river (i.e. which zone they were in).

Table E1. Categories of visually distinct flow types. After Rowntree 1996; Padmore *et al.* 1996; Newson *et al.* 1998; King and Schael this project.

Flow Type	Definition
Free falling (FF)	Water falls vertically without obstruction.
Cascade (CAS)	Water tumbling down a stepped series of boulders, large cobble or bedrock.
Boil (BOIL)	Water forming bubbles, as in rapidly boiling water; usually below a waterfall or strong chute
Chute (CH)	Water forced between two rocks, usually large cobble or boulders; flowing fast with the fall too low to be considered free falling.
Stream (STR)	Water flowing rapidly in a smooth sheet of water; similar to a chute but not forced between two bed elements
Broken standing waves (BSW)	Standing waves present which break at the crest (white water)
Undular standing waves (USW)	Standing waves form at the surface but there is no broken water
Fast riffle flow (FRF)	Very shallow, fast, flickering flow, still covering most of the substrata
Rippled surface (RS)	The water surface has regular smooth disturbances which form low transverse ripples across the direction of flow.
Slow riffle flow (SRF)	Very shallow, slower, flickering flow, still covering most of the substrata.
Smooth boundary turbulent (SBT)	The water surface remains smooth; medium to slow streaming flow takes place throughout the water profile; turbulence can be seen as the upward movement of fine suspended particles.
Trickle (TR)	Small, slow, shallow flow; when occurring with small or large cobbles, flow is between bed elements with few if any submerged.
Barely perceptible flow (BPF)	Smooth surface flow; only perceptible through the movement of floating objects.
No flow (NF)	No water movement.

Table E2. Categories of substrata.

Category	Size Range (mm)
Silt (SI)	< 0.063
Sand (SA)	0.063 - 2
Small Gravel (SG)	2 – 16
Large Gravel (LG)	16 – 64
Small Cobble (SC)	64 – 128
Large Cobble (LC)	128 – 256
Boulder (B)	> 256
Bedrock (BR)	

This initial assumption was revealed as simplistic. In a similarity analysis of invertebrate communities from each site, the sites grouped principally by catchment and not by zone. Mountain and foothill sites within one catchment linked together, rather than with other mountain or foothill sites respectively elsewhere in the region. This individuality of catchments was sufficiently strong to over-ride the differences in invertebrate communities that we know take place down the length of the rivers. We have called this indication of a catchment identity, the *catchment signature.*

At present, the nature and cause of catchment signatures are not understood and, until they are, management decisions should not be based on the assumption that specific rivers can be sacrificed to developments because other similar rivers exist. At present, the only safe assumption is that rivers in different catchments are not similar. In terms of the geomorphological hierarchy, this means that it can only partially guide on river groupings at the highest ecological level within a bioregion. Geographically, it is possible to delineate each catchment on maps, but not to indicate which ones are likely to be biologically similar. This next step might be possible in the future, once catchment signatures are better understood.

Within a catchment, sites displayed a further level of individuality that over-rode the influence of zone, and so caution should be exercised regarding any assumptions of similarity between a catchment's rivers. In terms of the invertebrates, bedrock sites were quite different from the alluvial rivers in the same catchment. As the nature of the riverbed is a physical feature, its details can be incorporated into the geomorphological hierarchy. Such information cannot be gleaned from maps, however, and so cannot be part of a desktop classification but rather requires field identification.

The river zone, far from being the expected over-riding influence on invertebrate distributions within the region, appeared at the third level of differentiation of sites, after catchment and riverbed. Zones are already recognised as one level of the geomorphological hierarchy, and the delineation of zones along the river can be done, using maps in a desktop exercise. The zones should be defined using ecological data, however. This appears to be necessary, as the analyses of zones done in this project by geomorphologists, using such variables as zone class and valley form, did not reflect the biological zones revealed by this study. The relevant ecological data for delineating zones can be gleaned, for any bioregion, from ecological studies within that region.

In summary, the overall ecological natures of the studied headwater streams appear to be dictated by three main factors: the catchment; the riverbed substratum; and the longitudinal zone. The top levels of the geomorphological hierarchy partially incorporate some of these factors, but not sufficiently accurately or comprehensively to allow the hierarchy to be a surrogate for ecological aspects in research and management decisions.

Assessment at the level of hydraulic biotope (Chapter 11)

Hydraulic biotopes (HBs) sit at the lowest level of the geomorphological hierarchy, and are seen as the building blocks for its intermediate levels. They can be envisaged as the small patches of different flow and substratum conditions (tumbling white water over cobble; slow smooth water over sand; and so on) that make up the mosaic of hydraulic conditions at a river site. Once distribution of the biota at this fine scale is understood, it should be possible to seek wider patterns of distribution at the next higher levels of the hierarchy (morphological units and reaches).

After discussions with ecologists, geomorphologists described 11 HBs, that they felt might support different invertebrate communities. In this project, only four of these HBs were shown to be ecologically relevant, with the others being encompassed within the main ones (Table E3).

Table E3. The grouping of geomorphological HBs by ecological HB.

Ecological HB	Geomorphological HB
run	run, fast glide
riffle	riffle
rapid	rapid, cascade, chute, waterfall, boil
pool	backwater, slack water, pool, slow glide

The characteristics of the four broad-ranging HBs can be summarised as follows (Table E4).

Table E4. Definition of each biologically-defined hydraulic biotope (HB) by depth (m), flow types, substrata, mean water column (0.6) velocity (m s^{-1}), and Froude number. Flow-type codes as per Table E1.

HB	Depth (m)	Flow Description	Substrata	Mean Velocity m s^{-1}	Froude Number	Comments
Rapid	shallow to deep: up to 0.70	turbulent, broken water: CAS, USW, BSW, CH, STR, FF, FRF, some fast RS	boulders and large cobbles	0.38 – 0.64	0.371 – 0.900	CAS is the dominant flow type; CH and FF are unique to this HB
Riffle	shallow: <0.30	fast, flickering flow: FRF, USW, BSW, CAS, some fast RS	cobbles and sometimes small boulders	0.27 – 0.39	0.332 – 0.425	FRF is the dominant flow type.
Run	shallow to moderately deep: up to 0.50	fast to moderately fast rippled flow: RS, SBT, some FRF	a range of substrata	0.05 – 0.19	0.070 – 0.200	RS is the dominant flow type.
Pool	shallow or deep: 0.03 - >1.00	slow, smooth flow: SBT, BPF, rarely NF	a range of substrata	0.00 – 0.10	<0.070	Bedrock and alluvial pools may have different species assemblages

In summary, the lowest level of the geomorphological hierarchy, which focuses on *the hydraulic biotopes of invertebrate communities,* distinguishes more HBs than the four that can be justified from the ecological data. Within the ecological HBs, however, individual species might inhabit slightly different hydraulic conditions. For this reason, it is suggested that another level of the hierarchy could perhaps be added, to describe the *hydraulic habitat of individual species*.

The four ecological HBs could form the basis for biomonitoring programmes in headwater streams. They are reasonably easy to distinguish on the ground, and present the four main instream conditions found in such streams. Each HB can be distinguished visually, but this should be done by judging the overall appearance of the flow as no one HB is uniquely described by one flow type (Table E4). To ensure collection of the greatest possible range of species, the full range of micro-environments within each HB should be sampled. This kind of broad-spectrum sampling of an HB is not suitable for species studies, because details of the specific micro-habitats will be lacking.

Finally, the analysis of HBs incorporated all 380 invertebrate samples, rather than a summary of them per site as used for the catchment analysis. This analysis revealed that the samples grouped by river as well as by catchment, and so *river signatures* exist as well as catchment signatures. In other words, in ways and for reasons not yet understood, every river is different.

Assessment at the level of morphological unit (Chapter 12)

Morphological Units (MUs) are the channel features one scale-size higher than HBs. Good examples are waterfalls and pools. In this study, the MUs were not particularly good predictors of the distribution of invertebrate communities. The concept of MUs remains useful, however, for preliminary assessment of a site. MUs inform on the overall nature of a studied river reach and thus provide an idea of the invertebrates likely to be present. Knowing this in advance allows sampling strategies to be planned that avoid spending unnecessary effort on areas unlikely to yield different assemblages.

In summary, the concept of MUs as a level in the hierarchy remains useful for organising thoughts and data, and for overall assessment of a study site. MUs are not particularly useful, however, as indicators of where to locate specific communities of invertebrates. In addition, use of the terms riffle, run, rapid and pool at two levels of the hierarchy (HB and MU), is confusing, and it is suggested that alternative terms be sought that are specific to one level.

Assessment at the level of reach (Chapter 13)

Reaches form the next level up from MUs in the hierarchy, with the level above them being zones. Reaches, nested within zones, are used to describe a length of river with similar channel and hydrological characteristics. A bedrock riverbed with a high volume of flow, for instance, would represent a different reach type to a cobble riverbed with a low volume of flow. Reaches can be tentatively delineated from maps, based on changes in slope, geological formations, valley form and runoff, and verified in the field by the composition of MUs.

Preliminary analysis of invertebrate data designed to assess the ecological relevance of reaches has not provided much insight. The two reaches studied were about 1 km apart, on the same river. They were geomorphologically different, but the overall densities or composition of their invertebrate communities were not significantly different. The faunal samples grouped mainly, not by site, but by whether they were in fast or slow flow. However, within the groups of fast-flow and slow-flow samples, those samples from each site (i.e reach) tended to cluster together. It seems possible that there are differences in invertebrate communities at the reach level, but any such subtleties will only be revealed with more intensive examination of the data. The data will be further analysed in the Ph.D. thesis of the second author.

In terms of biomonitoring, reach type is a useful guide to the mosaic of MUs and HBs likely to be encountered, and thus helps development of a sampling strategy. Reaches within one zone that have similar MUs and HBs will probably yield much the same invertebrates, whilst those with different sets of MUs and HBs, could yield different species. All reach types within a zone likely to add to the list of fauna present should therefore be considered for inclusion in the sampling programme.

In summary, reach types are as important as MUs in guiding overall structure of a river study, but are too coarse to guide on the exact location of individual species or species groups. Different reach types may yield different groups of species, and sampling strategies should recognise this. This can be done through a reach analysis, which highlights similar lengths of river, and can guide on the extent to which data can be extrapolated from a study site.

Assessment of the temporal stability of HBs over a range of discharges (Chapter 14)

HBs are at the only level of the geomorphological hierarchy that incorporates a flow characteristic as well as a geomorphological one. They can thus change in short to intermediate time scales as discharge changes. A preliminary analysis of their physical stability revealed that they persisted over a range of similar low discharges, and only changed when discharge increased substantially. Essentially, there was a 14 – 24% change in wetted area once there was a 50 – 80% increase in discharge. The faunal data will be further analysed in the Ph.D. thesis of the second author, to reveal how the invertebrates reacted to these physical changes.

The impact of anthropogenic disturbance (Chapter 15)

The ten rivers with a range of disturbances were studied to assess how disturbance might affect the abiotic-biotic trends described above. Disturbance was assessed in terms of changes in the species community. Studied disturbances were not rated for severity of their impact *a priori;* instead, severity was judged based on location of each river's invertebrate community on MDS similarity plots. These plots show the relationship between sites, in terms of their invertebrate communities, by the distance apart the sites appear in two-dimensional space. Similar sites appear clustered together. Based on the findings, the following hypothesis is suggested for further testing.

<u>The hypothesis: Increasing disturbance gradually leads to the loss of a river's catchment signature, and eventually to loss of its regional character.</u>

<u>Suggested explanation of the data, based on invertebrate assemblages, to support this hypothesis:</u> The most mildly disturbed rivers yield invertebrate communities that are similar to those of the least-disturbed rivers. In other words, these rivers remain well within their catchment clusters on the MDS plot, and so their catchment signatures remain intact. As disturbance increases, rivers become less similar to others within their catchment, moving to the edge of their catchment cluster on the MDS

plot. Moderately disturbed rivers lose their catchment signature completely, moving outside their catchment grouping on the MDS plot to cluster together in the middle of the ring of catchment groups. This suggests that they have lost their individuality and become more similar, as kinds of generalised rivers of their region. Possibly, by this stage, all sensitive species have disappeared and any coarser regional signature remaining is provided by hardy, opportunistic species. Highly disturbed rivers lose even this generalised signature, being located well outside all the catchment groupings. It is not known at this stage to what extent these rivers retain any kind of regional identity. A variation on the trend may occur for rivers receiving inter-basin transfers (IBTs) of water. One of the sites we studied was 1 km *upstream* of an incoming IBT, and had taken on the catchment signature of the donating catchment.

In seems important to discover exactly how different kinds of disturbances transform the invertebrate communities, resulting in the gradual erosion of catchment signatures. At this stage we cannot say if there are likely to be profound management implications, but we suggest that simply understanding better how disturbance affects the signatures would be a critical step forward. To this end, further analysis of this project's data is recommended.

Usefulness of the geomorphological hierarchy

A major impression from this project was that geomorphological hierarchies are exceedingly useful tools to aid organisation of thinking, studies and data analysis. Before such hierarchies were suggested, the country's ecologists were using a spatial hierarchy of sorts, but ones like that tested here enabled a giant step forward in the way ecologists viewed rivers. As a result, the study of physical-biotic links in rivers has gradually taken its place alongside studies of chemical-biotic links, providing a much more rounded perspective on river functioning, to the benefit of both fields of study.

Geomorphological studies based on a spatial hierarchy now form part of every environmental flow assessment done in South Africa, as well as contributing to the National River Health biomonitoring programme. We feel this involvement is essential, but suggest that discussions should be held with the geomorphologists on whether it is necessary for their approaches to accommodate the findings from this project. Specifically, discussions should be held on the following:

- the nature and significance of catchment and river signatures;
- use of biologically relevant zones, rather than geomorphologically derived ones;
- reduction in the number of HBs to the four ecologically relevant ones;
- re-naming HBs and/or MUs, so that each level of the hierarchy has unique names;
- further study of which kinds of physical change might be linked to each disturbance level in the above hypothesis.

Much of this discussion could well reflect the traditional contrast between "top-down" and "bottom-up" classifications. The "top-down" approach in this case is the geomorphological one of grouping similar rivers and parts of rivers based on easily measured abiotic and landscape features. The "bottom-up" approach in this case is the use of aquatic invertebrates to indicate which rivers or parts of rivers are similar. This project was, in essence, a "bottom-up" testing of a "top-down" approach.

Inevitably, mismatches occurred, but these were not of a severe nature and there seems every reasons to assume that the "top-down" approach could incorporate the biological findings, and thereby enhance its ecological relevance. This should be the main objective of the discussions suggested above.

Additional applications of the project's techniques and data (Chapters 16-19)

An extensive database on physical-biological links was populated during this project. Additionally, mapping techniques were developed that already are being used in consultancy work. Chapters 16 to 19 serve to briefly introduce suggested further applications of the project's data and techniques.

In Chapter 16, use of the data for biogeographical and biodiversity studies is illustrated. The 380 invertebrate samples collected contained 287 species from 83 families. Different numbers of species occurred in each catchment. Although this may be due to sampling strategies, there is a possibility that real catchment differences in biodiversity are being revealed. The Eerste and Molenaars catchments, for instance, clustered together in every analysis done, and yielded 40% more species than the catchment with the next highest number. Could these rivers be located within some centre of biodiversity? Or could the results simply be reflecting our sampling strategy? Further analyses of the dataset might provide answers to these questions.

Information on the hydraulic conditions in which each species was found is also available in the database, and examples are given in Chapter 17. A preliminary investigation of the hydraulic nature of flow types is reported on in Chapter 18, and use of the mapping techniques in the environmental flow assessment for all rivers in the Lesotho Highlands Water Project is illustrated in Chapter 19.

The analyses in Chapters 16 and 17, at least, could be taken much further, but this was not possible in this project. Together with the data on catchment and river signatures, yet to be analysed, the database represents a considerable resource that could enhance understanding of the nature and functioning of the region's rivers. For this reason, further analyses of the data are recommended.

The value of species data

In invertebrate studies it is becoming increasingly common to work only to family-level identifications, because of the time and other costs entailed in species identifications. If we had done that in this project, catchment and river signatures would not have been detected. There is no intention here to detract from the use of family-level data, for such data are well established and of great use, particularly for biomonitoring purposes. A deep understanding of ecosystem functioning and biogeographical trends, however, can only be obtained when working at the level of species. Here, we record our view that, to improve the quality of advice offered by ecologists on management practices for the sustainable use of our rivers, collection of biological data on invertebrate species, their behaviour and their life-cycle requirements, must continue to have a place in research programmes.

Recommendations

This project has produced a very comprehensive data set. The data have extra value because they cover many similar rivers, within one bioregion, and were collected by a single team in a standardised way. Because of the geographical spread of the data, previously unimagined characteristics of Cape rivers have been revealed. Region-wide patterns of river type have been detected, as well as trends in how human disturbance affects these patterns. Specifically, the invertebrate data clearly show that all rivers and catchments have their own signatures.

The management implications may be profound. Without an understanding of the detected signatures, we can no longer assume that all rivers within a region are ecologically similar, or that knowledge from one can be extrapolated to the rest, or that they will respond to disturbance in a common way. There may be other, presently unknown, factors that need to be considered before assuming, for instance, that some rivers can be sacrificed to development because we have many more like them.

It is therefore recommended that further analysis of the database be undertaken. Some of this will be done in the PhD thesis of one of the authors, as detailed elsewhere in this report. The following additional aims will still need to be addressed.

- Ascertain the proximal cause of the signatures. Two possible explanations are that they are due to unique species in each catchment/river (i.e. related to historical biogeographical distributions), or that there are unique combinations of common species in each catchment/river (i.e. each river is functioning slightly differently, perhaps due to climatic or geochemical influences).
- Analyse the species and geomorphological data for all the disturbed rivers, to ascertain the influence of disturbance on catchment signatures. Rate different kinds of disturbances on a severity scale.
- Convene a workshop, with selected river scientists, to reach consensus on the management implications of catchment and river signatures. Transfer the findings to the management arena.
- Allocate SASS-type scores to all 380 invertebrate samples in the database. Using the GIS site maps, assess how reach, MU, site and sample point selection affects the SASS score. These kinds of scores are now used at national level for management of river health, and so it is important to continue assessment of their strengths and weaknesses. Transfer the findings to the management arena.
- Ascertain, as far as possible, if it is true that some of the studied catchments had far higher numbers of species and higher numbers of unique species, than others.
- Refine and upgrade the interface and query centre of the database created in this project, and complete a quality-control assessment of the data housed in it. This should a) make the database accessible as a research tool, and b) allow other researchers to add their data to the database, thereby initiating a national database of biological and physical links in rivers. The database created in this project database is compatible with BIOBASE, developed by the Freshwater Research Unit at the University of Cape Town, which links biological and chemical data for South African rivers.

Extent to which the Terms of Reference have been met

All of the objectives listed at the beginning of this Executive Summary have been achieved.

Capacity building and technology transfer within the project

Seven post-graduate theses were produced from research linked to this project: four in the Departments of Zoology and Civil Engineering at the University of Cape Town (UCT), and three in the Department of Civil Engineering at the University of Stellenbosch. Not all of the researchers were funded from the project, but all used data collected during it. In addition, one of the authors of this report (DMS) is presently writing a Ph.D. thesis, and the other author (JMK) supervised another four Ph.D or MSc. students completing river studies.

Eight undergraduate or postgraduate students at UCT were employed part-time on the project, and received scientific training from project staff.

An extensive programme of technology transfer was completed, including:

- lectures;
- presentations at conferences;
- acting in planning, organising, advisory or review roles for various scientific workshops, programmes and journals;
- a specialist review for the new Water Law;
- application of techniques and knowledge developed, both within South Africa, and in England, Australia, Lesotho, America, Taiwan, Portugal, Zimbabwe, Mozambique and for the World Bank.

Full details are given in Appendix E3.

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LINKING ABIOTIC AND BIOTIC DATA ON SOUTH AFRICAN RIVERS

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Dr. SA Mitchell	Water Research Commission (Chairman)
Mr. DS vd Merwe	Water Research Commission
Dr. HC Biggs	South African National Parks
Dr. JA Day	University of Cape Town
Prof. J O'Keeffe	Institute for Water Research, Rhodes University
Prof. KM Rowntree	Rhodes University
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1. INTRODUCTION

South Africa is a semi-arid country. Water is scarce and a burgeoning human population is expected to increase its water demands beyond supply within the next two decades (Basson *et al.* 1997). Rivers supply most of that water, and increasing manipulation of their flow regimes and channels, habitual use of them as waste-disposal facilities, and a range of non-point impacts on them due to man's activities, are accelerating their degradation (Davies & Day, 1998). The cost to the country of rivers functioning poorly is unknown but undoubtedly very high.

Over the last two decades there have been concerted efforts by South African water managers and scientists to bring about more sustainable use of rivers. Assessments of the flows required for river maintenance were initially done for all rivers targetted for water-resource development (King & Louw 1998; Tharme & King 1998), but are now being done for all water resources within a national plan. This moves to meet the requirements of the new Water Act of 1998, which recognises aquatic ecosystems as one of only two sectors with a right to water, the other being people, whose basic water needs are protected. Together, the water required for sustaining people and aquatic ecosystems is termed the *Reserve,* and enjoys priority of use. Biomonitoring – the use of aquatic plants and animals to indicate river health – has also been introduced, to complement the chemical monitoring of rivers already done by the Department of Water Affairs and Forestry (DWAF) (Roux 1997).

With rivers now in the spotlight in a way never contemplated even a few years ago, the imperative for aquatic scientists to work hand-in-hand with government on river management has never been greater. Advice is sought from scientists on a wide range of issues, from dam design to conservation of Red Data species and management of channels. The capacity to be able to predict how rivers will react as ecosystems to proposed water-resource developments is becoming increasingly important. Accurate predictions will facilitate more informed management decisions about the sustainable use of rivers.

For most rivers in the country, at least in the short term, such predictions and management decisions will be made without the benefit of in-depth research on the rivers of concern. This is potentially a risky endeavour, but the risk can be reduced by optimising the way in which limited data and understanding are used. One such way that this already happens, often informally, is through regional generalisation on the nature and functioning of rivers. Data and understanding from studied rivers are used to infer the character of nearby unstudied rivers.

If this kind of general regional knowledge could be organised so that all that is known about similar rivers could be grouped in a scientifically acceptable way, then its use could validly be expanded through extrapolation to all rivers within the group. In this way, the nature and functioning of any one river could be assumed to a known extent through its membership within a specific group of rivers, some of which may have been the subject of some studies. Similarly, the effects of a proposed disturbance to one river could be predicted through knowledge of a similar disturbance to a similar kind of river. Rehabilitation of a river could be guided by the known range of conditions occurring within less disturbed rivers of its group.

Such partitioning of the rivers would have other benefits. For instance, biomonitoring of river health, using the South African Scoring System (SASS) (Dallas 1995; Chutter 1998), and State of the Environment assessments, are both required to be set within a regional and local spatial framework. Any river site being assessed can then be compared with similar least-impacted ones, which could provide a reference condition of how far removed from natural the site is. Additionally, when river-specific data are sparse, environmental flow assessments often draw on regional knowledge of the character and distribution of riverine species.

There has thus evolved both a long-term scientific and short-term management-orientated need to develop approaches that allow valid extrapolation. Such techniques require a good understanding of what constitutes a "similar" river or river site, so that it can reasonably be assumed that data collected in a known area truly represent the (similar) area to which they are extrapolated.

Broad-scale grouping of similar rivers or river sites within South Africa has been done in several ways. This is addressed in more detail in Chapter 2, but essentially, rivers can be grouped at many different scales, based either on biological distributions (bottom up), environmental variables (top down), or both. At the countrywide level, catchments can be grouped by region (e.g. all the rivers within the Fynbos Biome). At the catchment level, similar longitudinal zones of many rivers within a region might be grouped (e.g. all mountain streams within the Fynbos Biome). At the zonal level, similar channel types or smaller habitat-type features might be grouped together for study or other purposes (e.g. all the pools in mountain streams within the Fynbos Biome).

For both in-depth studies and rapid management methods, it is important to understand the implications of such groupings. Much of the proclaimed variability or "noise" in biological river data may be derived from our inability to truly compare like with like. For example, are all the pools in mountain streams in the Fynbos Biome so alike in physical, chemical and biological features that one could be used to represent them all? Being able to answer this kind of question might be important, for instance, in biomonitoring, when sampling a river upstream and downstream of an effluent in order to assess the impact of the effluent. If biological samples were not taken from both areas in places which the biota perceive as being similar, the samples will probably be different irrespective of the effluent. Some of this difference might be due to natural variability, whilst a major portion will very probably be due to the mismatch of sampling areas.

So how can we improve our understanding of what constitutes a similar river or river site, in order to maximise the validity of comparison and extrapolation? A promising starting point is the tacit recognition among river ecologists of the importance of the physical features of the channel. "Pools" and "riffles" are important descriptors of species' habitats, as are the size of substratum particle sizes, the shape of the banks and the extent of floodplains. Fluvial geomorphologists have suggested an hierarchy of scales for structuring river studies, which allows all such physical features to be placed into context within the landscape. Their hierarchy is potentially of great use for ecologists, and indeed a similar, less-structured, spatial hierarchy is already used by them (Section 2.2).

If a geomorphological hierarchy proved also to be valid ecologically, then easily-recognised physical features of rivers (position in landscape, slope, substratum particle size, kind of flow) could be used as biological surrogates, in order to recognise and group ecologically similar rivers or river sites. Ecologists could more easily and surely choose truly comparable *sampling sites* in different rivers and comparable *sampling points* within different sites. Further, sites and sampling points in anthropogenically disturbed rivers could be more surely matched with ones in undamaged ones through use of robust geomorphological features, in order to assess the degree of impact of the disturbance. Biomonitoring results would thus have one layer of “noise” removed. A greater understanding of the driving forces behind species distributions would also be gained, at scales from catchment to microhabitat, and the scientific study of patch dynamics would be facilitated over a range of scales.

The present project thus poses and is designed to answer the following question:

Is the geomorphological character of a river a useful guide to its ecological character?

This report details the research undertaken to address the above question. Chapters 2 - 4 complete the Introduction. Chapter 2 gives an explanation of geomorphological and ecological river hierarchies, and provides various perspectives of physical habitat. The Aims and Tasks of the project are then listed (Chapter 3), followed by details of the Methods used (Chapter 4).

Chapters 5 - 9 contain the Results of the research. An introduction to the Results section is given in Chapter 5. This is followed by an independent geomorphological assessment of the study sites by Prof. Kate Rowntree of Rhodes University (Chapter 6). The physical and chemical data for each site appear in Chapter 7, and the biological data, with related environmental data, in Chapter 8. The database created to contain all the above data is then described (Chapter 9).

Chapters 10 – 15 report on use of the data to test the ecological relevance of various scale levels of the geomorphological hierarchy. Starting at the largest scale in the hierarchy, Catchment and river longitudinal Zones are addressed in Chapter 10. Then, attention is turned to the smallest scale of the hierarchy, Hydraulic Biotopes (Chapter 11), in order to define these, the building blocks of the intermediate scales. Morphological Units, consisting of few to many hydraulic biotopes, are dealt with in Chapter 12, and Reaches in Chapter 13. Discharge-related changes in the proportions and distributions of Hydraulic Biotopes and of invertebrate species are described in Chapter 14. The final chapter in this Part introduces sites on selected disturbed rivers, and describes how different kinds of disturbance impact the patterns revealed in the previous chapters (Chapter 15).

Chapters 16 – 19 illustrate further applications of the project data. Biodiversity issues are discussed in Chapter 16. Taxon-specific hydraulic habitat requirements are provided in Chapter 17, the hydraulic character of flow types is explored in Chapter 18, and application of the developed habitat-mapping techniques in the Lesotho Highland Water Project is described in Chapter 19.

Finally, Chapter 20 provides Conclusions on the project and Recommendations regarding future research.

2. GEOMORPHOLOGICAL HIERARCHIES, ECOLOGICAL HIERARCHIES, PHYSICAL HABITAT AND HABITAT MAPPING

2.1 Geomorphological hierarchies

Historically, the ecological study of rivers has largely focussed on chemical and biological aspects, such as pollution levels and community distributions (Hynes 1960; Hynes 1970). Physical aspects of channels received cursory attention. More recently, study of the physical character of rivers has gained prominence in South Africa, perhaps because it was becoming clear that many rivers with relatively minor water-quality problems are nevertheless seriously degraded. In different rivers across the country, channel shape, features of the riverbed and the flow regime are all undergoing intense modification to suit short-term human requirements. The resulting structure of the channel profoundly influences the kinds of physical habitat available for riverine biotas, and thus the whole functioning of these ecosystems. Recognising this, water managers and river ecologists turned to fluvial geomorphologists for advice on the study and management of physical aspects of rivers.

Geomorphologists point out the importance of placing the river within the context of its catchment, and of viewing river systems as hierarchically organised, at scales from catchment to aggregates of substratum particles. River classifications expounding this view (Frissell *et al.* 1986; Naiman *et al.* 1992) have been suggested as useful tools for river management. Derived from these, and from relevant studies on rivers in several parts of South Africa (Cheshire 1994; James *et al.* 1996; Jewitt *et al.* 1998; and Rowntree & Wadeson 1999), a local geomorphological hierarchy has been proposed as a framework for river studies (Rowntree & Wadeson 1999). Working from Rhodes University, Rowntree & Wadeson described the hierarchy as being based on "spatially nested levels of resolution that recognise that the structure and dynamics of the river channel are determined by the surrounding catchment". They give the levels of the hierarchy as catchment, segment, zone, reach, morphological unit and hydraulic biotope (Table 2.1).

Higher levels of the hierarchy impose constraints on lower levels and, because of their different spatial and temporal scales, are characterised by different geomorphological processes. All tiers of the hierarchy, except hydraulic biotopes, are defined through geomorphological and allied characteristics, and hence are relatively stable in space and time. Hydraulic biotopes have local flow characteristics as an additional descriptor, and so are spatially and temporally more ephemeral than the higher levels of the hierarchy.

Table 2.1 Definition of geomorphological classification levels (Rowntree & Wadeson 1999).

Hierarchical unit	Description	Scale
Catchment	The catchment is the land surface which contributes water and sediment to any given stream network.	Can be applied to the whole river system, from source to mouth, or to a lower order catchment above a specified point of interest.
Segment	The segment is a length of channel along which there is no significant change in the flow discharge or sediment load.	Segment boundaries will tend to be co-incident with major tributary junctions.
Longitudinal zone	The zone is a sector of the river long profile which has a distinct valley form and valley slope. River zones fall within segments and are delineated according to *macro-reaches*.	Sectors of the river long profile.
Macro-reach	The macro reach describes the valley form characteristics, including valley shape, valley floor slope, and valley floor width.	
Reach	The reach is a length of channel characterised by a particular channel pattern and channel morphology, resulting from a uniform set of local constraints on channel form.	Scale level of hundreds of meters
Morphological unit	Morphological units are the basic structures recognised by fluvial geomorphologists as comprising the channel morphology, and may be either erosional or depositional features.	Occur at a scale order similar to that of the channel width.
Hydraulic biotope	Hydraulic biotopes are spatially distinct instream flow environments with characteristic hydraulic attributes.	Occur at a spatial scale of the order of 1 m^2 to 100 m^2 and are discharge dependent.

Segments and zones are derived from maps showing catchment features such as rainfall, runoff, sediment production zones, and the longitudinal profile of the river. *Reaches* describe lengths of river with a similar set of controls. They are initially identified from maps, using contour lines and channel gradient (Prof. Rowntree, pers. comm.). They are then further defined in the field by their channel type, through substratum characteristics (bedrock, alluvium or mixed) and channel pattern (single, braided, anastomosing, sinuosity). Reaches that are similar in terms of these characteristics form one reach type. Reaches of two or more reach types can be repeated along the length of one zone.

Morphological units are identified in a field exercise, at the site level. Occurring on a channel-spanning scale, suites of morphological units are envisaged as occurring within a reach, with similar reach types supporting similar assemblages of morphological units. *Hydraulic biotopes* are the smallest unit in the hierarchy, and are defined by their substratum and flow characteristics. Different suites of hydraulic biotopes are envisaged as occurring in different morphological units. The assemblage of hydraulic biotopes within any one morphological unit will change with discharge.

A similar hierarchy is described by scientists working at the University of the Witwatersrand (James *et al.*, 1996). Their approach starts at the lower end of the hierarchy, with geomorphological units being at the finest scale, followed by reaches, macro-reaches and zones. A later publication (Heritage *et al.*, 1997) mentions channel types and functional groupings of geomorphological units. This publication also provides an excellent discussion on scale issues. Focussing on the relationship between riparian tree communities and river features, this group did not initially address the level of small-scale (spatial and temporal) instream habitat, as had been done by the group introducing hydraulic biotopes. However, later additions to their approach, to accommodate fish studies, provided a "top-down" component for dealing with instream habitat. The coarse to finer scale levels were, respectively, channel type, geomorphological unit and cover/substratum categories. In contrast to the hydraulic-biotope approach, no explicit use of instantaneous flow conditions was used.

The two approaches have triggered considerable interest among South African river ecologists. The two geomorphological approaches share many characteristics with each other and with the ecological scale-related perspective of rivers. This latter perspective is described in the next section.

2.2 Ecological hierarchies

Ecologists have long sought to impose order on their studies of rivers, at scales from regions to instream habitat.

2.2.1 Ecological regions

In South Africa, *regions* of the country with similar rivers have been delineated, either directly, using the biota to define similarity, or indirectly, using environmental variables. Harrison (1959), for instance, recognised 12 hydrobiological regions within South Africa, based on water chemistry and distributions of the aquatic biota. Noble & Hemens (1978) recognised seven regions, based on much the same features, together with geological and zonation aspects of the rivers. In 1994, the Department of Water Affairs and Forestry funded a Spatial Framework Workshop, designed to further define areas within the country with different kinds of rivers (Brown *et al.* 1996). Derived from this and parallel research, Eekhout *et al.* (1997) recognised ten bioregions for rivers, based on the oldest available records (i.e. to the extent possible, those recording pre-disturbance conditions) of the distributions of fish, riparian vegetation and aquatic invertebrates. Although the details may differ, there was good general agreement between these analyses on which parts of the country are biologically different in terms of rivers.

Adopting the alternative approach, Kleynhans *et al.* (1998) used map overlays of mostly environmental variables with some biological input to subjectively determine ecoregions. Information on physiography, climate, geology and soils, and potential natural vegetation was used to delineate 18 ecoregions in a first broad assessment. This approach recognised much the same broad areas as the earlier mentioned biological approaches.

2.2.2 Longitudinal biological zones

Within regions of similar rivers, *biological zones* along the rivers have long been recognised as the next level of spatial organisation. Illies (1961) was prominent among those introducing the concept at an international level, and Noble & Hemens (1978) expanded on this concept when suggesting a characteristic set of biological zones for South African rivers. Rivers in different parts of the country exhibited different combinations of the zones. South-western Cape clear acid rivers, for example, contain all five zones (mountain source and cliff waterfall, mountain stream, foothill sandbed, low and midland river and estuary), generally all well developed. In comparison, the short southern Cape rivers have only the mountain source, mountain stream and estuarine zones, whilst the southern Karoo rivers have no mountain source or mountain stream zones.

Harrison & Elsworth (1958), Oliff (1960), Chutter (1970), King (1981), King & Tharme (1994), and many others have described such zonation along South African rivers. The biological differences between zones have been linked to a range of physical and chemical features characteristic of the zones. Water temperature and chemistry are often markedly different between zones, although there is usually a gradual downstream transition rather than an abrupt change. The same is true for physical features, with the main characteristics that differ between zones often being geomorphological in nature. Slope, substratum particle size and shape of the channel within its valley have all been recognised as important physical descriptors of the available living space for riverine biota.

Eekhout *et al.* (1997) saw their regional groupings (bioregions) as potentially subdividing into subregions, each of which contained the same zone of many rivers. For instance, Sub-region One of the Capensis bioregion could contain all the mountain streams within this Western Cape bioregion.

2.2.3 Instream habitat at the mesohabitat level

Within zones, ecologists partition the instream component of rivers further using physical habitat. This reflects an implicit understanding that the major determinant of biotic distributions, not only at the level of zones but also at finer scales, is the physical environment. Chemical variables also determine distributions at larger scales (i.e. zone), but do not appear to have such a clear influence at finer scales (i.e. morphological unit). This is because most chemical or physico-chemical variables have different values along the length of a river, but much the same value within any one site. There are some within-site differences, such as increased levels of dissolved oxygen in riffles or higher phosphate levels in pool sediments, but these are usually reflections of local differences in channel morphology. This suggests that the physical structure of the site is the primary determinant of the environmental conditions experienced by instream biota.

There are several well-used terms to describe such physical habitat at what might be described the mesohabitat level (10^0 –10^1 m). Older terms, such as “ripple” and “stickle” may have been taken from fishermen’s language and are rarely used by river ecologists now, whilst others from the same probable origin, such as “run”, “pool” and “backwater” are in common use. These, and terms such as “riffle”, “cascade”, “rapid”, “backwater”, “chute” and “waterfall” are routinely used by river ecologists. Chutter (1970) introduced “stones-in-current” and “stones-out-of-current”, which added an explicit substratum element to the descriptions of where riverine biota lived. The characteristics of all of these kinds of areas are implied through use of these familiar terms, and not well described.

Wadeson (1995) provided a detailed review of the terms used by ecologists and an excellent comparison of how geomorphologists and ecologists named the same channel-flow features. Both groups, for instance, were in agreement as to what constitutes a riffle, but ecologists used the terms pool, run, glide, flats and backwaters for a geomorphological pool. Wadeson suggested that this difference in perception of a pool may be because geomorphologists recognise distinct physical features (the zone of deposition (bar; riffle) and the zone of scour (pool)), whilst ecologists also take into account the way water is flowing through the site. Wadeson concluded that both disciplines are somewhat “woolly” in their descriptions of these channel features, with much reliance on others’ intuitive understanding of what was meant by a term.

2.3 Comparing geomorphological and ecological hierarchies

12. MORPHOLOGICAL UNITS

12.1 Recap

The third aim listed for this project (Section 3.4) was to assess the biological significance of geomorphologically derived morphological units (MUs). MUs were mapped for each study site (for example, Figures 7.4c, 7.5c and 7.6c), so that every invertebrate sample could be linked to one. Thus, the twelve samples from each least-disturbed river, and the 52 replicate samples from the Eerste, were again available for the analyses. It should be noted, however, that because the MUs were not mapped until the second year of the study, that is until after the invertebrate samples had been collected, biological sampling could not be designed specifically to test MUs.

It was thought that each study site could differ in its combination of MUs, and thus could either be supporting different combinations of species or the same species assemblages but in different proportions. Either way, samples collected for instance for biomonitoring purposes, could produce different results simply because of the areas within the site that were sampled. Bio-riffles, and bio-rapids on boulder, cobble or bedrock, all have the appearance of turbulent, fast-flowing water over rock, and could be sampled together in one comprehensive biomonitoring sweep. In Chapter 11, however, they have been shown to have distinct species assemblages. In this chapter, we report on initial analyses designed to investigate the nature of within-site physical differences, and how these might be affecting animal distributions.

12.2 Physically similar sites

The number, type and area of coverage of each MU were outputted from the digitised GIS maps. The number and type of each MU within each site was used to run the CLUSTER module of PRIMER, just as invertebrates were used in Chapters 10 and 11, to determine which sites were similar in terms of MUs. Four main groups (Figures 12.1 and 12.2) were recognised. Group 1 consisted of six mountain sites. Altitudes ranged 100-350 m, and slopes were very similar (0.060-0.100) (Table 12.1). Group 2 consisted of four transitional/upper foothill sites, with an altitude range of 380-700 m and similar slopes (0.013-0.030). Group 3 consisted of the bedrock streams, although one mixed alluvial/bedrock site (Bakkerskloof) was included. There were wide ranges of altitude (80-860 m) and slope (0.005-0.100). Group 4 consisted of two sub-groups. Sub-group 4a included the two lower foothill sites at relatively low altitudes (260, 430 m), and relatively low slopes (0.002, 0.010). Sub-group 4b consisted of what we have previously identified (Chapter 11) as a mixed bedrock-alluvial site (Steenbok) and a transitional mountain/foothill site (Du Toits). These two are recognised as outliers, probably due to Steenbok having some unusual MUs (bedrock pavement, slump) and Du Toits consisting almost entirely of the one MU, Plane-bed.

