Links Between Riparian Vegetation and Flow

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by

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EXECUTIVE SUMMARY

INTRODUCTION

Riparian vegetation communities occur along rivers in lateral zones parallel to the direction of river flow. These zones are sub-sections of a riparian area where groups of plants preferentially grow in association with one another as a result of shared habitat preferences and adaptations to the prevailing hydrogeomorphological conditions. The objective of this project was to quantify the links between components of the flow regime and the occurrence of riparian species in lateral zones alongside rivers. The need to understand and quantity these links rose from the need to predict changes in riparian communities in response to changes in river flow. The central hypotheses under investigation were:

- Vegetation zonation patterns along rivers result from differential species responses to a combination of abiotic factors that vary in space and time.
- It is possible to identify one or two key abiotic factors to predict change in the zonation patterns in response to changes in the flow regime of rivers.

To develop a framework that explains the existence of different plant communities in different lateral zones, a mechanistic explanation for characteristic differences between the lateral zones must be established.

The project aims were:

1. to identify the position, number and composition of lateral zones in riparian vegetation communities in a selection of rivers in South Africa;
2. to suggest standardized names for the identified lateral vegetation zones;
3. to explore the relationships between these lateral vegetation zones and aspects of the daily flow hydrology and, if possible, link the identified zones to flows of particular return periods;
4. to seek simple methods for the identification of the lateral vegetation zones; and
5. to produce guidelines on the identification of lateral vegetation zones, and their links to flow, for use in South Africa.

Aims 1 and 2 are addressed in Chapter 3 where the existence of lateral zones is explored and their vegetative characteristics described. Aim 3 is addressed in Chapter 4 where links between lateral zones and the flow regime are explored. Aims 4 and 5 are addressed in Chapter 5, which provides a step-by-step procedure for the collection and analysis of data in order to produce results comparable with those presented in Chapters 3 and 4. Chapter 5 also contains a decision tree that can be used to identify lateral zones along rivers inhabited by Fynbos Riparian Vegetation (Mucina and Rutherford 2006). The final chapter, Chapter 7, draws together the conclusions of Chapters 3 and 4, which test hypotheses that assume water availability is a primary determinant of the occurrence and characteristics of lateral vegetation zones.

LITERATURE REVIEW

The composition and structure of riparian communities are influenced primarily by river channel shape and water flow (Naiman et al. 2008). Rivers adjust their morphology (width, depth, slope and planform) to transport the water and sediment supplied from the drainage basin (Newson and Newson 2000). River channels and floodplains increase in width and complexity down the rivers length as the balance between sediment supply and transport shifts from supply limited channels upstream to transport limited channels downstream. Channels in the upper reaches of river basins are laterally constrained with limited capacity to store sediment and other organic matter. Upland rivers and floodplain systems operate under different hydrological regimes and as such exhibit different physical structure/habitat availability. Aside from creating and maintaining physical habitat, the flow regime of a river also has a direct influence on the riverine biota. The conceptual understanding of this influence has been captured in the Natural Flow Regime paradigm (Poff et al. 1997) based on the principle that the integrity of lotic (flowing) ecosystems depends upon their natural dynamic character.

The flow regimes of southern African rivers differ considerably from rivers in the temperate climates where many of the studies of riparian ecology have taken place. Unlike Northern hemisphere rivers, South African river flow is ‘predictably unpredictable’ and apart from some coastal regions, the country is semi-arid, and only very few of the rivers are associated with extensive floodplains (Davies et al. 1995). Much of the country experiences summer rainfall and dry winters. The Western Cape with its Mediterranean climate, i.e., winter rainfall and a dry summer is the exception, although rainfall in the mesic southern coastal region tends to be aseasonal. Joubert and Hurly (1994) showed that while the pattern of flow along the subtropical coast and the plateau slopes of the Transkei, KwaZulu-Natal and Mpumalanga were similar (moderate mid-late summer with perennial flow) but the southern and eastern Cape coastal belt was clearly distinct and characterised by aseasonal flow or a slight early spring peak. Almost all the rivers in South Africa exhibit a ‘flashy’ runoff response that is considered to be fairly typical of arid or semi-arid countries (Gordon et al. 2002). This means flood events have short lag times relative to rainfall events in the basin, and steep ascending and receding limbs. Although the wet and dry seasons occur with some regularity, the frequency and magnitude of floods in the wet season are unpredictable relative to Northern hemisphere rivers. The Western Cape, in particular, has low overall predictability and high seasonal predictability.

Riparian vegetation communities are dynamic and the proportions of dominant species change down the length of a river. The likelihood of a species growing and persisting at a particular location depends upon the stability of the site for germination and establishment, and the ambient environmental conditions at the site that permit persistence until age of reproduction (Hupp and Osterkamp 1996). Sufficient flows are required seasonally to recharge ground water levels at the end of the dry season and to facilitate vegetation recruitment (dispersal, germination and growth of seedlings), often toward the end of the flood season. The life histories of some species on large floodplain rivers of the northern hemisphere are intimately linked with the annual flood peak. Flowering and seed set are cued such that seed dispersal takes place as flood waters recede (Mahoney and Rood 1998). Hughes (1988; Tana River floodplain in Kenya) and van Coller (1992; Sabie River in the Kruger National Park) presented empirical evidence for the existence of plant communities in lateral zones and sought links to link community descriptions with indirect gradients, such as elevation and distance from the active channel. Both authors introduced lateral zonation in their categorisations of riparian communities describing a combination of hydraulic and geomorphic factors for the patterns described. These studies differed from ours in that they:

- were on large rivers lower down the longitudinal profile, and
- dealt with seral succession of floodplain communities in lateral zones; much like the studies of northern hemisphere floodplain forests.

Both experienced difficulties in linking flow components to exact floodplain positions (elevation and distance vectors), which was attributed to a combination of the complexity of the floodplain geomorphic mosaic and inaccurate/incomplete hydrological data.

In this report we use the naming convention for lateral zones of Kleynhans et al. (2007a) as a starting point since many practitioners are already using it. Accordingly to Kleynhans et al. (2007a), the riparian zone comprises three lateral zones (Figure 2.2) bounded by a freshwater and terrestrial ecosystem. In general, water availability decreases laterally away from the river channel as the depth to groundwater increases and the frequency and duration of flooding decreases. The combination of a decrease in water availability and frequency of inundation equate to a higher probability of experiencing drought conditions. As such, there is a lateral gradation from the river channel as communities continually adapt to the seasonally recurring conditions, which characterise different hydrogeomorphic habitats. Thus, life history strategies between marginal, lower and upper zones are expected to differ.

CHARACTERISTICS OF LATERAL ZONES

Undisturbed headwaters are well-suited to the study of zonation patterns as the riparian communities are characterised by steep lateral gradients. The riparian vegetation of the Fynbos has not been intensively studied until recently and there is no formal classification of riparian vegetation communities for the Western Cape (Prins et al. 2004). Despite the seemingly obvious lateral patterning within riparian areas and the contention that different communities may be distinguished floristically *in situ* there are discrepancies between the results from different studies. To date, most studies have assumed the pattern exists and accommodated this assumption within the sampling protocol, usually by delineating sample plots within community types *a priori.*

The three lateral zones of Kleynhans et al. (2007a) were adopted and tested: marginal, lower and upper zones. The key question was “can characteristic species/taxa be used to identify lateral zones?” Three hypotheses were tested:

- Riparian plants are distributed in a repetitive and predictable manner.
- Groundcovers and canopy species contribute in different ways to the pattern.
- Characteristic taxa are restricted to specific lateral zones.

There were four lateral zones, which confirm the consensus presented by Kleynhans et al. (2007a); that there are two main lateral zones, a marginal and lower comprised of riparian species, and a third, the upper zone, comprised of a mixture of riparian and terrestrial species. The fourth lateral zone was transitional between the marginal and lower and could be most similar to either, depending upon whether it comprised obligate or facultative riparian species. Some species were considered to be useful indicators for the lateral zones:

- *Prionium serratum* and *Isolepis prolifera* for the marginal;
- *Calopsis paniculata* and *Morella serrata* for the lower dynamic;

- *Erica caffra* for the body of the riparian area, being equally distributed across the lower dynamic and lower zones, and at low abundance in the marginal and upper zones;
- *Metrosideros angustifolia* trees and *Elegia capensis* for the lower; and
- *Diospyros glabra* and *Pteridium aquilinum* for the upper zone.

LINKS BETWEEN LATERAL ZONES AND FLOW

The flow regime is considered to be the master variable responsible for the occurrence of lateral zones (Poff et al. 1997) as it directs, *inter alia*, river channel structure, water availability and the life histories of plants, which also interact and influence one another. Several authors have proposed links between inundation of a river bank and the plant communities that occur there, mostly along northern hemisphere rivers with flood plains. Thus, the conceptual framework for this chapter was based on the understanding that water availability decreases laterally away from the river channel. Similarly, depth to groundwater, the probability of being flooded and the duration of inundation when flooded also decrease. Using this, we proposed there would be two main lateral zones, one flooded intra-annually and the other inter-annually. The marginal and lower zones consisted of riparian species inundated intra-annually and every one to three years respectively, while the upper zone consisted of a mixture of riparian and terrestrial species and inundated at intervals greater than three years. The first objective of this chapter was to test whether the four lateral zones for Fynbos Riparian Vegetation occurred on other South African rivers.

Perennial rivers were selected in three regions with differing hydrograhs, viz.: summer peak flow in Mpumalanga; the aseasonal or early spring peak in the Southern Cape; and winter peak flow in the Western Cape. Not coincidently, distinct vegetation communities occur in each region (Mucina and Rutherford 2006): Lowveld Riverine Forest and Northern Mistbelt Forest in Mpumalanga; Southern Afrotemperate Forest in the Southern Cape and Fynbos Riparian Vegetation in the Western Cape.

The hypotheses tested were:

- If vegetation zones result from differential species responses to a combination of <u>abiotic factors</u> that vary in space and time, then the same pattern should be repeated on different rivers even though the species composition of the communities may differ. There should be two main lateral zones: a wet bank comprising the marginal and lower dynamic lateral zone, and; the dry bank comprising the lower and upper lateral zone.
- If there is a separation between the wet and dry bank zones, inundation duration should be a good predictor of the wet bank communities as the life histories of the plants must have evolved in response to regular inundation. The boundary between the wet and dry bank should thus be located at the limit of where intra-annual floods inundate the bank.
- If the dry bank is inundated inter-annually, the lower and upper zones will be subject to disturbance associated with large flood events, and it should be possible to demonstrate significant differences in flood recurrence within the ranges of these two communities along an inundation gradient.

Eleven of the 18 sites had four lateral zones, six sites had three zones and one site had two zones. The marginal zone was missing from seven of the 18 sites, which were either bedrock controlled or where the active channel comprised boulders and large cobble. The lower zone was missing at one site, where the bank was near vertical. The order of lateral zones did not follow the expected pattern at one site due to a flood channel. Thus, although the basic pattern can be discerned using the methods described, site specific factors resulted in some variations. Ten of the 18 sites demonstrated the expected relationship: that the marginal and lower dynamic were inundated by intra-annual floods and the lower and upper zone were inundated by inter-annual floods. The marginal zone was inundated every 1.1-1.6 years, while the lower was inundated every 1.3-1.6 years. Since both these recur intra-annually it was not possible to separate them using the stage of different flood events on a cross-section. It was however possible to separate them using the duration of inundation since the marginal was inundated for longer (12 to152 days each year), compared with the lower dynamic (8 to 12 days a year). The lower dynamic was separated from the two higher zones at the position of the 1:2 year flood on a cross-section. The marginal and lower dynamic collectively form the wet bank and the lower and upper zone collectively form the Dry bank and thus a wet bank/dry bank separation occurs at the point where the 1:2 flood recurs. The lower and upper zones were separable from the wet bank hydraulically but not from one another since their distributions overlapped; the lower zone and the lower limit of the upper zone were inundated for 1-7 days every 2.4 years. There was no relationship between the upper zone and these variables.

RULES TO IDENTIFY LATERAL ZONES

Physical rules to identify lateral zones in Fynbos Riparian Vegetation were produced from data on community structure of undisturbed rivers. It was not possible to provide a similar set of rules for riparian communities in other regions as there were insufficient data. Thus, guidelines were provided to allow for the collection and analysis of data to generate similar rules for other regions.

The rules are:

1. A sample plot placed within 1.5 m of the water's edge will either be in the marginal or lower dynamic zones. Of these:
    a. those positioned at elevations less than 0.12 m above the water's surface will be in the marginal zone; and
    b. those situated higher than 0.12 m would be in the lower dynamic zone.
2. Plots located at a distance greater than 1.5 m from the water's edge will be in the lower or upper zones. Of these:
    a. those lower than 1.29 m in elevation will be in the lower zone;
    b. those higher than 1.29 m in elevation could either be in the lower or upper zones based upon the difference in bank shape:
        i. those on a convex bank (WB-DB > 0.23) will be in the lower zone, and;
        ii. those on a concave bank (WB-DB <=0.23) will be in the upper zone.

Some species are particularly abundant in each lateral zone and can be used to verify/adjust the delineation of zones in the field. The shrub *Prionium serratum* and the sedge *Isolepis prolifera* are most abundant in the marginal zone. The restio *Calopsis paniculata* and the tree *Morella serrata* are most abundant in the lower dynamic zone. The restio *Elegia capensis* and the tree *Metrosideros angustifolia* are most abundant in the lower zone. The fern *Pteridium aquilinum* and the shrub *Diospyros glabra* are most abundant in the upper zone.

CONCLUSION

Most river ecologists have the general understanding that the riparian area is separated into a wet and dry bank, but it was not clear how many zones there were within these two basic groups or whether these were always present. The longitudinal dimension of how plants arrange themselves is a good avenue for further research. We have no knowledge of similar studies at lower reaches, such as lower foothills and lowlands. Lower reaches tend to have floodplains, which makes modelling flow more complicated as it is necessary to account for vertical and lateral exchanges, and storage, of surface flows and groundwater in and outflows. The understanding generated from, and the applicability of, the results of this report and the two theses are confined to headwaters *viz.* mountain streams, transitional zones and upper foothills.

In South Africa, river health is assessed in two (marginal and non-marginal) or three zones (marginal, lower and upper), depending upon the level of assessment, using the VEGRAI (Vegetation Response Assessment Index) method (Kleynhans et al. 2007a). However, the lower dynamic appears to be an area of preferential recruitment and, as such, its inclusion in an updated VEGRAI is worth consideration.

Inundation duration was shown to separate the wet bank into its two zones, the marginal and lower dynamic. Inundation duration is not currently specified in Environmental Water Requirements but is known and, as such, merits inclusion. Overall, it was possible to link the occurrence of lateral zones to flood recurrence or inundation duration as follows:

- the wet bank and dry bank may be separated using the stage of the 1:2 year flood on a cross-section;
- the marginal zone will be located where the cross-section is inundated for longer than one month per annum;
- the lower dynamic zone will be located where the cross-section is inundated for shorter than one month per annum;
- the lower zone is situated at a position on the cross-section that is inundated for shorter than one week every second year.

It was shown that from a species perspective, a combination of groundcovers and trees was best to distinguish the lateral zones. Trees did not produce a useful pattern alone, whereas the patterns produced by groundcovers on their own were similar to the patterns of the two combined. Thus, data that combine trees and groundcovers are recommended for studies of this nature. It is particularly useful to consider the responses of trees and groundcovers separately in each lateral zone, since they respond at different temporal scales to prevailing conditions.

There is little understanding of the recruitment and succession of riparian vegetation populations in southern Africa. Although, detailed studies have been done on the Northern Hemisphere rivers, their results are not directly applicable to southern African rivers. Experimental studies on the reproductive biology of southern African riparian flora would greatly improve the ability to prescribe flow regimes that cater for their needs. This field offers great scope for interesting and relevant experimental research that would directly contribute to more effective management of rivers in the sub-continent.

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1 INTRODUCTION

Riparian vegetation communities occur along rivers in lateral zones parallel to the direction of river flow. Similar patterns of lateral zonation occur on rivers across the world despite variability in flow regime, climate, bioregion and/or continent. The flow regime has been described as the master variable responsible for the occurrence of lateral zones as it directs, *inter alia*, river channel structure, moisture regimes and the life histories of riparian plants (Naiman et al. 2005).

Riparian vegetation plays a central role in the functioning of riverine ecosystems: bank erosion is reduced through armouring and reduced velocities; water quality is maintained through trapping of sediment, nutrients and other contaminants, and shading regulates river water temperature and thus primary productivity; food is provided for riparian animals in the form of fruits, nuts and leaves, and for aquatic macroinvertebrates in the form of leaf litter; the plants themselves offer a diverse array of habitats as well as a corridor for the movement of migratory terrestrial and semi-aquatic animals (Prosser 1999, Terrill 1999). The riparian vegetation also acts as a moderator of water flow and sediment transport by intercepting precipitation and runoff; increasing infiltration; reducing soil moisture, water levels in alluvial aquifers and river flow through evapotranspiration; effecting changes to soil nutrient cycles by leaf litter inputs; and also altering channel structure through inputs of large woody debris. The nature and extent of the riparian vegetation is intimately linked to river channel structure and the occurrence of moisture, including river water, groundwater, and soil moisture. Riparian vegetation, sediment transport and water flow all interact and influence the kinds of plants suited to a particular river channel shape and water regime. Consequently, changes in the flow regime illicit a response in the nature and extent of the riparian vegetation. This response, and its knock-on effects on other aspects of the riverine ecosystem, is fundamental to the science of Environmental Flows, as is an understanding of the commonalities between river systems, so that knowledge developed on one system can be transferred to other, lesser-known but similar, systems.