In summary, substratum, via MUs, remained a good distinguisher of different kinds of sites at the second (bedrock v alluvial) and third (mountain v foothill) levels of distinction, with slope also providing a tight, consistent pattern within the alluvial groups (1, 2 and 4a). Altitude was a less useful guide.

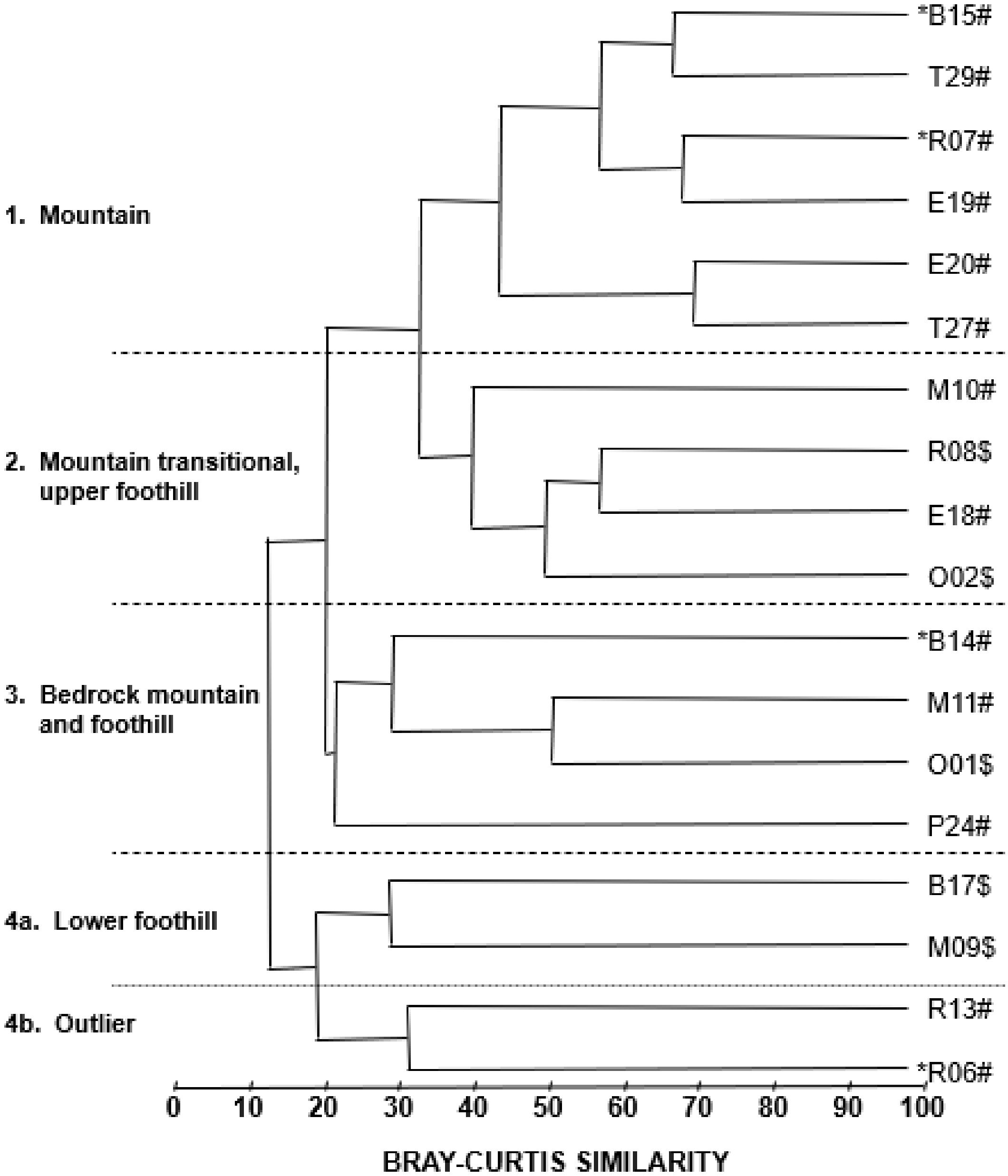

Figure 12.1 **Dendrogram of the similarity of 18 least-disturbed sites, based on the number and types of MUs mapped at the sites. .** # = pre-identified as biological mountain zone and $ as a biological foothill zone. * denotes mixed alluvial-bedrock streams.

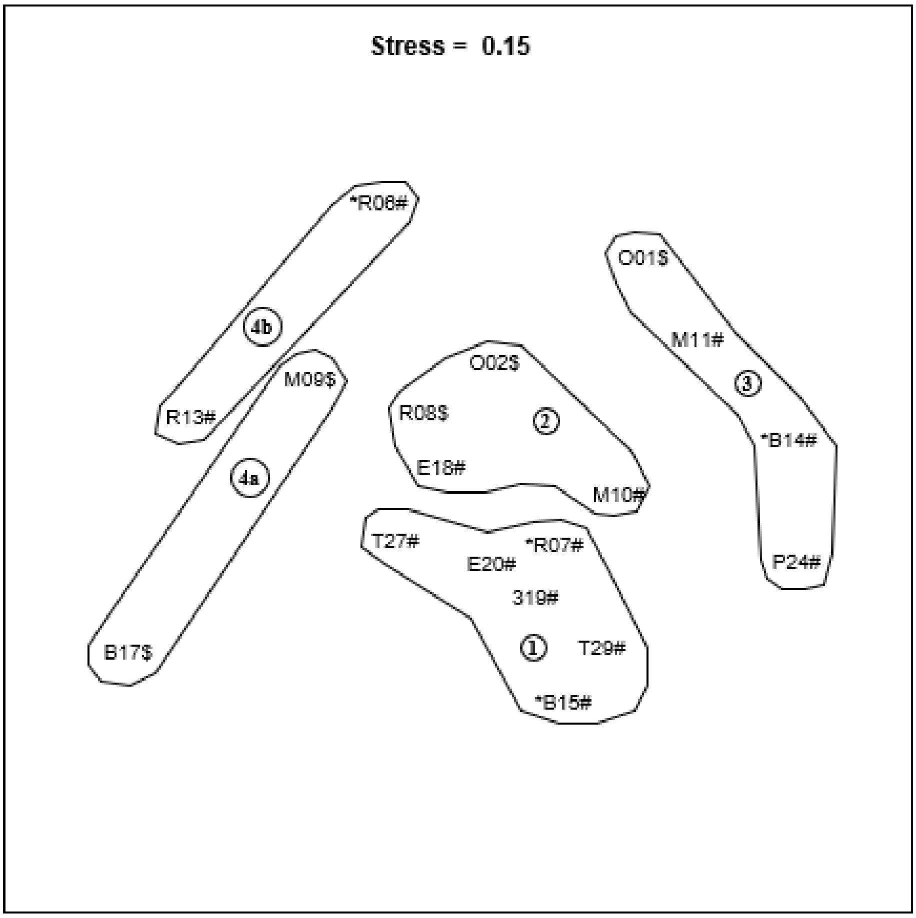

Figure 12.2 Two-dimensional MDS configuration of the 18 least-disturbed sites, based on the number and types of MUs mapped at the sites. Group 1 = mountain zone; Group 2 = mountain-upper foothill zone; Group 3 = bedrock sites in mountain and foothill zones; Group 4a = lower foothill zone; Group 4b = outliers. # = pre-identified as biological mountain zone and $ as a biological foothill zone. * denotes mixed alluvial-bedrock streams.

Table 12.1 Summary of altitude and map slope data for the groups recognised in Figures 12.1 and 12.2. # pre-identified as in a biological mountain zone and $ as in a biological foothill zone. * mixed alluvial-bedrock streams.

Group	River	Code	Zone	Altitude (m asl)	Map Slope
1	Zachariashoek*	B15#	Mountain	310	0.100
	Disa	T29#		100	0.080
	Wolvekloof*	R07#		350	0.100
	Langrivier	E19#		350	0.080
	Swartboskloof	E20#		340	0.080
	Newlands	T27#		180	0.060
2	Elands	M10#	Mountain transitional to upper foothill	460	0.020
	Wit	R08$		700	0.013
	Eerste	E18#		380	0.030
	Rondegat	O02$		470	0.026
3	Bakkerskloof*	B14#	Bedrock mountain and foothill	320	0.100
	Elandspad	M11#		860	0.200
	Jan Dissels	O01$		190	0.005
	Dwars	P24#		80	0.040
4a	Berg	B17$	Lower foothill	260	0.002
	Molenaars	M09$		430	0.010
4b	Du Toits	R13$	Outlier	400	0.020
	Steenbok*	R06#		290	0.060

The four categories of sites recognised in Figures 12.1 and 12.2 (i.e. excluding the outlier group) have different percentages of each MU (Table 12.2), with a pattern emerging of characteristic MUs. Alluvial mountain sites are dominated by step and pool MUs, with a minor presence of many other MUs, of which the most common are lateral bars and plane-bed. Lower down, alluvial mountain/upper-foothill sites also have a high number of pools, fewer steps than the mountain sites, but more lateral bar and plane-bed MUs. Further downstream, alluvial lower foothills are dominated by runs, with a range of less-abundant MUs, including pools, plane-bed, rapids, riffles and several kinds of bars. The familiar downstream transformation of channel morphology is shown, from step-pool in the upper reaches, through the confused pattern of change characterised by plane-bed in the upper foothills, to the classic riffle-run configuration of the lower foothills. It should be noted, however, that even in the riffle-run zone, riffles are far less common than runs.

Rapids and pools (Table 12.2) dominate bedrock mountain and foothill sites. It was expected that the same clustering of sites would emerge when the number of each MU was replaced by percentage area, but this did not emerge (Figure 12.3).

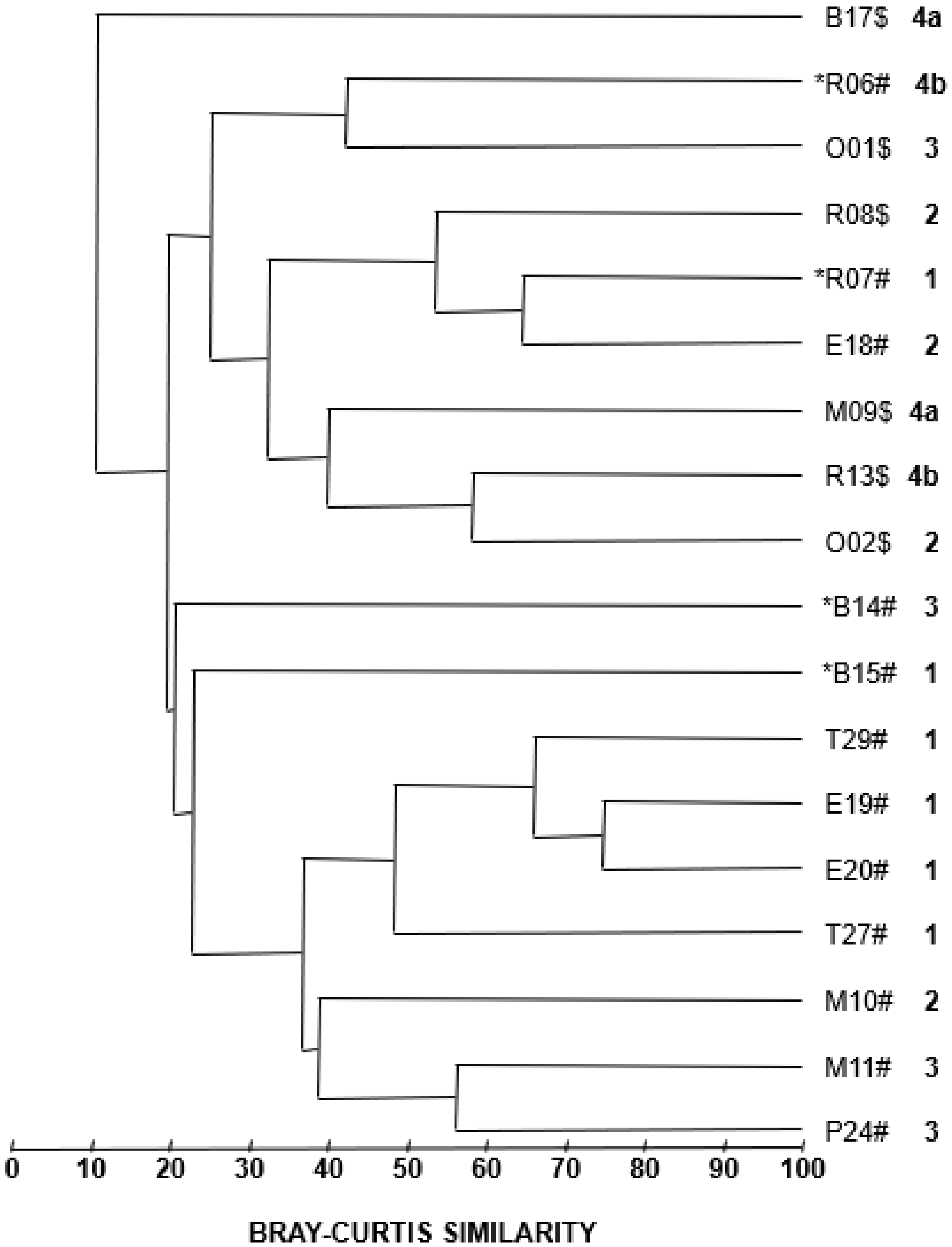

Figure 12.3 Dendrogram of the similarity of 18 least-disturbed sites, based on the area of each type of MU mapped at the sites. # = pre-identified as biological mountain zone and $ as a biological foothill zone. * denotes mixed alluvial-bedrock streams. Numbers in bold to the right of each site code indicate the group number of each river site in Table 12.1: 1 = mountain zone (alluvial); 2 = mountain-upper foothill zone (alluvial); 3 = mountain and foothill zones (bedrock); 4a = lower foothill zone (alluvial); 4b = outliers (alluvial).

Table 12.2 Percentage of MUs (by number) found within the sites in each classified stream zone, with the groups based on Figure 12.1 MUs are defined in Table 6.3**.**

Morphological Unit	Alluvial Mountain	Alluvial Mountain Transitional to Upper Foothill	Bedrock Mountain and Foothill	Alluvial Lower Foothill
Step	36.0	8.6	3.5	0.0
Pool	30.2	22.9	15.8	7.7
Lateral Bar	8.1	17.1	0.0	7.7
Plane Bed	7.0	17.1	0.0	7.7
Rapid	3.5	2.9	24.6	7.7
Riffle	3.5	0.0	0.0	7.7
Run	1.2	0.0	0.0	30.8
Bedrock Pool	1.2	2.9	1.8	0.0
Bedrock Rapid	1.2	0.0	0.0	0.0
Boulder Bank	1.2	0.0	0.0	0.0
Boulder Bar	1.2	0.0	0.0	0.0
Boulder Rapid	1.2	2.9	0.0	0.0
Lee Bar	1.2	5.7	5.3	0.0
Mid-Channel Bar	1.2	2.9	0.0	7.7
Proto Step	1.2	0.0	1.8	0.0
Sandy Lee Bar	1.2	0.0	0.0	0.0
Backwater	0.0	5.7	3.5	0.0
Bar	0.0	0.0	1.8	0.0
Bedrock Core Bar	0.0	0.0	1.8	0.0
Bedrock Pavement	0.0	0.0	5.3	0.0
Bedrock Step	0.0	0.0	7.0	0.0
Canal	0.0	0.0	8.8	0.0
Cataract	0.0	0.0	1.8	0.0
Flood Bench	0.0	2.9	0.0	0.0
Flood Channel	0.0	0.0	1.8	0.0
Island	0.0	0.0	1.8	7.7
Lateral Channel	0.0	5.7	0.0	0.0
Lateral Channel /Plane Bed	0.0	0.0	0.0	7.7
Mid-Channel Bar Remnant	0.0	0.0	0.0	7.7
Plunge Pool	0.0	0.0	8.8	0.0
Sculptured Bedrock	0.0	0.0	1.8	0.0
Secondary Channel	0.0	2.9	1.8	0.0
Waterfall	0.0	0.0	1.8	0.0

12.3 The distribution of hydraulic biotopes among MUs

Each invertebrate sample, with the exception of a few outliers, had been allocated to a hydraulic biotope (bio-rapid, bio-riffle, bio-run or bio-pool) (Chapter 11). These samples and thus their hydraulic biotopes were now allocated to MUs. In order to preserve the pattern emerging in Chapter 11, separate analyses were done for alluvial foothill, alluvial mountain, bedrock, and mixed alluvial-bedrock sites (Table 11.1), and for the replicate-sampling site on the Eerste. The breakdown by individual rivers is given in Appendix 12.1.

12.3.1 Alluvial foothill sites

All four hydraulic biotopes were recorded in the alluvial foothill sites (Figure 11.2a), with bio-rapids being least represented. Twenty-two of the 60 samples occurred in Plane-bed MUs (Table 12.3), with eight in run MUs, six in riffle MUs, six in pool MUs, five in rapid MUs, and four or less in secondary channels, lee bars, flood channels, steps, middle-channel bars and lateral bars. These proportions cannot automatically be accepted as representative of the proportion of MUs in alluvial foothills, as no attempt was made to randomly sample. The four outlier samples recognised in Chapter 11 were not allocated to a MU. There was little consistency in the distribution of hydraulic biotopes within a MU. Invertebrates in the 22 Plane-bed samples were from bio-runs (6), bio-riffles (10), bio-rapids (3), and bio-pools (3). Run MUs yielded five bio-pool samples, two bio-riffle samples and only one sample from a bio-run. Only the riffle and rapid MUs yielded mainly invertebrates from a similar hydraulic biotope: five of the six samples from riffle MUs were bio-riffle assemblages; and four of the five samples from rapid MUs were bio-rapid assemblages.

Table 12.3 Alluvial foothill sites: allocation of invertebrate samples, identified by hydraulic biotope, within MUs. Each of the entries in the body of the table represents one invertebrate sample. Each sample is designated by the hydraulic biotope from which it was taken: Ri = bio-riffle; Ru = bio-run; Ra = bio-rapid; Po = bio-pool.

River	Sandy lee bar	Secondary channel	Flood channel	Pool	Riffle	Plane bed	Rapid	Step	Run	Mid-channel bar	Lateral bar	Outlier
Berg					5 Ri 1 Po				5 Po			1
Molenaars				1 Ru		1 Ri 2 Ru 1 Ra			2 Ri	1 Ru 3 Ri		1
Rondegat		1 Po		1 Ri		3 Po 3 Ri 2 Ra					1 Ri	1
Du Toits						6 Ri 4 Ru			1 Ru			1
Elands	1 Ru		1 Ru	3 Ru 1 Ra			4 Ra 1 Ri	1 Ri				

12.3.2 Alluvial mountain sites

None of the 60 samples collected in the alluvial mountain sites were from bio-riffles (Figure 11.4a), although nine of the Newlands samples were from areas categorised as "fast". Although these areas contained more cobble than expected for bio-rapids, their flow types were characteristic of bio-rapids and in both its proportion of MUs (Figure 12.1) and its slope (Table 12.1), Newlands was identified as a mountain rather than foothill site and so more likely to have rapids than riffles. For the purpose of this analysis, the nine "fast" sites at Newlands have therefore been called bio-rapids. Nineteen of the samples from alluvial mountain sites were from step MUs, 24 from pool MUs, nine from pool MUs, with three or less from lateral channel, riffle and rapid MUs. There was one outlier (Table 12.4). Again, there was no great consistency in the distribution of hydraulic biotopes among MUs, with bio-run and bio-rapid samples constituting 42% of the samples taken from pool MUs, and Plane-bed MUs supporting a mixture of samples. Bio-pool samples, however, were mostly confined to the Pool MU, and step MUs yielded almost entirely bio-rapid samples.

Table 12.4 Alluvial mountain sites: allocation of invertebrate samples, identified by hydraulic biotope, within MUs. Each of the entries in the body of the table represents one invertebrate sample. Each sample is designated by the hydraulic biotope from which it was taken: Ru = bio-run; Ra = bio=rapid; Po = bio-pool.

River	Lateral channel	Pool	Riffle	Plane bed	Rapid	Step	Lateral bar	Outlier
Eerste	1 Ra 1 Ru	2 Ra 2 Ru		3 Ra 1 Ru			1 Ra	1
Langrivier		3 Po 2 Ru	2 Ra 1 Ru	1 Po	1 Ra	2 Ra		
Swartboskloof		4 Po		4 Ra		4 Ra		
Disa		4 Po 4 Ru				2 Ra 2 Ru		
Newlands		3 Po				9 Ra		

12.3.3 Bedrock mountain and foothill sites

Of the 36 invertebrate samples taken from bedrock sites, none were from riffle MUs as these do not occur in bedrock areas (Table 11.8c) (Figure 11.5a). Eleven of the samples were from bedrock pool MUs (Table 12.5), eight from other pools, nine from rapids, and two or less from canal, step, backwater and cataract MUs. Pool and bedrock pool MUs yielded almost as many samples from faster-flowing hydraulic biotopes as from slow ones (three bio-rapid samples; six bio-run; ten bio-pool), and typical fast-flowing areas such as rapid and cataract MUs also produced a mixture. Too few samples were taken from other MUs to attempt generalisations.

12.3.4 Mixed alluvial-bedrock sites

The 48 invertebrate samples taken from mixed alluvial-bedrock sites, represented bio-pools, bio-rapids, bio-runs, the unusual hydraulic biotope "stream", with one outlier (Figure 11.6a). The distribution of samples among MUs was: eight from rapid MUs, seven from step MUs, twelve from plane-bed MUs, and 13 from various kinds of pool MUs (Table 12.6). One sample was taken from a riffle MU, and there were several samples from unusual MUs such as plunge pools, bedrock pavements and sandy lee bars. The wide range of MUs reflects the diversity of this group of sites: the mountain sites provided rapid, step and pool MUs, and the foothill sites, riffle MUs. Additionally, bedrock sites provided pavement, cataract and plunge pool MUs and alluvial sites plane-bed MUs. Again, there was no consistency in the distribution of hydraulic biotopes among MUs, although bio-pools were the most common hydraulic biotope in pool MUs and bio-rapids in rapid MUs.

Table 12.5 Bedrock mountain and foothill sites: allocation of invertebrate samples, identified by hydraulic biotope, within MUs. Each of the entries in the body of the table represents one invertebrate sample. Each sample is designated by the hydraulic biotope from which it was taken: Ru = bio-run; Ra = bio-rapid; Po (BR) = bedrock bio-pool.

River	Bedrock pool	Canal	Pool	Rapid	Step	Backwater	Cataract
Jan Dissels	3 Ru 1 Po (BR)		1 Po (BR) 1 Ra 1 Ru	3 Ra 1 Ru		1 Po (BR)	
Elandspad			5 Po (BR)	1 Ra 2 Ru			1 Po (BR) 1 Ru 2 Ra
Dwars	2 Ra 2 Ru 3 Po (BR)	1 Ra		1 Po (BR) 1 Ra	2 Ra		

Table 12.6 Bedrock mountain and foothill sites: allocation of invertebrate samples, identified by hydraulic biotope, within MUs. Each of the entries in the body of the table represents one invertebrate sample. Each sample is represented by the hydraulic biotope from which it was taken: Ru = bio-run; Ra = bio-rapid; Po = bio-pool; Po (BR) = bedrock bio-pool. Stream = very fast, shallow, smooth flow over rock.

River	Sandy lee bar	Bedrock pool	Plunge pool	Flood channel	Pool	Riffle	Plane-bed	Rapid	Bedrock pavement	Step	Run	Outlier
Bakkerskloof		3 Po (BR)	1 Po (BR) 1 Po	1 Po	2 Po			1 Ra 1 Stream		1 Ra 1 Po		
Zachariashoek	1 Po				2 Ra 2 Po	1 Ra		1 Po 2 Ra		1 Ra	1 Ra	1
Steenbok		1 Ru					5 Ru 3 Ra		1 Ru 1 Stream		1 Ra	
Wolwekloof		1 Stream					4 Ru	2 Ra 1 Stream		3 Ra 1 Po		

12.3.5 Summary

In summary, Tables 12.3-12.6 suggest that there is a mixture of biological assemblages within any one MU type. The total array of MUs provided a good indication of whether a site is bedrock or alluvial, and mountain or foothill, but individual MU-types provided a poorer indication of the species assemblages they support. Some MUs, however, provided a better indication than others did. Of the 19 samples taken over all the rivers from step MUs, 15 (80%) were designated bio-rapid assemblages. Scoring somewhat poorer, of the 54 taken from Pool MUs, 30 (56%) were designated bio-pool assemblages. Riffle MUs scored better in alluvial foothills sites (83% of samples were designated bio-riffle assemblages), where riffles are most prolific, than in alluvial mountain sites (0%) where they are small and rare. This suggests a prerequisite of some minimum amount of riffle area or abundance before a distinct riffle assemblage develops. Scoring among the lowest in terms of predictability were plane-bed MUs, where of the 43 samples, ten (23%) were designated bio-riffle, 16 (37%) bio-run, 13 (30%) bio-rapid, four (10%) bio-pool assemblages. This reflects their somewhat unstructured mixture of physical and hydraulic conditions.

12.4 The distribution of hydraulic biotopes within a single MU

The high mix of biological assemblages within any one MU type might be a reflection of having pooled data from the same MU-type in different rivers. Individual MUs might show higher consistency. The 52 samples from the Eerste site were used to investigate this. The locations of the 52 samples were plotted on a map of MUs, with each sample represented by its hydraulic biotope as designated in Figure 11.3a (Figure 12.4).

The site consisted of the following MUs:

- 3 plane-bed;
- 2 pool;
- 1 step;
- 1 lateral channel.

Analysis of the hydraulic biotope linked to each sample (Table 12.7) revealed a range of species assemblages within any one MU. Again, the step MU was the most consistent, yielding only the fast-flow bio-riffle and bio-rapid communities. Similar to the findings from the other sites (Section 12.3.5) sixty-two percent of the samples from pool MUs were of bio-pool assemblages. Plane-beds again were the least consistent, with samples allocated to hydraulic biotopes as follows: 20% bio-riffle; 15% bio-run; 30% bio-rapid; and 35% bio-pool. Two of the three plane-bed MUs had samples representing all four of the main hydraulic biotopes, whilst the third had samples representing three. The data suggest that in any MU there would be considerable spatial variability in the distribution of invertebrate species.

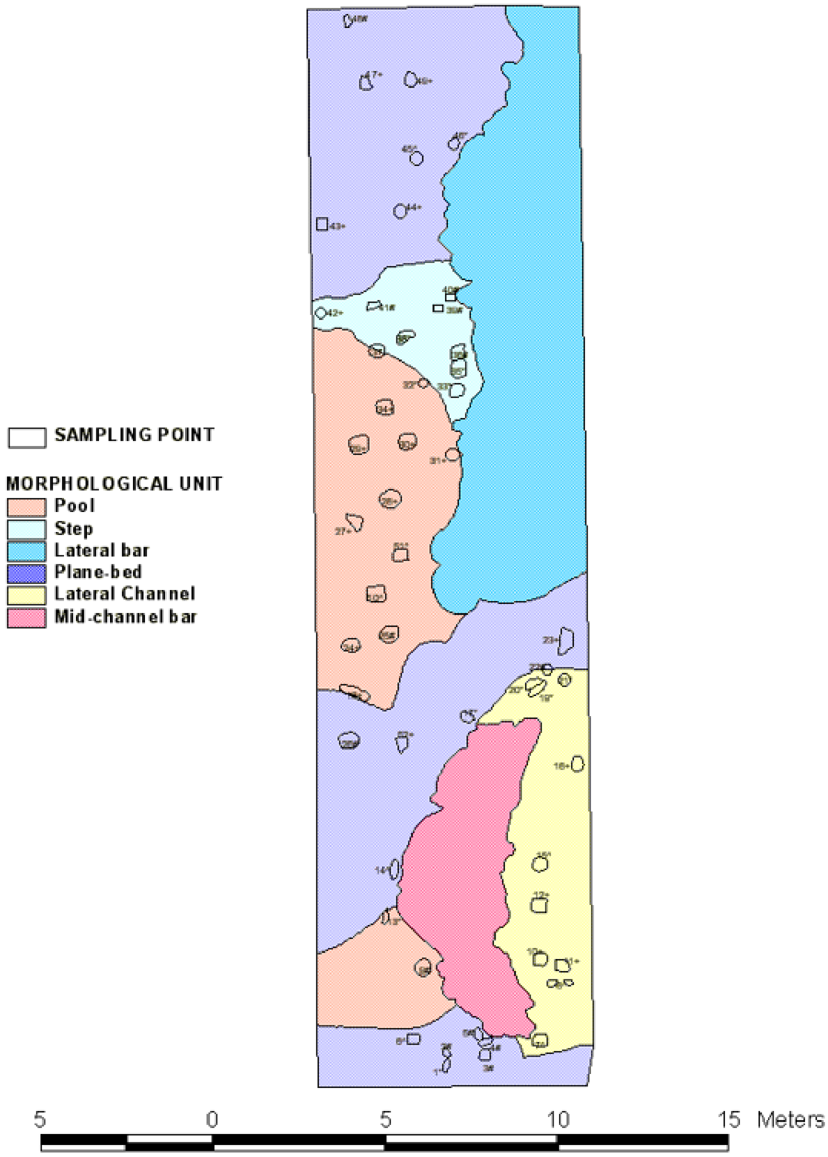

Figure 12.4 Map of the morphological units of the Eerste River site, with the location of the 52 invertebrate samples collected as part of the intensive survey (Section 11.3.2). Samples are numbered on the map 1 to 52, with an accompanying symbol to illustrate the major hydraulic biotope which they represent: * = bio-riffle; ^ bio-run; # bio-rapid; + bio-pool.

Table 12.7 The 52 invertebrate samples from the Eerste River site allocated by MU and hydraulic biotope. Each sample is indicated by its code number (Table 11.3). Sample 37 was identified as an outlier in Figure 11.3a, and is not included.

MU	Bio-riffle	Bio-run (cobble, boulder)	Bio-run (bedrock)	Bio-rapid	Bio-pool (cobble)	Bio-pool (boulder)
Plane-bed 1	46	45		48,	42, 43	44, 47, 49
Plane-bed 2	17	14		22, 26	23	52
Plane-bed 3	1, 3	6		2, 4, 5		
Pool 1			50, 51	25	18, 27, 28, 29, 31, 34	24, 30
Pool 2	13			9		
Step	32, 33, 35, 38			36, 39, 40, 41		
Lateral channel	19, 20, 21	7, 8, 15			10, 11, 12, 16	

12.5 Hydraulic biotopes versus MUs as indicators of species assemblages

MUs and hydraulic biotopes each have advantages and disadvantages as indicators of invertebrate assemblages. MU types provide a useful guide to the overall nature of a river reach, and create awareness of the likelihood of finding any one kind of invertebrate assemblage. Bio-rapid assemblages, for instance, would not be found in a site consisting of riffle and pool MUs. At the level of the individual MU, some types such as steps and to a lesser extent pools, may be better guides than others as to what might be present. Even with the better performers, however, there is sufficient diversity in invertebrate assemblages within any one MU to create considerable “noise” in distribution patterns (Table 12.7). Larger animals such as fish may be responding to MUs as single habitats, but invertebrates appear to be distributed within MUs according to a finer-resolution influence.

If MUs cannot be used with any great certainty to locate a specific invertebrate assemblage, then can hydraulic biotopes? The four hydraulic biotopes recognised in Chapter 11 were defined by their different invertebrate assemblages, and so should be good indicators of where those assemblages could be found. Unlike MUs, however, they cannot easily be pinpointed within a stream, as they are areas that have a characteristic spread of flow types and substrata rather than a single one of each (Tables 11.8).

Riffle hydraulic biotopes, for instance, are dominated by FRF and USW flow types and by boulder and large cobble substrata. In the intensive sampling site on the Eerste, 61% of the samples taken from one these two flow types combined with one of these substrata were bio-riffle samples. The picture is more complex than this suggests, however. When all the alluvial foothill and mountain sites were assessed, 90% of the foothill samples (n = 10) with this same combination (FRF or USW flow-types with boulder or large cobble) were of bio-riffle assemblages, but 0% (n = 11) of the mountain samples were. The mountain samples with this combination of flow and substratum contained bio-rapid assemblages. This suggests that bio-riffle assemblages will not occur if environmental conditions other than the flow type and the substratum are unsuitable. Alternatively, perhaps insufficient riffle habitat occurs in mountain streams for a riffle community to develop.

Similarly, rapid hydraulic biotopes are dominated by the CAS flow type and are the only biotope to have CH and FF flow types. They are also dominated by boulder and bedrock substratum types (Table 11.8). In the intensive sampling site on the Eerste, 86% of the samples with one of these flow types combined with one of the substratum types were bio-rapid samples. When all the alluvial foothill and mountain sites were assessed, 100% (n = 11) of the samples with one of these combinations from mountain sites were of bio-rapid assemblages, as were 60% (n = 5) of the samples from foothill sites. Overall, the likelihood of locating a bio-rapid assemblage, using just the flow type and substratum for guide, is thus quite high.

Bio-runs can occur on any substratum, and RS is their most common flow type. In alluvial foothill sites, 71% of the samples (n = 14) with RS (any substratum) held bio-run assemblages, whilst only 25% of mountain samples (n = 12) held such assemblages; the remainder were almost entirely bio-rapid assemblages. As with bio-riffle fauna, this may reflect the relative rarity of runs in mountain streams.

Bio-pools can also occur on any substratum, and are dominated by BPF and SBT flow types. Only 47% of alluvial foothill samples (n = 17) with these flow types held bio-pool assemblages, with an even lower score of 38% in mountain samples (n = 13). Areas with slow flow types in high-gradient streams are often very small, and it seems possible that the invertebrates may be responding to faster water at the edge or bottom that is not reflected by the flow type.

Both MUs and hydraulic biotopes thus are imperfect guides to specific invertebrate assemblages, although the latter appear to be the better. Undoubtedly there is another finer level of physical resolution that is one of the final determinants of species' distributions. This topic is revisited in Section 12.7 and Chapter 17.

12.6 The influence of discharge

The distribution of flow types changes with changing discharge, and so their proportions within any one MU will also change over time. In order to ascertain how this might affect hydraulic biotopes, that is, the areas within which specific assemblages sit, one site on the Eerste River was sampled on six different occasions within two seasons (summer base flow and winter base flow). This investigation is reported on in Chapter 14.

12.7 Conclusion

The objective of this section of the project was to assess the extent to which faunal distributions are explained by their presence in different MUs. The overall message appears to be that MUs are not particularly good predictors of local species distributions, but can guide on the overall nature of a river reach and thus of the invertebrate assemblages likely to be present. MUs such as 'step' are among the better predictors of invertebrate assemblages and 'plane-bed' is the worst. To actually locate the assemblages, hydraulic biotopes – through their component parts substratum and flow - are better guides than MUs, but have to be used with caution for two reasons.

- The river zone must be pre-identified, as some species assemblages do not occur in all zones. For example, bio-riffle assemblages are rare in mountain streams, even in flow-substrata combinations characteristic of riffles.
- Even if both zone and flow-substrata combinations have been identified, the expected species assemblage will not always be collected. The area of the "habitat" patch (flow and substrata combination) may affect the ability of an appropriate species assemblage to become established, with smaller areas possibly less able to support an appropriate assemblage than bigger areas, because of edge effects. Alternatively, conditions not reflected by the substrata and flow type might be affecting distributions.

The above reasons might explain why there is so much 'noise' in benthic invertebrate samples from rivers – even in what appears to be a fairly uniform area within a site, we may well be sampling a mixture of species assemblages. For biomonitoring and other similar purposes, this 'noise' would probably be reduced if the following were used to guide collection of a sample.

- Use information such as that used in Table 5.1 and 12.1 to identify the biological zone in which the study site is located. This provides an initial indication of the kinds of MUs and hydraulic biotopes likely to be present.
- Map the distribution of MUs within the site, at least mentally, to develop an understanding of where different kinds of species assemblages might be most common.
- Sample in the middle of hydraulic biotopes that cover larger rather than smaller areas.
- Sample plane-bed MUs if a high diversity of possible hydraulic biotopes and species assemblages is desired, as they seem to contain a mixture of most possible hydraulic biotopes. Avoid them, however, if the objective is to collect specific species or species assemblages.

13. REACHES

13.1 Recap

The fourth aim listed for this project (Section 3.5) was to test the biological significance of geomorphologically defined reaches. As the data used thus far in this report were not collected specifically to test reach types, an additional sampling programme was designed specifically to asses reaches, using two sites on one river within the same biological zone but in different reach types (Section 4.6.3).

Different types of reaches have different combinations of morphological units, which define them, and therefore different proportions and types of available hydraulic biotopes (Rowntree and Wadeson 1999). These could in turn manifest as differences in invertebrate assemblages or in the proportions of species within assemblages. If different reach types within the same biological river zone do support different taxa, proportions of taxa, or abundances there could be implications, for instance, for biomonitoring results. In this chapter we report on initial analyses of the physical and biological differences between two adjacent but different reach types. Data from one of four sampling trips is presented (29 and 28 October 1997) for two sites representing the two reach types (Table 14.1). Further analyses of these data will be in D.M. Schael's PhD thesis.

13.2 Methods

Overall sampling methods have been described in Chapter 4 (Sections 4.3-4.5). The methods specific to the reach assessment are reiterated briefly here.

Two 50-m long sites on the Eerste River within the Jonkershoek Nature Reserve in Stellenbosch were chosen for the study. One site (E18#) was also used in the main and intensive study programmes, but extended to 50 m from its original 40 m length to make it the same length as the second site. Study sites were chosen to be 50-m long in order to provide adequate areas for sampling invertebrates (Section 4.5). Substrata were mapped once at each site, prior to the collection of any invertebrate samples, whereas flow types were mapped several times, i.e. on each day when invertebrates were collected. Invertebrates were sampled at both sites on four different occasions for assessing the impact of changing discharge on physical habitat and invertebrate distributions, only one of these data sets is used here. Sampling points were decided upon on site using maps of flow and substratum as discussed in Section 13.3. Invertebrates were collected quantitatively, using a 0.5 x 0.5 x 0.5-m box sampler with a 250 µm mesh on the downstream collecting side and two adjacent sides. A 500-µm mesh was used on the upstream side, so as to allow fast flow into the sampler that would carry the animals disturbed from the bed downstream into the collecting net. Because of the size of the box sampler sample points had to have uniform conditions over at least 0.5 x 0.5-m in area. Each flow/substratum combination also needed to be sufficiently abundant within each study site to allow for three replicate samples of that combination to be sampled. If these criteria were not met within a site, a particular flow and substratum combination could not be used in the study for that site.

After all the sampling points were chosen and delineated on the flow/substratum maps, hydraulic data were collected within each (depth, near bed velocity and mean water column (0.6) velocity). These measurements were made at four different places within the 0.5 x 0.5-m area. The box sampler was put on the sampling area and a substratum grid was placed over the top of the box sampler in order to record the proportion of each type of substratum present. The bed profile was then measured, using the profiler (described in Section 4.3.5) which was placed inside the box sampler. The substrata were then picked up and scrubbed with a brush and all animals collected into the net. The animals were sorted in the laboratory as described in Section 4.5, with most samples processed in full. Identifications of invertebrates were done to species where possible or to morphological types. Two family groups have not been identified to species for these analyses, the Baetidae (Ephemeroptera) and Simuliidae (Diptera). Specialists aided in the identification of type specimens for the Chironomidae (Diptera), Hemiptera, Leptoceridae and Hydroptilidae (Trichoptera) and Teloganodidae (Ephemeroptera) (see Table 8.1 for specialists). Species/morph type level or closest taxonomic level data (Appendix 13.1) were used for the analysis of similarity between samples.