The belief that these commonalities exist and that it is possible to develop a framework that can be used across river types, stems from evidence that suggests the structure of riparian vegetation in different lateral zones is strikingly similar within and between river basins, although the species and community composition may differ considerably (Reinecke et al. 2007). In southern Africa these lateral gradients in riparian vegetation have been correlated with, *inter alia*:

- indirect gradients, such as elevation, distance from channel and substratum type (van Coller 1992, van Coller et al. 1997, 2000; Reinecke et al. 2007);
- direct gradients such as flood frequency, stream power and depth to ground water (Hughes 1988, 1990; Boucher 2002); and
- resource gradients, such as water availability, soil moisture and nutrient status (Birkhead et al. 1997, Botha 2001).

However, since these are interrelated, it is likely that one or more key abiotic variable could be used to understand the structure and arrangement of riparian vegetation along rivers in relation to their flow regimes (or changes therein).

The objective of this project was to quantify the links between components of the flow regime and the occurrence of riparian species in lateral zones alongside rivers. The need to understand and quantity these links has arisen from the necessity to predict and understand changes in riparian communities in response to changes in river flow driven by climate change, water-resource developments on rivers and/or water abstraction from rivers. Once these links have been established for different kinds of rivers and/or flow regimes in an area, then they could be used to inform Environmental Flow studies for other rivers where there may be a dearth of information on either the riparian vegetation or the flow regimes.

Thus, the central hypotheses under investigation were:

- Vegetation zonation patterns along rivers result from differential species responses to a combination of abiotic factors that vary in space and time.
- It is possible to identify one or two key abiotic factors that can be used to predict change in the zonation patterns in response to changes in the flow regime of rivers.

In order to develop a framework that explains the existence of different plant communities in different lateral zones, a mechanistic explanation for characteristic differences between the lateral zones must be established. We set out to do this by investigating some aspects of the ecology of lateral zones on South African rivers in two post-graduate research projects. Mr Reinecke wrote five papers for his PhD while Ms Otto produced two for her MSc. Both students are expected to graduate December 2013 and the abstracts of their respective papers are included in this report. The link to the University of Stellenbosch website is also given so that the theses can be downloaded post 2013. This report has been prepared from findings of the two theses and focuses on the project aims. Readers are referred to the theses for a more thorough account and exploration of some of the underlying themes.

The project aims were:

1. to identify the position, number and composition of lateral zones in riparian vegetation communities in a selection of rivers in South Africa;
2. to suggest standardized names for the identified lateral vegetation zones;
3. to explore the relationships between these lateral vegetation zones and aspects of the daily flow hydrology and, if possible, link the identified zones to flows of particular return periods;
4. to seek simple methods for the identification of the lateral vegetation zones; and
5. to produce guidelines on the identification of lateral vegetation zones, and their links to flow, for use in South Africa.

This report comprises seven Chapters:

- Chapter 1 – Introduction
- Chapter 2 – Flow and the structure of river channels
- Chapter 3 – Characteristics of lateral zones
- Chapter 4 – Links between lateral zones and flow
- Chapter 5 – Guidelines to identify lateral zones
- Chapter 6 – Capacity building
- Chapter 7 – The way forward

Aims 1 and 2 are addressed in Chapter 3 where the existence of lateral zones is explored and their vegetative characteristics described. Aim 3 is addressed in Chapter 4 where links between lateral zones and the flow regime are explored. Aims 4 and 5 are addressed in Chapter 5, which provides a step-by-step procedure for the collection and analysis of data in order to produce results comparable with those presented in Chapters 3 and 4. Chapter 5 also contains a decision tree that can be used to identify lateral zones along rivers inhabited by Fynbos Riparian Vegetation (Mucina and Rutherford 2006). The final chapter, Chapter 7, draws together the conclusions of Chapters 3 and 4, which test hypotheses that assume water availability is a primary determinant of the occurrence and characteristics of lateral vegetation zones.

1.1 Focus of the report

The report focuses on the riparian vegetation of perennial rivers. The riparian zones of lakes and wetlands are excluded. Rivers (lentic systems) and lakes/wetlands (lotic systems) operate under different hydrogeomorphic[1] controls and thus support a different biota and ecological functioning. Lakes and wetlands are generally lower-energy environments with less dynamic and more diffuse flow than are rivers, and so are subjected to lower levels of disturbance. Rivers, by comparison, are higher-energy ecosystems associated with flow in well-defined channels that are shaped by system resetting disturbances (Innis et al. 2000, Rountree et al. 2008). Two main characteristics separate riverine riparian areas from other aquatic ecosystems (Rogers 1995):

- a linear form dictated by their connection with rivers; and
- a hydrological connection to upstream and downstream areas.

1.2 Definitions

1.2.1 Riparian zone

A riparian zone[2] is an area of land directly influenced by the presence of a flowing river (Naiman et al. 2005). Riparian zones are ecotones (Swanson et al. 1992) that occupy a three-dimensional (Wilson and Imhoff 1998) transitional area between aquatic and terrestrial ecosystems. They serve as conduits for the exchange of materials and energy between the two ecosystems (Richardson et al. 2007) and generally exhibit sharp gradients in environmental and ecological processes (Swanson et al. 1992, Naiman et al. 1998). Typically, the biotic communities that occupy the banks of rivers and floodplains occur as a mosaic of vegetation communities that are associated with variation in soil type and moisture (Naiman and Decamps 1997) and thus show considerable variation in species richness and composition (Corbacho et al. 2003).

[1] Hydrogeomorphological: the interaction of hydrologic processes with landforms and/or the interaction of geomorphic processes with surface and subsurface water (Sidle and Onda 2004).

[2] Please note that we have the term *riparian area* and riparian zone interchangeably, to reduce the incidence of the word zone in this report, as there are also longitudinal and lateral zones mentioned.

1.2.2 Riparian vegetation

Riparian vegetation is the riverine plant community sustained by river flow or groundwater, or generally moist conditions along river margins. The riparian vegetation of perennial rivers can be defined as the vegetation community supported by the area of land adjacent to the active channel of a permanently flowing river, and which is distinctly different in species composition from neighbouring terrestrial communities.

1.2.3 Environmental flows

Environmental flows are the water that is left in a river system, or released into it, for the specific purpose of managing the condition of that river system (King et al. 2003). Environmental flows are typically described in terms of an annual volume of water and its temporal and spatial variability.

1.2.4 Lateral vegetation zones

We have used the term *lateral zone* for sub-sections of the riparian area where groups of plants preferentially grow in association with one another due to shared habitat preferences and adaptations to withstand prevailing hydro-geomorphological conditions. The term *sub-zone* (Boucher 2002) has been used in the past.

2 FLOW AND THE STRUCTURE OF RIVER CHANNELS

The physical structure of a river ecosystem and its associated habitats are determined by the size of the river channel; its position in the drainage basin; the underlying geology and geomorphological setting; the hydrological (flow) regime; and the regional climate (Naiman et al. 2005). At a local level, however, the composition and structure of riparian communities are influenced primarily by river channel shape and water flow (Naiman et al. 2008). These are represented by the inter-related disciplines of hydrology and geomorphology, often combined into the field of hydro-geomorphology.

Rivers adjust their morphology (width, depth, slope and planform) to transport the water and sediment supplied from the drainage basin (Newson and Newson 2000). As river gradient decreases downstream, so does the capacity of the river to transport sediment. As this occurs ever smaller calibre sediments are deposited on the river bed. Thus mountain streams consist of larger calibre sediment, such as boulders and cobbles, whereas lowland rivers usually have beds comprised of fine sediment, such and gravel, sand and mud. Although changes in river channel structure occur on a continuum from source to mouth, various authors have described geomorphic zones characterised by differences in sediment transport and deposition. Concepts at a basin scale are discussed first followed by a classification system for South African rivers that includes geomorphic descriptions at a finer scale.

2.1 Basin-scale concepts of river channel structure

Schumm (1977) considered a river basin to consist of three transfer zones: a production zone in the headwaters where erosion and transport of sediment is higher than deposition; a transfer zone where sediment transport and deposition are in equilibrium; and a deposition zone at the lower end of a river system. This idea was incorporated into the thinking of Montgomery (1999) who introduced the concept of Process Domains, which are river basin components characterised by differences in sediment supply and transport. Hill slopes were the primary source of sediment supplied to river channels and are sediment supply limited. Channels were described as links between headwaters and lowlands where sediments were re-cycled through processes of erosion and deposition. Floodplains were described to be activated only during large flood events and were said to store sediment for the long cycles between floods. Church (2002) and Ward et al. (2002) developed these concepts further in their descriptions of river channels, riparian zones and floodplains. They described river systems as alternating series' of laterally constrained channels and laterally expansive floodplains, driven by changes in flow and sediment transport. These concepts may be used to introduce ideas about changes in riparian zone structure along a rivers length.

Both authors separated rivers with floodplains from narrow, constrained river channels and described how changes to both of these kinds of rivers take place from source to mouth. River channels and floodplains increase in width and complexity down the rivers length as the balance between sediment supply and transport shifts from supply limited channels upstream to transport limited channels downstream. As more sediment is deposited, river channel structure changes from straight to meandering, and then to braided and anastomosing. Straight channels are those with a sinuous thalweg and alternate bars that move slowly downstream. Meandering channels are single thread with alternating eroding (concave) and aggrading (convex) channel banks that migrate downstream. There are two kinds of braided rivers:

- Island-braided rivers comprise multiple shifting channels that are highly mobile with un-vegetated, unconsolidated gravel and sand bars, or mid-channel bars stabilised by vegetation.
- Anastomosing rivers that are large and comprise large permanently vegetated islands.

Channels in the upper reaches of river basins are laterally constrained with limited capacity to store sediment and other organic matter. The dominant direction in which matter and biota are transported is longitudinal. Since there is limited floodplain development, river flow acts directly on the hill slopes (said to be coupled, Church (2002)), the riparian zone is often narrow, and the influence of groundwater and the presence of alluvial aquifers is limited. Further downstream, floodplain valleys and meandering lowland rivers receive larger quantities of sediment from upland channels and are un-coupled from hill slope sediment sources. Floodplain development increases with distance downstream and results in a greater complexity of interactions that include vertical interactions (between the river and its bed) and lateral interactions (between the river and its floodplain). As floodplains increase in extent and frequency, the influence of, and exchange between, the river and its subterranean counterpart, the alluvial aquifer, also increases (Ward and Stanford 1995). This is associated with an increase in the complexity and variety of riparian habitat type as a result of increased variation in topography and water availability, and vertical exchange between the surface waters of the river channel and ground water of the alluvial aquifer. These longitudinal, vertical and lateral exchanges of matter and biota are important aspects of the functioning of floodplain systems (Ward et al. 2002). The ecotone between surface water and alluvial groundwater is termed the hyporheic zone and may extend for kilometres beneath a floodplain.

2.1.1 A hierarchical geomorphological classification for South African rivers

Geomorphologists tend to describe drainage basins as multi-scaled nested hierarchies where the basic building blocks (patches) of landscape elements are grouped beneath larger elements, which are controlled and operate over successively longer time frames and larger spatial scales. Rowntree et al. (2000) developed such a classification system for use on South African rivers that has remained the standard for the purposes of delineating geomorphological zones along South African rivers.

According to the South African classification system, river basins (catchment in Figure 2.1) are divided into zones, while channel features are divided into segments, reaches, morphological units and biotopes. Zones are areas within the basin that are considered to be uniform with respect to flood runoff and sediment production. Zones are the unit that freshwater ecologists most frequently use to describe differences along the continuum of change down a river; for example mountain streams versus foothills (Table 2.1). Within zones, segments are described as channel lengths over which no significant change in discharge or sediment load occurs.

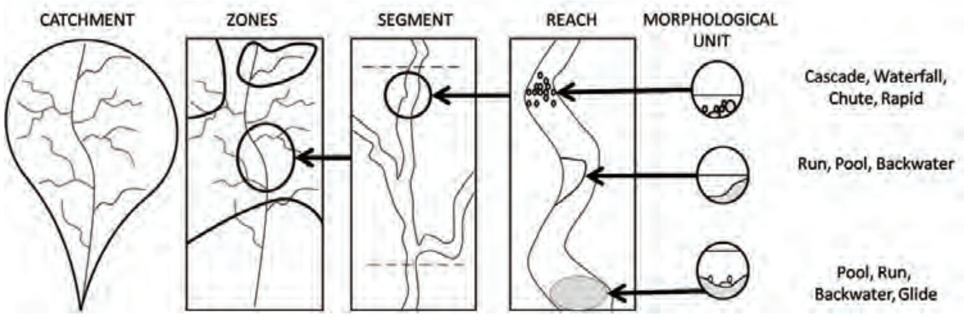

Figure 2.1 **Hierarchies in the geomorphological classification system (adapted from Rowntree et al. 2000).**

Table 2.1 **Longitudinal zones along South African rivers (from Rowntree et al. 2000).**

Longitudinal Zone	Range of slope	River characteristics
Source zone	Not specified	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	>0.1	A very steep gradient river dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain stream	0.04-0.099	Steep gradient river dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool. Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Transitional	0.02-0.039	Moderately steep river dominated by bedrock or boulder. Reach types include plane-bed, pool-rapid or pool-riffle. Confined or semi-confined valley floor with limited flood plain development.
Upper foothills	0.005-0.0019	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plane-bed, pool-riffle, or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain or sand, gravel or cobble often present.
Lower foothills	0.001-0.005	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types include pool-riffle or pool rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Flood plain often present.
Lowland river	0.0001-0.0009	Low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.
Additional zones associated with a rejuvenated longitudinal profile		
Rejuvenated bedrock fall/cascades	>0.02	Moderate to steep gradient, often confined channel (gorge) resulting from uplift in the middle to lower reaches of the long profile, limited lateral development of alluvial features, reach types include bedrock fall, cascades and pool-rapid.
Rejuvenated foothills	0.001-0.0019	Steepened section within middle reaches of the river caused by uplift, often within or downstream of gorge; characteristics similar to foothills (gravel/cobble bed rivers with pool-riffle/ pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro-channel activated only during infrequent flood events. A flood plain may be present between the active and macro-channel.
Upland flood plain	>0.005	An upland low gradient channel often associated with uplifted plateau areas as occur beneath the eastern escarpment.

2.1.2 A landscape perspective of riparian zones

Upland rivers and floodplain systems operate under different hydrological regimes and as such exhibit distinct physical structure/habitat availability. This has implications for aquatic communities occupying different positions in the drainage basin as life histories are expected to have evolved in response to drivers that create and maintain the habitats. Running water erodes bedrock and terrace soils and redistributes alluvium (Standford 1998), thus the pattern and variety of flows ultimately determine the landscape. Natural variations in fluvial action (erosion, sediment transport, deposition) creates and maintains a high diversity of morphological units, such as pools, riffles, runs, gravel bars, avulsion channels, islands, debris dams and lateral floodplain terraces (Stanford et al. 1996). At the scale of these morphological units, certain landscape elements turnover at a high rate as pools are scoured and/or lateral bars formed. When viewed at a reach or zone scale, however, and in the absence of serious modifications to the flow regime and sediment supply, the matrix of characteristic landscape elements remains constant over ecological time (Ward et al. 2002).

Wu and Loucks (1995) proposed the Hierarchical Patch Dynamics paradigm based on the assumption that geomorphic processes vary spatially and temporally across a basin and biotic systems respond dynamically to this variation. It is a useful paradigm for understanding links between geomorphology and riparian zones and it combines four major limnological concepts that shift in importance at different positions in the river basin. These are the River Continuum Concept (Vannote et al. 1980), the Serial Discontinuity Concept (Ward and Stanford 1983), the Flood-Pulse concept (Junk et al. 1989) and the Hyporheic Corridor Concept (Stanford and Ward 1993). The River Continuum Concept and the Serial Discontinuity Concept explain upstream-downstream linkages longitudinally along a rivers length, while the Flood-Pulse and the Hyporheic Corridor concepts explain lateral and vertical interactions between the river channel, the floodplain and groundwater.

The Hierarchical Patchy Dynamics paradigm encompasses the idea that riverine ecosystems are structured according to the degree to which connectivity is shared between different landscape elements. Along the continuum from source to mouth, and between hill slopes to lowland floodplains, riparian substrata are continually created, built up, left fallow, gradually deconstructed or spontaneously eroded (Naiman et al. 2005). For example, if the physical structure of a river limits lateral and vertical connectivity, as occurs in bedrock controlled systems, the riverine communities are likely to be controlled by upstream-downstream processes, as described by the River Continuum Concept and Serial Discontinuity Concept. If on the other hand, a river’s structure emphasizes lateral or vertical connectivity, such as in floodplain systems, riverine communities are likely to be controlled by lateral and vertical processes, as described by the Flood-Pulse Concept and the Hyporheic Corridor Concept.