13.3 Physical comparisons

The two sites chosen for this study were classified as being in the same biological zone, a mountain zone. However, geomorphological assessment of the sites classified them as being in two different geomorphological zones (Table 6.6 and Table 13.1), Eerste site 1 (E18#) being in a mountain stream zone and Eerste site 2 (E21#) in a mountain stream (transitional) zone.

Table 13.1 Geomorphological characteristics of both Eerste river sites. MU = Morphological Unit. The number of each type of MU found in each site is given in parenthesis after each type. Site code as in Table 5.3.

Site (code)	Geomorphological Zone	Reach Type	MU Type (No.)	MU % Area
1 (E18#)	Mountain Stream	Step-pool/ Plane-bed	Plane-bed (3)	34
			Step (1)	5
			Pool (2)	19
			Mid-channel bar (1)	9
			Lateral bar (1)	23
			Later channel (1)	10
2 (E21#)	Mountain Stream (transitional)	Pool-rapid	Boulder rapid (1)	32
			Plane-bed (1)	47
			Pool/Plane-bed (1)	21

Classification of Eerste site 1 (E18#), using the morphological units (MUs) in Chapter 12 (Table 12.1) with the other least disturbed sites in the main study, showed that site 1 grouped with the mountain stream/transitional/upper foothill zone sites. Based on that analysis, the two different reaches could be considered to be in the same geomorphological zone.

Site 1 is a hybrid Step-pool/Plane-bed reach; characterised by six different MUs, the dominant one being plane-bed, both in number and area of reach (Table 13.1). Site 2 was classified as a Pool-rapid reach, and consists of three MUs: plane-bed, rapid and pool/plane-bed. The plane-bed MU at site 2 covers the greatest percentage of the site (Table 13.1) and is in one contiguous area, whereas the three separate plane-bed areas in site 1 cover 5, 14 and 15% of the site respectively.

The dominant substratum by area in both sites is boulder (B) with large cobble (LC) sub-dominant (Figure 13.1, definition and codes as per Table 2.4). The main difference between the substrata of the two sites is the proportion of mixed substrata and smaller bed material (small cobble, large and small gravel, and sand). Mixed substrata categories comprise 22.2% of the total area in site 2 and smaller substrata 9.3% (Figure 13.1). In site 1, mixed substrata comprise only 3.4% of the area and small bed material 6.1%.

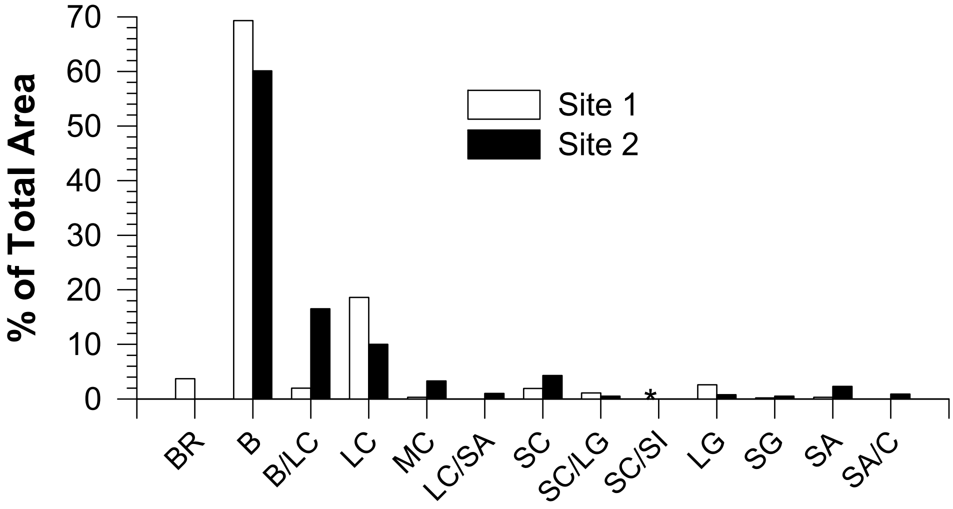

Figure 13.1 Percent cover of each substratum category for each Eerste river site. Substratum codes as per Table 2.4, with exception of "MC" which denotes mixed large and small cobble. The * denotes site 1 = 0.1% which is not visible on this scale; this category was not present in site 2.

Rippled surface (RS) was the dominant flow type during the sampling event reported here, covering 41.6% and 54.2% of the area at sites 1 and 2 respectively, with undular standing waves (USW) sub-dominant (Table 13.2, definitions and codes as per Table 2.3). Thereafter there was a difference between the two sites in the types and proportions of flow recorded (Table 13.2). Site 1 had a greater diversity of flow types, with 13 different types recorded as opposed to nine types in site 2.

The mapped proportions of substrata and flow types guided the choice of flow-substratum combinations for this study. To be consistent between reaches and between sampling times (Chapter 14), a standard set of combinations was decided upon. Even before analysis it was clear that boulder and large cobble dominated each site, and these categories would consistently meet the criteria listed in section 13.2. Flow types that were thought to be present within each reach with areas large enough to be sampled were: BSW, USW, RS, SBT, and BPF and originally FRF. As Table 13.2 shows, these were indeed the dominant flow types, with the exception of FRF, which was not considered further for the study. There remained ten possible flow/substratum combinations for the sampling programme, all of which were used when available in each site (combinations were used as available in a site and were site specific; sampling choices in one site did not dictate the combinations sampled in the other site.).

Table 13.2 Flow type proportions (shown as percent of area covered) for sampling sites 1 and 2 on 29 and 28 October 1997 respectively. The five flow types used in sampling are listed first from fastest flow to slowest, followed by the other flow types recorded at each site but not used in sampling invertebrates, also fastest to slowest.

Flow Type	Site 1	Site 2
Broken Standing Waves	7.2	10.1
Undular Standing Waves	18.3	24.0
Rippled Surface	41.6	54.2
Smooth Boundary Turbulent	8.4	1.6
Barely Perceptible Flow	15.9	6.1
Free Fall	0.1	0.0
Cascade	0.5	0.5
Chute	1.1	1.2
Stream	0.7	0.7
Fast Riffle Flow	4.6	1.6
Slow Riffle Flow	0.3	0.0
Trickle	0.7	0.0
No Flow	0.6	0.0

The distribution of these combinations in site 1 (Figure 13.2) is more evenly divided between the boulder and large cobble substrata than in site 2, which is dominated by boulder. The RS/B and RS/LC combinations cover most of the area at site 1 and RS/B and USW/B at site 2. Figure 13.2 and Table 13.2 also show that there was very little SBT, over either boulder or large cobble, at either site, with the exception of SBT/B at site 1. Barely perceptible flow over large cobble was also not available in large enough proportions or patch sizes to sample at site 2. As a result of the various levels of availability, not all of the flow/substratum combinations were sampled, with 27 samples being collected at site 1 and 21 samples at site 2 (Table 13.3).

Table 13.3 Flow/substratum combinations sampled within each site on 29 and 28 October. Flow and substratum codes as per Tables 2.3 and 2.4. Each flow/substratum combination listed was replicated at three different places within each site.

	Site 1		Site 2	
Flow Type	**Substratum**		**Substratum**	
BSW	B	LC	B	LC
USW	B	LC	B	LC
RS	B	LC	B	LC
SBT	B			
BPF	B	LC	B	

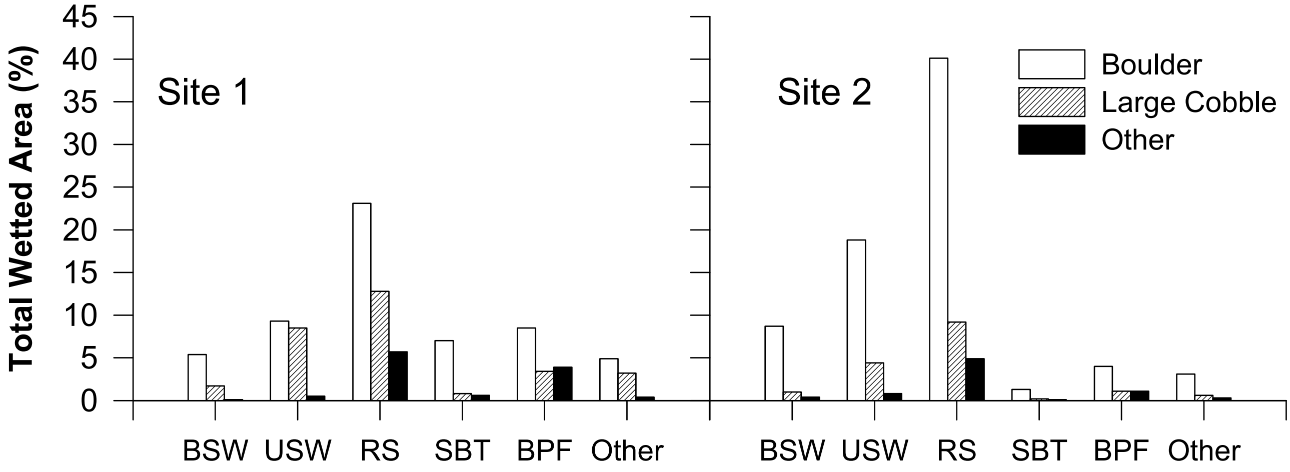

Figure 13.2 Proportions by area of flow type and substrata combinations for both Eerste River sites on 29 and 28 October 1997 (sites 1 and 2 respectively). All flow types (codes as per Table 2.3) and substrata not used for sampling invertebrates were combined into "other".

Water temperature, pH, conductivity, air temperature, and stream discharge were recorded at each site. Water temperature, conductivity and pH readings between sites were similar on average, suggesting that there was not a difference between the two sites (Table 13.4). Discharge between the two sites is different, as site 2 is approximately 1.5 km downstream from site 1 with two tributaries (Jakkels and Lang) entering between the sites.

Table 13.4 Average and standard deviation of values for water chemistry, air temperature, and discharge for each site on 29 and 28 October 1997 (sites 1 and 2 respectively).

Variable	Site 1 Mean ± SD	Site 2 Mean ± SD
Water Temperature (°C)	14.8 ± 3.2	14.8 ± 1.5
Conductivity (mS cm^{-1})	29.0 ± 5.9	26.0 ± 1.2
pH	5.6 ± 0.15	5.9 ± 0.08
Air Temperature (°C)	26.0 ± 8.5	27.0 ± 2.8
Discharge (m^3 s^{-1})	0.065 ± 0.003	0.140 ± 0.063

13.4 Biological comparison of reaches

Invertebrate densities for each replicate sample within each reach were calculated from species counts. Invertebrate densities per sample ranged from 192 – 6,000 animals per m^2 in Eerste site 1 and site 2 respectively (Table 13.5). Overall mean densities between the reaches are slightly different, with site 1 having a lower abundance than site 2.

Table 13.5 Number of samples (N), minimum, maximum, mean and standard error (SE) of invertebrate densities (# m^{-2}) of samples in each site.

Sample Statistics	Site 1	Site 2
N	27	21
Minimum sample density	192	204
Maximum sample density	5,328	6,000
Mean sample density	1,755	2,361
SE sample density	306	409

In order to determine if there is a significant statistical difference between animal abundances in the two reaches, the data were first assessed to see if they meet the criteria of normalcy. The distribution of invertebrate density data did not fit the normal distribution assumption (Kolmogorov-Smirnov test, d=0.197, p< 0.01), which is needed for parametric statistical tests. Therefore, all data were 4th root transformed (typical for invertebrate samples, Clark and Warwick, 1994). The distribution of the transformed data was not significantly different from a normal curve (Kolmogorov-Smirnov test, d=0.083, p=n.s.). To assess if there was a significant difference between reaches an analysis of variance (ANOVA) on transformed invertebrate densities was run using Statistica (1999). There was no statistical significant difference between reaches using overall invertebrate densities (p=0.254, Table 13.6).

Table 13.6 General ANOVA table examining the effect of reach on invertebrate densities. d.f. = degrees of freedom; MSS = Mean Sums of Squares, F = test statistic and P = significance level.

	d.f.	MSS	F	P
effect	1	3.218	1.3	0.254
error	46	2.413		

Clearly this sort of analysis does not take into account the different species found or the proportion of each species identified within each reach, as it integrates all species into a comparison of single numbers. In order to take these individual species and their densities into account, the full set of data or species lists (densities 4th root transformed), for each reach was then used for agglomerative hierarchical cluster analysis in PRIMER using the CLUSTER module.

The result of the cluster analysis shows that the primary split in the dendrogram (Figure 13.3) is between the faster hydraulic conditions (BSW, USW, and RS) and slower (RS, SBT and BPF) conditions with some overlap of samples with RS (further explanation in section 13.5). As all samples were from the same river, the catchment signature that was evident in Chapter 10 is not apparent. It was thought, however, that the major split would be between reaches, followed by different flow type/substrata combinations or hydraulic biotopes (as defined in Chapter 11) groupings. At first inspection the split is only between hydraulic conditions with no effect of reach type. However on closer examination within the "fast" group there does seem to be some site differentiation with hydraulic biotopes grouping out by site rather than mixing between sites (Figure 13.4). This pattern is not seen as strongly within the "slow" group, perhaps because of an unbalanced representation of slower flow/substrata combinations in site 2 compared to site 1 (no SBT combinations and only BPF/B sampled in site 2).

At this point, with the data from this one analysis, there is no significant difference between the two studied reaches in terms of overall invertebrate density. A species-level multivariate analysis also showed that there was not a strong difference between the reaches and that the hydraulic condition (fast or slow flow) was the primary split of groups. However, within the two major groups there were subtle sub-groupings that seemed to reflect the two different sites. Sub-groupings by hydraulic biotope and reaches are discussed in Section 13.5.

13.5 Hydraulic Biotopes

Examining the dendrogram outputted by the cluster analysis beyond the initial split of the two main groups of "fast" and "slow" groups, sub-groups of invertebrate samples delineating different hydraulic biotopes can be identified (Figure 13.4). The MDS plot (Figure 13.5) further shows the split between "fast" and "slow" groups of samples as well as specific sub-groupings. Eighteen such sub-groups were identified: five from pools, four from runs, three from riffles, four from rapids and two undefined. Most of these sub-groups were site specific, but four groups were indeterminable (50/50 split) and two groups had the majority of their samples from one site. Table 13.7 gives information on each hydraulic biotope derived from Figure 13.4.

As discussed in Section 13.4, some samples observed as RS on boulder and large cobble fell within the "Fast" and some within the "Slow" hydraulic groupings. Hydraulically the samples that group with the "Fast" category are more closely related to USW sample than to samples in the "Slow" group, with animals reflecting this. Rippled surface as shown in Chapter 11, is one of the more hydraulically variable flow types, and does tend to bridge the two major hydraulic groupings.

Tables 13.8 and 13.9 are summaries of the hydraulic data for each hydraulic biotope, giving the range, mean and standard deviations for the parameters recorded at each sampling area within a biotope type and the average percentage of substrata present. These hydraulic ranges and means fall well within those seen in Chapter 11, and most importantly demonstrate that most sub-groups contained samples from one site. Although there were sub-groups containing samples from both sites, these were not the norm. There is a basic affiliation with site and hydraulic biotope.

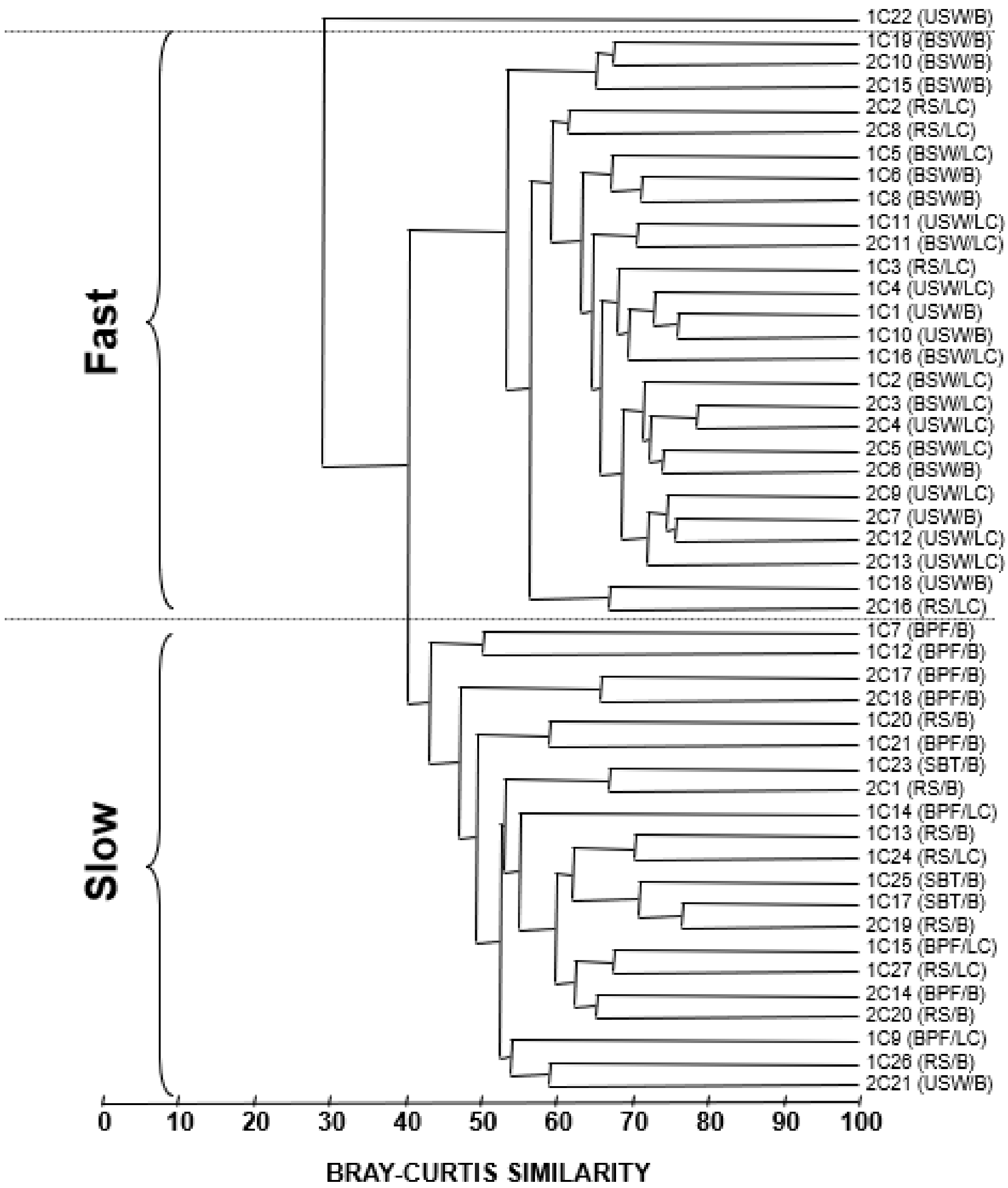

Figure 13.3 Species-level dendrogram for individual samples at the two sites in different reach types on the Eerste River. Lines represent the split between the two major groupings of flow conditions, with the outlier at the top. 1 = Eerste site 1, 2 = Eerste site 2, C = sampling period (Table 14.1), 29 October (site 1) and 28 October (site 2) 1997. Number after the data code is the sample number. Flow and substrata combinations appear in parentheses after each sampling point, categories as per Tables 2.3 and 2.4.

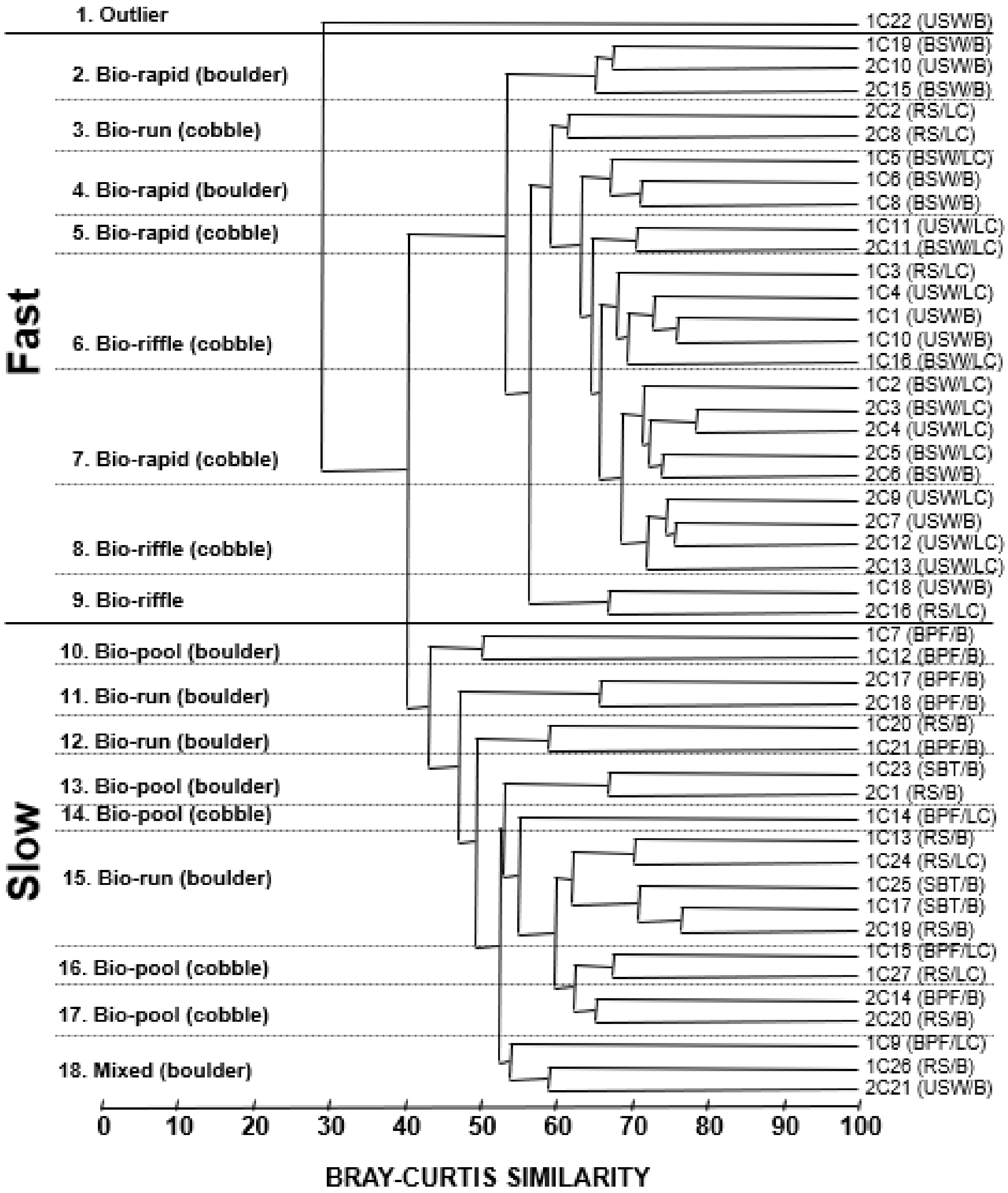

Figure 13.4 Species-level dendrogram (same as Figure 13.3) for individual samples at the two sites in different reach types on the Eerste River, demarcating different hydraulic biotopes. Codes as described for Figure 13.3.

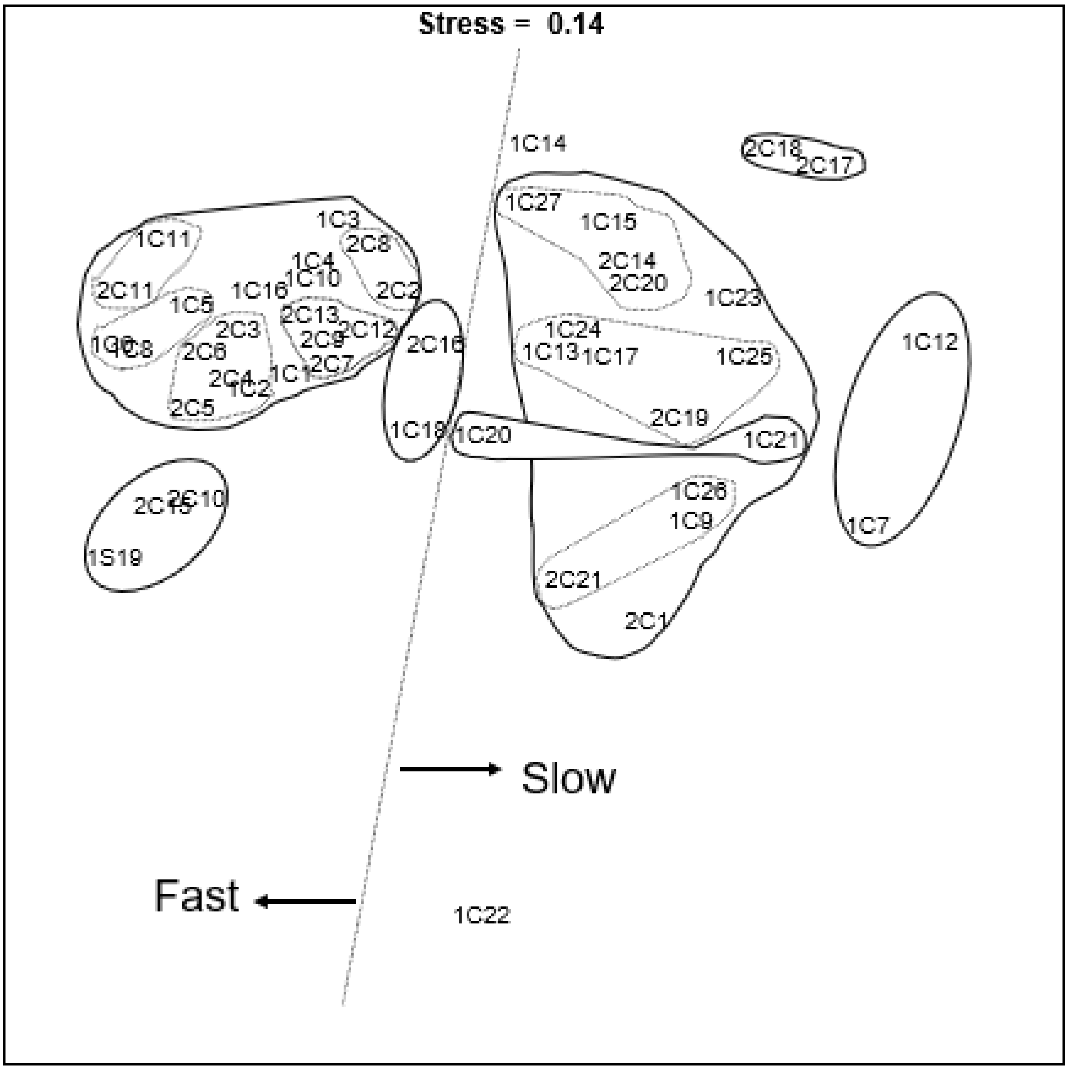

Figure 13.5 MDS plot of invertebrate samples from two sites in different reach types on the Eerste River. Codes as described for Figure 13.3. Solid circles demarcate major groupings and dotted circles smaller sub-groups. The dotted line shows the split into two planes between the hydraulically fast and slow samples.

Table 13.7 Hydraulic characteristics of the 18 groups of samples from both sites on the Eerste River, as recognised in Figure 13.5. The sub-groups are recognised as biologically derived hydraulic biotopes. Site number, sampling code (S.C.) and flow types sampled are also given. Statistics are: mean and standard deviations (SD) of the four readings taken within each sampling area, of Depth (m); near-bed (NB) and Mean-column (0.6) velocity (m s^{-1}) and Froude number.

Sub-group	Hydraulic Biotope	Site	S.C.	Flow Type	Depth		NB		0.6		Froude	
					Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Outlier	1	22	USW	0.31	0.10	0.12	0.11	0.26	0.02	0.155	0.022
2	Bio-Rapid (boulder)	1	19	BSW	0.20	0.10	0.55	0.20	0.48	0.09	0.369	0.094
		2	10	BSW	0.20	0.04	0.77	0.26	0.52	0.15	0.382	0.133
		2	15	BSW	0.15	0.02	0.26	0.16	0.34	0.07	0.291	0.075
3	Bio-Run (cobble)	2	2	RS	0.43	0.05	0.14	0.09	0.22	0.08	0.107	0.038
		2	8	RS	0.16	0.03	0.05	0.03	0.08	0.04	0.059	0.033
4	Bio-Rapid (boulder)	1	5	BSW	0.17	0.05	0.35	0.47	0.49	0.38	0.424	0.409
		1	6	BSW	0.10	0.04	0.36	0.16	0.46	0.13	0.464	0.093
		1	8	BSW	0.07	0.01	0.99	0.38	1.01	0.36	1.246	0.527
5	Bio-Rapid (cobble)	1	11	USW	0.21	0.04	0.17	0.11	0.32	0.10	0.226	0.080
		2	11	BSW	0.15	0.04	0.17	0.15	0.32	0.20	0.274	0.182
6	Bio-Riffle (cobble)	1	3	RS	0.20	0.04	0.05	0.06	0.10	0.06	0.074	0.052
		1	4	USW	0.25	0.01	0.42	0.11	0.49	0.10	0.312	0.068
		1	1	USW	0.08	0.02	0.20	0.19	0.22	0.18	0.262	0.215
		1	10	USW	0.09	0.03	0.30	0.11	0.31	0.10	0.359	0.154
		1	16	BSW	0.11	0.04	0.35	0.14	0.44	0.11	0.442	0.136
7	Bio-Rapid (cobble)	1	2	BSW	0.16	0.06	0.24	0.16	0.24	0.20	0.203	0.185
		2	3	BSW	0.35	0.05	0.49	0.22	0.87	0.07	0.472	0.025
		2	4	USW	0.23	0.06	0.19	0.37	0.59	0.26	0.416	0.232
		2	5	BSW	0.09	0.04	0.28	0.10	0.43	0.14	0.475	0.114
		2	6	BSW	0.24	0.04	0.38	0.25	0.36	0.26	0.244	0.186
8	Bio-Riffle (cobble)	2	9	USW	0.20	0.01	0.18	0.04	0.30	0.02	0.213	0.014
		2	7	USW	0.17	0.04	0.09	0.11	0.16	0.12	0.132	0.104
		2	12	USW	0.30	0.04	0.23	0.05	0.28	0.03	0.163	0.019
		2	13	USW	0.30	0.04	0.07	0.04	0.16	0.06	0.095	0.031
9	Bio-Riffle (cobble)	1	18	USW	0.17	0.09	0.12	0.11	0.15	0.10	0.143	0.116
		2	16	RS	0.29	0.04	0.24	0.03	0.30	0.02	0.182	0.012
10	Bio-Pool (boulder)	1	7	BPF	0.15	0.03	0.03	0.01	0.05	0.01	0.038	0.006
		1	12	BPF	0.12	0.04	0.01	0.01	0.02	0.01	0.022	0.004
11	Bio-Run (boulder)	2	17	BPF	0.43	0.02	0.13	0.02	0.14	0.02	0.067	0.010
		2	18	BPF	0.42	0.05	0.09	0.01	0.11	0.02	0.053	0.015
12	Bio-Run (boulder)	1	20	RS	0.29	0.02	0.13	0.02	0.21	0.04	0.123	0.022
		1	21	BPF	0.16	0.15	0.03	0.03	0.05	0.03	0.051	0.046
13	Bio-Pool (boulder)	1	23	SBT	0.41	0.03	0.04	0.01	0.06	0.01	0.029	0.005
		2	1	RS	0.28	0.01	0.00	0.01	0.01	0.01	0.005	0.006
14	Bio-Pool (cobble)	1	14	BPF	0.41	0.01	0.02	0.01	0.05	0.01	0.025	0.007
15	Bio-Run (boulder)	1	13	RS	0.34	0.08	0.06	0.06	0.14	0.05	0.082	0.040
		1	24	RS	0.41	0.06	0.06	0.03	0.12	0.01	0.062	0.008
		1	25	SBT	0.43	0.07	0.02	0.00	0.03	0.01	0.014	0.003
		1	17	SBT	0.28	0.07	0.07	0.01	0.09	0.01	0.058	0.013
		2	19	RS	0.20	0.04	0.11	0.03	0.15	0.01	0.105	0.017
16	Bio-Pool (cobble)	1	15	BPF	0.24	0.05	0.03	0.01	0.04	0.01	0.025	0.009

Sub-group	Hydraulic Biotope	Site	S.C.	Flow Type	Depth		NB		0.6		Froude	
					Mean	SD	Mean	SD	Mean	SD	Mean	SD
		1	27	RS	0.34	0.02	0.05	0.01	0.14	0.02	0.079	0.012
17	Bio-Pool (boulder)	2	14	BPF	0.11	0.03	0.01	0.01	0.02	0.01	0.019	0.006
		2	20	RS	0.44	0.05	0.13	0.05	0.18	0.03	0.085	0.018
18	Mixed (boulder)	1	9	BPF	0.22	0.07	0.03	0.00	0.05	0.01	0.033	0.003
		1	26	RS	0.50	0.07	0.07	0.05	0.14	0.05	0.061	0.019
		2	21	USW	0.32	0.06	0.10	0.01	0.16	0.01	0.090	0.013

//Table 13.7 continued

There are some differences between the proportions of hydraulic-biotope types identified within each site. Site 1 had three bio-pools (one boulder and two cobble), two boulder bio-runs, one cobble bio-riffle and one bio-rapid, with a total of seven hydraulic biotopes of four different types. Site 2 also had four different hydraulic biotope types, but in a different configuration. There was one bio-pool (boulder), two bio-runs (one cobble and one boulder), one cobble bio-riffle and two bio-rapids (one cobble and one boulder) for a total of six defined hydraulic biotopes. These differences mirror differences in the distribution of flow types between the sites and demonstrates that there were more "turbulent" hydraulic biotopes (i.e. rapids and riffles) present in the reach characterised as Pool-rapid (site 2) and more "quiet" hydraulic biotope types (i.e. pools and runs) identified in site 1 (Step-pool/Plane-bed reach type).

13.6 Further analyses

As could be seen by the analyses completed to date, comparing the reaches by examining overall density does not show any difference between the two. However, by using a cluster analysis and identifying hydraulic biotopes, it can be shown that different reach types within the same zone have some differences in their invertebrate assemblages.

As these are preliminary analyses, there is more to accomplish with these data. Identifying the species or groups of species that are creating these differences will be done using SIMPER in Primer (Clark and Warwick 1994), as well as an investigation of the different proportions of species within a biotope, and the relationship between sample location and species composition. Additionally, as there are samples from three more sample dates that have not yet been analysed, it will be possible to ascertain if these patterns are repeated through time and changes in discharge (Chapter 14 and PhD thesis of D.M. Schael).

Table 13.8 Summary statistics for each group of samples recognised in Table 13.6: range, mean and standard deviation (SD) of depth and percent composition of substrata. These statistics are listed by hydraulic biotope, sub-group number, site representation and number of samples (N) within each hydraulic biotope. Depth data calculated from the means from Table 13.7. Substratum averages from all contributions within the group. Site designation is based on group composition; none means that both sites were equally represented in the sub-group; and a * denotes that the majority of samples were from that site, but that one sample in the sub-group was from the other site.

				Depth (m)			Substrata (% coverage)				
Hydraulic Biotope	**Sub-group**	**Site**	**N**	**Range**	**Mean**	**SD**	**B**	**LC**	**SC**	**LG**	**SG**
Bio-Pool (boulder)	10	1	2	0.12 – 0.15	0.13	0.02	98	2	0	0	0
Bio-Pool (boulder)	13	none	2	0.28 – 0.41	0.34	0.09	66	28	6	0	0
Bio-Pool (cobble)	14	1	1	.	0.41	.	20	40	36	4	0
Bio-Pool (cobble)	16	1	2	0.24 – 0.34	0.29	0.07	20	54	18	6	2
Bio-Pool (boulder)	17	2	2	0.11 – 0.44	0.28	0.24	62	6	24	0	8
Bio-Rapid (boulder)	2	2	3	0.15 – 0.20	0.18	0.03	85	3	9	3	0
Bio-Rapid (boulder)	4	1	3	0.07 – 0.17	0.11	0.05	48	37	9	5	0
Bio-Rapid (cobble)	5	none	2	0.15 – 0.21	0.18	0.05	36	18	24	22	0
Bio-Rapid (cobble)	7	2*	5	0.09 – 0.35	0.21	0.10	36	46	10	6	2
Bio-Riffle (cobble)	6	1	5	0.08 – 0.25	0.14	0.08	16	40	28	10	6
Bio-Riffle (cobble)	8	2	4	0.17 – 0.30	0.24	0.07	26	29	28	15	2
Bio-Riffle (boulder)	9	none	2	0.17 – 0.29	0.23	0.08	52	38	6	4	0
Bio-Run (cobble)	3	2	2	0.16 – 0.43	0.30	0.19	28	40	32	0	0
Bio-Run (boulder)	11	2	2	0.42 – 0.43	0.43	0.01	74	4	8	0	14
Bio-Run (boulder)	12	1	2	0.16 – 0.29	0.23	0.10	76	16	4	4	0
Bio-Run (boulder)	15	1*	5	0.20 – 0.43	0.33	0.09	66	19	11	3	0
Mixed (boulder)	18	none	3	0.22 – 0.50	0.35	0.14	84	3	8	5	0
Outlier	1	1	1	.	0.31	.	80	0	20	0	0

Table 13.9 Summary statistics for each sub-group of samples recognised in Table 13.7: ranges, means and standard deviations of mean-column (0.6) velocity, near-bed (NB) velocity and froude number. These statistics are listed by hydraulic biotope, sub-group number, site representation and number of samples (N) within each hydraulic biotope. Four individual sets of velocity measurements were made within the area where each invertebrate sample was collected. The means of these values are given in Table 13.6. The values in this summary table are the ranges, means and standard deviations of these means. Velocity is measured as m s^{-1}, and Froude number is dimensionless. Site designation is based on group composition; none means that both sites were equally represented in the sub-group; and a * denotes that the majority of samples were from that site, but that one sample in the sub-group was from the other site.

				Near Bed Velocity (m s^{-1})			Mean (0.6) Velocity (m s^{-1})			Froude Number		
Hydraulic Biotope	**Sub-group**	**Site**	**N**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**
Bio-Pool (boulder)	10	1	2	0.01 – 0.03	0.02	0.01	0.02 – 0.05	0.03	0.02	0.022 – 0.038	0.030	0.012
Bio-Pool (boulder)	13	none	2	0.00 – 0.04	0.02	0.02	0.01 – 0.06	0.03	0.04	0.005 – 0.029	0.017	0.017
Bio-Pool (cobble)	14	1	1	.	0.02	.	.	0.05	.	.	0.025	.
Bio-Pool (cobble)	16	1	2	0.03 – 0.05	0.04	0.01	0.04 – 0.14	0.09	0.07	0.025 – 0.079	0.052	0.038
Bio-Pool (boulder)	17	2	2	0.01 – 0.13	0.07	0.08	0.02 – 0.18	0.10	0.11	0.019 – 0.085	0.052	0.047
Bio-Rapid (boulder)	2	2	3	0.26 – 0.77	0.53	0.25	0.34 – 0.52	0.45	0.09	0.291 – 0.382	0.348	0.049
Bio-Rapid (boulder)	4	1	3	0.35 – 0.99	0.57	0.37	0.46 – 1.01	0.65	0.31	0.424 – 1.246	0.711	0.464
Bio-Rapid (cobble)	5	none	2	0.17 – 0.17	0.17	0.01	0.32 – 0.32	0.32	0.00	0.226 – 0.274	0.250	0.034
Bio-Rapid (cobble)	7	2*	5	0.19 – 0.49	0.32	0.12	0.24 – 0.87	0.50	0.24	0.203 – 0.475	0.362	0.129
Bio-Riffle (cobble)	6	1	5	0.05 – 0.42	0.26	0.14	0.10 – 0.49	0.31	0.16	0.074 – 0.442	0.290	0.138
Bio-Riffle (cobble)	8	2	4	0.07 – 0.23	0.14	0.07	0.16 – 0.30	0.22	0.07	0.095 – 0.213	0.151	0.050
Bio-Riffle (boulder)	9	none	2	0.12 – 0.24	0.18	0.09	0.15 – 0.30	0.22	0.11	0.143 – 0.182	0.162	0.028
Bio-Run (cobble)	3	2	2	0.05 – 0.14	0.10	0.06	0.08 – 0.22	0.15	0.10	0.059 – 0.107	0.083	0.034
Bio-Run (boulder)	11	2	2	0.09 – 0.13	0.11	0.03	0.11 – 0.14	0.12	0.02	0.053 – 0.067	0.060	0.010
Bio-Run (boulder)	12	1	2	0.03 – 0.13	0.08	0.07	0.05 – 0.21	0.13	0.11	0.051 – 0.123	0.087	0.051
Bio-Run (boulder)	15	1*	5	0.02 – 0.11	0.06	0.03	0.03 – 0.15	0.11	0.05	0.014 – 0.105	0.064	0.034
Mixed (boulder)	18	none	3	0.03 – 0.10	0.07	0.04	0.05 – 0.16	0.11	0.06	0.033 – 0.090	0.061	0.028
Outlier	1	1	1	.	0.12	.	.	0.26	.	.	0.155	.