The Hierarchical Patch Dynamics paradigm is useful as it incorporates interactions between spatial patterns and ecological processes in a way that is relevant to river channels and riparian zones (Naiman et al. 2005). It describes a dynamic riparian landscape composed of different riparian habitat patches sculpted by the interactions of vegetation, water and sediment flow at different scales of space and time. It emphasises a non-linear functioning of community dynamics by considering the context of riparian habitat patches. This means understanding top-down influences on the habitat patch that operate at a larger spatial and temporal scale. It also means considering bottom-up influences that contribute to properties of a higher level. The contribution of the Hierarchical Patch Dynamics paradigm was to highlight the interaction between a river and its valley and to emphasize the unique nature of each lotic ecosystem's patch hierarchy (Poole 2002).

2.2 The consequences of variable flow regimes for riparian vegetation

Aside from creating and maintaining physical habitat, the flow regime of a river also has a direct influence on the riverine biota. The conceptual understanding of this influence has been captured in the Natural Flow Regime paradigm (Poff et al. 1997). This is briefly discussed next, followed by a summary of some of the main ways that flow of South African rivers differs from that in rivers elsewhere. The influence of flow on the life histories of riparian plants follows and then the conceptual framework of this study is presented.

2.2.1 The natural flow regime paradigm

The natural flow regime paradigm is based on the principle that the integrity of lotic (flowing) ecosystems depends largely on their natural dynamic character since the timing and quantity of flow is correlated with many other critical physicochemical characteristics of riverine ecosystems (Poff et al. 1997). As such, flow is considered the 'master variable' that dictates the abundance and distribution of riverine species (Resh et al. 1998). The natural flow regime varies on time scales of hours and days and between seasons over years and longer. Components of the flow regime are described in terms of magnitude, frequency, duration, timing and rate of change of flow. These components characterise the entire range of flows and specific hydrologic phenomena, such as floods and low flows, which are critical for certain species (Poff et al. 1997):

- Flow magnitude, or discharge, is the amount of water moving past a fixed point per unit time, usually measured in cumecs (m^3/s).
- Flow frequency of occurrence describes how often a flow of certain magnitude recurs over a specified time interval. For example, a 100-year flood is equalled or exceeded once every 100 years so has a 0.01 chance of occurring in any one year.
- The average (median) flow is determined from a data series over a specific time interval and has a frequency of occurrence of 0.5, i.e., 50%.
- Flow duration is the period over which a flow event is experienced, usually measured in days.
- Flow timing, or predictability of a flow event, refers to the regularity that this event re-curs. For example, annual peak flows may occur with low or high seasonal predictability.
- The rate of change or flashiness refers to how quickly flow changes from one magnitude to another. So-called 'flashy rivers' have rapid rates of change in the volume of water flowing down them.

Surface flow in rivers ultimately derives from precipitation but, at any given time, may comprise a combination of surface water, soil water and groundwater. Climate, geology, topography, soils, and vegetation all play a role in water supply and the path flow may take. Variability in intensity, timing and duration of precipitation combined with the effects of soil texture, topography and plant evapotranspiration all contribute to locally and regionally variable flow patterns. Physical river habitat has been described in terms of sediment calibre and heterogeneity, channel and flood plain morphology and other geomorphic features (Section 2). Flow and sediment transport across river basins fluctuate dynamically over different spatial and temporal scales and respond to variation in the hydrological cycle within and between years. Generalisations about hydrologic properties, between upland and lowland rivers for example, should be made with caution. Natural flow characteristics across river basins are highly variable and relate to basin specific properties such as climate, geology and topography (Naiman et al. 2008). Baker and Wiley (2009) found that different valley types may present the same hydrologic conditions and thus elicit the same response from different riparian vegetation communities. For example, prolonged seasonal variation can occur in small catchments with brief lag times and high water tables as well as in larger catchments with attenuated lag time and low groundwater yields. Conversely, it may be possible that similar catchments manifest different hydrological conditions through different combinations of valley shape or other topographical or localised factors. While elevation above and distance from a river channel may result in flood gradients at specific cross-sections, these patterns of flood frequency or stream power may not be applicable up- or downstream or in neighbouring rivers (Magilligan 2002, cited by Baker and Wiley 2009).

Hydrological records may be modelled or extrapolated from other neighbouring basins to rivers that don't have their own gauged flow records. Some studies have compared South African river flow to rivers on other continents and also have categorised river flow of South African rivers into groups based on characteristics of their flow regime. These are discussed next.

2.2.2 River flow in South Africa compared to that elsewhere in the world

Walling (1996) compared southern African rivers to those in Australia, the South Pacific, Asia, South America, North America and Europe and found that southern African rivers had the highest coefficient of variation[3] in mean annual runoff, the highest storage requirement for regulation of flow, the highest variability in flooding (measured as the standard deviation of the logarithms of the annual peak discharge) and the greatest extreme flood index (measured as the ratio between the 100-yr flood and the mean annual flood). Australian rivers were a close second while rivers on other continents had much lower values. Similarly, Görgens and Hughes (1982) showed that the average inter-annual variability of runoff (Coefficient of variation [CV] = 1.13) was much higher for South African rivers than for rivers in Australia (CV = 0.7) and the rest of the world (0.25 < CV < 0.4). Furthermore, the conversions of mean annual precipitation (MAP) into mean annual runoff (MAR) are extremely low compared to rivers in other countries; South Africa has the lowest ratio of 8.6%, followed closely by Australia with 9.8%, while Canada by comparison has a conversion of 65.7% (Dollar and Rowntree 2003). Thus, the flow regimes of southern African rivers differ considerably from rivers in the temperate climates where many of the studies of riparian ecology have taken place. South African river flow is 'predictably unpredictable' and apart from some coastal regions, the country is semi-arid, and only very few of the rivers are associated with extensive floodplains (Davies et al. 1995), unlike Northern hemisphere rivers.

[3] CV is measured as the ratio of the standard deviation and the mean. A high CV may be indicative of high disturbance and low predictability (Gordon et al. 2002).

Much of the country experiences summer rainfall and a dry winter. The Western Cape with its Mediterranean climate, i.e., winter rainfall and a dry summer is the exception, although rainfall in the mesic southern coastal region tends to be aseasonal. Almost all the rivers in South Africa exhibit a ‘flashy’ runoff response which is considered to be fairly typical of arid or semi-arid countries (Gordon et al. 2002). Flood events tend to have short lag times relative to rainfall events in the basin, and steep ascending and receding limbs. Although the wet and dry seasons occur with some regularity, the frequency and magnitude of floods in the wet season is unpredictable relative to northern hemisphere rivers. Flow variability is considered to be ecologically important as the life histories of riverine biota are thought to evolve in response to flow predictability (Resh et al. 1998). There are few detailed studies of flow-linked recruitment dynamics and/or community succession in South Africa (see Section 2.3.1).

Winterbourn et al. (1981, cited by Davies et al. 1995) suggest that rivers in the Southern Hemisphere are more variable and prone to extremes of flood and drought than those in the Northern Hemisphere and as a consequence biotic communities in the Southern Hemisphere should be less structured than the northern counterparts and be dominated by hardy opportunists. For instance, in the Western Cape with its cold, wet winters with high flow and hot, dry summers with low flows (Davies and Day 1998), one might expect species to have less specific regeneration requirements than their northern counterparts (Gooderham and Barmuta 2007).

2.2.3 Categorising rivers in South Africa

Generally, well-developed floodplains are an unusual feature of Southern African river systems and are mainly confined to the north-eastern parts of the country. The central highly elevated pediplain – the “Highveld” – is dissected by “older” rivers such as the Zambezi in the north, the Limpopo in the Northeast and the centrally situated Orange-Vaal system. These form the major arteries of the southern African region. The smaller “younger” rivers of the east and south coasts have cut down deeply as the coastal margins tilted and were subjected to enormous hydrological fluctuations (Davies et al. 1995). Flow regime characteristics have been investigated country wide in terms of the predictability and seasonality of flow. These data were incorporated into the hypotheses regarding the influence of timing and magnitude of flow on the life histories of riparian plants in subsequent Chapters.

Joubert and Hurly (1994) made use of daily flow data to classify South African rivers. They found that the rainfall:runoff ratio (MAP:MAR) varied considerably across the country due to climate, vegetation, geology, slope and when the basin was previously saturated. They analysed daily flow data from 352 gauging weirs situated upstream of all major impoundments or abstractions and that had a minimum record span of 20 years using two different sets of flow variables:

- one describing seasonal patterns of flow;
- and the other describing flow type characteristics, such as:
    - temporal predictability and variability; and

- flood characteristics, for example the number of floods per year, the median number of day intervals between floods, the median duration of floods, flood predictability, and the median day of the year on which floods occurred.

The seasonal analysis formed seven groups which were separated as follows:

- two groups that were geographically distinct:
    - the winter peak flow region of the south-western Cape;
    - the aseasonal/early spring region of the southern and eastern Cape;
- the summer rainfall region contained four groups that were not divided into clear geographic regions;
    - moderate summer peak (December to February) between KwaZulu-Natal and Mpumalanga;
    - midsummer extreme peak (January and February) throughout Mpumalanga and the Orange Free State;
    - midsummer moderate peak (February) inland of the coastal belt and mixed with others in Mpumalanga;
    - moderate late summer peak (February and March) in coastal Transkei and Natal; and
- one group with extreme spring peak flow in November in the eastern Cape.

The analysis based on flow type variables was broadly categorised into three super-groups separated further as follows:

- Stations with mainly extreme-seasonal but also episodic flow:
    - Rivers with flow that had a high degree of constancy[4] (zero flow in this instance) located in the interior.
- A mixture of stations recording extreme-seasonal, semi-perennial and perennial flow separated into two main groups based on the interval between floods:
    - Those with a short interval between floods, thus a medium to high flood frequency and with floods of long duration (10 days compared to all the other groups with 3 days). These rivers also had a high degree of constancy and were located in Mpumalanga and KwaZulu-Natal. Another group in this category of short interval between floods were rivers scattered throughout the country (with the exception of the Transkei and KwaZulu-Natal coastal belts) where overall predictability[5] was the lowest of any group, flood durations were shorter and constancy was medium to low.
    - Those with a long interval between floods with low overall predictability and low flood frequency and found along the southern and eastern Cape coastal belt. Another group in this category of long intervals between floods were rivers with very low constancy and with the highest degree of seasonal predictability of all the groups, and with low flood frequency. These were found mainly in the south-western Cape.

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[4] Constancy is that part of predictability, which describes flows that remain similar throughout a hydrological year.

[5] Predictability is defined in two parts: constancy and contingency, with contingency being that part of predictability, which describes the regularity of seasonal flow events (Colwell 1974, cited by Joubert and Hurly 1994).

- A perennial supergroup:
    - o Stations in this group recorded medium to low flood durations (1-6 days) with a high degree of constancy and medium predictability. One group recorded short intervals between floods and thus a high flood frequency, found mainly to the east of the escarpment and in the south-western Cape. Another group was the largest perennial flow group recording medium to long intervals between floods, very low flood frequencies and a high flood predictability, the highest of any group and also found mainly to the east of the escarpment and in the south-western Cape. A final group recorded slightly lower flood duration but extremely long intervals between floods and thus very low flood frequencies.

The analyses of seasonal and the flood characteristics revealed general patterns. The pattern of flow along the subtropical coast and the plateau slopes of the Transkei, KwaZulu-Natal and Mpumalanga were similar. The seasonal groups in these areas were moderate mid-late summer with perennial flow. The southern and eastern Cape coastal belt was clearly distinct in both groupings and characterised by aseasonal flow or a slight early spring peak; a flow regime not commonly found elsewhere in the country. Overall predictability was very low, with a fairly high flood frequency and the lowest flood predictability of all groups. The Western Cape recorded winter peak flow with low overall predictability and high seasonal predictability.

2.3 Flow and the response of riparian vegetation

A general overview of riparian vegetation recruitment dynamics is given. This is followed by a synopsis of studies that have investigated aspects of this on Southern African rivers. These studies lead toward establishing a naming convention with which to characterise lateral zones.

2.3.1 Riparian vegetation population dynamics

Riparian vegetation communities are dynamic and the proportions of dominant species change down the length of a river. Areas of broadly similar physical habitat contain broadly similar communities, but the species composition and density at any one site is affected by variations in soil moisture, nutrient status and topography (Van Coller 1992); the frequency and intensity of droughts and floods, fire, plant disease and grazing (Naiman et al. 2005); and species interactions (Francis 2006).

The likelihood of a species growing and persisting at a particular location depends upon the stability of the site for germination and establishment, and the ambient environmental conditions at the site that permit persistence until age of reproduction (Hupp and Osterkamp 1996). Successful recruitment depends upon:

- the availability of seeds or other propagules,
- the availability of colonisable habitat,
- the possibility of seedlings to develop before being inundated or to sustain growth in the absence of soil moisture, and

- the resilience of established populations to high (floods) and low (drought) flow periods (Tabacchi et al*.* 1998).

Sufficient flows are required seasonally to recharge ground water levels at the end of the dry season and also to facilitate vegetation recruitment (dispersal, germination and growth of seedlings), often toward the end of the flood season. A unique adaptation to the riparian environment is a strategy in which seed dispersal coincides with the seasonal retreat of floodwaters when moist seedbeds are available for successful germination and colonisation (Naiman et al. 2008). Newly established seedlings rely on the gradual recession of the water table as roots elongate to maintain contact with receding moisture. Contrastingly, high flow periods are necessary to open and maintain new areas for recruitment the following season (Rood et al. 1999). Plants that are cued in this way to disperse seeds over flood-recession are reproductive specialists that require specific conditions in order for recruitment to be successful. These reproductive specialists are the most sensitive to alterations in the flow regime, and may be subject to recruitment failure should the flow regime be altered. Other riparian plants may be less specific in their response, flowering and setting seed over many months of the year, or in response to periods of high flow only. These more generalist species are often pioneers and the first species to colonise new habitat (alluvial deposits) as their seedlings are able to germinate under a variety of hydro-geomorphological conditions and are less prone to recruitment failure as a result of changes to the flow regime.

The life histories of some species on large floodplain rivers of the northern hemisphere are intimately linked with the annual flood peak. Flowering and seed set are cued such that seed dispersal takes place as flood waters recede (Mahoney and Rood 1998). The hydrochorous (water-dispersed) seeds then preferentially germinate on new sandy alluvial deposits, termed nursery sites. The seedlings grow long tap roots that track the receding flood waters, sustaining development. The close links to the onset of flooding and rate of flood recession means that these species are vulnerable to recruitment failure should the flow regime be altered. For instance, seed release of *Populus* and *Salix* in the floodplain forest of the northern hemisphere is linked to a range of water levels that present optimal positions for seedling dispersal to germination sites. For successful seeding establishment, the rate of the surface/groundwater recession should be slow enough to allow seedling root extension to keep pace with the drop in water level, thereby avoiding moisture stress. Evidence suggests that pioneering soft-wood species such as these are tolerant of fluvial action, burial and submersion, but are vulnerable to shade and drought (Mahoney and Rood 1998). Once passed the seedling stage, water availability may be the dominant factor controlling survival. The flow-linked life histories of *Populus* and *Salix* are described in the 'recruitment-box model' (Mahoney and Rood 1998, Rood et al. 1999), which assumes that river stage and alluvial groundwater decline are closely coupled. The relatively clear-cut relationships between inundation levels and plant life-histories is the reason that attempts to reverse the negative impacts of development-linked flow changes on the riparian vegetation of these rivers has focused on reinstating the timing (and magnitude) of the natural flow regime.

There have been some studies of the ecology of southern African riparian vegetation. Four authors have investigated community structure and population dynamics of floodplain-rivers in the north of the country and in Kenya (Hughes, 1988, 1990; van Coller 1992; van Coller et al. 1997, 2000; Mackenzie 1999; Botha 2001). Four others have looked at rivers in the

Western Cape (Sieben 2003, Galatowitsch and Richardson 2005, Vosse et al. 2008). Each of these contributes towards the concept of lateral zone categorisation for South African riparian zones.

Hughes (1988; Tana River floodplain in Kenya) and van Coller (1992; Sabie River in the Kruger National Park) presented empirical evidence for the existence of plant communities in lateral zones and sought links to link community descriptions with indirect gradients, such as elevation and distance from the active channel. They described flood recurrence interval and the availability of water in the riparian zone, either as soil moisture or precipitation, to be important factors for community structure. Hughes (1990) linked her community types with flood recurrence intervals while van Coller (1997, 2000) linked his with geomorphic channel features and those of the floodplain. Both authors introduced lateral zonation in their categorisations of riparian communities describing a combination of hydraulic and geomorphic factors for the patterns described. Mackenzie et al. (1999; a population model for *Breonadia salicina* on the Sabie River) and Botha (2001; ecology of floodplain forests of the Luvhuvhu, Mkuze and Phongolo Rivers) both looked at recruitment dynamics incorporating the combined influences of hydrology, geomorphology (substrate types), rainfall, size class longevity, fecundity, survival probabilities, density dependence and population structure . Hypotheses likened change in community structure to flood events and geomorphic changes in river channel structure and sediment calibre. These studies differed to ours as they:

- were on large rivers lower down the longitudinal profile, and
- dealt with seral succession of floodplain communities in lateral zones; much like the studies of northern hemisphere floodplain forests.