14. THE RELATIONSHIP BETWEEN HYDRAULIC BIOTOPE AND DISCHARGE

14.1 Recap

The final aim of this project (Section 3.7) was to record changes in the distributions of flow types and invertebrates with discharge, and to assess the temporal stability of hydraulic biotopes and their biota.

Hydraulic biotopes are defined by their species assemblage and described by hydraulic conditions (flow type and substrata). Thus, as flow conditions change there will be a point where the biota changes and at that point, by definition, the hydraulic biotope also changes. If we can define and understand those points of change, understanding of hydraulic biotopes will be enhanced through a better understanding of the resilience of patches of different hydraulic character, and the relationship of this to invertebrate distributions.

In this chapter the stability of hydraulic conditions and invertebrate assemblages are tracked over a series of discharges. It was thought that up to a point, the discharge and resulting hydraulic changes would not be reflected in changes in the distribution of invertebrate species. However, discharge should eventually increase (or decrease) to a point where invertebrate distribution patterns would be significantly affected. Preliminary analyses of changes in hydraulic conditions with discharge, and the links with shifts in densities of invertebrates and changes in species composition of assemblages are presented here. Further analyses to be done in Ms Schael's PhD thesis are outlined here.

14.2 Methods

Flow types of both sites on the Eerste River (Chapter 13) were mapped, and discharge measured, on eight occasions within a single season (spring) of 1997. The objective was to document changes in wetted area and the proportions of different flow type (Table 14.1). Invertebrates were also collected on four of these occasions, together with allied physical measurements (see Chapters 4 and 13 for collection details). Two sample dates in summer 1997 on Eerste River site 1 are included in the analyses where appropriate, with differences in site length and sampling strategies noted (Section 13.2).

The study was confined to one season in order to eliminate noise in the data from seasonal invertebrate community shifts. Additionally, this should have allowed a wide range of discharges to be studied, as the winter rains gradually ceased and low summer flows ensued. In this case, the preceding winter had lower than normal rainfall, and the spring flows were lower than expected. One major rainfall event toward the end of spring provided the only high flow condition during the study period, with all other discharges studied being fairly similar.

On each sampling episode, each site was sampled within a day or two of the other, with the downstream site (Eerste site 2) being sampled first on all occasions except the last invertebrate sampling episode. Most invertebrate sampling sessions were over two days, with flow-type mapping completed on the first day and discharge measured on each day of the episode. For ease of reporting, all dates of mapping and sampling are represented by site number and letter codes for each sampling period (Table 14.1).

Table 14.1 Site number, data code, date of map, site area (total and wetted, m²) along with measured discharge (m³ s⁻¹) and description of main data types collected. Upper case letters (A-D, M and IS) used in the map code denote periods where invertebrates were sampled, lower case letters (w-z) denote when only flow types were mapped. M = first mapping and sampling date on Eerste River site 1 during the main study (Chapter 5) and IS = intensive sampling for testing hydraulic biotopes (Chapter 11).

Site No.	Data Code	Map Date	Total Mapped Area (m^2)	Wetted Area (m^2)	Discharge ($m^3\ s^{-1}$)	Data Collected
1	M[a]	15-Jan-97	326.2	158.2	0.132	substrata & flow maps and invertebrates
1	IS[a]	1-Apr-97	326.2	140.2	0.038	flow map and invertebrates
2	A	15-Sep-97	486.6	251.3	0.509	substrata & flow maps and invertebrates
1	A	18-Sep-97	394.6	221.9	0.184	flow map and invertebrates
1	w	3-Oct-97	394.6	206.0	0.082	flow map
2	w	3-Oct-97	486.6	217.6	0.272	flow map
2	B	8-Oct-97	486.6	248.7	0.339	flow map and invertebrates
1	B	10-Oct-97	394.6	218.3	0.110	flow map and invertebrates
1	x	22-Oct-97	394.6	194.2	0.067	flow map
2	x	22-Oct-97	486.6	215.5	0.216	flow map
2	C	28-Oct-97	486.6	206.8	0.141	flow map and invertebrates
1	C	29-Oct-97	394.6	190.8	0.067	flow map and invertebrates
1	y	10-Nov-97	394.6	190.2	0.072	flow map
2	y	10-Nov-97	486.6	213.0	0.200	flow map
1	z	25-Nov-97	394.6	282.8	0.781	flow map
1	D	28-Nov-97	394.6	236.8	0.451	flow map and invertebrates
2	z	28-Nov-97	486.6	263.4	0.619	flow map
2	D	30-Nov-97	486.6	259.3	0.559	flow map and invertebrates

[a]Site was 40-m in length rather than the 50-m at subsequent mapping trips.

14.3 Physical stability of hydraulic conditions

The first level of assessment was to examine the physical character of the two sites, which are in differnt geomorphological reach types, as discharge changed over time. Overall changes are described, and the sites compared.

There was a significant positive linear relationship between wetted area (WA) and discharge (Q), where: Q = 0.0077(WA) – 1.466 ($R^2 = 0.92$). As discharge increased, wetted area increased (Figure 14.1). However, the changes in wetted area are subtle, and a large change in discharge would be needed for a noticeable difference in wetted area. Measured discharges ranged from 0.038 $m^3\ s^{-1}$ in mid-summer of 1997 (IS) at site 1 to 0.781 $m^3\ s^{-1}$ in late spring (sampling period z), also at site 1 (Table 14.1). The lowest spring discharge was 0.067 $m^3\ s^{-1}$ (sampling period C). Over the measured spring discharges, wetted area ranged from 190.8 m^2 to 282.8 m^2, or 44.3-71.6% of total wetted mapped area respectively. Site 2 had a higher discharge than site 1, as noted in Chapter 13, because of the entry of two tributaries between the sites.

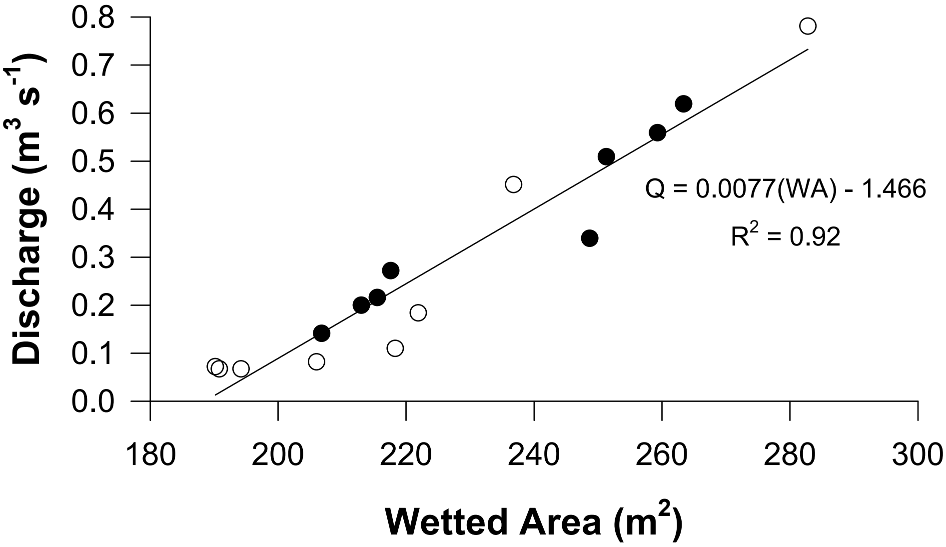

Figure 14.1 Total wetted area (WA) and measured discharge (Q) for site 1 (○) and site 2 (●) on the Eerste River, on all mapping and sampling occasions shown in Table 14.1.

The wetted area at site 2 was greater than that at site 1 on all occasions, providing for a greater overall area for invertebrates to settle in site 2 (Figure 14.2). As the total mapped area of site 2 was greater than that of site 1 due to channel size and shape, they can only be directly compared through their percentage of wetted area. Examining percentage of wetted area, site 1 actually had a slightly greater overall percentage of wetted area than did site 2 (ranging from 60 - 48% and 53 - 44% for sites 1 and 2 respectively). The patterns for both sites, however, remain the same, with the first two sampling periods being almost equivalent and the greatest differences being between sampling periods C and D.

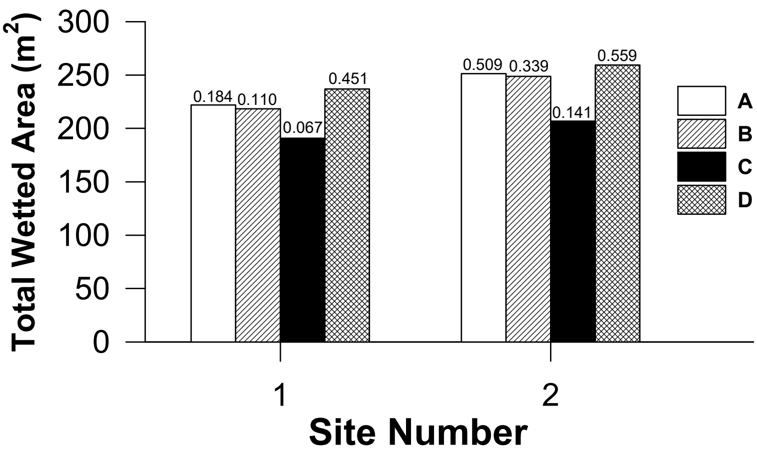

Figure 14.2 Total wetted area (m^2) on each of the main sampling occasions listed in Table 14.1. Site 1: A = 18 September; B = 10 October; C = 29 October; D = 28 November 1997. Site 2: A = 15 September; B = 8 October; C = 28 October; D = 30 November 1997. Measured discharges (m^3 s^{-1}) on top of each bar.

Although changes in discharge and wetted area were recorded, these had negligible effect on the proportions of different flow types for all but highest measured discharges (Table 14.2). On all mapping occasions but the last two, at both sites, rippled surface flow (RS) dominated, with undular standing waves (USW) and broken standing waves (BSW) being sub-dominant. On the penultimate sampling occasion, when higher discharges were measured, USW and BSW were the dominant flow types and, as flow dropped, USW dominated on the last sampling occasion. Within site 1, the five flow types used for sampling (BSW, USW, RS, SBT, BPF - Table 13.3) accounted for 77 - 92% of all recorded flow types during the study period. The same flow types accounted for a higher percentage (91 - 97%) of all the flow types at site 2. Site 1 tended to have a wider diversity of flow types with up to nine types in addition to the main five, whereas site 2 had three to four additional flow types. Examining the wetted area to discharge relationships and the types and proportions of various flow types recorded at each site, site 1 appears to be more hydraulically complex and more heterogeneous than site 2.

Analysis of the flow-type proportions (Table 14.2), using the CLUSTER module of Primer (Figure 14.3), reveals three major groups, which are correlated with discharge. One group represents the sampling occasions with the highest mapped discharges, the second represents the lowest mapped discharge during the Intensive Sampling period at site 1, and the third group consists of all of the other mapped discharges (here called the intermediate-discharge group). Within the intermediate-discharge group there are several sub-groups, clustered by site and, to some extent, discharge (Figure 14.3). The data from site 1 in the main sampling period (January 1997: M), link with other site 1 data in one of these sub-groups.

As shown with one sample period (C) in Chapter 13, the five chosen flow types, and the chosen substrata of boulder and large cobble, were appropriate choices of flow/substrata combinations for this discharge-related study of habitat. They constituted the dominant flow-substratum combinations over all the measured discharges, although proportions of the combinations changed with significant changes in discharge (Table 14.2 and Figure 14.4). During the first three sampling occasions, there was little change in the proportions of flow type/substratum combinations, with RS/B (Rippled surface flow over boulder) dominating (Figure 14.4). At site 1, RS/LC and USW/B were sub-dominant, as were USW/B and BSW/B at site 2. With the increase in discharge over the last sampling period, the dominant combinations shifted. At site 1, USW/B was dominant, and BSW/B and RS/B sub-dominant. At site 2, BSW/B was dominant and USW/B and RS/B sub-dominant.

There were thus three main differences between sites throughout the study. First, there was a more even distribution of flows over both boulders and large cobble at site 1 than at site 2 (Section 13.3). Second, there was a low percentage of SBT at site 2 over any substratum, and it completely disappeared as a flow type in the higher discharge conditions (Figure 14.4 and Table 14.2). Third, there was a higher percentage of "other" categories of flow at site 1 than at site 2, with this proportion increasing at the highest discharge.

Table 14.2 Proportions of flow types (shown as percent) for two sites on the Eerste River on each mapping occasion (codes as per Table 14.1). The five flow types selected for this study are listed first, from fastest flow to slowest, followed by the other flow types recorded at each site but not used for sampling invertebrates, also listed fastest to slowest. Data codes are listed by sampling period (Table 14.1) within each site. Upper case letters (M,IS, A-D) represent invertebrate sampling and lower case letters (w-z) represent mapping only occasions.

	Site 1										Site 2							
Flow Type	**M[a]**	**IS[a]**	**A**	**w**	**B**	**x**	**C**	**y**	**z**	**D**	**A**	**w**	**B**	**x**	**C**	**y**	**z**	**D**
Broken Standing Waves	12.2	0.5	11.2	13.4	15.1	5.5	7.2	5.6	39.0	20.9	14.6	13.3	13.9	11.7	10.1	6.5	37.5	36.0
Undular Standing Waves	15.5	5.3	16.4	16.6	24.1	10.5	18.3	16.8	25.9	32.3	16.9	31.0	36.8	22.0	24.0	28.9	34.5	36.9
Rippled Surface	40.8	36.0	46.3	45.9	32.1	53.0	41.6	43.5	10.5	18.9	47.2	42.7	40.6	49.0	54.2	43.8	20.7	20.7
Smooth Boundary Turbulent	10.8	34.4	3.8	6.2	2.8	5.2	8.4	5.9	0.0	0.4	1.8	3.0	0.9	0.0	1.6	0.0	0.0	0.0
Barely Perceptible Flow	5.6	6.7	9.5	6.6	10.1	10.9	15.9	17.6	2.1	7.6	10.9	5.5	4.7	12.8	6.1	16.3	1.9	2.4
Free Fall	1.8	0.0	0.2	0.7	0.6	0.3	0.1	0.2	1.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.1	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Cascade	2.5	1.4	1.0	0.8	1.3	0.4	0.5	0.5	1.1	1.2	0.6	0.0	1.1	0.5	0.5	0.2	1.8	1.7
Chute	3.3	2.1	1.5	1.2	1.3	1.1	1.1	0.9	2.8	1.9	2.1	0.6	0.4	1.7	1.2	1.2	0.9	0.7
Stream	1.7	1.3	0.9	1.2	1.3	0.4	0.7	0.7	5.1	2.2	4.7	1.4	1.0	1.1	0.7	0.8	2.2	1.4
Fast Riffle Flow	3.2	9.9	7.3	6.0	10.2	11.1	4.6	4.9	1.1	7.1	1.2	2.6	0.5	0.8	1.6	1.1	0.3	0.3
Slow Riffle Flow	0.1	0.4	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trickle	1.1	0.4	1.6	1.1	0.3	1.3	0.7	1.6	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.7	0.0	0.0
No Flow	1.3	2.4	0.4	0.4	0.6	0.3	0.6	2.0	0.7	1.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0

[a]Site 1 on these sampling occasions was 40-m in length whereas on subsequent sampling occasions it was 50-m long.

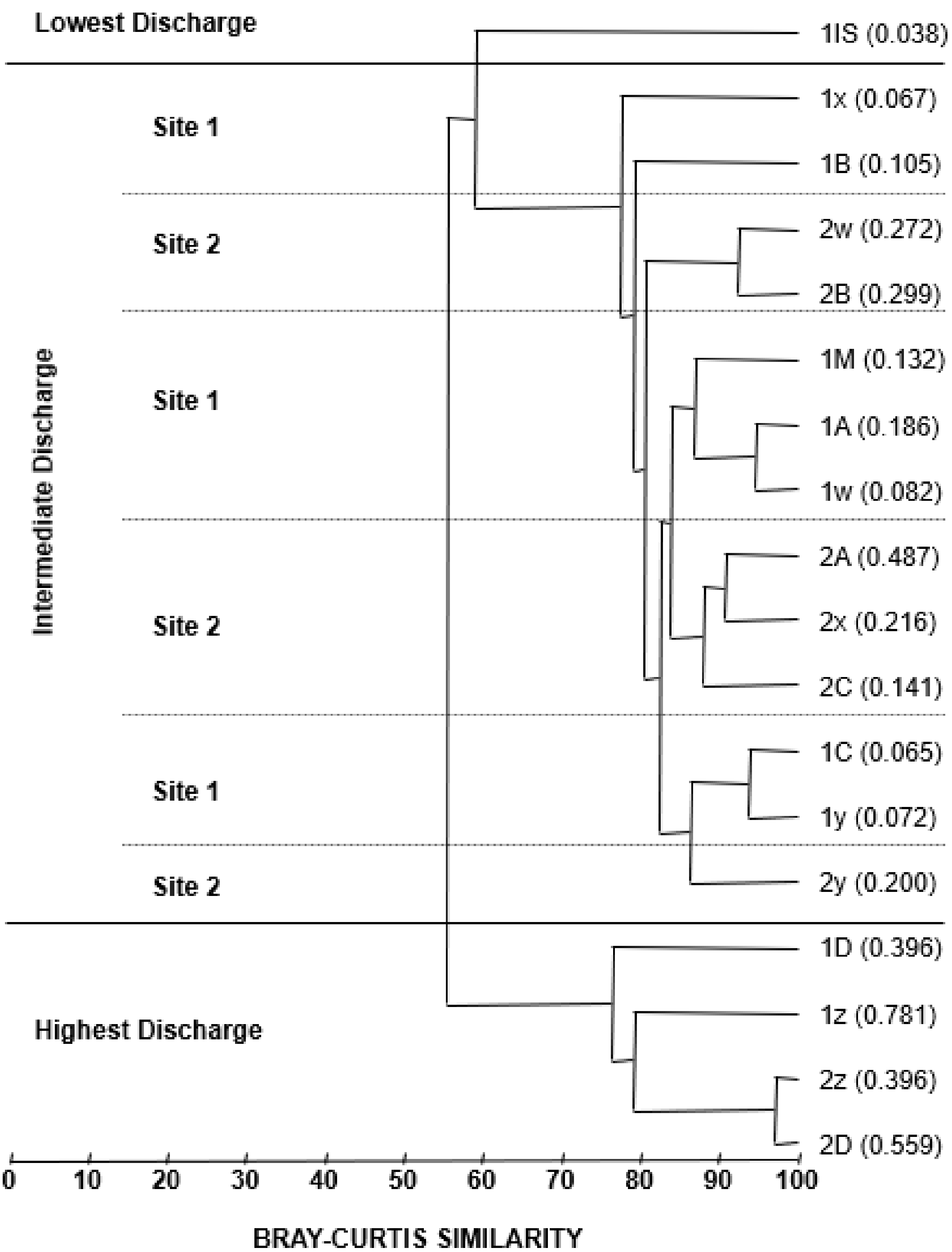

Figure 14.3 Dendrogram of flow-types mapped at sites 1 and 2 on the Eerste River in summer and spring 1997. Solid lines demarcate the three main discharge groups, with site level sub-groups separated by dotted lines. Data codes for site and mapping times as in Table 14.1, with measured discharge ($m^3 s^{-1}$) in parentheses after each code.

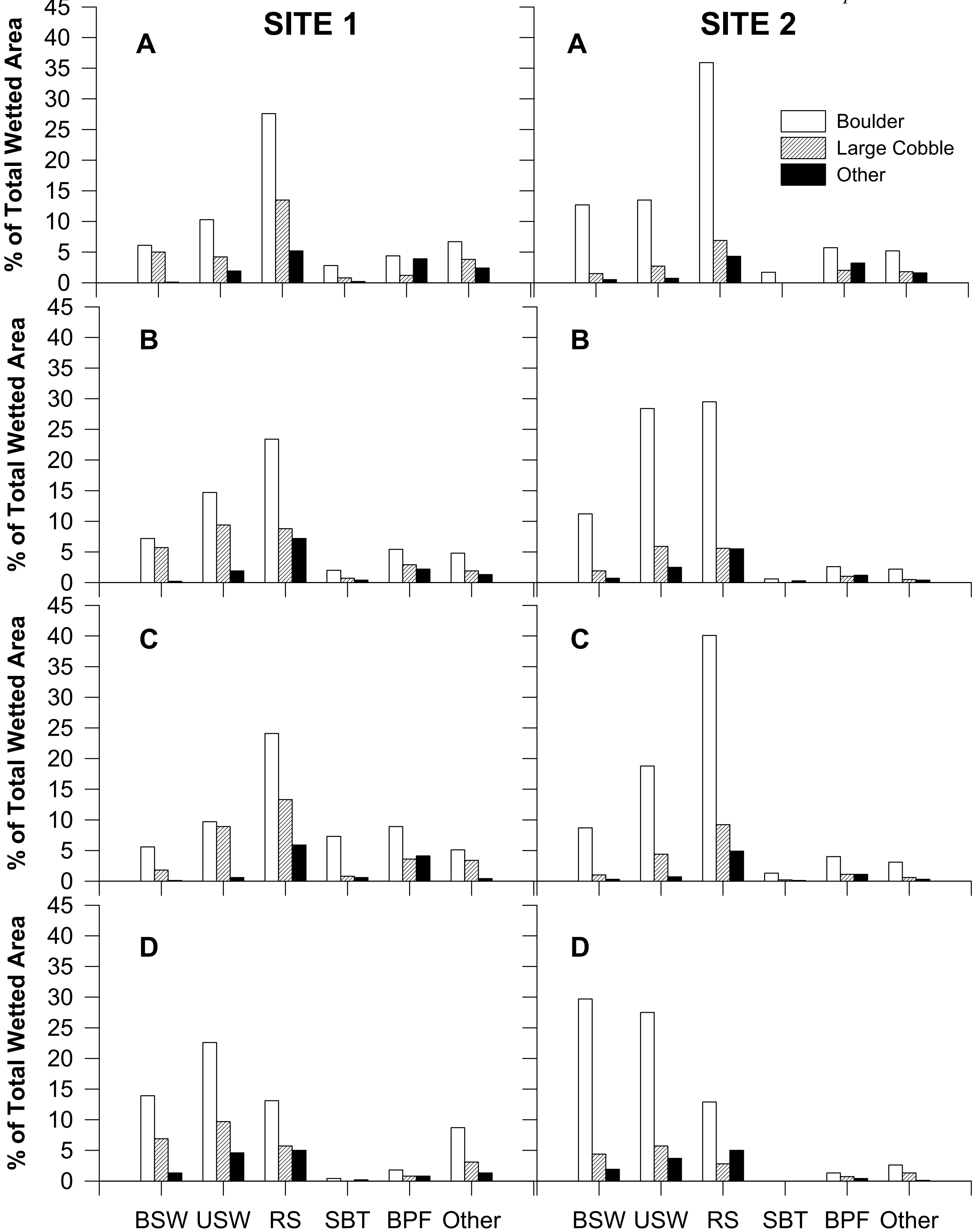

Figure 14.4 Proportions by area of flow-type and substrata combinations for both Eerste River sites on invertebrate sampling dates. Site 1: A = 18 September; B = 10 October; C = 29 October; D = 28 November 1997. Site 2: A = 15 September; B = 8 October; C = 28 October; D = 30 November 1997. All flow types (codes as per Table 2.3) and substrata not used for sampling invertebrates were combined into "other".

Given the flow and substrata combinations available at each site and each invertebrate sampling date (Table 14.2 and Figure 14.4), not all combinations were available at all sites on all sampling occasions (Section 13.3). For example, the increase in discharge during the last sampling occasion resulted in areas of BPF and SBT being small and rare at both sites. BPF and SBT represented respectively 7.6% and 0.4% of site 1, and 2.4% and 0.0% of site 2 during the last sampling period (D). This yielded only 18 invertebrate samples per site on this sampling occasion, as opposed to 27 (site 1) and 21 (site 2) samples during sampling period C. The greater number of available sampling points meeting the established criteria within site 1 during sampling period C could be as a result of the greater number and diversity of morphological units (6 and 3 in sites 1 and 2 respectively, Table 13.1) resulting in a higher diversity of flow and substratum combinations. The combinations sampled for each site during each sampling period are shown in Table 14.3.

Table 14.3 Flow/substratum combinations sampled within each site on 29 October (C) and 29 November (D) at site 1, and on 28 October (C) and 30 November (D) at site 2. Each flow/substratum combination listed was sampled at three different places within each site. Flow and substratum codes as per Tables 2.3 and 2.4.

Flow Type	Site 1 C Substratum		Site 1 D Substratum		Site 2 C Substratum		Site 2 D Substratum	
BSW	B	LC	B	LC	B	LC	B	LC
USW	B	LC	B	LC	B	LC	B	LC
RS	B	LC	B	LC	B	LC	B	LC
SBT	B							
BPF	B	LC			B			

When data on all the combinations of flow type and substratum present in the spring study were analysed, three groups of similar sampling occasions emerged (Figure 14.5). The first group, splitting off at 53% similarity with the rest, consisted of data collected during the highest discharges. This reflected the pattern shown by flow-type distributions. Within this group, each site formed its own sub-group, with samples from site 2, 97% similar and those from site 1, 72% similar. The second and third groups were site specific, and encompassed all the intermediate discharges. They had a common similarity level of 68%. The MDS plot clearly illustrates these different groups (Figure 14.6). There are two different planes of separation, one by site and the other by discharge.

If the flow type/substratum data from the summer sampling occasions (M and IS) are added, a similar pattern emerges. The data from M link with the other site 1/intermediate discharge samples (Figure 14.7). Also, the data from the IS sampling occasion, with the lowest discharge, split off as a new, separate group at a level of 45% similarity. The MDS plot now illustrates three planes of separation (Figure 14.8). The first is by site, and the second and third distinguish samples taken at low, intermediate or high discharges.

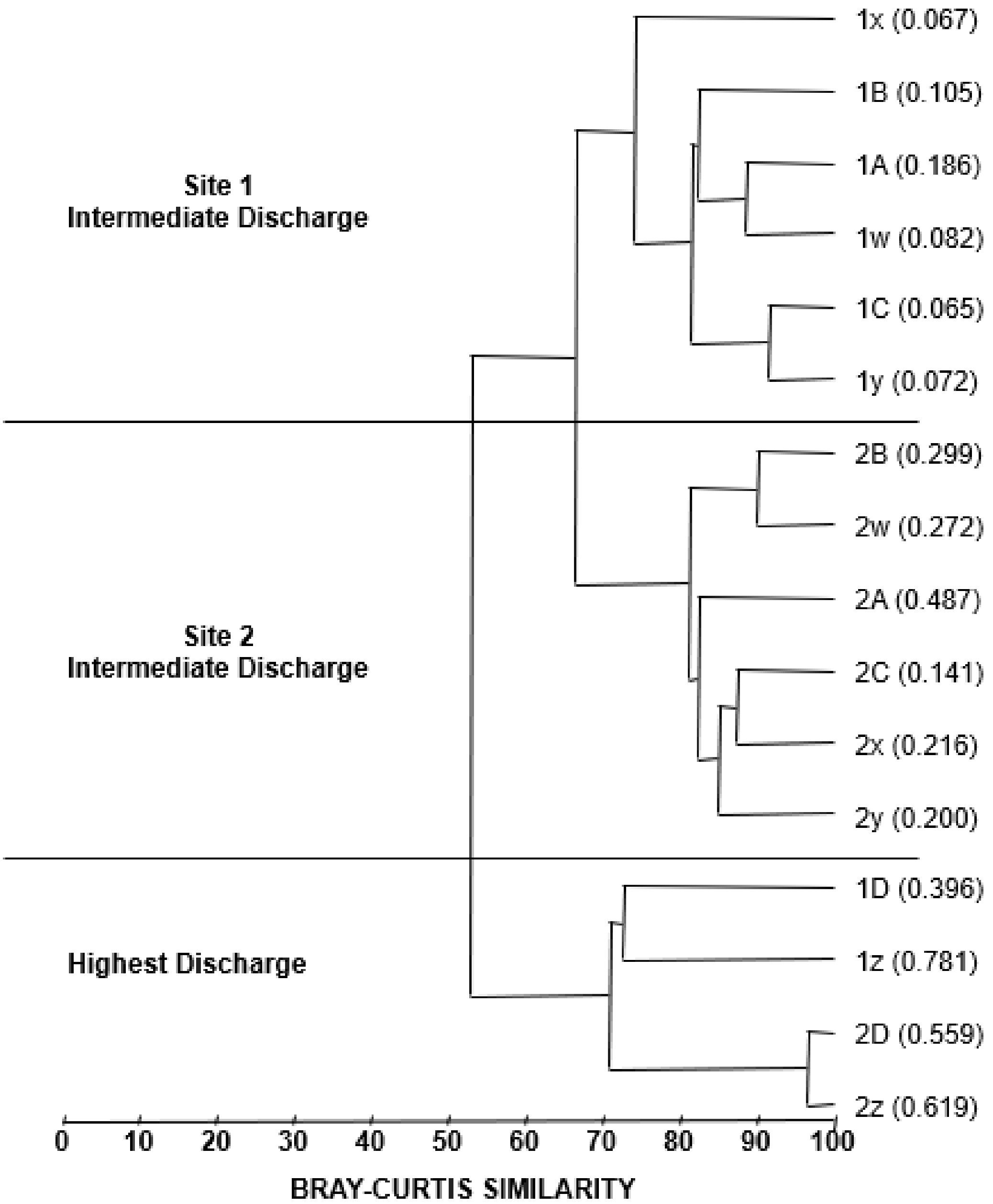

Figure 14.5 Dendrogram of flow-type and substrata combinations mapped at sites 1 and 2 on the Eerste River in spring 1997. Data codes for site and mapping times as in Table 14.1, with measured discharge ($m^3 s^{-1}$) in parentheses after each code.

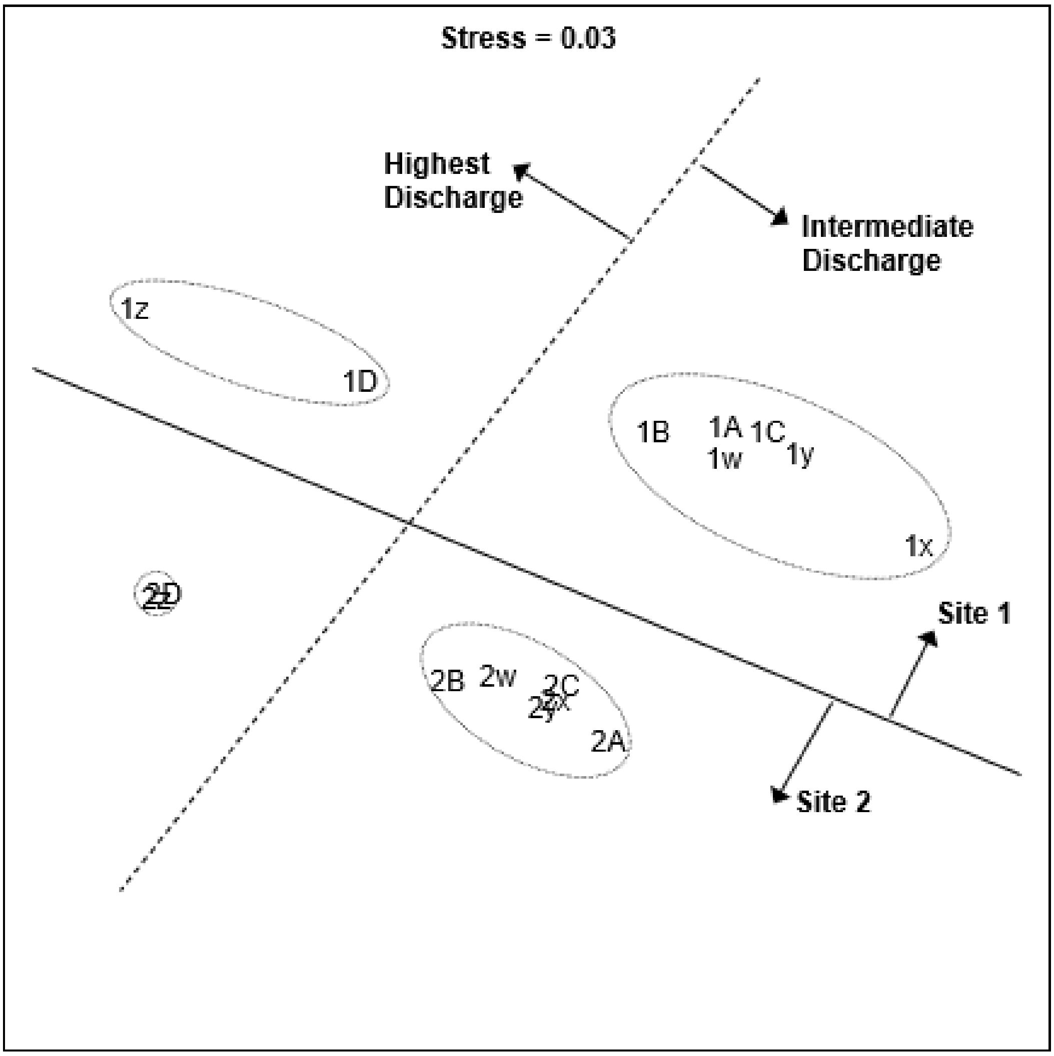

Figure 14.6 MDS plot of flow-type and substrata combinations mapped at sites 1 and 2 on the Eerste River in spring 1997. Data codes for site and mapping periods as in Table 14.1.

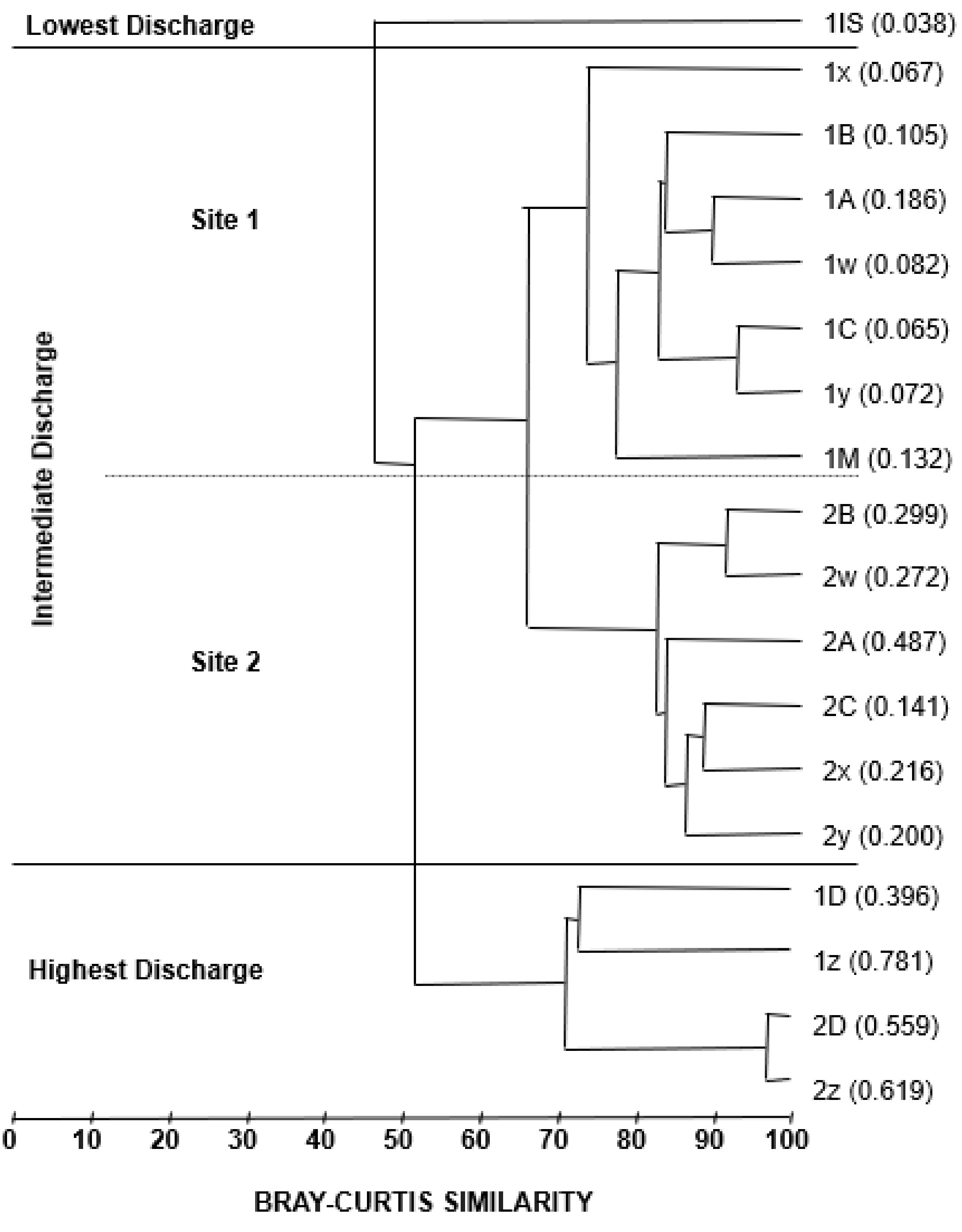

Figure 14.7 Dendrogram of flow-type and substrata combinations mapped at sites 1 and 2 on the Eerste River in summer and spring 1997. Data codes for site and mapping times as in Table 14.1, with measured discharges in parentheses after each code.