Both experienced difficulties in linking flow components to exact floodplain positions (elevation and distance vectors). This was attributed to a combination of the complexity of the floodplain geomorphic mosaic and inaccurate/incomplete hydrological data.

Sieben (2002) completed a detailed study of riparian vegetation communities for some upland rivers in the Western Cape and described many community types in lateral zones. He could not link these to flow, again due to inaccurate hydrological data. Galatowitsch and Richardson (2005) presented evidence suggesting that disturbance driven seedling recruitment, described riparian plants of floodplain-rivers, may not be an adaptive advantage for riparian trees along headwater reaches. This was based on the observation that seedlings germinated preferentially on stable banks and rock fractures rather than on recent alluvial deposits. Vosse et al. (2008) showed that the seeds of these same species were absent from the riparian seedbank and concluded that Western Cape riparian vegetation must be dominated by resprouters and not reseeders as postulated.

This initial evidence suggests that headwaters may function differently to floodplains. Certainly, the strength of the links between the life histories of South African riparian plants to the flow regime requires further investigation.

2.3.2 Lateral zone characterisation

The concept of riparian plants in lateral zones has been described for many rivers globally. Categorisations have been based upon links to flow (Shipley and Keddy 1987; Bendix 1999; Taman 2001; Boucher 2002; Lite et al. 2005; Thayer et al. 2005; Dwire 2006; and Baker and Wiley 2009) and to landforms (Harris 1988; Moon et al. 1997; Vadas et al. 1997; Bendix and Hupp 2000; Godfery 2000; van Coller 1992; van Coller et al. 1997, 2000; Rountree et al. 2008; and Sieben and Reinecke 2008). Essentially a riparian zone is divided into a number of lateral zones based on the species composition of each lateral zone and links are made between the zones and environmental data.

The most comprehensive categorisation locally is that of Boucher and Tlale (1999) from the Senqu River in Lesotho. They described plant communities in lateral zones and proposed links with these to specific flood recurrence intervals. This was formalised using data from the Breede River (Western Cape) into a categorisation of 7 lateral zones divided into three main groups (Boucher 2002). These were:

- The aquatic zone divided into the:
  - permanent aquatic, inundated 95% of the year; and
  - rooted aquatic, inundated 50% of the year.
- The wet bank zone divided into:
  - the sedge or moss zone, wetted by the Class 1 floods[6]; and
  - the shrub or *Prionium* sub-zone, wetted by the Class 2 and 3 floods;
- The dry bank zone divided into:
  - the lower dynamic zone, wetted by the Class 4 floods;
  - the tree-shrub zone wetted, by the 1:2 to the 1:20 year floods; and
  - the back dynamic zone wetted, by the 1:20 to 1:100 year floods.

This categorisation was tested by Reinecke et al. (2007) who found evidence for four lateral zones. Moving laterally up the bank from the water's edge these were termed wet edge, channel fringe (transitional), tree shrub and outer edge (transitional to terrestrial).

The Riparian Vegetation Response Assessment Index (VEGRAI, Kleynhans et al. 2007a) is used to assess the condition of riparian vegetation on South African rivers. The method compares the present day condition to that which would be expected under natural (reference) conditions, and considers how past impacts may have influenced the ecological condition over time. Assessments are made for three lateral zones that are loosely correlated to periods of inundation. Determining the position of the zones is based on their proximity to the active channel, bank topography and the presence of terrestrial species. The marginal zone is described to be inundated intra-annually, the lower zone with a recurrence of 1-3 years, and a upper zone said to be inundated at a recurrence of >3 years.

The categorisations compare quite well (Table 2.2) and this is somewhat surprising since the data from which they were compiled and the analytical methods used differed quite substantially. This cohesion between the descriptions provides some support for the notion

[6] Class 1 floods = dry season base flow; Class 2 floods = wet season base flow; Class 3 floods = wet season freshes; Class 4 floods = within year floods (Brown et al. 2006).

that characteristic features of lateral zone can be linked to flow patterns. They also illustrate the current problem of different terms used to describe the same lateral zone.

Table 2.2 A comparison of lateral zonation descriptions for South African riparian vegetation. (T = a transitional zone).

<table>
<tr><td>Bank position</td><td>Boucher (2002)</td><td>Reinecke et al. (2007)</td><td>Kleynhans et al. (2007a)</td></tr>
<tr><td rowspan="2">Aquatic</td><td>Permanent</td><td rowspan="2">Not addressed</td><td rowspan="2">Not addressed</td></tr>
<tr><td>Rooted aquatic macrophytes</td></tr>
<tr><td rowspan="3">Wet bank</td><td>Fringing sedge</td><td rowspan="2">Wet edge</td><td rowspan="2">Marginal</td></tr>
<tr><td>Shrub willow</td></tr>
<tr><td rowspan="2">Lower dynamic</td><td rowspan="2">Channel fringe</td><td rowspan="2">Not addressed</td></tr>
<tr><td rowspan="3">Dry bank</td></tr>
<tr><td>Tree shrub</td><td>Tree shrub</td><td>Lower</td></tr>
<tr><td rowspan="2">Back dynamic</td><td rowspan="2">Outer transitional</td><td rowspan="2">Upper</td></tr>
<tr><td>Terrestrial</td></tr>
</table>

Boucher’s (2002) transition from wet to dry bank was said to be located at the 1:2 year flood recurrence interval and this concurs with the change from the marginal to the lower zone (Kleynhans et al. 2007a) being located between the 1 and 3 year flood recurrence interval. The occurrence of lateral zones in riparian vegetation communities is expected to be linked to particular characteristic landforms (such as terraces, or mid-channel bars). It may be no co-incidence that these have been aligned with the channel forming discharge return period of 1 to 2 years (Gordon et al. 2002), another concept developed for northern hemisphere rivers. The applicability of channel forming discharge was tested on some South African rivers by Dollar and Rowntree (2003). They did not find compelling evidence for the idea that moderate flow events with a return period of 1 to 2 years are responsible for maintaining channel form. They proposed a two-tiered approach to understanding channel form and showed that a variable range of low flows were responsible for the bulk of bed material transport and morphological adjustment of the active channel. They proposed that a larger ‘reset’ discharge, on average every 20 years, maintains the macrochannel and mobilises the entire bed. It is necessary to consider both these perspectives in formulating the hypotheses regarding flood return period, explored in Chapter 4. Again, it may be no coincidence that Boucher’s (2002) transition between the outer dry bank communities, the tree-shrub and the back dynamic was said to be located at the 1:20 year recurrence interval.

Only Boucher (2002) addressed the aquatic zone. All three authors identified a lateral zone closest to the water’s edge with Boucher separating this into two. Both Boucher and [Reinecke] identified transitions; the lower dynamic [channel fringe] between the wet bank [wet edge] and dry bank, and the back dynamic [outer transitional] between the tree shrub and the terrestrial zones. Kleynhans et al. (2007a) described the upper zone as being transitional between riparian and terrestrial vegetation.

In this report we have assumed the naming convention of Kleynhans et al. (2007a) as a starting point to avoid confusion since many practitioners are already using the VEGRAI method and it represents the most current, and possibly the first, naming convention consensus by South African botanists for lateral zones. The data are however expected to reflect transitions between the three zones and these may become part of a future synthesis and naming convention adopted after the results of this research are disseminated. The three zones are the marginal zone, akin to the wet bank and wet edge zones, which is expected to flood intra-annually. The lower zone, akin to the tree-shrub zone that also incorporates the transition between the marginal and lower zones, is expected to be located between the 1 and 3 year flood recurrence interval. The upper zone, akin to the back dynamic and outer transitional, is expected to be located outside of the 3 year recurrence interval.

2.4 Conceptual framework

The central assumption is based on surface river flow being the driver of riparian habitat and vegetation dynamics. This is considered to influence the distribution of riparian plants in three main ways, after Van Coller (1992):

- river flow as a resource necessary for growth and reproduction;
- river flow (floods) as an agent of disturbance; and
- reduced river flow as a stressor during periods of drought or prolonged low flow.

The objective is to seek ecologically-relevant components of the flow regime that create and maintain patterns of lateral zonation in riparian zones and to develop a framework for this understanding to be transferred between rivers. Although there are likely to be community differences between river basins based on regional species pools and variation due to climate and geological differences, it is expected that similarities would be drawn between rivers based on the response of functional groups (Merrit et al. 2010) rather than species.