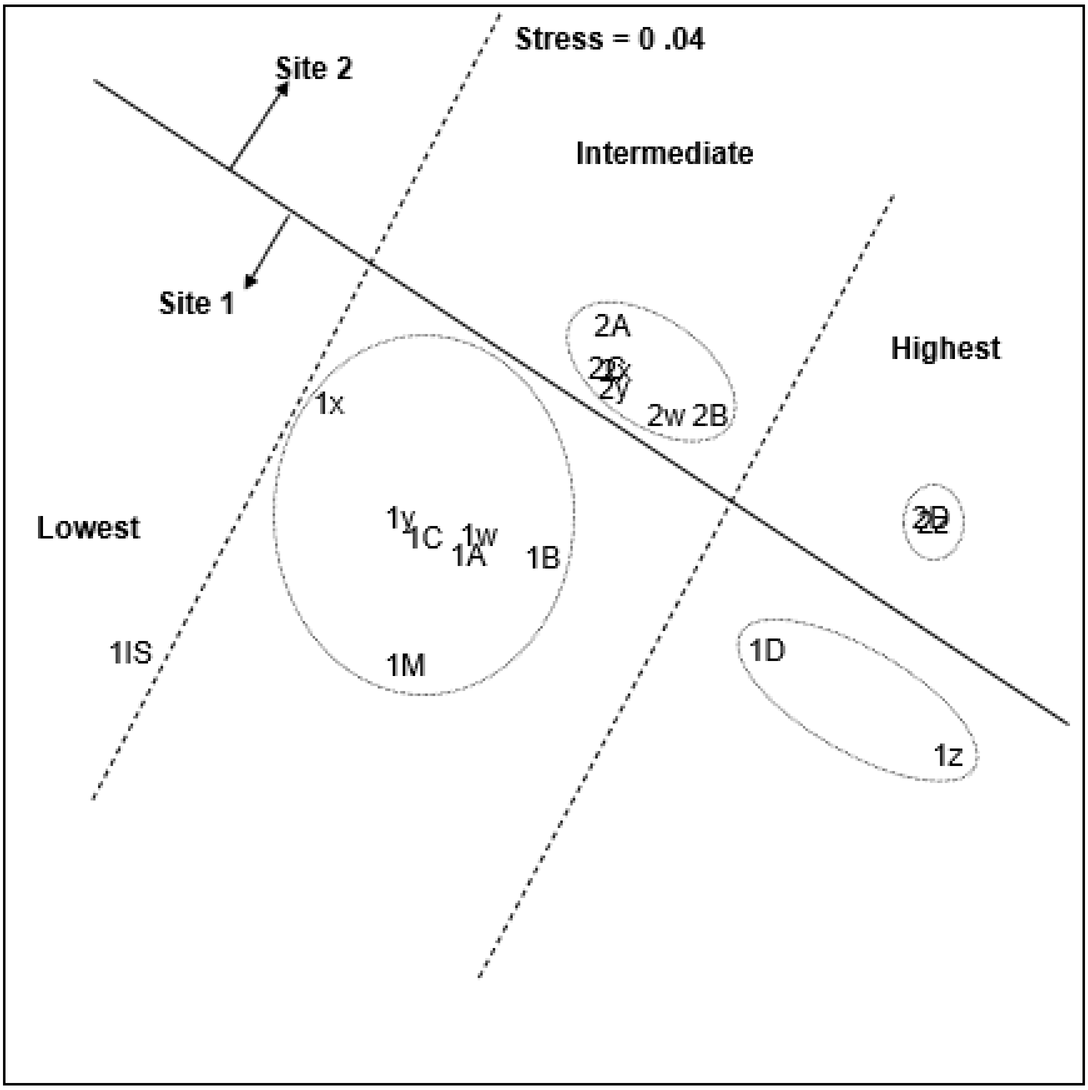

Figure 14.8 MDS plot of flow-type and substrata combinations mapped at sites 1 and 2 on the Eerste River in summer and spring 1997. Data codes for site and mapping times as in Table 14.1.

In general, wetted area and flow-type distributions are fairly stable with steady intermediate discharges and need a large shift, up or down, in discharge to effect an appreciable change. Taking the average of all discharges and wetted areas within each classified group (high or intermediate) and site, the percent change in discharge needed to change wetted area can be calculated. In order to increase the wetted area in site 1 by 24%, an 83% change in discharge was needed. For site 2, a change in discharge of 53% was needed to change the wetted area by 14%. Given there was only one low discharge event measured, and that was at one site, a comparison can not be made between the low and intermediate groups (as well as the total mapped area being less than that of the subsequent sites).

14.4 Physico-chemical and chemical comparisons between discharges and reaches

Temperature, pH and conductivity of the water at each site were recorded, as was air temperature. Overall, there was little measured difference in these variables between sites or sampling periods. Air temperature was also similar at both sites during each sampling period, but did show a continuous increase over the season. The pH at site 1 on three sampling occasions was consistent with the value on the first sampling date being slightly higher. The values at site 2 were also quite consistent but with the value at the last sampling occasion being lower. Although conductivity could not be measured during the last sampling period because of equipment failure the first three sampling dates showed a trend of increasing conductivity at both sites over time. Different sites had higher values on different days. Means are not presented for sampling period D (28 and 30 November) because all measurements were made on the same day.

Table 14.4 Physico-chemical and chemical variables, and air temperature, measurements for each sampling occasion and site. Codes as in Table 14.1. Readings taken over two days of sampling were averaged (sampling times: A, B and C) and means and standard deviations (SD) are given. Conductivity was not measured during sampling period "D".

	Site 1				Site 2			
	A	B	C	D	A	B	C	D
Variable	Mean ± SD	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	Mean ± SD	
Water Temperature (°C)	14.5 ± 0.7	11.5 ± 1.4	14.8 ± 3.2	16.0	15.0 ± 1.4	11.0 ± 2.1	14.8 ± 1.5	15.0
Conductivity (mS cm^{-1})	23.0 ± 7.0	23.9 ± 3.7	29.0 ± 5.9	-	22.4 ± 5.8	24.8 ± 2.1	26.0 ± 1.2	-
pH	5.8 ± 0.0	5.6 ± 0.05	5.6 ± 0.15	5.6	5.8 ± 0.07	5.8 ± 0.0	5.9 ± 0.08	5.3
Air Temperature (°C)	19.3 ± 6.0	22.0	26.0 ± 8.5	27.0	23.3 ± 1.8	20.5 ± 0.7	27.0 ± 2.8	29.0

14.5 Biological comparisons between discharges and reaches

14.5.1 Overall density and species comparisons

The invertebrate samples from sampling periods C and D (Table 14.1) are the only ones for which identifications have been completed to date. This preliminary analysis of invertebrate patterns is thus based on these two sets of data.

Invertebrate densities for each replicate sample within each reach were calculated from species counts. There was a decrease in sample densities of 46% (site 1) and 72% (site 2) from sampling period C to D (Table 14.5). There was not a consistent pattern as to which site had a greater number of animals. As shown in Chapter 13, site 2 had a greater number of animals than site 1 during sampling period C but in sampling period D site 1 had a higher density (Table 14.5).

Table 14.5 Number of samples (N), mean number (#) of animals per square meter and standard error (SE) for each site and each sampling period (data code as in Table 14.1).

Site	Data Code	N	Mean # / m^2 ± SE
1	C	27	1 755 ± 306
1	D	18	944 ± 130
2	C	21	2 361 ± 409
2	D	18	654 ± 159

A general analysis of variance (ANOVA) on 4th root transformed density data was run (Section 13.4), to reveal overall density patterns between sampling periods (discharge) and sites. Although there is no significant difference between invertebrate densities of each reach, there was a significant difference between the two sampled discharges, with a p-value of 0.0001 (Table 14.6). There was also no significant effect of site with discharge on overall invertebrate densities, $p = 0.076$ at a $p < 0.05$ level (Table 14.6).

Table 14.6 General ANOVA table examining the effect of reach, sampling period (discharge) and their interaction on invertebrate densities. d.f. = degrees of freedom, M.S.S. = mean sums of squares, F = test statistics and P = significance level, with an * denoting statistical significance at $p < 0.05$ level.

	d.f. effect	M.S.S. effect	d.f. error	M.S.S. error	F	P
Reach	1	0.003	80	1.857	0.004	0.948
Discharge*	1	29.673	80	1.857	15.975	0.0001
Interaction	1	6.005	80	1.857	3.233	0.076

In order to take individual species and their densities into account, the full set of data on species distributions (densities 4th root transformed) was analysed for differences between sites (reaches) and discharges (sampling periods) using the agglomerative hierarchical clustering module CLUSTER in Primer. The dendrogram of the cluster analysis supports the ANOVA results (Figure 14.9a), showing a split between the invertebrate samples taken at the highest discharge and those taken at the intermediate discharges, with a 62% similarity. The MDS of the similarity analysis (Figure 14.9b) demonstrates a prominent dissimilarity between samples taken at the two discharges, and a less prominent separation by site. This is similar to the patterns exhibited by the flow/substrata cluster and MDS plots (Section 14.3).

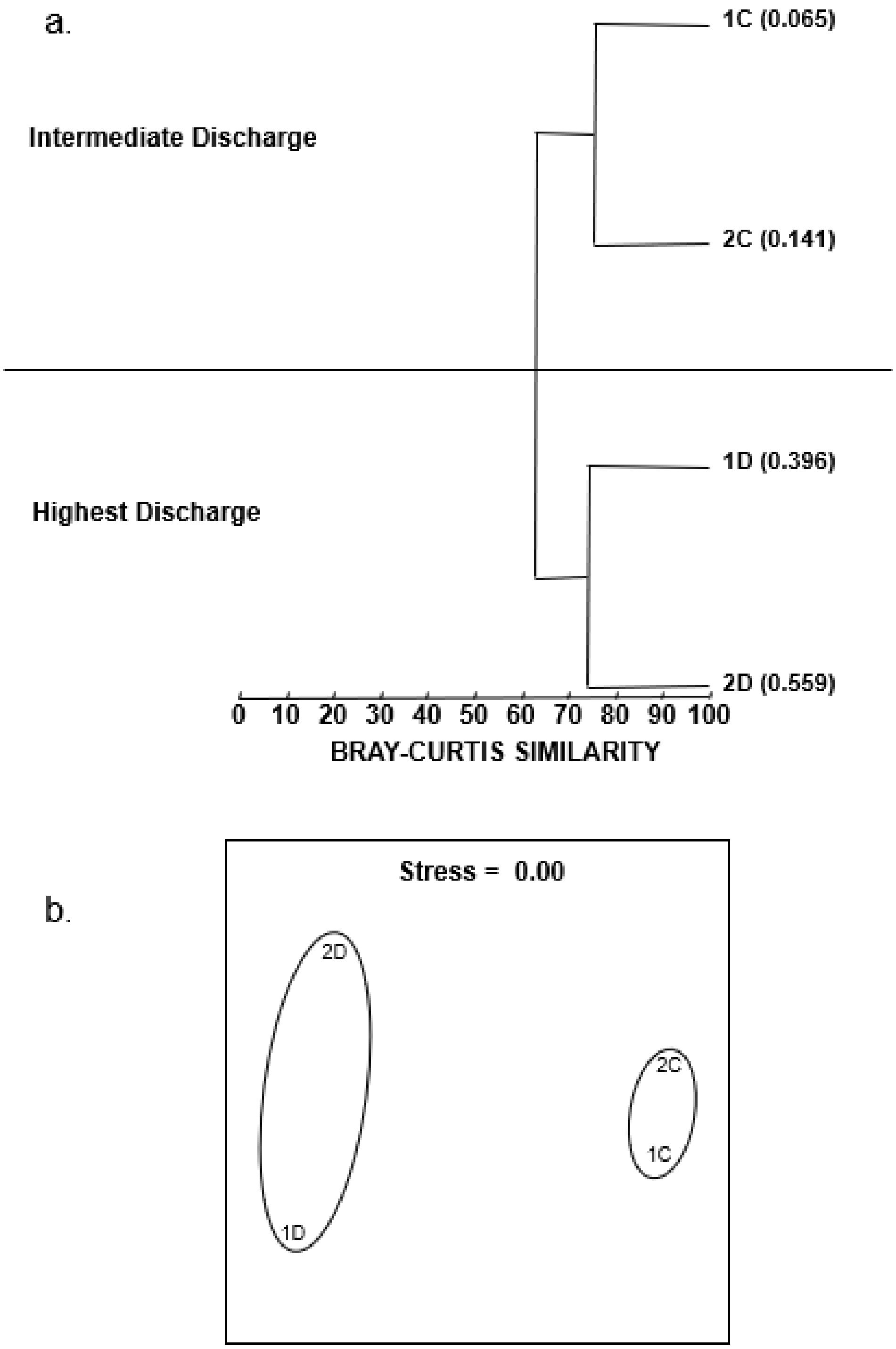

Figure 14.9 a) Species-level dendrogram for each site and discharge, showing the split between the discharges (discharge in parenthesis after each data code). b) MDS plot. Data codes for site and mapping times as in Table 14.1.

To include data from the IS sampling, a preliminary data standardisation exercise was completed, as invertebrate sampling methods (Section 4.5 and 13.2 for the later study) differed in these two studies. There were 52 samples and 18 different flow-type/substratum combinations sampled during the IS sampling period, but only five flow types and two substratum categories were used in the latter analysis. Thus, only samples using these categories were included from the latter study. Additionally, the IS sampling was qualitative rather than quantitative, requiring the invertebrate counts from sampling periods C and D to be converted to ratings (Chapter 11).

With this standardisation completed, the resulting dendrograms and MDS plots revealed that the sites clustered by discharge (sampling period) (Figure 14.10) as in the previous analysis. The IS sampling period at site 1 split off from the other two groups at approximately 53% similarity. The other two groups split from one another at 65% similarity, and were not site dependent, but rather discharge dependent. The MDS plot revealed that the invertebrate assemblage from the IS sampling period was less similar to those collected in the C and D sampling occasions than the latter were to each other. This may be because there is a seasonal difference being reflected as well as a difference in discharge. This seasonality aspect will be examined further in Ms. Schael's PhD thesis.

14.5.2 Hydraulic biotopes

The above analyses (Figures 14.9 and 14.10) combined all samples from a site, to represent each site at each sampling date in the analyses with a biological “fingerprint” or species assemblage. This is the same process as was used in Chapter 10 for the testing of biological zones, and is useful to display the overall differences between sampling periods (discharge) and sites. In order to examine the effect of sampling date and site on hydraulic biotopes, however, each sample was included separately in the next round of analyses.

The CLUSTER and MDS outputs revealed that the main split between samples was between hydraulically "fast" and "slow" conditions (Figure 14.11). This is the same result as seen in Chapter 13. All invertebrate samples taken from flow types BSW and USW, and some from RS, whether over boulder or large cobble regardless of sampling period or site, were in the "fast" group. Some taken from RS, and all those taken from BPF and SBT, over either substratum, were within the "slow" group. As in previous analyses at the hydraulic-biotope level (Chapters 11 and 13), the RS flow type occurred in both hydraulic groups, and appeared to be the most hydraulically varied of the flow types chosen for this study. Reference to the actual hydraulic measurements taken on each sampling occasion revealed that each RS in Figure 14.11 was in its appropriate “fast” or “slow” group (Table 14.7).

Within each main hydraulic group there were several sub-groups that could be identified as individual hydraulic biotopes (Figure 14.11). Twenty were recognised in total (Table 14.7): six were bio-rapids, five each were bio-riffles or bio-runs, and three were bio-pools and one a bio-run/pool transition. All of the bio-rapids and bio-riffles occurred in the hydraulically "fast" group, together with one bio-run. All of the bio-pools, and the majority of the bio-runs, were in "slow" group. The same hydraulic biotopes can be detected in the MDS plot, as can a general trend from "fast" hydraulic biotopes at bottom and left to "slow" ones at top and right (Figure 14.12). Ranges of depth and percentages of substrata (Table 14.8), and velocity and Froude number (Table 14.9), for each of the 20 hydraulic biotopes, are similar to those reported in Chapters 11 and 13 for described hydraulic biotopes.

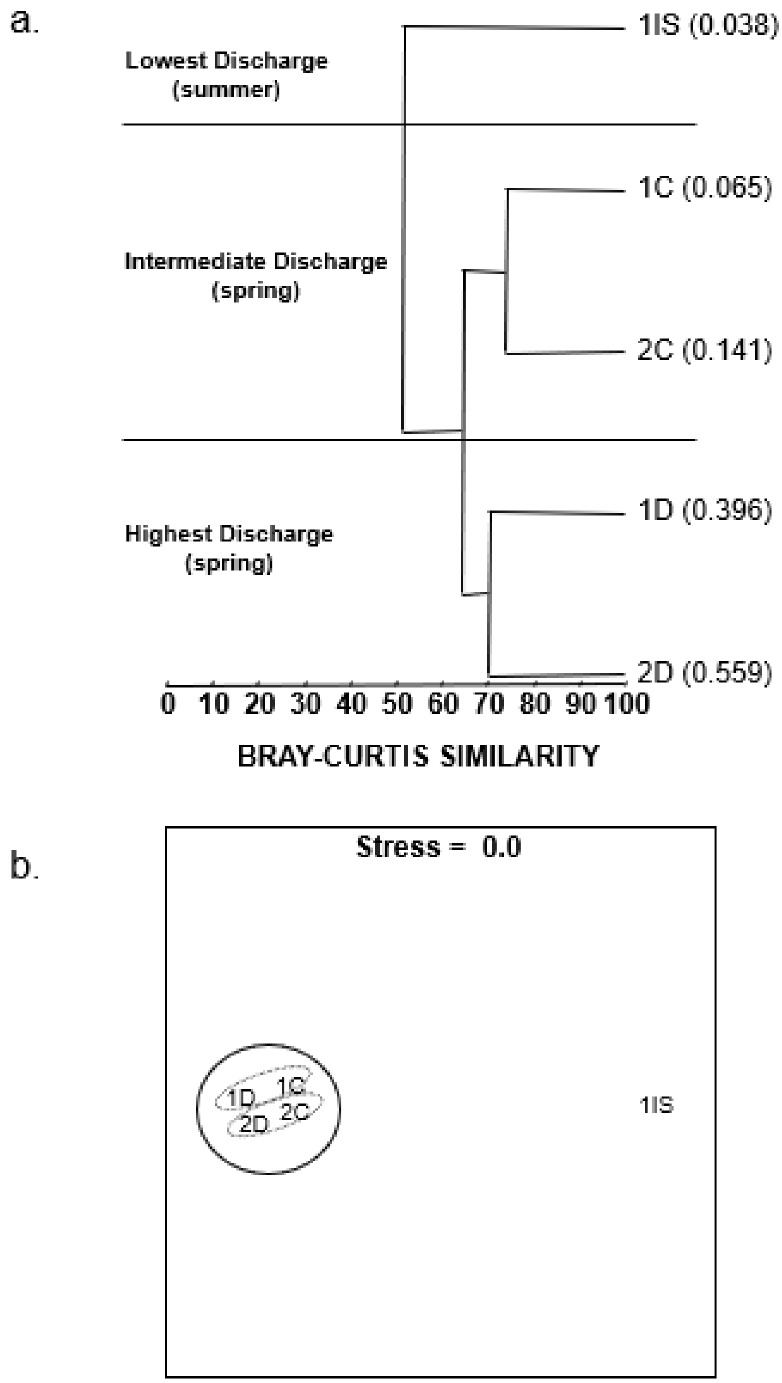

Figure 14.10 a) Species-level dendrogram for each site and discharge, showing the split between the discharges (discharges in parenthesis after each data code. b) MDS plot. Data codes for site and sampling times as in Table 14.1.

Mapped substrata areas represent the majority of substratum present in a particular part of the streambed, but it is recognised that there could be small areas within the main patch with different substratum types. Therefore, as stated in Section 13.2, a substratum grid was used at all sample points to determine the percentage of each substratum type present within the 0.5 x 0.5-m area. Table 14.8 reflects the local or micro-scale diversity of the substrata representing the sampling areas.

Table 14.7 Hydraulic characteristics of the 20 groups of samples from both sites and two discharges on the Eerste River as recognised in Figure 14.11. The sub-groups are recognised as biologically derived hydraulic biotopes. Site code (site number, data code, and sample number) and flow types are also given. Mean and standard deviation (SD) for the four readings taken within each sampling area are reported. Statistics given: depth (m); near-bed and mean water column (0.6) velocity (m s^{-1}); and Froude number.

Sub-group	Hydraulic Biotope	Site Code	Flow Type	Depth (m) Mean	Depth (m) SD	Near-bed Mean	Near-bed SD	0.6 Mean	0.6 SD	Froude Number Mean	Froude Number SD
1	Bio-riffle (boulder)	1C22	USW	0.31	0.10	0.12	0.11	0.26	0.02	0.155	0.022
		1D6	RS	0.29	0.04	0.01	0.01	0.03	0.02	0.018	0.010
		1D14	RS	0.22	0.19	0.10	0.06	0.15	0.02	0.166	0.031
		1D17	USW	0.56	0.06	0.30	0.02	0.39	0.09	0.167	0.028
		2D17	USW	0.21	0.08	0.28	0.17	0.31	0.28	0.222	0.200
		2D18	USW	0.43	0.02	0.12	0.03	0.17	0.02	0.083	0.010
2	Bio-rapid (boulder)	2D6	BSW	0.23	0.03	0.83	0.16	0.82	0.12	0.545	0.090
		2D11	BSW	0.13	0.04	0.35	0.24	0.40	0.10	0.377	0.130
		2D13	BSW	0.13	0.04	0.73	0.63	1.04	0.52	1.012	0.700
3	Bio-rapid (boulder)	2D2	BSW	0.37	0.09	0.56	0.45	0.98	0.26	0.530	0.181
		2D5	BSW	0.36	0.06	0.69	0.68	1.08	0.58	0.581	0.330
		2D9	USW	0.38	0.04	0.31	0.04	0.30	0.16	0.154	0.081
4	Bio-rapid (boulder)	1D1	USW	0.27	0.04	0.42	0.13	0.58	0.06	0.354	0.033
		1D2	BSW	0.22	0.04	0.28	0.24	0.76	0.23	0.542	0.215
		1D4	BSW	0.18	0.04	0.52	0.25	0.76	0.13	0.592	0.168
		1D5	USW	0.32	0.06	0.06	0.08	0.13	0.08	0.073	0.045
		1D11	USW	0.44	0.06	0.13	0.20	0.35	0.28	0.177	0.149
		1D12	BSW	0.34	0.11	0.33	0.38	0.65	0.19	0.383	0.186
		1D18	BSW	0.47	0.03	0.02	0.04	0.48	0.10	0.224	0.053
		2D10	USW	0.19	0.05	0.43	0.22	0.34	0.13	0.242	0.072
5	Bio-rapid (boulder)	1C19	BSW	0.20	0.10	0.55	0.20	0.48	0.09	0.369	0.094
		2C10	BSW	0.20	0.04	0.77	0.24	0.52	0.14	0.382	0.123
		2C15	BSW	0.15	0.02	0.26	0.15	0.34	0.06	0.291	0.069
6	Bio-run (cobble)	2C2	RS	0.43	0.05	0.14	0.09	0.22	0.08	0.107	0.038
		2C8	RS	0.16	0.03	0.05	0.03	0.08	0.04	0.059	0.031
7	Bio-rapid (boulder)	1C2	BSW	0.16	0.05	0.24	0.15	0.24	0.18	0.203	0.172
		1C5	BSW	0.17	0.05	0.35	0.44	0.49	0.35	0.424	0.379
		1C6	BSW	0.10	0.03	0.36	0.15	0.46	0.12	0.464	0.086
		1C8	BSW	0.07	0.01	0.99	0.38	1.01	0.36	1.246	0.527
		1C11	USW	0.21	0.04	0.17	0.11	0.32	0.10	0.226	0.080
		2C3	BSW	0.35	0.05	0.49	0.22	0.87	0.07	0.472	0.025
		2C4	USW	0.23	0.06	0.19	0.37	0.59	0.26	0.416	0.232
		2C5	BSW	0.09	0.04	0.28	0.10	0.43	0.14	0.475	0.114
		2C6	BSW	0.24	0.04	0.38	0.25	0.36	0.26	0.244	0.186
		2C11	BSW	0.15	0.04	0.17	0.14	0.32	0.18	0.274	0.168
8a	Bio-riffle (cobble)	1C1	USW	0.08	0.02	0.20	0.17	0.22	0.17	0.262	0.199
		1C3	RS	0.20	0.04	0.05	0.06	0.10	0.06	0.074	0.048
		1C4	USW	0.25	0.01	0.42	0.10	0.49	0.09	0.312	0.063
		1C10	USW	0.09	0.03	0.30	0.11	0.31	0.10	0.359	0.154
		1C16	BSW	0.11	0.04	0.35	0.14	0.44	0.11	0.442	0.136
		2C12	USW	0.30	0.04	0.23	0.05	0.28	0.03	0.163	0.018

Sub-group	Hydraulic Biotope	Site Code	Flow Type	Depth (m) Mean	SD	Near-bed Mean	SD	0.6 Mean	SD	Froude Number Mean	SD
8b	Bio-riffle (cobble)	2C7	USW	0.17	0.04	0.09	0.10	0.16	0.11	0.132	0.096
		2C9	USW	0.20	0.01	0.18	0.04	0.30	0.02	0.213	0.013
		2C13	USW	0.30	0.03	0.07	0.04	0.16	0.05	0.095	0.028
		2D12	USW	0.45	0.04	0.26	0.24	0.56	0.09	0.264	0.038
9	Bio-riffle (cobble)	1D3	USW	0.27	0.03	0.05	0.06	0.08	0.10	0.050	0.058
		1D15	RS	0.27	0.03	0.06	0.02	0.09	0.05	0.057	0.026
		1D16	RS	0.15	0.02	0.09	0.03	0.11	0.01	0.090	0.016
		2D3	RS	0.46	0.01	0.04	0.01	0.12	0.03	0.054	0.014
		2D4	RS	0.48	0.02	0.19	0.06	0.16	0.06	0.075	0.027
10	Bio-rapid (cobble)	1D13	BSW	0.16	0.04	0.16	0.14	0.18	0.13	0.141	0.096
		2D7	BSW	0.18	0.05	0.35	0.30	0.53	0.26	0.442	0.319
11	Bio-riffle (cobble)	1C18	USW	0.17	0.09	0.12	0.11	0.15	0.10	0.143	0.116
		1D7	BSW	0.14	0.04	0.56	0.21	0.61	0.25	0.515	0.186
		1D8	RS	0.18	0.02	0.13	0.03	0.22	0.04	0.167	0.022
		1D9	USW	0.18	0.03	0.27	0.06	0.35	0.04	0.263	0.046
		1D10	RS	0.54	0.03	0.29	0.08	0.34	0.03	0.149	0.016
		2D8	RS	0.29	0.06	0.15	0.08	0.20	0.04	0.120	0.029
12	Bio-riffle (cobble)	2C16	RS	0.29	0.04	0.24	0.03	0.30	0.02	0.182	0.011
		2D15	USW	0.61	0.01	0.14	0.05	0.21	0.09	0.086	0.038
13	Bio-pool (boulder)	1C7	BPF	0.15	0.03	0.03	0.01	0.05	0.01	0.038	0.006
		1C12	BPF	0.12	0.04	0.01	0.01	0.02	0.01	0.022	0.004
14	Bio-run (boulder)	2C17	BPF	0.43	0.02	0.13	0.01	0.14	0.02	0.067	0.009
		2C18	BPF	0.42	0.05	0.09	0.01	0.11	0.02	0.053	0.013
		2D14	RS	0.48	0.02	0.13	0.03	0.17	0.05	0.078	0.024
15	Bio-run (boulder)	1C20	RS	0.29	0.02	0.13	0.02	0.21	0.04	0.123	0.022
		1C21	BPF	0.16	0.15	0.03	0.03	0.05	0.03	0.051	0.046
16	Bio-pool (boulder)	1C23	SBT	0.41	0.03	0.04	0.01	0.06	0.01	0.029	0.005
		2C1	RS	0.28	0.01	0.00	0.01	0.01	0.01	0.005	0.006
		2D1	RS	0.20	0.02	0.00	0.01	0.03	0.01	0.020	0.010
17	Bio-pool (cobble)	1C14	BPF	0.41	0.01	0.02	0.01	0.05	0.01	0.025	0.007
		1C15	BPF	0.24	0.05	0.03	0.01	0.04	0.01	0.025	0.009
		1C27	RS	0.34	0.02	0.05	0.01	0.14	0.02	0.079	0.012
18	Bio-run (boulder)	1C17	SBT	0.28	0.07	0.07	0.01	0.09	0.01	0.058	0.013
		1C24	RS	0.41	0.06	0.06	0.03	0.12	0.01	0.062	0.008
		1C25	SBT	0.43	0.07	0.02	0.01	0.03	0.00	0.014	0.003
		2C19	RS	0.20	0.03	0.11	0.03	0.15	0.01	0.105	0.016
19	Bio-run/pool (boulder)	1C13	RS	0.34	0.08	0.06	0.06	0.14	0.05	0.082	0.040
		2C14	BPF	0.11	0.03	0.01	0.01	0.02	0.01	0.019	0.005
		2C20	RS	0.44	0.05	0.13	0.05	0.18	0.02	0.085	0.016
20	Bio-run (boulder)	1C9	BPF	0.22	0.07	0.03	0.00	0.05	0.01	0.033	0.003
		1C26	RS	0.50	0.08	0.07	0.05	0.14	0.05	0.061	0.019
		2C21	USW	0.32	0.05	0.10	0.01	0.16	0.01	0.090	0.012
		2D16	RS	0.47	0.02	0.08	0.06	0.14	0.01	0.065	0.008

//Table 14.7 continued.

Although there is not an overwhelmingly strong pattern of site and discharge (sampling period) groupings in the overall pattern (Figure 14.11), there is a pattern within each hydraulic biotope (Tables 14.8 and 14.9). Of the twenty sub-groups, eight were from one site and seven had all but one of its samples from one site. Thus, in total, 15 hydraulic biotopes had a strong affiliation to one of the two sites. The link between hydraulic biotopes and sampling period was stronger, with 13 hydraulic biotopes linked to solely to one discharge, five predominantly representing one discharge but containing a sample from another discharge and only one with no particular affiliation. Hydraulic biotopes from the "slow" group were all classified as linked to sampling period C, as there were only three samples from period D within the “slow” group as a whole. Overall, there were few samples in the hydraulically slower group, as SBT and BPF flow types either disappeared with the higher discharge from sampling period D or did not cover sufficiently large areas to allow sampling (Section 13.2).

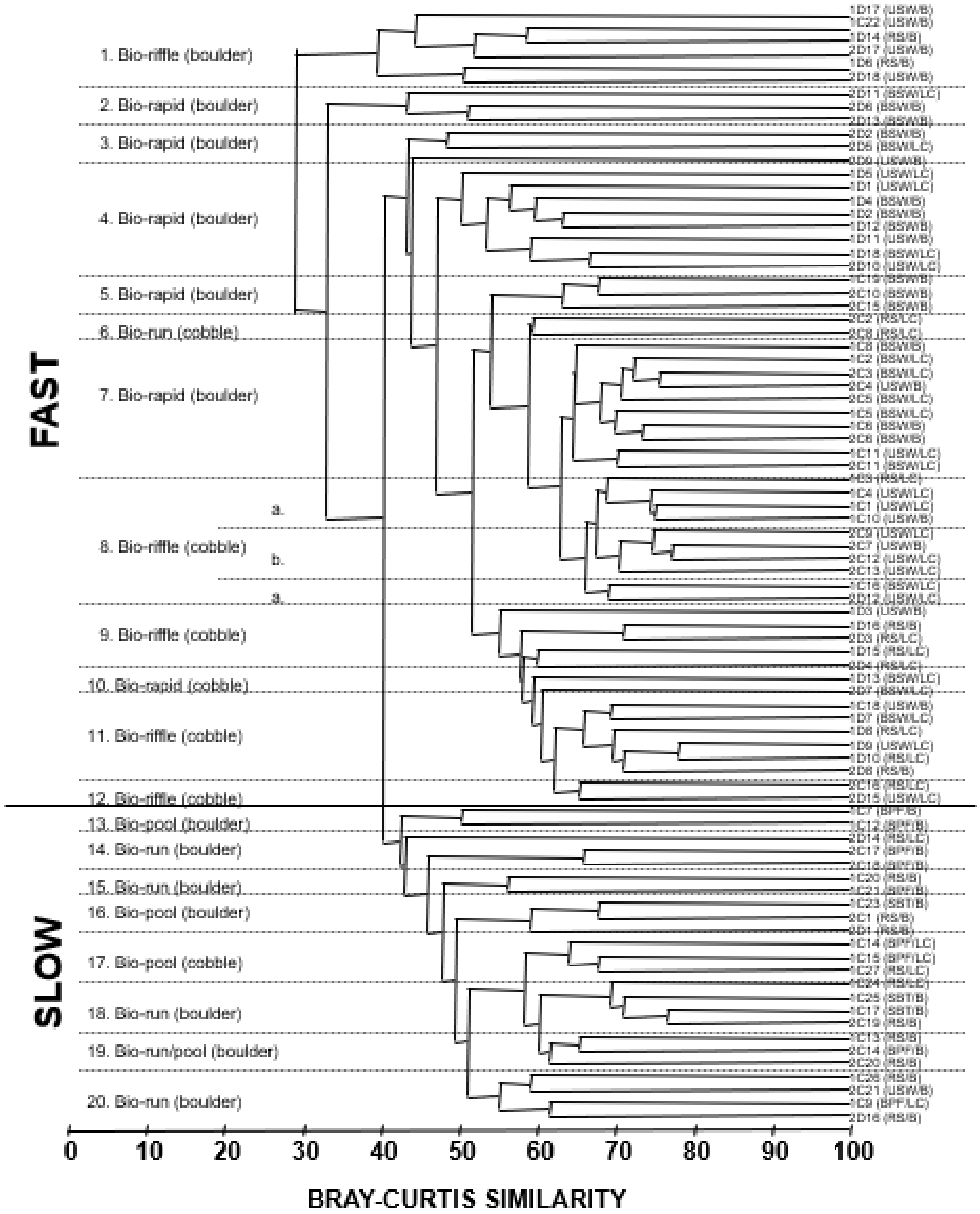

Figure 14.11 Species-level dendrogram for individual samples at the two sites. The solid line represents the split between the "fast" and "slow" hydraulic conditions. Data codes for site and sampling periods as in Table 14.1 and sample point number as in Table 14.7. Flow/substratum (defined in Tables 2.3 and 2.4) combinations are in parenthesis after reach sample code.

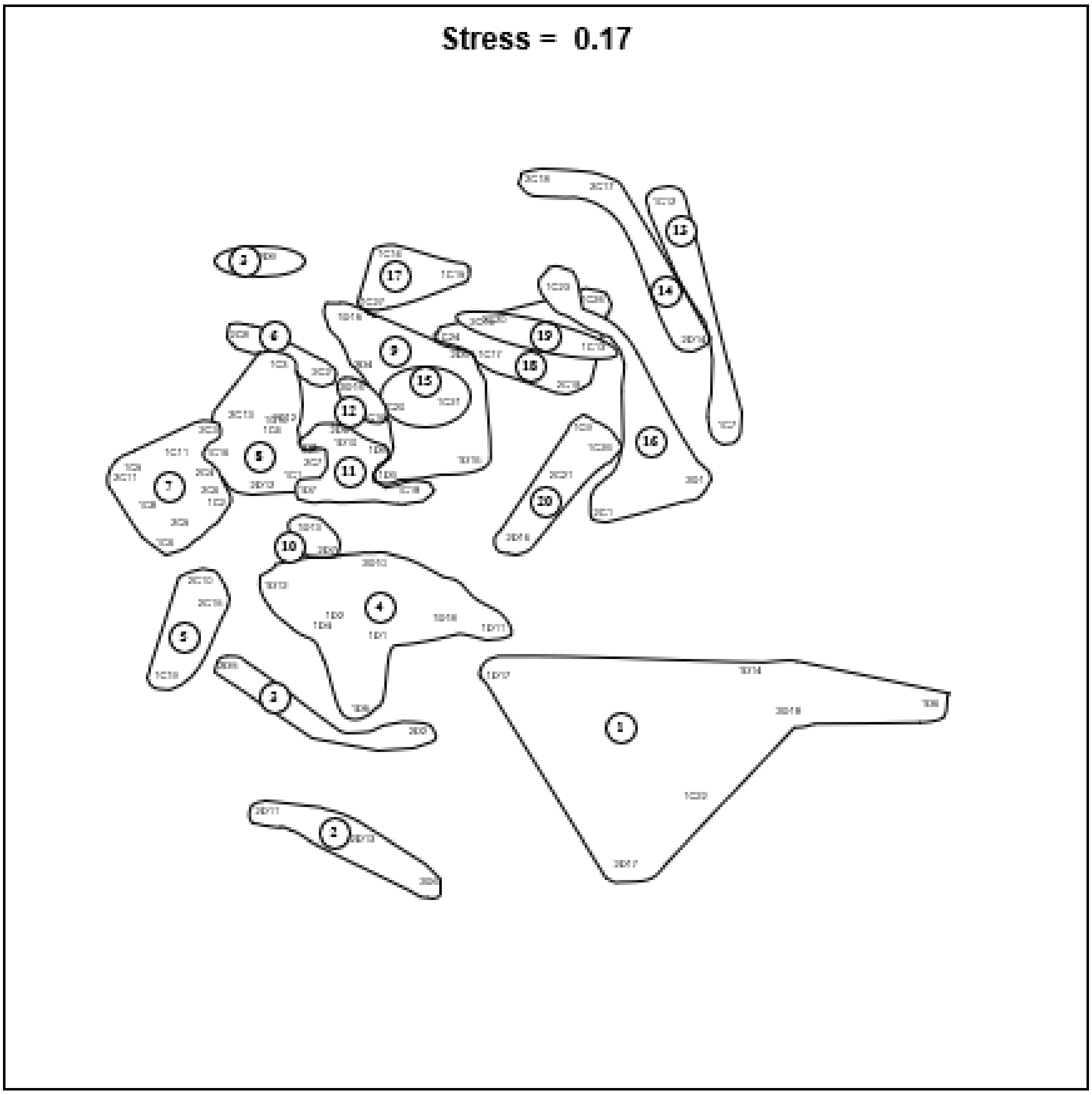

Figure 14.12 Species-level MDS for individual samples at the two sites. Data codes for site and mapping times as in Table 14.1 with the attachment of sampling point number (Table 14.7).

Table 14.8 Summary statistics for each group of samples recognised in Table 14.7: range, mean and standard deviation (SD) of depth and percent composition of substrata. The statistics are listed by hydraulic biotope, sub-group number, site representation, discharge code (Q), and number of samples (N) within each hydraulic biotope. Depth data calculated from the means in Table 14.7. Substratum averages from all contributions within the group. Site and discharge (Q) designation are based on group composition; "none" means that sites or discharges were equally represented in the sub-group; * denotes that the majority of the samples were from that site or discharge, but that one sample in the sub-group was from the other site or discharge. Substrata codes as in Table 2.4.

	Sub-				Depth (m)			Substrata %					
Hydraulic Biotope	group	Site	Q	N	Range	Mean	SD	B	LC	SC	LG	SG	SA
Bio-pool (boulder)	13	1	C	2	0.12 – 0.15	0.13	0.02	98	2	0	0	0	0
Bio-pool (boulder)	16	2*	C*	3	0.20 – 0.41	0.29	0.11	73	20	5	0	0	1
Bio-pool (cobble)	17	1	C	3	0.20 – 0.41	0.33	0.08	20	49	24	5	1	0
Bio-rapid (boulder)	2	2	D	3	0.13 – 0.23	0.16	0.06	79	9	11	1	0	0
Bio-rapid (boulder)	3	2	D	3	0.36 – 0.38	0.37	0.01	75	15	3	5	3	0
Bio-rapid (boulder)	4	1*	D	8	0.18 – 0.47	0.30	0.11	58	24	11	6	3	0
Bio-rapid (boulder)	5	2*	C	3	0.15 – 0.20	0.18	0.03	85	3	9	3	0	0
Bio-rapid (boulder)	7	none	C	10	0.07 – 0.35	0.18	0.08	40	38	12	9	1	0
Bio-rapid (cobble)	10	none	D	2	0.16 – 0.18	0.17	0.01	30	44	16	8	2	0
Bio-riffle (boulder)	1	none	D	6	0.21 – 0.56	0.33	0.13	88	2	7	3	0	0
Bio-riffle (cobble)	8a	1*	C*	6	0.08 – 0.30	0.17	0.09	13	47	25	8	7	0
Bio-riffle (cobble)	8b	2	C	4	0.17 – 0.45	0.28	0.13	26	29	28	15	2	0
Bio-riffle (cobble)	9	none	D	5	0.15 – 0.48	0.32	0.14	34	31	20	10	2	2
Bio-riffle (cobble)	11	1*	D*	6	0.14 – 0.54	0.25	0.15	29	29	21	16	3	2
Bio-riffle (cobble)	12	2	none	2	0.29 – 0.61	0.45	0.23	34	52	10	4	0	0
Bio-run (boulder)	14	2	C*	3	0.42 – 0.48	0.44	0.03	55	25	8	3	9	0
Bio-run (boulder)	15	1	C	2	0.16 – 0.29	0.23	0.10	76	16	4	4	0	0
Bio-run (boulder)	18	1*	C	4	0.20 – 0.43	0.33	0.11	62	21	13	4	0	0
Bio-run (boulder)	20	none	C*	4	0.22 – 0.50	0.38	0.13	86	2	6	6	0	0
Bio-run (cobble)	6	2	C	2	0.16 – 0.43	0.30	0.19	28	40	32	0	0	0
Bio-run/pool (boulder)	19	2*	C	3	0.11 – 0.44	0.30	0.17	67	18	14	1	0	0

14.6 Conclusions

14.6.1 Changes in physical hydraulic conditions with discharge

Overall, during the relatively low-flow conditions during this study, it required a major change in discharge to significantly change the wetted area and hydraulic conditions. This held equally true for both reach types studied. Flow-type proportions remained steady over a range of similar discharges and only shifted when discharges changed by 84 to 53% (sites 1 and 2 respectively). The shifts in flow-type proportions were fairly site specific, with the more specialised (chute, free fall, trickle, etc.) flow-types being more dominant and widespread in site 1 and very rare in site 2 (Figure 14.3 and Table 14.2).

Table 14.9 Summary statistics for each group of samples recognised in Table 14.7: ranges, means and standard deviations (SD) of near-bed and mean-column (0.6) velocity (m s^{-1}) and Froude number. These statistics are listed by hydraulic biotope, sub-group number, site representation, discharge code (Q), and number of samples (N) within each hydraulic biotope. Four individual sites of velocity measurements were made within the area where each invertebrate sample was collected. The means of these values are given in Table 14.7. The values in this summary table are the ranges, means and standard deviations of these means. Site and discharge (Q) designation are based on group composition; "none" means that sites or discharges were equally represented in the sub-group; * denotes that the majority of the samples were from that site or discharge, but that one sample in the sub-group was from the other site or discharge.

					Near-bed Velocity (m s^{-1})			Mean (0.6) Velocity (m s^{-1})			Froude Number		
Hydraulic Biotope	Sub-group	Site	Q	N	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Bio-pool (boulder)	13	1	C	2	0.01 – 0.03	0.02	0.01	0.02 – 0.05	0.03	0.02	0.022 – 0.038	0.030	0.012
Bio-pool (boulder)	16	2*	C*	3	0.00 – 0.04	0.01	0.02	0.01 – 0.06	0.03	0.03	0.005 – 0.029	0.018	0.012
Bio-pool (cobble)	17	1	C	3	0.02 – 0.05	0.03	0.01	0.04 – 0.14	0.08	0.06	0.025 – 0.079	0.043	0.031
Bio-rapid (boulder)	2	2	D	3	0.35 – 0.83	0.63	0.25	0.40 – 1.04	0.75	0.32	0.377 – 1.012	0.645	0.329
Bio-rapid (boulder)	3	2	D	3	0.31 – 0.69	0.52	0.19	0.30 – 1.08	0.79	0.42	0.154 – 0.581	0.421	0.233
Bio-rapid (boulder)	4	1*	D	8	0.02 – 0.52	0.27	0.18	0.34 – 0.76	0.51	0.22	0.073 – 0.592	0.324	0.179
Bio-rapid (boulder)	5	2*	C	3	0.26 – 0.77	0.53	0.25	0.34 – 0.52	0.45	0.09	0.291 – 0.382	0.348	0.049
Bio-rapid (boulder)	7	none	C	10	0.17 – 0.99	0.36	0.24	0.42 – 1.01	0.51	0.25	0.203 – 1.246	0.444	0.302
Bio-rapid (cobble)	10	none	D	2	0.16 – 0.35	0.25	0.14	0.18 – 0.53	0.35	0.24	0.141 – 0.442	0.292	0.213
Bio-riffle (boulder)	1	none	D	6	0.01 – 0.30	0.16	0.11	0.03 – 0.39	0.22	0.13	0.018 – 0.222	0.135	0.073
Bio-riffle (cobble)	8a	1*	C*	6	0.05 – 0.42	0.26	0.13	0.10 – 0.49	0.31	0.14	0.074 – 0.442	0.269	0.134
Bio-riffle (cobble)	8b	2	C	4	0.07 – 0.26	0.15	0.09	0.16 – 0.56	0.29	0.19	0.095 – 0.264	0.176	0.077
Bio-riffle (cobble)	9	none	D	5	0.04 – 0.19	0.09	0.06	0.06 – 0.16	0.11	0.03	0.050 – 0.090	0.065	0.017
Bio-riffle (cobble)	11	1*	D*	6	0.12 – 0.56	0.25	0.17	0.15 – 0.61	0.31	0.17	0.120 – 0.515	0.226	0.150
Bio-riffle (cobble)	12	2	none	2	0.14 – 0.24	0.19	0.07	0.21 – 0.30	0.26	0.07	0.086 – 0.182	0.134	0.067
Bio-run (boulder)	14	2	C*	3	0.09 – 0.13	0.12	0.02	0.11 – 0.17	0.14	0.03	0.053 – 0.078	0.066	0.012
Bio-run (boulder)	15	1	C	2	0.03 – 0.13	0.08	0.07	0.05 – 0.21	0.13	0.11	0.051 – 0.123	0.087	0.051
Bio-run (boulder)	18	1*	C	4	0.02 – 0.11	0.06	0.04	0.03 – 0.15	0.10	0.05	0.014 – 0.105	0.060	0.037
Bio-run (boulder)	20	none	C*	4	0.03 – 0.10	0.07	0.03	0.05 – 0.16	0.12	0.05	0.033 – 0.090	0.062	0.023
Bio-run (cobble)	6	2	C	2	0.05 – 0.14	0.10	0.06	0.08 – 0.22	0.15	0.10	0.059 – 0.107	0.083	0.034
Bio-run/pool (boulder)	19	2*	C	3	0.01 – 0.13	0.07	0.06	0.02 – 0.18	0.11	0.08	0.019 – 0.085	0.062	0.037

The same pattern occurred with flow/substrata proportions, with a more site specific pattern emerging (Figures 14.5 - 14.8). This pattern reflected difference in proportions of large cobble and boulder over which the different flow-types were recorded. Site 1 tended to have more boulder over all (Section 13.3), however site 2 had a greater proportion of wetted boulders (smaller boulder material and deeper channel) with three main flow types, RS, USW and BSW than did site 1, which had a more even spread (Figure 14.4).

Future analyses in Ms. Schael's PhD will focus on micro scale patterns of these flow/substrata combinations, through studies of the digitised site maps (e.g. Figures 7.4-7.6). A number of flow/substratum patches will be tracked over time to see how resilient each physical patch is, how long it retains its shape and position within the site, and which changes in discharge or other measured hydraulic variables cause it to shift to another flow type. Flow duration curves and time-series analysis of daily hydrological data will also be completed and linked to the results from the study reported in this chapter, to illustrate the proportion and individual spells of time that the measured conditions are likely to prevail in the sites. Until these analyses are completed, conclusions cannot be drawn on the discharge-related behaviour of individual hydraulic patches within the mosaic of the site, but only on the site as a whole.

14.6.2 Changes in invertebrate densities and species assemblages with discharge

Overall invertebrate densities decreased between sampling periods C and D within both sites. There was a significant effect of sampling time, which is linked to discharge that suggests that the increase of flow during the last sampling periods shifted the numbers of animals. Examining the species composition or "fingerprint" of each site, the importance of this discharge change is also evident. When examining each sample in the context of hydraulic biotopes the pattern remained similar to that of the reach comparison in Chapter 13 where hydraulic preferences superseded affinities to site or discharge. At this point in the analyses it can not be pointed out if animals moved from one area to another due to shifts in local hydraulics (Section 14.6.3), but that there were overall species assemblage shifts.

14.7 Future analyses

Not all of the biological data have been analysed to date, so conclusions can only be based on these two sampling periods. These represented the lowest and highest measured discharges, and revealed a clear pattern of differences both in overall invertebrate densities (Tables 14.5 and 14.6) and species structure (Figure 14.9). The two remaining sampling occasions should show similar results to sampling period C, as the discharges were similar. The report on this will form part of Ms. Schael's PhD.

The implications of hydraulic biotopes (and thus the invertebrate assemblages defining them) identifying with one discharge and, to a lesser extent, one site, requires further careful analysis and thought. Where do the invertebrates from "slow" hydraulic biotopes go in high flows if they do not remain in the "fast" hydraulic biotopes that replace the slow ones? The data suggest that, because the biotas define the hydraulic biotopes, when the slow-flow HBs disappear, so by definition do the slow-flow invertebrates. But is this so, or are they still there, masked by the fast-flow species moving into the area? This can only be answered by tracking the fate of individual species types through the series of samples, as will be done in Ms Schael's PhD thesis.

15. IMPACTS OF ANTHROPOGENIC DISTURBANCE

15.1 Recap

The fifth aim listed for this project (Section 3.6) was to search for trends in the ways that anthropogenic (man-made) disturbances of rivers alter the river ecosystems. Re-iterating Section 3.6, it was suggested that such disturbances could alter the distribution and proportions of hydraulic biotopes, species assemblages, and possibly even of morphological units, away from the ranges recorded for least-disturbed sites. Physical disturbance might result in persistence of the original species assemblage of invertebrates, but in some depauperate form, with few new species. Chemical disturbance, on the other hand, might leave the basic morphological structure intact, but change the overall chemical environment. It could, however, also change physical microhabitat conditions by, for instance, covering rocky-bed elements with algae. Thus, in several ways and depending on its severity, chemical disturbance could change the faunal assemblage, with a loss of original species and either addition of new pollution-tolerant species or, in toxic situations, no additional species. Some other disturbances, such as dams and infestation by alien trees, could provide additional impacts, by changing the river's flow and temperature regimes, destabilising banks, or changing the dynamics of sediment transport.

Within this project it was not possible to investigate the full array of disturbances present in Western Cape rivers. Instead, ten river sites were identified that are within the same bio-region and longitudinal zones as the least-disturbed rivers (Table 5.1), and that had single specific disturbances. The disturbances included bulldozing of the river bed, dams, alien trees and agriculture (Table 15.1). Eight of the sites were within catchments or catchment groups already represented by the least-disturbed rivers (*Olifants*: disturbed river numbers 3, 4 and 5; *Breede*: number 12; *Berg*: number 16; *Palmiet*: number 23; and *Table Mountain*: numbers 26 and 28). Two of the sites were on short rivers (numbers 22 and 25) with their own estuaries.

Table 15.1 Summary of the ten disturbed river sites used in the investigation, and their major anthropogenic disturbances. For more details, see Table 5.1.

River #	River Name	Catchment	Disturbance
3	Noordhoek	Olifants	Bulldozed river bed and banks
4	Middeldeur	Olifants	Agriculture – upstream nutrient enrichment
5	Grootrivier	Olifants	Agriculture – upstream nutrient enrichment
12	Holsloot	Breede	Upstream dam –continual hypolimnetic release with thermal modification to very cold water
16	Wemmershoek	Berg	Upstream dam – no flow in dry season except from minor tributaries. Site bulldozed after sampling – MUs eradicated before mapped.
22	Lourens	Lourens	Orchards, piggery, disturbed banks with alien trees
23	Palmiet	Palmiet	Upstream dams and weirs
25	Davidskraal	Davidskraal	Upstream dam, downstream weir, retaining walls at site
26	Window	Table Mountain	Botanical garden
28	Cecilia	Table Mountain	Alien trees *Populus canescens,* with much woody debris and little surface flow

Abiotic and biotic data were collected and analysed as per Chapter 4, with field mapping and sampling done in the 1997/98 summer low-flow season.

15.2 Biologically-defined groups of sites, with disturbed rivers included

The CLUSTER module in PRIMER, used for grouping the least-disturbed sites (Section 10.2), was re-run with the ten disturbed sites included. The catchment groupings were the same as for the least-disturbed rivers (Figure 10.4), with the Olifants/Berg group separating off first, followed by the Table Mountain streams and then the Breede and the Eerste/Molenaars groups, and lastly the single river from the Palmiet catchment (the Dwars) (Figure 15.1). Overlaid on this pattern, however, was the distribution of the disturbed rivers: four grouped within established catchment groups whilst the other six formed two 'outliers groups'.

Two of the rivers that entered an established group were in the appropriate catchment from a geographical perspective: the Groot appeared with the other Olifants rivers and Window with the other Table Mountain rivers. The two short rivers appeared in two other established groups: the Lourens with the Breede rivers, and the Davidskraal with the Eerste/Molenaars rivers. Neither of these link-ups was with the geographically nearest catchment, which for the Lourens is the Eerste, and for Davidskraal is the Palmiet (Figure 5.1). It is not understood why they joined these catchment groups. The matter is discussed further in Chapter 20.

Three of the four rivers just mentioned (Groot, Lourens, Davidskraal), were among the least similar within their adopted groups, lying between the bedrock and alluvial rivers or near the group outliers. These three rivers were recognised as having agricultural disturbance (Groot, Lourens) and a dam and retaining walls (Davidskraal). Both the Groot and the Lourens sites had approximately natural size channels, and flow regimes that were somewhat modified but that remained perennial with close-to-normal flooding. Their main impacts were from upstream nutrient inputs and bank disturbance. The Davidskraal site had a major dam directly upstream releasing little flow, retaining walls through the site, and a downstream weir that pushed settled fine sediments back into the site. Judging from the invertebrates present, its water quality appeared good, though the dam must have had thermal impacts. The fourth river that joined an established group (Window) runs through Kirstenbosch Botanical Gardens. It has a low level of disturbance of its banks and a near-natural channel width and morphology. From its position well within the Table Mountain group (Figure 15.1), it appears less impacted than the others.

Though set apart from the main groups of least-disturbed rivers, the two outlier groups of disturbed rivers were not necessarily less similar to them than the main groups were to each other. Disturbed Group 1 was more similar to the Eerste/Molenaars and Breede groups (33% similarity) than were the Table Mountain (32%) and Olifants/Berg (27%). It contained rivers with dams (Wemmershoek – B16, Palmiet – P23), agriculture (Middeldeur – O04) and a bulldozed bed (Noordhoek – O03). The Wemmershoek site received no water from its upstream reaches unless Wemmershoek Dam was spilling, but flow from three minor tributaries (Bakkerskloof – river B14 and Zachariashoek – river B15 and one other). It had collapsing banks, extensive sandy deposits on its cobble bed, and appeared to have been widened with a berm and loss of riparian trees on the left bank. The Palmiet site was downstream of one dam (Nuweberg Dam) and agricultural areas, and had recently burnt. It had a bedrock channel that appeared unmodified, and its main

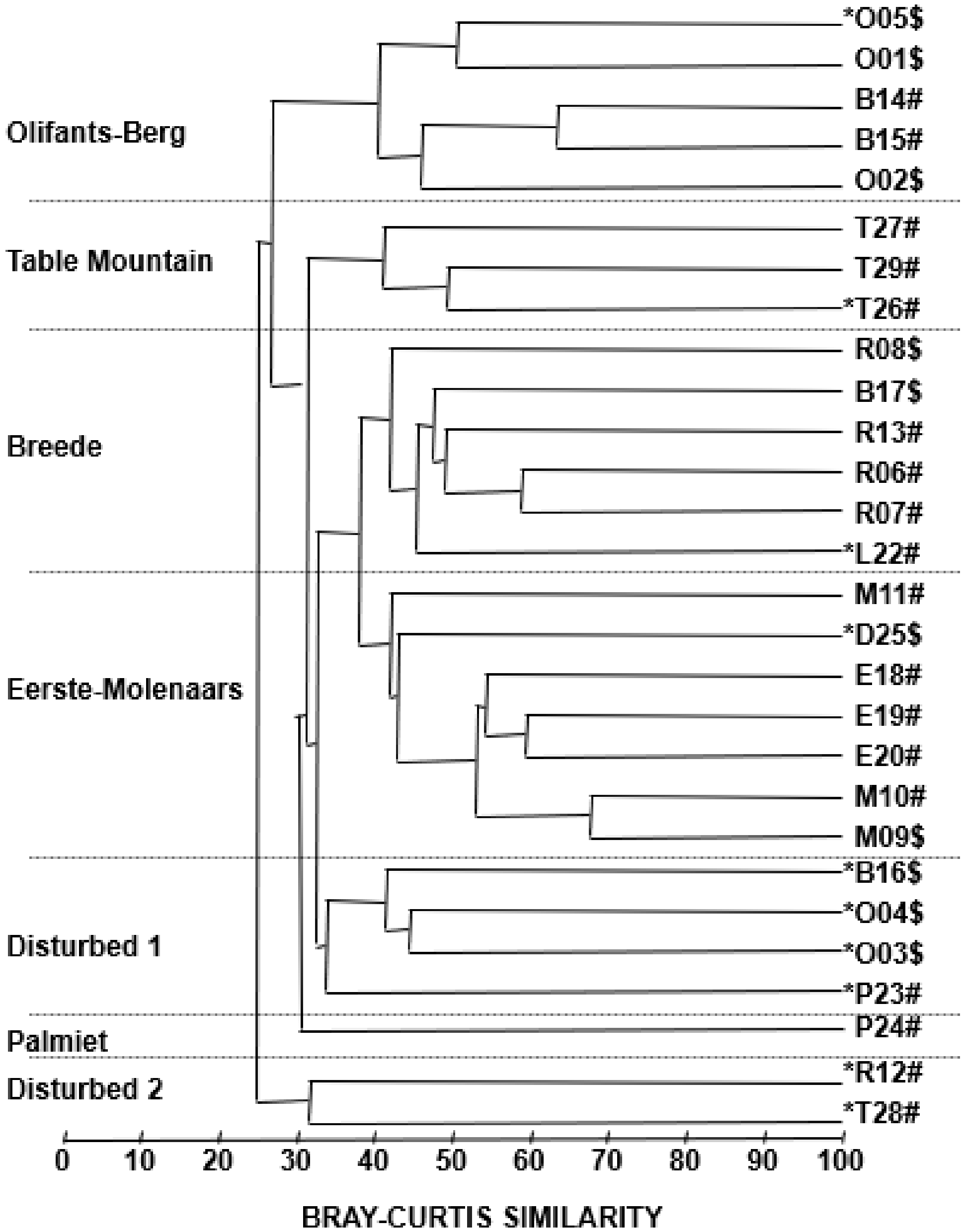

Figure 15.1 Dendrogram of the 18 least-disturbed sites and ten disturbed sites, using species level data of invertebrates. The groups recognised in Figure 10.4 are shown, together with two groups of disturbed rivers. # = predetermined mountain zone based on literature; $ = predetermined foothill zone based on literature; * = disturbed rivers.

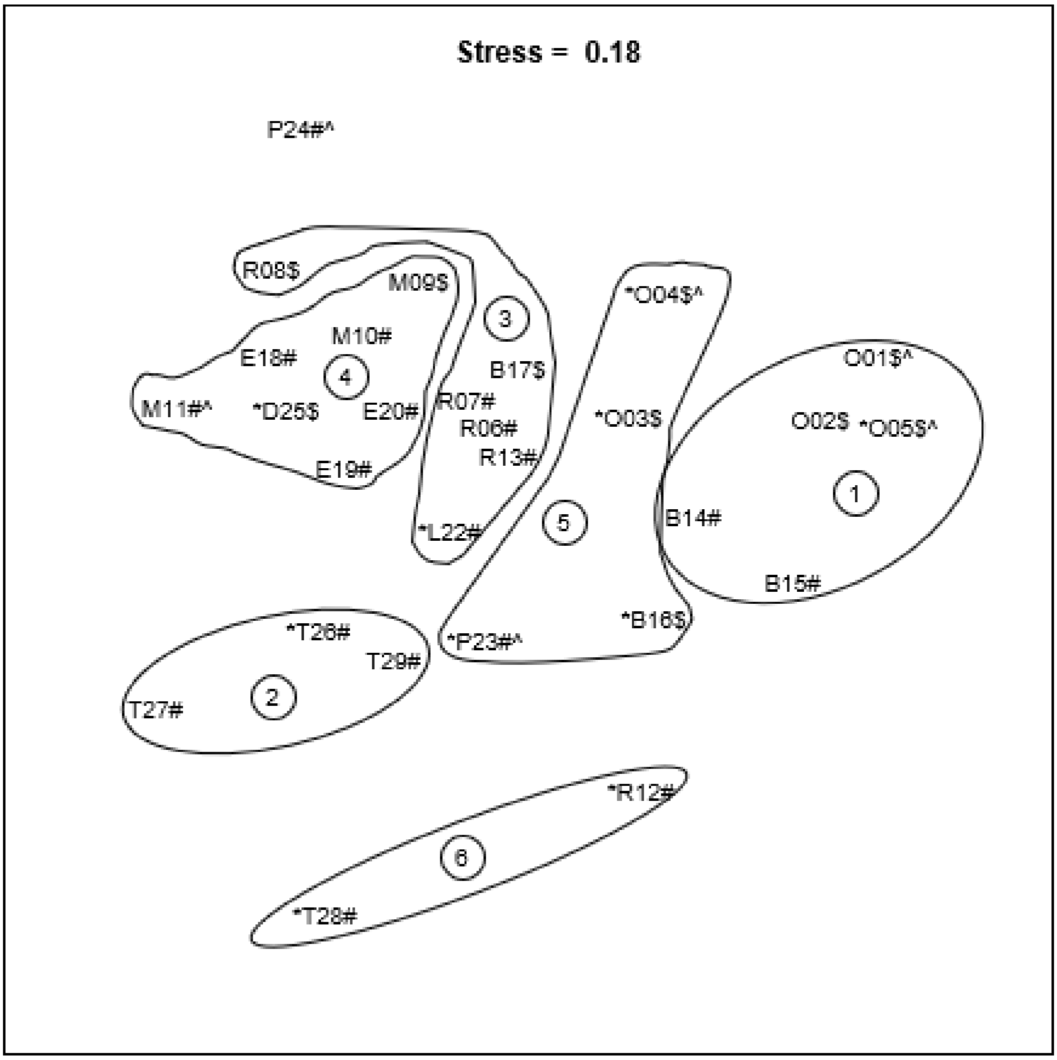

Figure 15.2 Two-dimensional configuration of the 18 least-disturbed sites and ten disturbed sites, using species level data of invertebrates. The groups recognised in Figure 10.4 are shown, together with the two groups of disturbed rivers. # = predetermined mountain zone based on literature; $ = predetermined foothill zone based on literature; * = disturbed rivers; ^ bedrock rivers. Numbers represent the different sub-groups: 1 = Olifants-Berg; 2 = Table Mountain; 3 = Breede; 4 = Eerste-Molenaars; 5 = Disturbed 1; 6 = Disturbed 2.

impacts were the reduction in flows and upstream nutrient enrichment. The Middeldeur site had a bedrock channel with spectacular cascades and waterfalls downstream of the site. The channel did not appear to be modified, except perhaps by a greater than usual growth of riparian trees. Its most obvious impact was algal growth from upstream nutrient enrichment. The Noordhoek site was in mountain fynbos with no upstream dams, and so the chemical and thermal regimes were near natural. Its main impact was a bulldozed channel with an artificial cobble berm on the right bank, presumably to constrain flow within a narrow channel. Part of the bulldozing activity had been to create an abstraction channel upstream of the site, to take water to a nearby farm. This resulted in dry-season flows through the site being noticeably lower than natural.

The two rivers in Disturbed Group 2 were least similar to any other river. This group contained rivers with a dam (Holsloot – R12) and alien vegetation (Cecilia – T28). The Holsloot site received a continuous, very powerful, hypolimnetic release. Very cold water (Table 7.1: 12.3 ºC, compared to the range 15.3 – 24.1 ºC for all other sites) flowed turbulently over a riverbed 90% covered with dense, green filamentous algae. The Cecilia site was choked with woody debris and fallen leaves of *Populus canescens.* There was little surface water. This was the only river in which the abundant invertebrate group Ephemeroptera (mayflies) was not found.

The ordination plot of the same data was drawn with an acceptable stress of 0.18 (Figure 15.2). This also showed the established groups, each (except the Palmiet group with its one river) containing one disturbed river. Only the Wit (R08), which has shown up as an outlier in several earlier analyses, did not sit obviously with its group. Bedrock sites tended to be located around the outer edges of groups. Disturbed Group 1 was centrally placed among the recognised catchment groups, perhaps reflecting that these rivers had lost their catchment and river signatures, and had become increasingly similar to each other. Perhaps unique or sensitive species had been lost, leaving a core assemblage of hardy species that are common to most rivers. This grouping occurred despite the rivers having experienced a range of impacts (see descriptions above). This topic is revisited in Chapter 16.

Disturbed Group 2 was least similar to any other group of rivers (Figure 15.2). This may reflect a much more drastic disturbance, with a loss of even the hardy species, and the presence of a completely new assemblage of invertebrates. Again, this is discussed further in Chapter 16.

Following the conclusions given in Section 10.3, ANOSIM was not used to further explore differences between sites.

15.3 Correlation between biological groupings and environmental variables

BIOENV runs were completed for all groups recognised in Figure 15.1, that is, the Olifants/Berg catchment with the Grootrivier included; The Table Mountain catchments with Window; the Breede catchment with the Lourens, the Eerste/Molenaars catchments with Davidskraal; and the two disturbed groups. The results are not useful in some ways, as they characterise groups of rivers in which at least one river is no longer like the rest – hence the characterisation essentially becomes “noisy”. Nevertheless, they provide an indication of how the overall driving variables of the groups changed with a disturbed river added in. If

Table 10.2 (for the least-disturbed rivers) is compared with Table 15.2 (for all rivers), for instance, algae and macrophytes gain prominence once the disturbed rivers have been added.

Table 15.2 Variables used and coefficients derived from the BIOENV matching exercise of biotic and abiotic similarity matrices of all sampled rivers. An * indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	*Scirpus* (0.213)
2	Conductivity and macrophytes (0.309)
3	Algae, conductivity and macrophytes (0.326)
4	Algae, conductivity, macrophytes and *Scirpus* (0.338)
5	Algae, conductivity, macrophytes, cobbles and *Scirpus* (0.351)
6	Algae, conductivity, macrophytes, site slope, cobbles and *Scirpus* (0.360)
7	Algae, conductivity, macrophytes site slope, altitude, cobbles and *Scirpus* (0.372)
8*	**Algae, conductivity, macrophytes, site slope, altitude, boulder, cobbles and *Scirpus* (0.381)**

Similarly, algae gains prominence once the Davidskraal is added to the Eerste/Molenaars group (Tables 10.3 and 15.3), and moss once the Lourens is added to the Breede (Tables 10.4 and 15.4).

Table 15.3 Combinations of 12 environmental variables yielding the best matches of biotic and abiotic similarity for the Eerste/Molenaars catchments and Davidskraal grouping. An * indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	Altitude (0.764)
2	Conductivity and bedrock (0.839)
3	Conductivity, bedrock and *Scirpus* (0.845)
4	Conductivity, moss, altitude and bedrock (0.856)
5	Algae, colour, site slope, altitude and cobbles (0.871)
6	Algae, conductivity, macrophytes, site slope, altitude and cobbles (0.871)
7*	**Algae, conductivity, colour, site slope, altitude, cobbles and *Scirpus* (0.888)**

Table 15.4 Combinations of 12 environmental variables yielding the best matches of biotic and abiotic similarity for the Breede catchment and Lourens River grouping. An * indicates overall best match.

Number of variables	Best variable combinations (ρ_w)
1	Altitude (0.496)
2	Altitude and boulder (0.655)
3*	**Moss, altitude and boulder (0.660)**
4	Macrophytes, moss, altitude and boulder (0.602)
5	Conductivity, moss, altitude boulder and cobbles (0.595)
6	Conductivity, moss, colour, altitude boulder and gravels (0.579)

Predictably, the best overall match in each case had a lower correlation value than when only the least-disturbed rivers were included.

15.4 Changes in MUs

When the disturbed rivers are included in the analysis of numbers of MUs, all but three of them group together but apart from the zonal groups recognised in Figure 12.1 (Wemmershoek - B16 not included as MUs eradicated, probably by bulldozing). The four main zonal groups: alluvial mountain; alluvial mountain/upper foothill; alluvial lower foothill; and bedrock mountain and foothill, are still apparent (Figure 15.3), although one site (M10 - Elands) has shifted groups from "mountain/upper foothill" to "bedrock mountain and foothill". But superimposed on this is a clear grouping of disturbed rivers, which together are less than 15% similar to almost all reference rivers in terms of the number and types of MUs. Even the two disturbed bedrock rivers group together, but separately from all other rivers including the other bedrock ones. All of the remaining disturbed rivers, except Cecilia (T28), group with the two lower foothill sites (Berg - B17 and Molenaars - M09) and the two outliers (R06 and R13). In terms of their slopes, all but the Groot (O05) should be well within the upper foothill to mountain zone (Tables 12.1 and 15.5), and so the disturbances appear to have transformed them to less heterogeneous sites typical of more downstream reaches. Further analysis is needed to compare, for instance, all the pristine mountain sites with all the disturbed mountain sites, to see which MUs are typical of each and what has been lost with disturbance (Chapter 20).

Table 15.5 Recap of map slope data for the disturbed rivers, and revised zone description based on analyses to date (see Section 15.6). # pre-identified as in a biological mountain zone and $ as in a biological foothill zone.

River Code	River Name	Map slope	Catchment	Revised zone
O03$	Noordhoek	0.020	Olifants	alluvial mountain-transitional
O04$	Middeldeur	0.011	Olifants	bedrock mountain and foothill
O05$	Grootrivier	0.002	Olifants	alluvial foothill
R12#	Holsloot	0.020	Breede	alluvial mountain-transitional
B16$	Wemmershoek	0.010	Berg	alluvial foothill
L22#	Lourens	0.020	Lourens	alluvial mountain-transitional
P23#	Palmiet	0.022	Palmiet	bedrock mountain and foothill
D25$	Davidskraal	0.010	Davidskraal	alluvial foothill
T26#	Window	0.087	Table Mountain	alluvial mountain
T28#	Cecilia	0.220	Table Mountain	alluvial mountain

15.5 Changes in substrata

The attempt to define physical reference conditions in Cape headwater streams (Section 10.6), revealed that there was an insufficiently detailed pattern of distribution of substrata to be able to distinguish river zones purely on the substrata (Figure 10.11). The distribution of flow types was even less useful for this purpose (Figure 10.12).

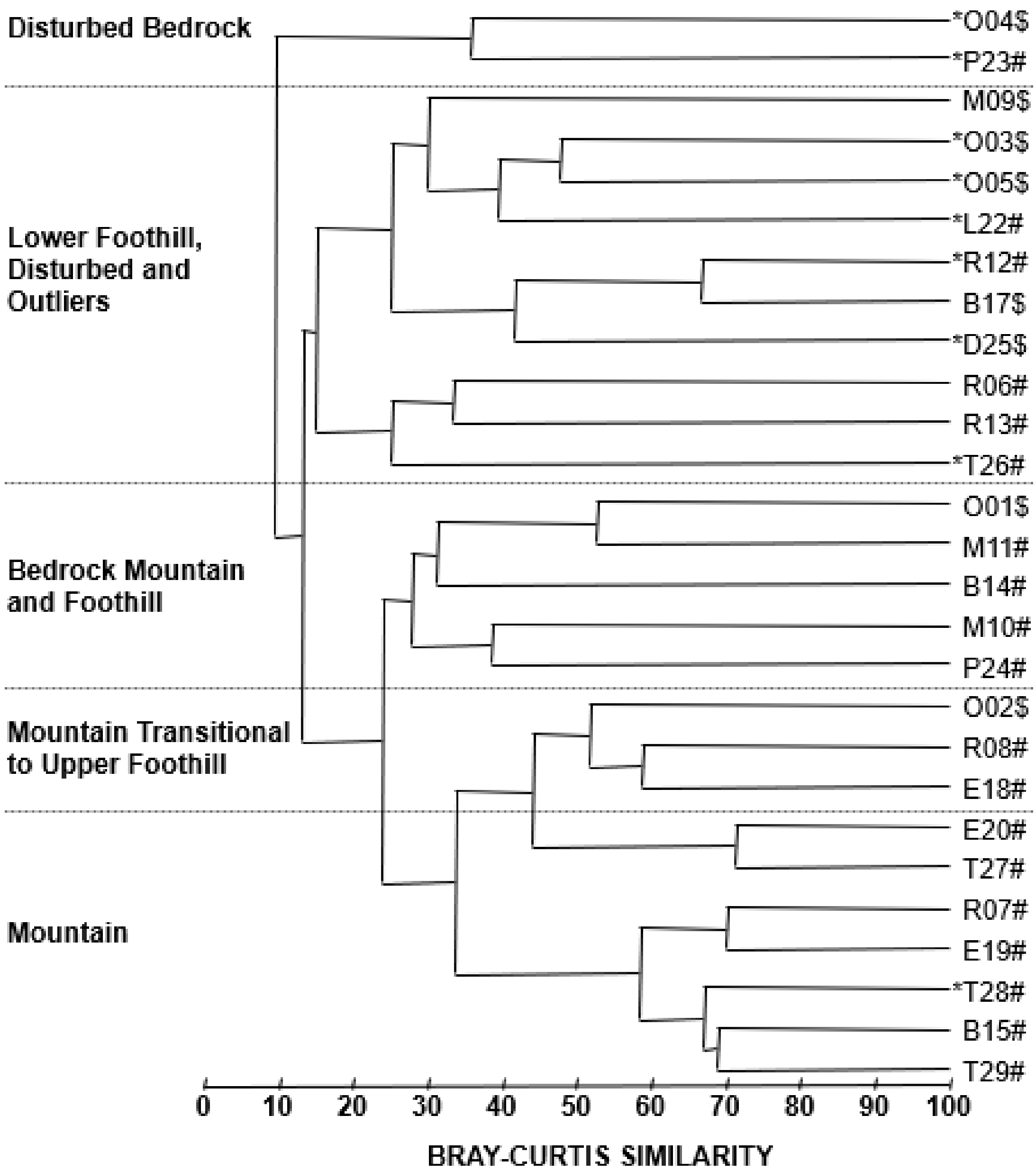

Figure 15.3 Dendrogram of the similarity between 18 least-disturbed and ten disturbed river sites, based on the number and type of MUs mapped at the sites. Zones marked on dendrogram are those recognised in Figure 12.1. # = predetermined mountain zone based on literature; $ = predetermined foothill zone based on literature; * = disturbed rivers.

The exercise of grouping rivers by substrata was repeated, however, as it might reveal why some of the disturbed rivers grouped as outliers. On the dendrogram of all 28 rivers, based on substrata data, the three main kinds of river channels – bedrock, mixed alluvial-bedrock, alluvial - were grouped (Figure 15.4). The two disturbed bedrock sites linked with the undisturbed sites, suggesting no major change in substrata. The mixed alluvial-bedrock sites still linked together, as in Figure 10.11. The alluvial group was increased by the inclusion of three disturbed sites (Window, Groot, Holsloot), but the remaining disturbed sites were in a swathe of dissimilar sites which also contained the two lower-foothill sites (Berg and Molenaars).

The MDS ordination of the same data (Figure 15.5) also reflected these groupings, but gave more details on the alluvial and ungrouped sites. The overall trends of the plot were: from left to right - bedrock to alluvial; and possibly from top to bottom – coarse to fine sediments. The least-disturbed bedrock sites were to the left, the least-disturbed mixed alluvial-bedrock sites in the centre, and the least-disturbed alluvial mountain sites formed a tight group to the right of the plot, surrounded by the least-disturbed alluvial foothill sites. The Holsloot (R12) grouped with these foothill sites but toward the top of the plot, perhaps reflecting the coarse sediments in this eroding, high-flow site. The remaining disturbed sites, apart from the two bedrock ones which were located in the bedrock group, were scattered to the lower right of the plot, all located outside any of the established groups. Again, the Window site (T26) appeared the least-impacted, being closest to the established mountain-alluvial group, and the Davidskraal (D25) and Cecilia (T28) sites most impacted.

Considering site slopes, the reference mountain-alluvial group had slopes ranging 0.020-0.080, and the alluvial foothills 0.002-0.026 (Table 5.3). The disturbed alluvial sites to the bottom right of the plot should have grouped within one of these two groups (Table 15.5). If increasing distance from these groups in the MDS plot is interpreted as increasing change in substrata, then the very high-gradient Cecilia site (T28), though with its MUs apparently intact, clearly is the most disturbed in terms of substrata, with Davidskraal (D25) a close second. These two sites are the only ones with more than 60% of their mapped substrata in the gravel and finer categories (Table 15.6). By comparison, among the least-disturbed alluvial rivers, gravels and fines made up 21% or less of the substratum, and among the other disturbed rivers 26% or less. This difference in substrata could partially explain why Cecilia does not group with other Table Mountain sites in terms of fauna (Figure 15.1 and 15.2), although with this reasoning Davidskraal should also be set outside recognised catchment groups. If substratum changes alone do not place sites outside the catchment groups (as happened with Davidskraal), then there must be additional forces influencing invertebrate distributions in Cecilia, and also in Holsloot (R12), for the latter has reasonably "normal" substrata but an unusual species assemblage (Figure 15.5 and 15.2). These forces could be physico-chemical changes (from the alien vegetation in Cecilia and hypolimnetic releases in Holsloot), flow changes (very low flows in Cecilia and very high flows in Holsloot), or temperature changes (very cold water in Holsloot). This matter is discussed further in Chapter 20.

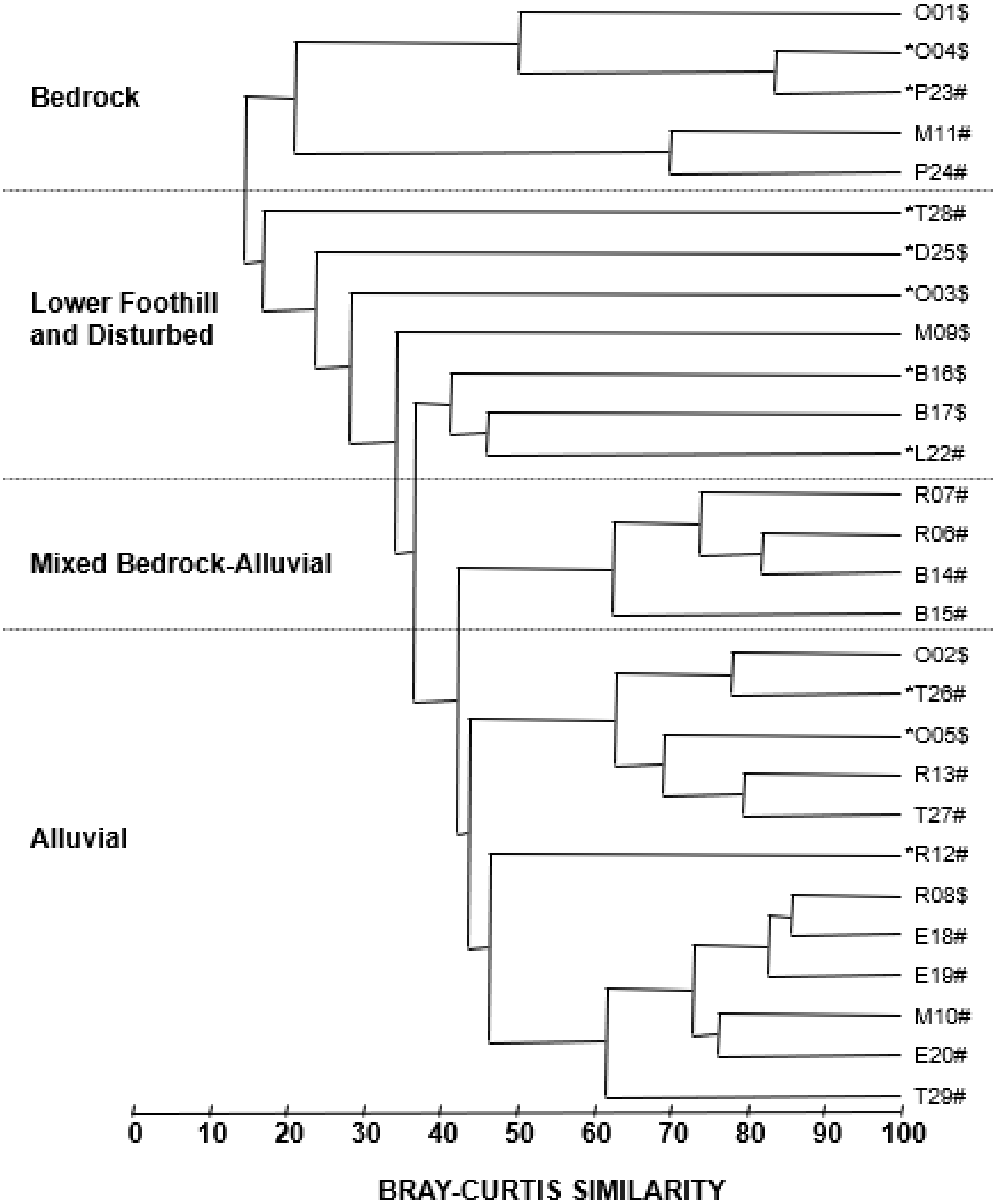

Figure 15.4 Dendrogram of the 18 least-disturbed sites and ten disturbed sites, using data on categories and proportions of substrata. The groups of least-disturbed rivers recognised in Figure 10.11 are shown, together with the disturbed rivers. # = predetermined mountain zone; $ = predetermined foothill zone; * = disturbed rivers.

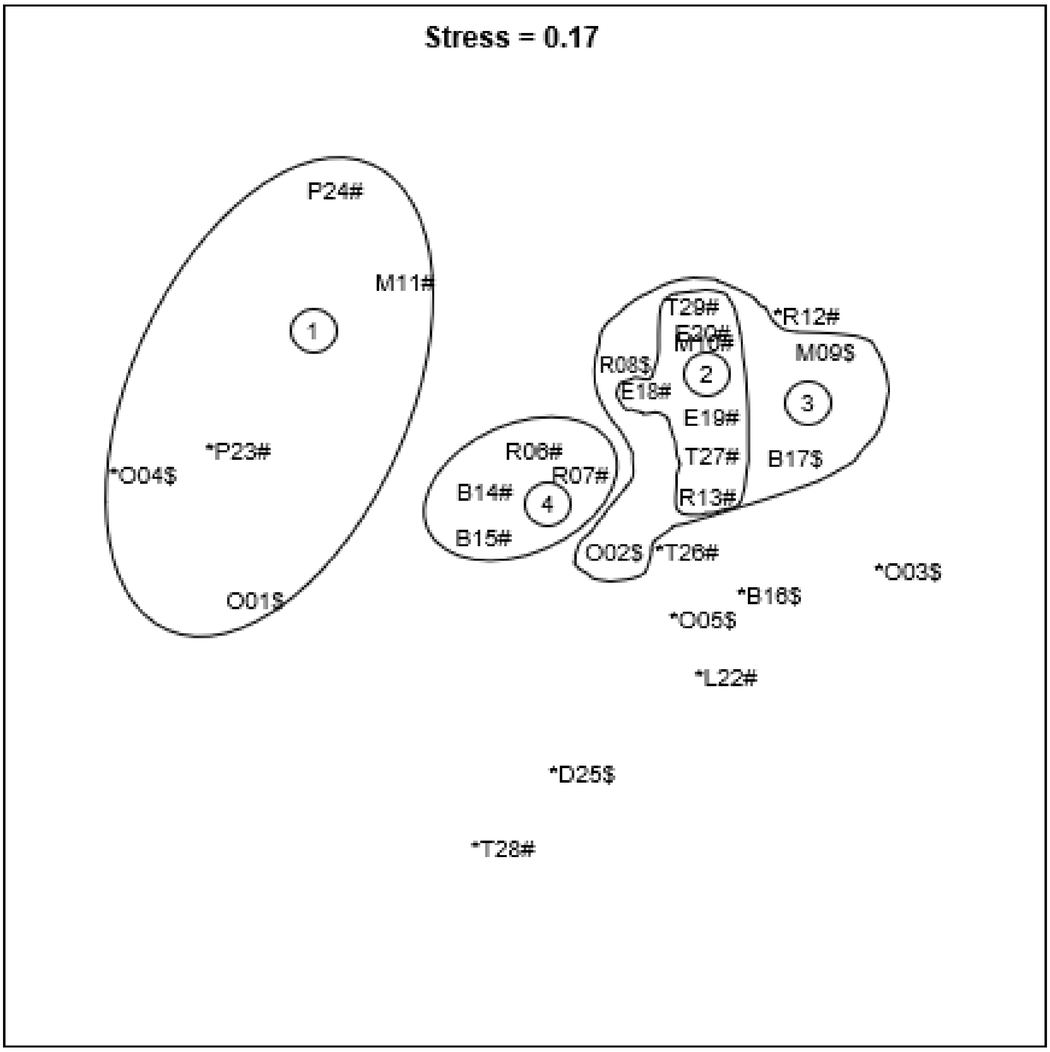

Figure 15.5 MDS ordination of the 18 least-disturbed sites and ten disturbed sites, using data on categories and proportions of substrata. The groups of least-disturbed rivers recognised in Figure 10.11 are shown, together with the disturbed rivers. # = pre-determined mountain zone; $ = pre-determined foothill zone; * = disturbed rivers. Numbers represent different groups: 1 = Bedrock; 2 = Least-disturbed Mountain; 3 = Least disturbed Foothill; 4 = Mixed Alluvial-bedrock.

Table 15.6 Percentages of wetted substrata in ten disturbed rivers, mapped with mixed categories allocated equally to one of the eight main categories. Substrata categories are explained in Table 2.4 with the exception of "plants" which are instream macrophytes not including *Scirpus* and palmiet; "concrete/rubble" which is concrete slabs or rubble instream and on banks; "roots" which are roots of trees or other riparian vegetation.

Substrata	O03$	O04$	O05$	R12#	B16$	L22#	P23#	D25$	T26#	T28#
BR	0.0	98.9	0.0	0.0	0.0	0.0	85.9	0.02	0.0	0.0
B	18.7	0.8	8.0	41.5	21.3	18.6	9.2	6.1	13.2	11.8
LC	44.3	0.0	69.3	15.6	50.8	26.1	0.3	2.9	38.0	16.9
SC	35.4	0.0	7.6	20.5	7.4	29.4	0.1	13.5	39.4	9.6
LG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.2	5.6	0.0
SG	0.0	0.0	1.3	10.0	0.0	2.8	0.03	31.8	0.6	3.5
SA	0.3	0.0	11.7	5.3	16.5	18.9	0.0	9.4	2.8	49.1
SI	0.0	0.0	1.9	0.0	0.0	4.3	0.0	0.0	0.0	0.8
Concrete/Rubble	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.0	0.0	0.2	0.0	0.0	0.0	1.0	0.0	0.4	4.8
Roots	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	3.4
Palmiet	0.0	0.04	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Scirpus	0.0	0.3	0.0	0.0	3.6	0.0	3.0	0.0	0.0	0.0
Plants	1.2	0.0	0.0	1.8	0.4	0.0	0.0	0.0	0.0	0.0

15.6 Changes in hydraulic biotopes, and recognition of an additional longitudinal zone

In Chapter 11, the individual invertebrate samples from the 18 least-disturbed rivers were analysed, to detect conditions (hydraulic biotopes) that supported similar species assemblages. The same analyses were repeated for the ten disturbed rivers and are reported on here. Again, the samples had to be divided into logical groups, in recognition of the PRIMER limitations in terms of number of samples.

During the preceding analyses it had become increasingly apparent that the split of samples from alluvial rivers into mountain or foothill zone was simplistic. Several different sets of data indicate a third zone between these two (Tables 6.1; 6.8; 12.1; 12.2; Figure 12.1; 12.2). Thus, at this point, we suggest recognition of a third zone in alluvial rivers and, pending further discussion with geomorphologists and other ecologists on it, have temporarily called it the mountain-transitional zone (Table 15.5). The zone appears to be related to map slopes of about 0.020-0.030.

In the following analyses of hydraulic biotopes, alluvial mountain and alluvial mountain-transitional were placed in one group, and alluvial foothills in a second. This allocation was done simply to achieve the best balance of numbers per group, and without suggestion of the closest affinity of the new mountain-foothill zone.

15.6.1 Alluvial mountain and mountain-transitional rivers

Five rivers, represented by 51 samples, were included in the analysis. Two were from Table Mountain, one from the Breede system, one from the Olifants, and one (Lourens) within its own small catchment. As reported in Section 11.3.2, the least-disturbed headwater streams consisted of complex mosaics of small patches with very different hydraulic conditions. Hydraulic biotopes were difficult to characterise, because samples were organised mainly by catchment, and so "groups of samples that might be representing different hydraulic biotopes were divided into three, if not four, main sub-groups" within a catchment group. These very small groups of similar samples were essentially inadequate for good characterisation of hydraulic biotopes.

In the analysis of disturbed rivers, the catchment signature was still very clear, with all samples from any one river holding together (Figure 15.6 and 15.7). Because of this, the hydraulic biotopes again had to be distinguished from very small groups of samples within each catchment group, and patterns detected should be regarded as tentative.

The overall trend appeared to be that each river had a group of bio-pool samples and loose group of faster-water samples. A few of the "fast" samples could best be characterised as being from bio-runs, but most were from groups that could not be distinguished as either riffles or rapids. Some of this confused pattern may have been the result of both mountain and mountain-transitional rivers being included in the analysis, for the former tend to have bio-rapids and the latter to be making the transition toward bio-riffles. Even the high-gradient mountain sites (Cecilia - CR and Window - WS) which should have had bio-rapids, however, presented the same confused picture, suggesting that disturbance may also have played a role.

Closer inspection of the hydraulic details of the sub-groups (Table 15.7) revealed that in most cases the boulder substratum typical of bio-rapids was not present. Fast flow types usually associated with rapids (e.g. USW, CAS) were present, but they flowed over smaller substrata. In Window Stream, for instance, which with its high gradient was clearly a mountain site, bio-rapids should have been very evident (compare with Langrivier and Swartboskloof at the same gradient – Section 11.3.2). Instead of flowing over boulders, however, the flow types CH and CAS flowed over mixed small and large cobble. At the Cecilia site, which is even steeper, CAS and FRF flowed over wood. The mountain-foothill sites showed a similar picture. Noordhoek, for example, had mean velocities and Froude numbers well within those given earlier for bio-rapids, with velocities generally higher than those given for bio-riffles (Section 11.4). All of its fast flow types were nevertheless over mixed large and small cobble. Much the same picture emerged for the Lourens. Only the Holsloot, with its strong, hypolimentic dam release, still displayed a boulder bed with the appropriate flow types, velocities and Froude values.

In summary, in terms of hydraulic biotopes, these disturbed river sites appeared to display two major differences to comparable least-disturbed sites. First, boulder substrata were virtually absent. Second, sorting of cobble and smaller particles was poor, with about half of the invertebrate samples being taken from mixed substrata. The result was a continuing strong catchment signature superimposed on an array of pool biotopes and indistinct fast-flow biotopes with poorly-sorted, relatively homogeneous substrata.

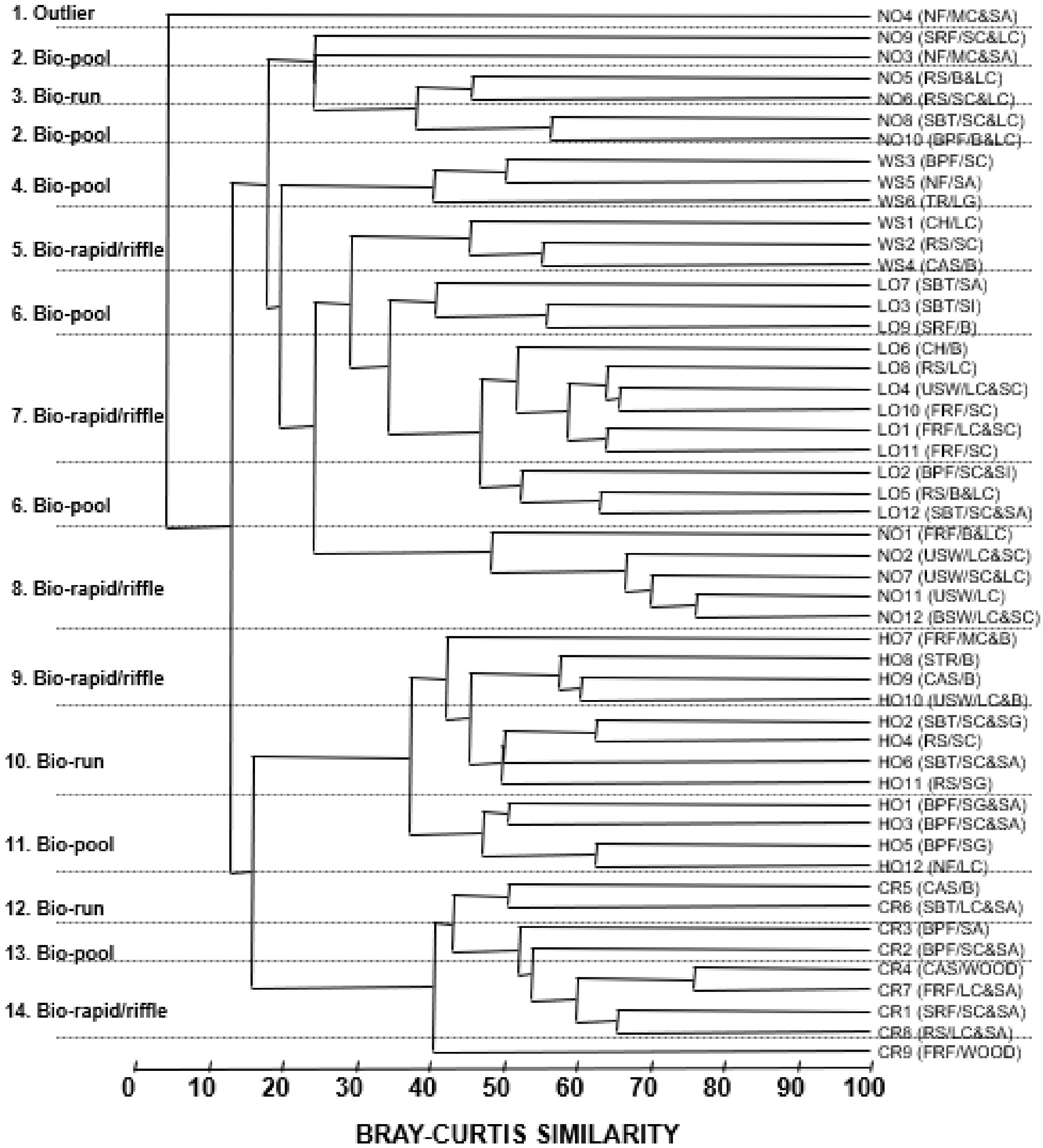

Figure 15.6 **Cluster analysis to identify similar invertebrate samples from five disturbed mountain or mountain-foothill sites.** Samples are coded by river and invertebrate sample number. NO = Noordhoek; WS = Window Stream; LO = Lourens; HO = Holsloot; CR = Cecilia Ravine. Substratum and flow-type codes as per Tables 2.3 and 2.4.

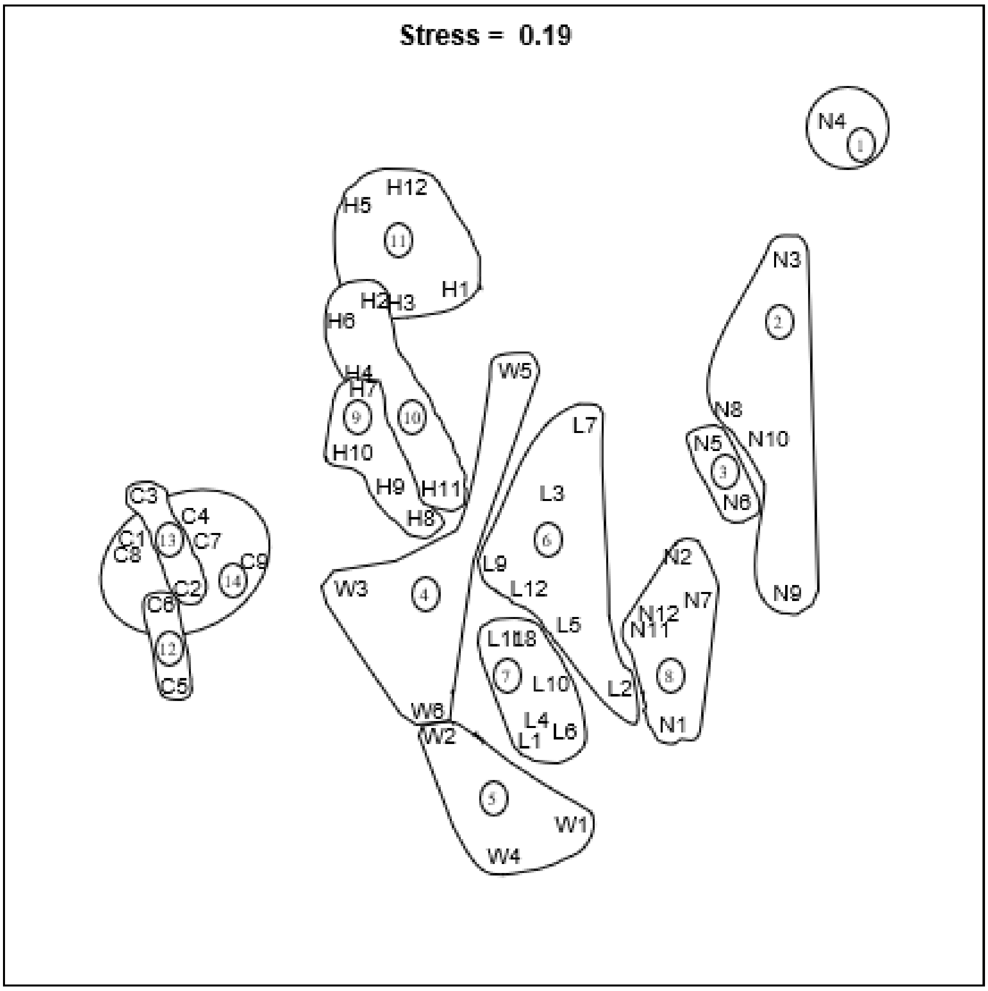

Figure 15.7 **MDS ordination of invertebrate samples from five disturbed mountain or mountain-foothill sites. Groups denoted are those identified in Figure 15.6.** Samples are coded by river and invertebrate sample number. N = Noordhoek; W = Window Stream; L = Lourens; H = Holsloot; C = Cecilia Ravine.

Table 15.7 Hydraulic characteristics of the 14 groups of samples from disturbed alluvial mountain and mountain-foothill sites, as recognised in Figure 15.6. Depth (m); mean-column (0.6) and near-bed (NB) velocity (m s^{-1}). NO = Noordhoek; WS = Window Stream; LO = Lourens; HO = Holsloot; CR = Cecilia Ravine. Substratum and flow-type codes as per Tables 2.3 and 2.4. MC = mixed cobble.

Sub-group No.	Hydraulic biotope	Sample code	Flow/ substrata	Depth	0.6	NB	Froude No.
1	Outlier	NO04	NF/MC&SA	0.04	0.01	0.01	0.016
2	Bio-pool	NO09	SRF/SC&LC	0.03	0.07	0.07	0.135
		NO03	NF/MC&SA	0.06	0.01	0.01	0.008
		NO08	SBT/SC&LC	0.08	0.04	0.04	0.049
		NO10	BPF/B&LC	0.15	0.03	0.01	0.025
3	Bio-run	NO05	RS/B&LC	0.14	0.20	0.16	0.181
		NO06	RS/SC&LC	0.15	0.21	0.14	0.181
4	Bio-pool	WS03	BPF/SC	0.24	0.00	-	0.000
		WS05	NF/SA	0.16	0.00	0.00	0.000
		WS06	TR/LG	0.08	0.07	0.11	0.084
5	Bio-rapid/riffle	WS01	CH/LC	0.11	0.45	-	0.422
		WS02	RS/SC	0.12	0.27	-	0.252
		WS04	CAS/B	0.12	0.46	0.54	0.479
6	Bio-pool	LO07	SBT/SA	0.21	0.01	0.01	0.007
		LO03	SBT/SI	0.09	0.08	0.01	0.082
		LO09	SRF/B	0.20	0.00	0.01	0.002
		LO02	BPF/SC&SI	0.09	0.03	0.02	0.035
		LO05	RS/B&LC	0.21	0.00	0.00	0.000
		LO12	SBT/SC&SA	0.22	0.09	0.04	0.059
7	Bio-rapid/riffle	LO06	CH/B	0.12	0.93	1.13	1.030
		LO08	RS/LC	0.30	0.34	0.22	0.200
		LO04	USW/LC&SC	0.23	0.52	0.33	0.373
		LO10	FRF/SC	0.18	0.27	0.13	0.209
		LO01	FRF/LC&SC	0.06	0.18	0.18	0.238
		LO11	FRF/SC	0.06	0.29	0.29	0.380
8	Bio-rapid/riffle	NO01	FRF/B&LC	0.13	0.38	0.28	0.352
		NO02	USW/LC&SC	0.14	0.22	0.19	0.203
		NO07	USW/SC&LC	0.14	0.62	0.54	0.559
		NO11	USW/LC	0.16	0.88	0.76	0.718
		NO12	BSW/LC&SC	0.16	0.42	0.23	0.341
9	Bio-rapid/riffle	HO07	FRF/MC&B	0.06	0.24	0.23	0.348
		HO08	STR/B	0.14	0.89	0.71	0.773
		HO09	CAS/B	0.11	0.55	0.47	0.554
		HO10	USW/LC&B	0.15	0.81	0.67	0.709
10	Bio-run	HO02	SBT/SC&SG	0.29	0.11	0.07	0.065
		HO04	RS/SC	0.53	0.29	0.23	0.128
		HO06	SBT/SC&SA	0.36	0.00	0.00	0.000
		HO11	RS/SG	0.18	0.03	0.03	0.020
11	Bio-pool	HO01	BPF/SG&SA	0.10	0.04	0.02	0.041
		HO03	BPF/SC&SA	0.21	0.01	0.01	0.005
		HO05	BPF/SG	0.19	0.01	0.00	0.006
		HO12	NF/LC	0.05	0.00	0.00	0.000
12	Bio-run	CR05	CAS/B	0.01	0.13	0.13	0.471
		CR06	SBT/LC&SA	0.07	0.08	0.08	0.103
13	Bio-pool	CR03	BPF/SA	0.10	0.05	0.04	0.053
		CR02	BPF/SC&SA	0.05	0.03	0.03	0.039
14	Bio-rapid/riffle	CR04	CAS/WOOD	0.02	0.14	0.14	0.399
		CR07	FRF/LC&SA	0.05	0.28	0.28	0.473
		CR01	SRF/SC&SA	0.05	0.08	0.08	0.108
		CR08	RS/LC&SA	0.04	0.06	0.06	0.096

Sub-group No.	Hydraulic biotope	Sample code	Flow/ substrata	Depth	0.6	NB	Froude No.
		CR09	FRF/WOOD	0.01	0.20	0.20	0.572

15.6.2 Alluvial foothill rivers

Three rivers, represented by 36 samples, were included in the analysis. One was from the Berg catchment, one from the Olifants, and one in its own small catchment. The catchment signatures were distinct, with each river's samples clustered together and the Olifants River representative (Groot) splitting off first (Figures 15.8). Each river group contained sub-groups of fast and slow-flow samples, with the exception of the Wemmershoek, the fastest samples of which showed greater similarity to the Davidskraal samples. In the MDS plot, these samples appeared equidistant from Davidskraal and the other Wemmershoek samples. Using the guidelines given in Tables 11.8a and 11.8b, and the accompanying text, nine sub-groups of samples were recognised. The Groot and Davidskraal were represented by riffle, run and pool biotopes, and the Wemmershoek by a large heterogeneous pool group of samples and the two isolated samples from riffle biotopes. There was one outlier sample. On the MDS plot (Figure 15.9), the sub-groups were arranged from the slowest flows at the top of the page to fastest at the bottom, with all rivers well separated.

The hydraulic data associated with the sub-groups (Table 15.8) revealed some mixed substrata, but less so than for the mountain and mountain-transitional sites. This may be because many sample points contained few, if any larger substrata. Twenty-two percent of the samples were collected where sand or silt was the dominant substratum, compared with 3% in the least-disturbed sites. Similarly, 31% of samples were from small cobble, compared with 15% for the least-disturbed sites. These figures cannot be used to indicate the percent composition of substrata at the site, as stratified sampling was not done. They do suggest, however, that the range of conditions was different between the two sets of sites, with the disturbed sites probably having more areas of small substrata than the least-disturbed ones. Overall, these three sites displayed the following characteristics:

- two of them located within a recognised catchment group of least-disturbed rivers (Figure 15.1) (Wemmershoek - B16 did not);
- they retained their river signatures (Figure 15.8);
- two of them retained a fair representation of bio-riffles, bio-runs and bio-pools (Wemmershoek did not).

One might speculate from this that Wemmershoek, with its major modification of channel bed and flow regime, was the most seriously impacted of the three sites, even though visual assessment might have led to the conclusion that Davidskraal was more disturbed.

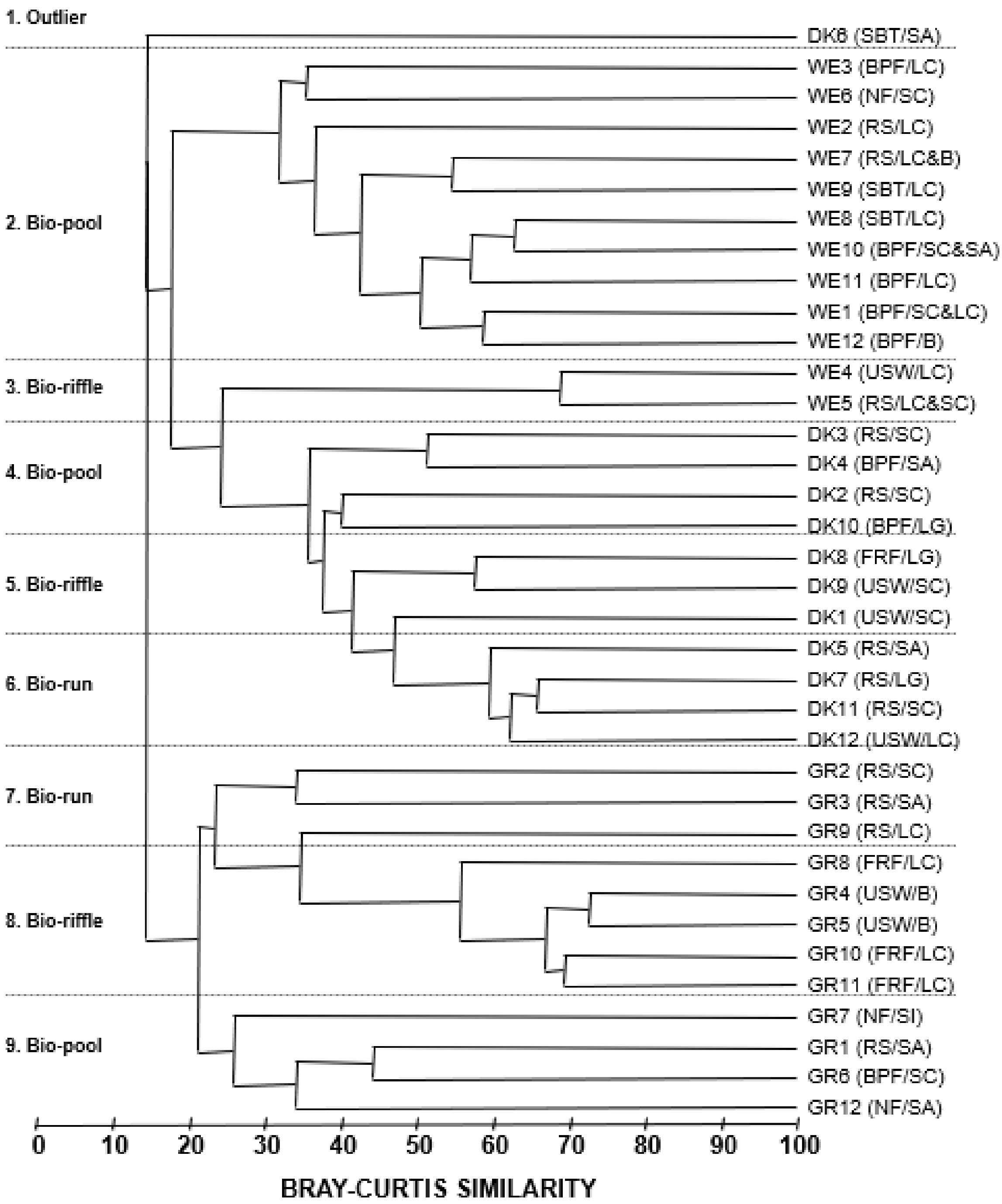

Figure 15.8 Cluster analysis to identify similar invertebrate samples from three disturbed foothill sites. Samples are coded by river and invertebrate sample number. DK = Davidskraal; WE = Wemmershoek; GR = Grootrivrier. Substratum and flow-type codes as per Tables 2.3 and 2.4.

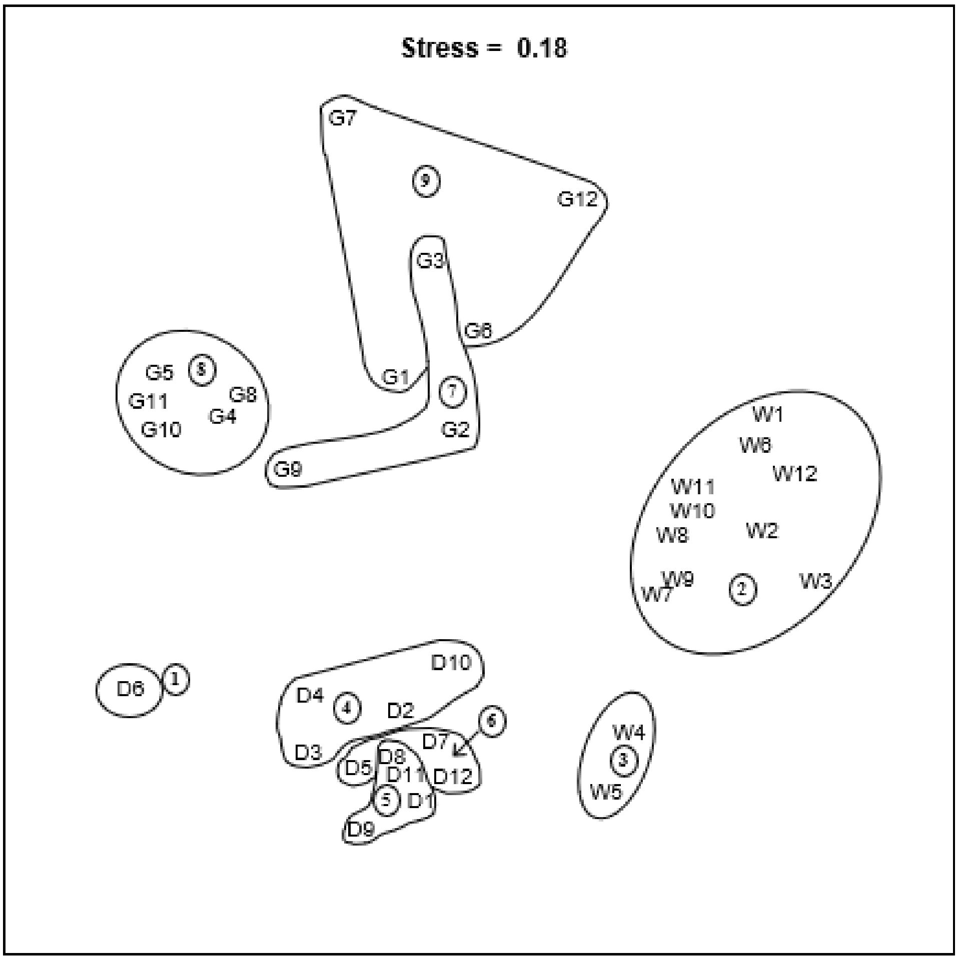

Figure 15.9 MDS ordination of invertebrate samples from three disturbed foothill sites. Groups denoted are those identified in Figure 15.8. Samples are coded by river and invertebrate sample number. D = Davidskraal; W = Wemmershoek; G = Grootrivrier.

Table 15.8 Hydraulic characteristics of the nine groups of samples from disturbed alluvial foothill sites, as recognised in Figure 15.8. DK = Davidskraal; WE = Wemmershoek; GR = Grootrivrier. Substratum and flow-type codes as per Tables 2.3 and 2.4. Depth (m); Mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Sub-group No.	Hydraulic biotope	Sample code	Flow/ substrata	Depth	0.6	NB	Froude No.
1	Outlier	DK06	SBT/SA	0.24	0.08	0.04	0.049
2	Bio-pool	WE03	BPF/LC	0.17	0.04	0.04	0.033
		WE06	NF/SC	0.06	0.03	0.03	0.034
		WE02	RS/LC	0.41	0.26	0.09	0.130
		WE07	RS/LC&B	0.14	0.08	0.08	0.072
		WE09	SBT/LC	0.24	0.16	0.14	0.109
		WE08	SBT/LC	0.11	0.06	0.05	0.064
		WE10	BPF/SC&SA	0.10	0.06	0.04	0.055
		WE11	BPF/LC	0.08	0.03	0.03	0.038
		WE01	BPF/SC&LC	0.37	0.03	0.03	0.017
		WE12	BPF/B	0.32	0.06	0.06	0.032
3	Bio-riffle	WE04	USW/LC	0.14	0.58	0.39	0.0529
		WE05	RS/LC&SC	0.08	0.34	0.34	0.396
4	Bio-pool	DK03	RS/SC	0.23	0.08	0.04	0.054
		DK04	BPF/SA	0.26	0.06	0.01	0.038
		DK02	RS/SC	0.08	0.08	0.08	0.078
		DK10	BPF/LG	0.08	0.00	0.00	0.002
5	Bio-riffle	DK08	FRF/LG	0.04	0.21	0.21	0.322
		DK09	USW/SC	0.08	0.33	0.25	0.429
		DK01	USW/SC	0.08	0.47	0.41	0.607
6	Bio-run	DK05	RS/SA	0.08	0.15	0.13	0.173
		DK07	RS/LG	0.09	0.07	0.05	0.084
		DK11	RS/SC	0.11	0.17	0.13	0.159
		DK12	USW/LC	0.08	0.40	0.39	0.458
7	Bio-run	GR02	RS/SC	0.13	0.07	0.04	0.066
		GR03	RS/SA	0.08	0.07	0.04	0.077
		GR09	RS/LC	0.21	0.19	0.06	0.134
8	Bio-riffle	GR08	FRF/LC	0.19	0.35	0.21	0.251
		GR04	USW/B	0.14	0.48	0.31	0.461
		GR05	USW/B	0.14	0.51	0.49	0.508
		GR10	FRF/LC	0.09	0.17	0.13	0.205
		GR11	FRF/LC	0.12	0.33	0.15	0.297
9	Bio-pool	GR07	NF/SI	0.11	0.00	0.00	0.000
		GR01	RS/SA	0.07	0.06	0.05	0.079
		GR06	BPF/SC	0.09	0.00	0.00	0.003
		GR12	NF/SA	0.04	0.00	0.00	0.000

15.6.3 Bedrock mountain and foothill rivers

Two bedrock sites, represented by 24 samples, were included in the analysis. The Middeldeur is in the Olifants catchment, and the Palmiet in its own catchment. Again, there were good catchment groupings, but the faster-flow sub-groups from each river grouped with each other rather than each river first linking its fast and slow sub-groups (Figure 15.10). The one slow-flow sample from the Palmiet was an outlier. In the MDS plot (Figure 15.11), samples from the two rivers remained distinct and the rapid, run and pool from the Middeldeur remained linked, so the suggested over-riding of fast flow types over the catchment signature was not supported, and the trend would not be particularly strong.

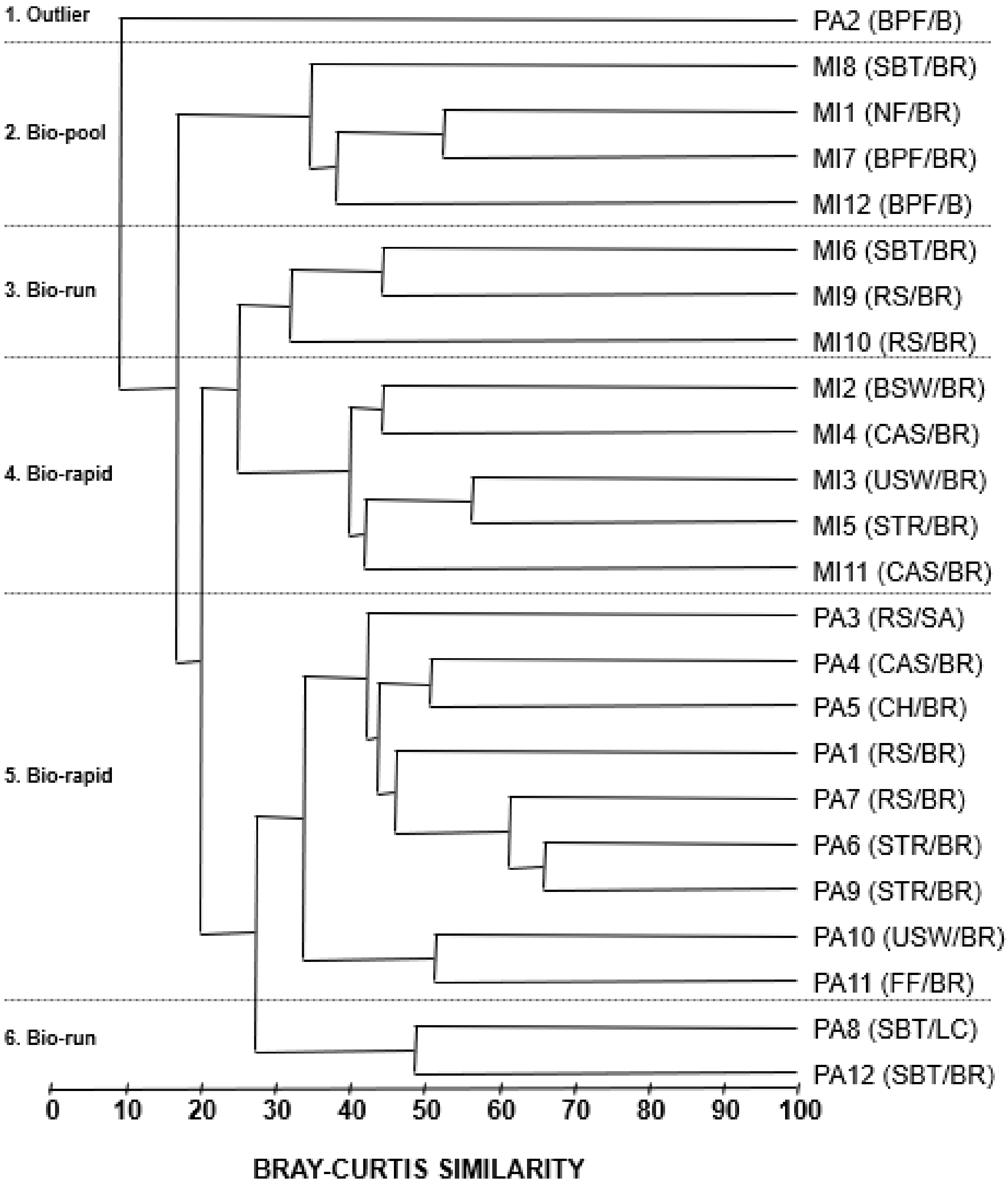

Figure 15.10 Cluster analysis to identify similar invertebrate samples from two disturbed bedrock sites. Samples are coded by river and invertebrate sample number. PA = Palmiet; MI = Middeldeur. Substratum and flow-type codes as per Tables 2.3 and 2.4.

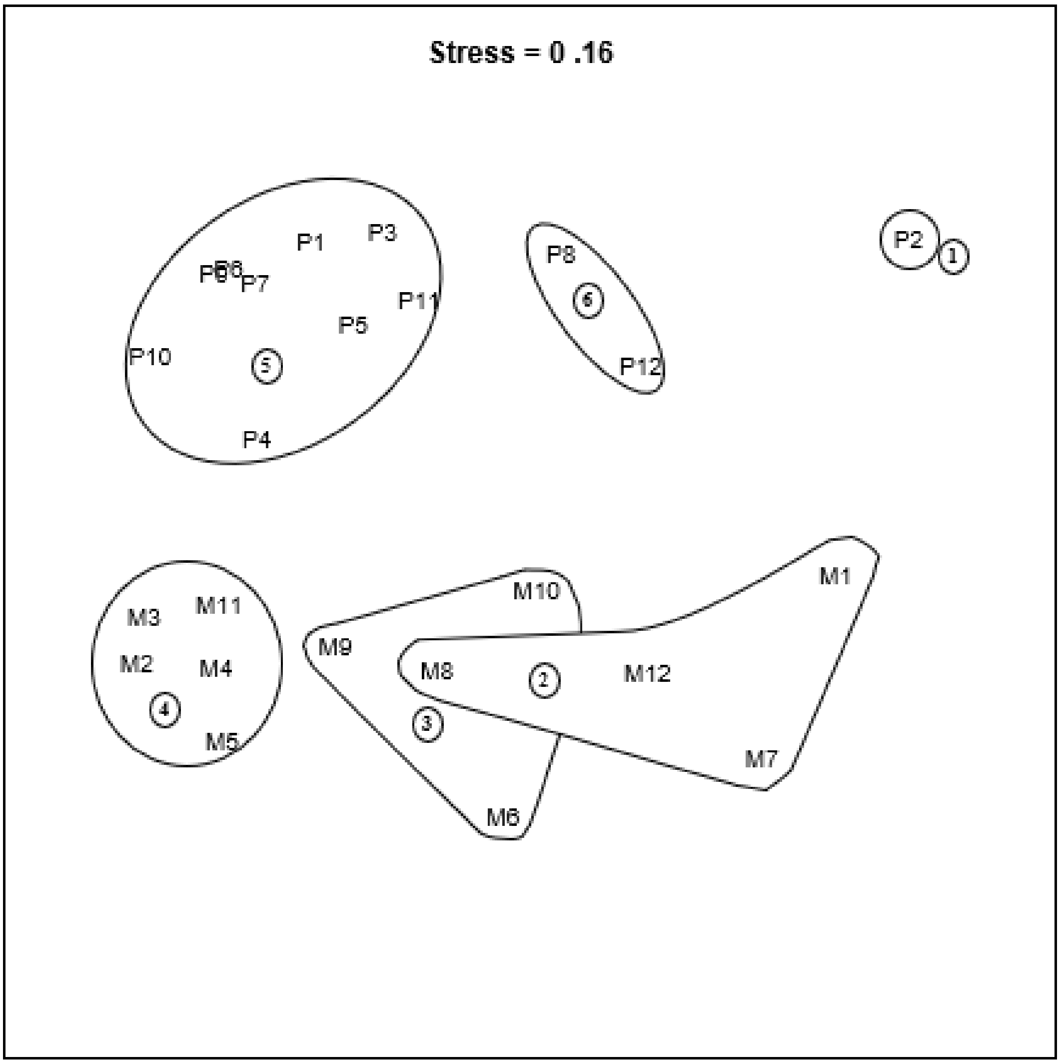

Figure 15.11 MDS ordination of invertebrate samples from two disturbed bedrock sites. Groups denoted are those identified in Figure 15.10. Samples are coded by river and invertebrate sample number. P = Palmiet; M = Middeldeur.

The hydraulic data (Table 15.9) revealed that bio-rapid and bio-run sub-groups were clearly distinguishable within the fast-flow groups. This mirrored the situation with the least-disturbed bedrock rivers (Figure 11.5a), and possibly reflects the fact that substratum conditions can change less with disturbance than in an alluvial river. Therefore, as long as chemical and flow changes are not too great, it might be presumed that the different fast-flow biotopes, at least, will continue to support distinct communities.

Table 15.9 Hydraulic characteristics of the six groups of samples from disturbed bedrock sites, as recognised in Figure 15.10. PA =Palmiet; MI = Middeldeur. Substratum and flow-type codes as per Tables 2.3 and 2.4. Depth (m); Mean-column (0.6) and near-bed (NB) velocity (m s^{-1}).

Sub-group	Hydraulic biotope	Sample code	Flow/substratum	Depth	0.6	NB	Froude No.
1	Outlier	PA2	BPF/B	0.09	0.25		0.269
2	Bio-pool (bedrock)	MI08	SBT/BR	0.31	0.12		0.066
		MI01	NF/BR	0.23	0.00		0.000
		MI07	BPF/BR	0.18	0.13		0.025
		MI12	BPF/B	0.66	0.08		0.033
3	Bio-run (bedrock)	MI06	SBT/BR	0.28	0.26		0.160
		MI09	RS/BR	0.31	0.25		0.147
		MI10	RS/BR	0.69	0.08		0.032
4	Bio-rapid (bedrock)	MI02	BSW/BR	0.47	0.21		0.119
		MI04	CAS/BR	0.14	0.36		0.302
		MI03	USW/BR	0.30	0.46		0.280
		MI05	STR/BR	0.24	0.61		0.415
		MI11	CAS/BR	0.23	0.79		0.597
5	Bio-rapid (bedrock)	PA03	RS/SA	0.53	0.25		0.108
		PA04	CAS/BR	0.36	0.54		0.354
		PA05	CH/BR	0.12	0.74		0.696
		PA01	RS/BR	0.23	0.54		0.369
		PA07	RS/BR	0.15	0.49		0.398
		PA06	STR/BR	0.19	1.07		0.842
		PA09	STR/BR	0.42	1.67		0.882
		PA10	USW/BR	0.52	0.60		0.281
		PA11	FF/BR	0.01	-		-
6	Bio-run (bedrock)	PA08	SBT/LC	0.12	0.14		0.055
		PA12	SBT/BR	0.30	0.22		0.138

15.7 Conclusions

In terms of their invertebrate assemblages, some disturbed rivers retained their catchment signature, whilst other did not. Acknowledging this, it is suggested that the impact of disturbance could be rated on a scale of 1-4 that reflects how well a river, as represented by its invertebrate biota, resists change and retains its catchment signature. Rivers that:

- retain their catchment signature and are located well within a catchment cluster could be demonstrating a state of mild disturbance (Rating 1);
- remain within their own catchment cluster, but as an outlier, could be demonstrating a moderate level of disturbance (Rating 2);
- relocate outside their catchment group, but still within the overall grouping of the region's catchments, could be demonstrating a high level of disturbance (Rating 3);

- relocate outside their catchment group, and also outside the overall grouping of the region's catchments, could be demonstrating a severe level of disturbance (Rating 4).

A variation on this theme is provided by rivers that relocate to another catchment group, perhaps through the introduction of species from that catchment. These rivers could probably sit at any of the disturbance levels, depending on the nature of the impact from the donor catchment.

Using this interpretation, examples of all levels of disturbance are present within the studied rivers (Figure 15.2). Window Stream (T26) exhibits some alteration of MUs, substrata and a confused riffle-rapid biotope, but in most ways clusters very closely with the other Table Mountain streams, suggesting that it is mildly disturbed (Rating 1). This stream runs through the Kirstenbosch National Botanical Gardens, and has some disturbance of its banks, including the presence of alien oaks *Quercus robur* and some abstraction of water.

An example of an outlier within a group (Rating 2) is the Groot (O05). This site retained its catchment signature, but as the site within its group that was furthest from all other groups. In terms of MUs and substrata, it was also located among a loose group of disturbed rivers. It retained distinct species assemblages in riffles, runs and pools, however. The river runs through the Cedarberg Wilderness Area, but is subject to extensive abstraction of water in upstream farming areas.

Those sites sitting outside catchment groups but still with an overall similarity to the other catchment groups (B16 Wemmershoek; P23 Palmiet; O03 Noordhoek; O04 Middeldeur), could be seen as highly disturbed (Rating 3). These rivers appear to have lost their individual signatures, ands become like kinds of generalised rivers of that bioregion. Possibly, by this stage of disturbance, sensitive species have disappeared, and any coarser bioregion identity is provided by hardy, opportunistic species.

The most disturbed sites are probably those sitting outside any catchment groups (Rating 4). Cecilia (T28) and Holsloot (R12) provide examples, being least similar to any other river in terms of invertebrate assemblages. They exhibit alteration in either MUs or substrata, but no more so than any other of the disturbed rivers. Their hydraulic biotopes are no more disrupted than any other of the rivers, with runs, riffle/rapids and pools distinguishable. It is suggested that their greater dissimilarity is due to chemical and physico-chemical change as well as physical change. Holsoot receives very cold, hypolimnetic water from a dam, and the riverbed was covered with filamentous algae, drastically reducing the normal rocky habitat. Cecilia has deciduous alien trees growing into the tiny channel, its flow is reduced to a trickle, and the bed is choked with leaves and other debris from the trees, with unknown effects on water chemistry. The natural riparian vegetation of the region is evergreen with far lower leaf-fall loads scattered over most of the year (King 1981), and so such clogging of the river channel and bed as seen in Cecilia is not natural.

There is one example of a site relocated to another catchment group. The Berg (B17) site appears with the Breede River group (Figure 10.4), in what might be an upstream influence of an inter-basin transfer of water. Breede River water enters the Berg about 1 km downstream from our Berg site, and may temporarily change the upstream species assemblage of the Berg site during the summer months of water transfer. This topic is discussed further in Section 10.2.

The above trend is suggested based on species composition and a coarse assessment of abundances (Table 10.1). It is possible that some rivers are more disturbed than the data suggest because species could be markedly rarer than normal without the abundance rating being affected. Additionally, the trend does not indicate an obvious relationship between type of disturbance and degree of impact. The two most impacted sites had quite different disturbances (alien trees and a dam), whilst other very disturbed sites were impacted by farming, dams and bulldozing. Some of the less disturbed sites were also downstream of farming.

Further analysis of the species data is needed to understand what kinds of species changes were linked to each river and thus to each disturbance; and to ascertain the relationship between kind of disturbance and level of disturbance. Specifically, the data should be assessed to test if some disturbances (e.g. the mainly physical ones) provide a depauperate version of the original set of species, and perhaps a less drastic disturbance to ecosystem functioning, than others (mainly the physico-chemical or chemical ones) where major species changes occur. This topic is re-visited in Chapter 20.

This project focused on the physical variables, and an underlying trend that seemed to emerge is that disturbed rivers exhibit loss of physical heterogeneity of the riverbed. First, at the largest scale, Morphological Units (MUs) had been obliterated in some rivers, seemingly through bulldozing or becoming in-filled by fine sediments. Second, fast-flow hydraulic biotopes were difficult to distinguish in some rivers, with bio-rapids in alluvial mountain and mountain-foothill zones appearing most vulnerable to change. In all disturbed sites in such zones, bio-rapids had been replaced by mixed rapid/riffle species assemblages. Bio-riffles and bio-runs in mountain-transitional zones retained their identities better, as did bio-rapids and bio-runs in bedrock rivers, presumably because such sites were not losing their natural substrata to the extent that higher-slope sites were. At this stage it is not understood why high-gradient sites should be losing boulder substratum. Third, many sites exhibited poor sorting of sediments into size classes, with mapping of substrata for disturbed sites being noticeably more difficult than for the reference sites. The overall impression was that physical heterogeneity was being lost at several scales.

16. SPECIES DISTRIBUTIONS AND BIODIVERSITY PATTERNS

16.1 Catchment and river signatures

An unexpected finding of this project was that, when working at the species level of invertebrate identification, each catchment and river had a clear identity. Such a phenomenon had been suspected before (Eekhout *et al.* 1997). At that time, however, it had been thought possible that the grouping of invertebrate samples by river might have been due either to the analytical methods used, or to the fact that different specialists collected and identified the animals in each of the studied rivers (sampling and/or identification bias). No such bias could be attributed to this study, because the same small group of people did the invertebrate collections and identifications for all 28 rivers, and in a standardised way. The results, that in least-disturbed rivers the invertebrate samples grouped very strongly by catchment and by river (Chapters 10 and 11), provides compelling proof that catchment and river signatures do exist. Samples from disturbed rivers also grouped by river, but some of these disturbed rivers appeared to have lost their catchment signature (Chapter 15).

Further proof that the analytical methods employed were not producing nebulous signatures comes from Chapter 14. Here, invertebrate samples were taken from two sites in adjacent reaches within one river. If the analytical methods had been causing the signatures in some way, then each site should have shown up as a different "river". But this did not happen, with the grouping of samples being based on current speed (fauna from fast or slow-flowing areas grouping independently) and then on discharge (i.e. sampling date), and not on site.

16.2 The nature and underlying causes of catchment and river signatures

Two possible reasons for the signatures can be suggested, and more might suggest themselves to the reader. They could be due to some unique species within each river and catchment. Alternatively, they could be due to unique combinations of common species within each river and catchment.

The first explanation could reflect biogeographical influences, with catchments being isolated from each other to some extent, and the catchment divides offering barriers to the distribution of some species. The grouping together of the Olifants and Berg Rivers in the catchment analyses, in isolation from the other studied catchments, perhaps supports this theory. They are the only two catchments studied that drain into the Atlantic Ocean and in the distant past the main stems of the two rivers shared a common estuary. But could it be that species moved down from the headwaters of one of these river systems to a lowland confluence with the other, and thus back up to the headwaters of the other system, more easily than they could move across a single line of mountains to a third unrelated catchment? Even if this could happen, this explanation does not reveal why the Eerste and Molenaars systems grouped together in the catchment analysis. These two rivers are not linked, and are not geographically contiguous as the Berg system lies in between their headwaters. Additionally, the Molenaars is a tributary of the Breede, and so the expectation might be that it would link with that system rather than with the Eerste.

The second explanation for the signatures suggested above is that they reflect unique combinations of common species and thus, perhaps, differences in ecosystem functioning. There could be differences in the driving variables of the catchments, in terms of their geological, geochemical, climatic or other nature. These could be resulting in subtle chemical signals characteristic of each river or catchment, or ones based on different levels or kinds of nutrient processing, and so on.

Sections 16.3-16.7 serve to briefly introduce some of the data available for further analysis of such biogeographical and biodiversity issues. Only data from the least-disturbed rivers are used.

16.3 Species numbers and assemblages per catchment

The original summary data set of species (Appendix 8.1) consists of average rated-abundances per site for 287 species. These species represented eight phyla, 26 orders, 83 families and 171 genera. Because of PRIMER restrictions on the number of species, the data set was reduced to 149 species, by deleting any species that occurred in only one of the 18 rivers *and* that had an average abundance rating of <1. This, for instance, excluded all the Hydracarina.

The data set based on these 149 species revealed diverse but different assemblages in each catchment (Table 16.1). The Eerste/Molenaars group of sites had 99 species, the Breede 71 species, the Olifants/Berg 57 species, and the Table Mountain group 42 species. The Dwars site, sole member of the Palmiet catchment group, had 35 species.

Table 16.1 Species average abundance ratings and distributions per catchment. Species also found in the Dwars River (only representative of the Palmiet catchment that is least disturbed) are represented by an * on the species number (No.)

		Catchment Group			
No.	Species/Morph Type	Breede	Olifants-Berg	Eerste-Molenaars	Table Mountain
1*	*Paramelita nigroculus*	0.40	0.00	0.00	2.17
2	Dryopidae sp.1	0.40	0.00	0.72	0.00
3	Dryopidae sp.2	0.00	0.00	0.42	0.00
4	*Strina* sp. 1	1.60	0.00	1.41	0.00
5	*Strina* sp. 2	0.00	0.50	0.00	0.00
6	Dytiscidae sp. 2	0.00	0.50	0.00	0.00
7*	Elmidae sp.	0.00	1.00	1.57	0.00
8	Elmidae sp. 1	0.00	0.00	1.42	0.83
9	Elmidae sp. 2	0.35	0.00	1.57	0.50
10	Elmidae sp. 3	0.00	0.00	0.92	0.00
11*	*Epidelmis* sp. A	0.25	0.00	1.73	3.17
12	*Epidelmis* sp. B	0.53	0.00	1.48	0.90
13	Helodidae sp. 2	1.10	0.00	0.39	1.00
14	Helodidae sp. 4	0.20	0.44	0.00	2.17
15*	Helodidae sp. 5	0.00	0.00	2.13	0.00
16*	Helodidae sp. 6	1.90	1.37	1.49	1.25
17*	Helodidae sp. 7	0.40	1.19	0.64	0.00
18	Hydrophilidae sp. 1	0.00	0.00	0.00	1.00
19*	Cyclopoida sp. 1	0.20	0.00	0.50	0.00
20	Cyclopoida sp. 2	0.00	0.00	0.17	0.00
21	Cyclopoida sp. 3	0.00	0.00	0.50	0.00
22	*Atherix* sp. 1	0.00	0.00	0.33	0.00
23*	*Atherix* sp. 2	1.93	0.00	0.76	0.50
24	*Atherix* sp. 3	1.40	0.00		

Appendix E.1. Questionnaire to assess present methods used by scientists too choose sampling sites and sampling areas within sites.

This was originally referred to as Attachment A in WRC Steering Committee Progress Report 2 submitted in January 1997

E1.1 Overview

The purpose of the field portion of the project is to enhance understanding of correlations between the geomorphological structure of Western Cape rivers and distribution of aquatic macroinvertebrate (and to a lesser extent, riparian vegetation) taxa. If the correlations are strong, easily measured geomorphological surrogates could be used to provide a framework that would help river ecologists choose sampling sites and sampling points within those sites in a structured way, and interpret the data collected. With such a framework in place, different kinds of data sets could be brought together for the same river or same river type, in order to contribute to a regional knowledge of river types using a common language and compatible scales.

A questionnaire was compiled to determine the ways in which South African river scientists presently decide on site and sampling-point selection, and how well their selections would enable their data to be linked to those of others researching the same river or river type. Thus, in the questionnaire, scientists were asked how they knew where they were in a stream at differing levels of resolution from catchment to microhabitat; how they presently made decisions on where to sample; and whether or not they were identifying their sampling areas in a way that others could understand and duplicate. The questionnaire also presented an opportunity to find out how data were stored and interpreted and what sorts of data were being collected. No attempt was made to interview all river scientists in the country; rather, those available during the normal course of other work were interviewed.

E1.2 Participants

Twelve river scientists in the country were interviewed (Table A.1). Every province was not represented but scientists in the Western Cape, Eastern Cape and KwaZulu-Natal were interviewed. Scientists across different disciplines with a wide range of perspectives were contacted.

Table E1.1 The participants in the questionnaires, region of the country and institution at which they work and their primary expertise.

Scientist	Province	Institution	Speciality
Mr. J. Alletson	KwaZulu-Natal	Natal Parks Board	macroinvertebrates and fish
Dr. C. Boucher	Western Cape	University of Stellenbosch	riparian vegetation
Dr. J. Boelhouwers	Western Cape	University of the Western Cape	geomorphology
Ms. C. Brown	Western Cape	Southern Waters	macroinvertebrates
Dr. J. Cambray	Eastern Cape	Albany Museum	fish
Dr. A. Channing	Western Cape	University of the Western Cape	amphibians
Dr. M. Coke	KwaZulu-Natal	Natal Parks Board	fish
Ms. H. Dallas	Western Cape	Freshwater Research Unit	macroinvertebrates
Dr. C. Dickens	KwaZulu-Natal	Umgeni Water Board	macroinvertebrates
Mr. B. Fowles	KwaZulu-Natal	CSIR- Durban	macroinvertebrates
Mr. D. Impson	Western Cape	Cape Nature Conservation	fish
Ms. G. Ractliffe	Western Cape	Southern Waters	macroinvertebrates

E1.3 SCIENTIFIC AND MANAGEMENT ISSUES ADDRESSED

As a reflection of the needs of the country, common themes occurred in the scientific and management issues that the scientists were addressing. Most of those interviewed were interested in some aspect of biomonitoring, such as water quality issues, species conservation, habitat preservation or the determination of conservation status of rivers. These issues were being addressed in two ways: through direct monitoring of systems, using available biomonitoring techniques; or through researching ways to change or upgrade current techniques and procedures. Data were also being collected for studies on species distributions and behaviour and on river rehabilitation. The researchers were conducting applied rather than traditional research programmes.

E1.4 RECOGNITION AND CHOICE OF SAMPLING SITES

According to Rowntree and Wadeson (1996), there are several possible scales for site selection: catchment, segment, reach, (site,) geomorphological unit and hydraulic biotope. The extent to which researchers within the country had already recognised these or similar hierarchical scales and used them for site selection was investigated.

The largest scale, at a regional level, was almost always recognised and recorded by researchers, and communicated well from one researcher to another. Regional designations and catchment information can be gained from well established maps. It is at the next hierarchical level, of segment (Rowntree and Wadeson, 1996) or zone (Eekhout *et al,* 1996), that site selection begins to be less well organised and recorded by researchers.

For the most part, researchers with strict management goals selected sampling areas where their management issues would be addressed. For example, such scientists responded to the question “How do you select your sampling sites?” with the answer that sites were selected upstream and downstream from a disturbance in order to monitor its effect. This is understandable, but leads to the next question "Was the segment/zone/reach in which the sites occurred recorded and, if so, how?". Most scientists did not formally record where they were, but when asked were able to give an answer, such as "lower river". When asked how they had reached that particular conclusion, the answer was almost always "intuition", "gestalt" or "just know". Other than one person who used a reach-break analysis, there was no structured attempt to identify the location of the site within an hierarchical framework, either geomorphological or ecological. Some people did have an intuitive feel for the slope of the area, but had not translated this into calculated gradients.

Selection of a sampling site was also overwhelming based on accessibility. Concern was expressed over the representativeness of such sites, but few people made any attempt to establish if their chosen sites were representative. Representativeness of a site was most commonly determined by the fact that it "looked as if it had the right sort of habitats". However, no-one could provide data on what combination of physical conditions would be within the range of normal for any chosen site. Thus, there seems to be a great body of intuitive knowledge on sites around the country, but little attempt by most scientists to place their sites in context.

E1.5 CHOICE OF SAMPLING POINTS WITHIN SITES

The choice of where to sample within a particular site was done in a similar way to that of choosing a site. Researchers using the SASS approach to pollution assessment followed Dr M. Chutter's lead by sampling macroinvertebrates in "stones-in-current" and "stones-out-of-current". Others, especially fish scientists, sampled areas that they knew from past experiences or from intuitive feel would contain the animals they sought. Researchers with a primary goal of finding a certain species tended to sample where they felt that species would be found, in part to save time, hence money; they did not usually choose or describe such areas in any structured, measurable way. Mostly, where different combinations of hydraulics and substrata were sampled, each area was given a name, such as riffle, run, or pool. However, usually, no clear definitions of these terms were given or, if they were, these tended to be descriptive rather than including measurable characteristics. Thus, knowledge of sampling areas could not easily be transferred between scientists, misunderstandings could arise and opportunities for linking data sets were reduced.

E1.6 FATE OF SAMPLES AND DATA

When samples of plants and animals are collected, the majority of researchers send voucher specimens/catalogue specimens to the relevant museums around the country, and so all common species as well as new species are catalogued in the national archives. In a few instances, samples remain in the possession of individual researchers for the duration of the project and for a set time period after the completion of the project for future validation purposes. National respositories do exist for fish, vegetation and invertebrates.

Data storage, or the transfer of data from sheets to some sort of permanent storage record, varies from scientist to scientist. A fair number of projects still have their data on data sheets and have not transferred the information to either a spreadsheet or database. Of those who have transferred their data to an electronic medium, packaged database programs seem to be the primary storage method, although spreadsheets are also in use. Overall, there is not a consistent method of storing data and, for the most part, the use of these data collections is set up for personal use in each individual project.

None of the studies surveyed have been submitted out for journal publication, although some are in preparation and could very well be submitted to a refereed journal. Primarily, data have been analysed and written up either in internal reports or for reports to a particular funding agency. In a few instances data collected have been incorporated in the relevant national Red Data Book for rare and endangered species.

E1.7 CONCLUSIONS

The main finding, based on these questionnaires, is that there is a need and a desire for the development of guidelines on where to sample in a structured way. All but two of the scientists interviewed felt that a geomorphological template that was ecologically relevant, or something similar, would be very helpful to them in their work. Use of this kind of physical template can enhance understanding of relationships between biological communities and their environment, and give researchers clues as to how communities could change with anthropogenic disturbances of a river's physical structure. Most researchers are presently using an intuitive rather than explicit rationale for choosing sampling sites and sampling points within a site.

There thus seems a need for a framework and a common language to guide such selections. With these in place, data collected in different ways by different specialists can be linked to create a growing body of knowledge on specific rivers or river types. Thus far there is not such a system in use in the country. The geomorphological template proposed by Rowntree and Wadeson is a recent development and requires validation as to its ecological relevance. Once the validation process has been completed for Western Cape rivers and if the template is found to be valid, this could be used for development of guidelines that will aid Cape researchers in site selection, and production of a protocol for undertaking the same process in other regions of the country.

Appendix E2. Liaison with the Kruger National Park Rivers Research Programme, through its abiotic-biotic links project

This was originally referred to as Attachment B in WRC Steering Committee Progress Report 2 submitted in January 1997

E2.1 Introduction

Meeting objective 3.2(a), JMK and DMS participated in meetings of Phase II of the Kruger National Park Rivers Research Programme (KNPRRP). The KNPRRP was one of the principle influences in the design of this project (as cited in the explanatory memorandum of May 1996) and continues to influence it. The last year of Phase II was a project to model abiotic conditions within the Sabie River and use the results to predict biotic responses. After several years of research on the Sabie River, the project is operating in a relatively data-rich environment. The project reported on here is designed to develop a framework for organising and interpreting scientific data on rivers, which can be used in data-poor situations. The main purposes of project staff attending workshops on the KNPRRP Abiotic-biotic links project were a) to learn the KNPRRP methodologies being developed and to assess the potential for their application in data-poor situations, and b) to contribute to model development where expertise allowed. The complexities of linking geomorphological data to biological/ecological data were evident, as were the differing time scale factors at work. It became clear that data collection needed to be done with the appropriate abiotic-biotic linkages in mind, something that had not always been possible in the KNPRRP because of the lack of co-ordination of projects in the early stages.

E2.2 Activities

The specific activities in which JMK and DMS participated are outlined below. Appendices referred to are not attached, but are available on request.

- April 1996. Attended KNPRRP workshop, where the model which would link hydrology, geomorphology and fish community composition was presented. The core group that developed the model were G. Jewitt, A. van Niekerk, G. Heritage and D. Weeks.
- JMK and DMS, together with R. Tharme of the Freshwater Research Unit, communicated with the core group by email and eventually wrote a feedback document (Appendix 1) to the group. This expressed some concerns with the modelling process and with some of the assumptions made in the model itself. The main concerns were:
- Confusion as to how the suitability indices (SI) were calculated, used and interpreted. Channel index appeared to have been used to create SI curves, but with no explicit inclusion of hydraulic processes. The codes could thus code different habitats similarly, although the areas would be preceived differently by instream biotas.
- The calculation used to to produce the “fishy index of niceness” or FIN seemed to be an inappropriate use of the SIs calculated by the fish specialist. The mis-use of the SI was queried by JMK and R. Tharme, through their experience with a similar mis-use of data in the instream flow incremental methodology (IFIM).

The feedback document was sent out May 1996, email dialogue continued April-June 1996.

- May - July 1996. A paper, authored by Heritage, van Niekerk and Weeks, on the KNPRRP abiotic-biotic links research had been submitted to the Ecohydraulics 2000 conference held in

Canada. Project staff and R. Tharme compiled a five-page informal review of the manuscript, upon request from the core group (Appendix 2).

- June 1996. A written response to the feedback document was received from the core group, (Appendix 3). Project staff met with Messrs. Weeks and Jewitt in Stellenbosch to discuss development of the abiotic-biotic links models. One of the main issues discussed was the codes used for describing the abiotic environment, which still seemed to exclude appropriate information on hydraulic conditions. JMK and DMS agreed to design another set of codes that could help solve this problem.
- June 1996. An alternative set of cover codes was developed by project staff and sent to the core group.
- July 1996. Continued email dialogue between DMS/JMK and the core group.
- August 1996. A meeting between the core group, JMK, DMS and R. Tharme was set up to find solutions to outstanding points still in contention. FIN and FIN2 (a second version by Dr Heritage) were still seen by JMK, DMS and Ms Tharme as taking the data further than was valid. Project staff suggested an alternative way of linking the geomorphological and fish data, that was similar to that used to link the hydrological and fish data. The core group agreed to consider this approach, and also decided not to use the alternative set of cover codes suggested by project staff due to the work load involved in new analyses. JMK and DMS left the core group to continue model development and conclude the project, which was nearing its end.
- December 1996. JMK and DMS attended the final workshop of the KNPRRP abiotic-biotic links project. In this, the last meeting of Phase II, the contributors to the modelling process presented the up-dated form of their models and demonstrated how the models linked. It was discussed that these were prototype models and that there was still much development needed to finalise them and test their applicability outside the Sabie River. A proposal to refine and advance these models was discussed.

E2.3 Conclusions

There were few direct similarities between the KNPRRP abiotic-biotic links project and the WRC-funded Western Cape one. However, as both groups are focussed on essentially the same problem, there is much to be gained by continued strong collaboration between them and it is hoped that this will continue. It is clear from the KNPRRP project that a geomorphological template for biological data organisation for rivers can work, although there can be problems with this if the details are not thought out fully before data collection begins. For instance, when the abiotic model outputs are to be linked to **instream** biota, as opposed to **riparian** biota, it is still felt that there needs to be an explicit hydrological component in the linkage rather than an implied one through the presence of different geomorphological units. The geomorphological units can still be there, implying (say) a riffle, long after all water has disappeared from a river, with obvious consequences for instream biotas.

We were also able to see, through this exercise, the benefits of having a conceptual and practical framework in place to facilitate link-ups of data on a regional basis and national basis. Without such a framework, at this stage, there is no procedure for extrapolating the Sabie River data and models to other areas.

Appendix E3 Capacity Building

This was originally in WRC Steering Committee Progress Report 5 submitted in June 2000

Capacity Building

The following university theses are linked to this project:

- There has been close contact with Prof André Görgens and Prof Albert Rooseboom of the Civil Engineering Department, Stellenbosch University, throughout the project, particularly with regard to possible research projects with an environmental slant for engineering students. The engineering students used the study sites from this project, or data collected, as one or more of the foci of their theses:
    - Ralph Canto completed a fourth-year engineering thesis ***Channel maintenance flows for pristine Western Cape rivers.*** This project won the Departmental and Faculty awards at the University of Stellenbosch.
    - A. P. Zeeman completed a fourth-year engineering thesis ***Investigation of the depth-discharge relations of Western Cape cobble-bed streams.***
    - Verno Jonkers is presently writing a PhD thesis within the linked WRC project ***Hydraulic characteristics of ecological flow requirement components in winter rainfall rivers.***
- There is also close liaison with Mr Neil Armitage at the Civil Engineering Department at the University of Cape Town. As a result one fourth-year engineering project has been completed based on the hydraulic data from this project:
    - Sonja Karassellos: B.Sc (Eng.) thesis project ***Exploring the links between ecological flow types in rivers and local hydraulics***, completed 1999.
- In the Zoology Department at the University of Town, JMK supervised the following postgraduate students directly linked to this project:
    - Jennifer Botha: BSc.(Hons.) project ***Indentifying hydraulic biotopes in a mountain stream using the community structure of benthic macroinvertbrates***, completed 1997.
    - Carryn Manicom: BSc. (Hons.) project ***Effect of the Black Wattle Acacia mearnsii on a Cedarberg river ecosystem*** completed 1999.
    - Denise Schael: PhD thesis ***Distributions of physical habitats and benthic invertebrates in Cape headwater streams at multiple temporal and spatial scales***, due for submission in 2002.
    - Bruce Paxton: BSc. (Hons) project ***Distribution and biodiversity patterns of invertebrates in a Cape foothill river,*** completed 2000.
- In addition, during the course of this project JMK acted as supervisor or co-supervisor to the following postgraduates:
    - Cate Brown: PhD thesis ***Modelling and managing the effects of trout farms on Cape rivers.*** Completed 1997.
    - Sharon Pollard: PhD thesis ***Instream flow requirements for the Marite River based on a habitat-assessment approach***, completed 2001.
    - Rebecca Tharme: PhD thesis. ***Towards the incorporation of low flow requirements of riverine benthic macroinvertebrates in environmental flow methodologies***, due for submission 2002.
    - Geordie Ractliffe. MSc thesis, ***Changes in macroinvertebrate assemblages in the Molenaars River, du Toits Kloof, during bridge construction***, due for completion in 2001, but now upgraded to Ph.D. for completion in 2002.

University of Cape Town undergraduate students employed part-time on this project, who received scientific training from project staff:

- Helen Syfret
- Belinda Day
- Brett Macey
- Tim Corver
- Glen Malherbe

- Bruce Paxton
- Allistair McMaster
- Peta Binedell (GIS)

Technology transfer

1996/97

- JMK acted as scientific consultant to the Institute of Water Quality Studies for the design phase of the National Aquatic Ecosystem Biomonitoring Programme, and sat as scientific advisor on its National Co-ordinating Committee until mid 1997.
- JMK was the senior planner and organizer of the IWQS-funded Spatial Framework workshop in Cape Town in January 1996, she co-authored the report on Technical Considerations and Protocols for the Selection of Reference and Monitoring Sites (Eekhout *et al.* (1996), and acted as facilitator at the National Biomonitoring Programme consultation planning meeting in September 1996.
- JMK attended the Third National River Bioassessment workshop of the Australian National River Health Programme in Canberra, October 1996, and wrote a report for the Water Research Commission and IWQS.
- JMK and DMS liaised with the Kruger National Park Rivers Research Programme's (KNPRRP) Abiotic-biotic Links project, to provide input to the fish-habitat modeling component.
- JMK served on the KNPRRP's Programme Development and Management Committee.

1997/98

- The habitat-mapping techniques developed in the project were applied by consultants advising on environmental flows from the newly-built on the Koekoedouw River, Ceres. Mapping of downstream reaches was used to assess the success of flood releases in re-establishing appropriate aquatic habitat in the heavily silted-up river.
- The habitat-mapping techniques developed allowed Australian taxonomists specializing in the Gondwanaland links between Australia, southern Africa and South America, to visit, re-locate and collect rare and relevant species recorded during the project.
- The habitat-mapping techniques were used in the major international consultancy on environmental flows for the Lesotho Highlands Water Project. The maps were used as guides when setting flows for the rivers, and will provide the base-line description of habitat and channel conditions for future monitoring programmes. There is no doubt that contact with the international team employed on the Lesotho Project, and particularly with Prof Angela Arthington of Brisbane, greatly benefited the mapping techniques being developed within this WRC project.
- JMK was invited to a joint Australian/Great Britain workshop on river biomonitoring at Oxford University. Report submitted to IWQS(DWAF).
- JMK presented a paper ***Exploring the links between geomorphological and biological river data, at scales from catchment to hydraulic biotope***, co-authored by Ms Schael and Prof. Rowntree of Rhodes University, at the annual congress of the South African Society of Aquatic Scientists, Mtunzini, June 1997.
- JMK lectured on ***Physical conditions in aquatic*** systems to the third-year Zoology course on Inland Aquatic Ecosystems and, with DMS, ran the associated Hydrology-hydraulics practical sessions.
- JMK organized the three-week section on Conservation and Management in the same course, and lectured on ***Managing river flow.***
- JMK lectured on ***Inland Water Systems*** in the professional IEM course rune by the Environmental Evaluation Unit at UCT.
- DMS participated in the Western Cape testing of field data sheets for the development of a geomorphological index for Prof. Rowntree.
- DMS attended a KNPRRP workshop on future development of the Biotic-abiotic Links programme within the Kruger Park.
- JMK contributed to the review of the Water Law, including writing the discussion document ***Quantifying the amount of water required for the maintenance of aquatic ecosystems.***

- JMK became an inaugural member of the international Advisory Panel for the journal Marine and Freshwater Research.

1998/99

- JMK delivered a paper at the Third International Ecohydraulics Symposium in Salt Lake City ***Mosaics of flow types: an ecologist's perspective of local hydraulics***. Paper co-authored by DMS. As a result of this visit, JMK was approached to organise the Fourth International Ecohydraulics Symposium in Cape Town in March 2002.
- JMK visited the World Bank in Washington at their invitation and gave a presentation ***Environmental flow assessments for the Lesotho Highlands Water Project.***
- JMK visited Taiwan at the invitation of the Commissioner of the Taiwanese Provincial Government. She ran a two-day workshop for river engineers ***Sustainable Use of Rivers***, and visited water-resource projects**.**
- JMK visited Portugal, at the invitation of the Instituto da Agua, Lisbon, to run an introductory workshop on ***Environmental Flow Assessment Techniques.***
- JMK joined the International Aquatic Modelling Group, to exchange information and ideas with (mostly) American and European modellers.
- JMK lectured on ***Physical conditions in aquatic systems*** to the third-year Zoology course on Inland aquatic ecosystems and ran the associated Hydrology-hydraulics practical sessions.
- JMK organized the three-week section on Conservation and Management in the same course, and lectured on ***Managing river flow.***
- JMK refereed papers in Biodiversity and Conservation, the Australian Journal of Ecology, Water SA and the Southern African Journal of Geography. She acted as Evaluator of Research Outputs for the Foundation of Research Development for two senior scientists, Assessor for one institutional application for funding and UCT Internal Examiner for one MSc thesis.
- JMK served on six Steering Committees for the Water Research Commission.
- JMK attended the SASAQS conference on the National Rivers Initiative, Pietermaritzburg, and a two-day Planning Workshop for defining research issues related to assessment of the Ecological Reserve for rivers.

1999/2000

- JMK attended a regional SADC workshop on Water Resources in Southern Africa: Enhancing Environmental Sustainability in Harare, Zimbabwe, November 1999, and co-authored a chapter ***Environmental flow assessments and requirements*** in the resulting World Bank/IUCN publication.
- JMK taught at a ***Training Workshop for Undertaking Research to Assess the Socio-economic Benefits off Improved Water Resources Management in the Lower Zambezi Valley*** as the specialist on environmental flows. Organised by CalTech (USA) and funded by IUCN. Held in Mozambique, March 2000.
- JMK was one of four international specialists invited to make a presentation at the World Bank's Water Week, Washington April 2000.
- JMK lectured on ***Physical conditions in aquatic*** systems to the third-year UCT Zoology course on Inland aquatic ecosystems and ran the associated Hydrology-hydraulics practical sessions. She also lectured on ***Managing river flow*** in the section on Conservation and Management**.**

Planned technology transfer

It is hoped that the mapping techniques can be developed into a model for predicting discharge-linked changes in river physical habitat. This process was begun in this project, and will form a component of Ms Schael's PhD thesis. It was also pursued in the Lesotho project and developed further in the Breede River Basin Study by the consultants Southern Waters. A similar idea appears in a new WRC project at the University of the Witwatersrand, for which JMK serves on the steering committee.

Implications of the findings of the project regarding river typing need further thought and data analysis, before presentation to the national community of water scientists and managers.

Additional publications

During the course of the project, JMK also co-authored the following publications:

- King, J.M. and D. Louw. 1998. Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. Aquatic Ecosystem Health and Management 1:109-124.
- Cambray, J.A., J.M. King and C. Bruwer. 1997. Spawning behaviour and early development of the Clanwilliam yellowfish (*Barbus capensis:* Cyprinidae), linked to experimental dam releases in the Olifants River, South Africa. Regulated Rivers: Research and Managament 13: 579-602.
- King, J., J.A. Cambray and N.D. Impson. 1998. Linked effetcs of dam-released floods and water temperature on spawning of the Clanwilliam yellowfish *Barbus capensis.* Hydrobiologia 384: 245-265.
- King. J.M., R.E. Tharme and C.A. Brown. 1999. Definition and implementation of instream flows.