In all cases, the availability of water is assumed to be the primary determinant of riparian vegetation lateral zone structure. This includes, but is not restricted to the incidence of flooding. The two avenues of investigation are: water as a resource for growth and reproduction and flow as an agent of regeneration in facilitating seedling establishment and persistence. Plants are expected to evolve to exploit favourable conditions and avoid/resist unfavourable conditions. Available water drives sediment supply and maintains landforms, but also provides resources to sustain plant life. However, it is a combination of abiotic and biotic forces that control population demography (Seabloom et al. 2001). Lateral zones may result from flow driven events, competition, or persistence mechanisms, or a combination thereof. The influence of these factors is likely to differ at different bank positions.

A hypothetical riparian zone (Table 2.3) consists of three lateral zones (Figure 2.2) bounded by a freshwater and terrestrial ecosystem on either side. Dotted vertical lines represent the riparian area, while dashed-dotted vertical lines represent the transitions between the lateral zones. Abiotic influences are described in three categories: flow factors, patch factors and plant traits. The central hypothesis is: Vegetation zonation patterns along rivers result from differential species responses to a combination of abiotic factors that vary in space and time.

In general, water availability decreases laterally away from the river channel as the depth to groundwater increases and the frequency of flooding decreases. The probability of being flooded and the duration of inundation decrease laterally with increasing distance and elevation away from the active channel. Inundation duration also influences vegetation structure, with permanent to frequently inundated areas dominated by herbaceous perennials and graminoids, and less frequently inundated areas by shrubs and trees, with an understory of herbaceous perennials and graminoids. The combination of a decrease in water availability and frequency of being flooded equate to a higher probability of experiencing drought conditions. As such, there is a lateral gradation from the river channel as communities continually adapt to the seasonally recurring conditions, which characterise different hydrogeomorphic habitats.

Table 2.3 Conceptual framework of abiotic influences on lateral zonation patterns.

Flow factors		Marginal zone	Lower zone	Upper zone
Surface flow	Maintenance	Base flows ↔ Inter-annual floods		
	Disturbance	Intra-annual floods ↔ Inter-decadal floods		
	Periodicity	Annually regular ↔ Annually stochastic/ decadally regular		
Subsurface flow	Water table	Permanent access ↔ Seasonal access		
Patch factors				
	Substratum type	BR/ alluvium ↔ Alluvium/ colluvium		
	Stability	Stable/ mobilised ↔ Increasing stability		
	Hydraulic conductivity	High ↔ Low		
	Soil nutrients	Low ↔ High		
Plant traits				
	Growth rate	High ↔ Low		
	Water use efficiency	Low ↔ High		
	Flood tolerance	High ↔ Low		
	Drought tolerance	Low ↔ High		

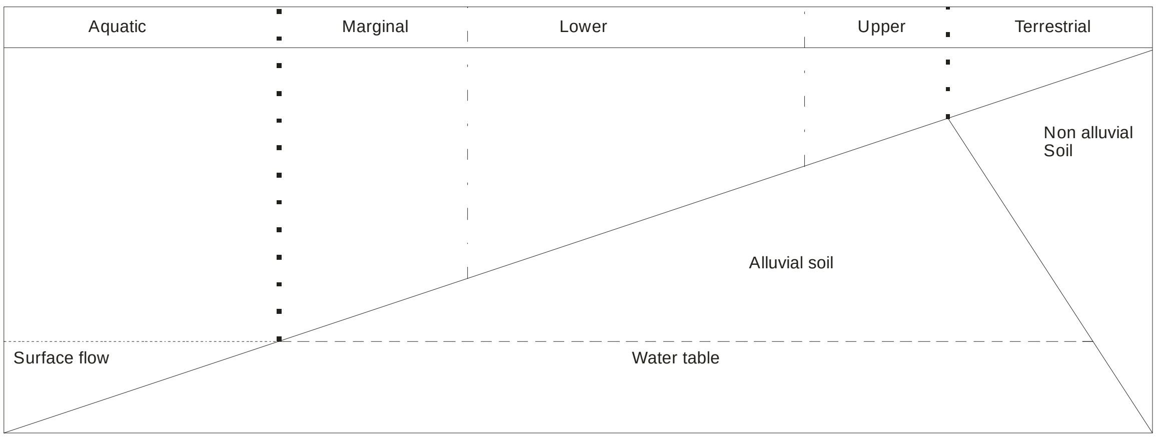


Figure 2.2 Stylised riparian zone showing lateral zones in relation to flow and patch components.

For plants situated in the marginal zone, the annual predictability of a wet season with floods and a dry season with periods of low flow is high and the proportion of the year spent exposed to periods of high flow is greater than for a plant in the lower or upper zones. On average, the plants in this zone have access to permanent surface flow, other than during times of severe drought. The regularity of the intra-annual floods represents the disturbance regime for plants in this zone as many are submerged during larger flood events. The regularly washed alluvium is more frequently mobilised and does not offer a stable landform for colonisation. If the channel is bedrock-controlled however, a stable bedrock pavement may be available and certain specialist plants, such as *Breonadia salicinia,* have evolved to take advantage of this niche. Being regularly disturbed and having permanent access to water, plants in this zone are expected to have high growth rates and low water use efficiencies. In the same way, plants of the marginal zone are expected to have a high tolerance to flooding and correspondingly a low tolerance to drought. Being in such close proximity to water one would expect marginal plants to be predominantly hydrochorous although alternative mechanisms of seed dispersal may also be characteristic. Many marginal zone species are soft-stemmed or fleshy and thus may easily suffer stem snap, be uprooted or broken into fragments during periods of high flow respectively. Some clonal species disperse vegetative fragments (diaspores) that take root on new sediment deposits. Any terrestrial species colonising this zone are expected to be flushed out annually.

Abiotic controls on lower and upper zone plants differ in the same way to that of the marginal zone but the extent to which they differ is greater for plants of the upper zone. These two zones are discussed together. Moisture levels in the lower zone are maintained by the intra-annual floods while the inter-annual floods, of a larger magnitude and lower frequency of occurrence, disturb plants in this zone. Similarly, plants in the upper zone, further up the bank, are maintained by inter-annual floods and disturbed by inter-decadal floods. For plants in this zone, the regularity of floods occurring in any one year is less predictable when compared to those occupying the marginal zone. For plants in the lower zone, and to a greater extent those of the upper zone, the year to year variation in timing, intensity, frequency of floods, and the rate of drying are of critical importance to survival. Over a period of decades, the likelihood of wet years with floods of a large magnitude and also drought years is somewhat predictable, but the timing within that cycle is not (Gasith and Resh 1999). Unlike the marginal zone plants, those occupying the lower and upper zones don't have permanent access to surface flows. They rely instead on groundwater that is replenished during periods of high flow. The depth to the water table increases with increasing distance and elevation from the river channel, and can extend for some distance across a floodplain in bedrock-controlled rivers. In alluvial channels however, there is expected to be an abrupt change in species composition as access to groundwater becomes limiting.

In conjunction with this, there is increasing stability of the river bank as sediments of the lower, and to a greater extent the upper zones, are only mobilised by large flood events. River washed alluvium is mixed with colluvial soils from the hill slopes; soil structure and complexity increases along with organic matter content and water holding capacity. While the life histories of marginal zone plants are dominated by regularly available water, those of the lower and increasingly the upper zones have to contend with periods of low soil moisture during seasonal droughts. This is particularly the case for rivers in semi-arid and Mediterranean climates (Stella et al. 2010) where periods of low flow are coupled with extreme heat during summer. Plants occupying these two zones are expected to have slower growth rates, higher water use efficiencies, greater tolerances to drought and decreased tolerances to flooding.

Thus, life history strategies between marginal, lower and upper zones are expected to differ. Francis (2006) proposed that allogenic (hydrogeomorphic) factors play a larger role in the lives of marginal zone (water-edge) plants and that autogenic (plant-induced) factors play a larger role in the lives of plants higher up the bank (in the lower and upper zones). Taking this concept into our lateral zone framework, factors influencing zone structure should alternate between periods of high and low abiotic stress. Periods of high abiotic stress occur during flooding and towards the end of the dry season (drought); allogenic factors are expected to dominate. During periods of low abiotic stress and moderate conditions, at the end and before the onset of the flood season respectively, resource use is expected to be at a maximum and autogenic factors are expected to dominate. Species are expected to differ in their resistance and resilience to alternating abiotic/biotic drivers, thus the competitive advantages between species in a community is expected to differ over time and between seasons. Yet the role of density dependence and competition and other interactions between riparian plants is not well understood. The role of water availability on establishment and persistence is poorly understood for many riparian plants. Data are few on the prevalence of seed dormancy, germinability, propensity to form seedbanks, the rooting depth of adults, phenology (flowering and seed set), resistance to floods and resilience during droughts. Data on the modes of reproduction of riparian plants and factors controlling their dispersal will help formulate better predictions about the consequences of alterations to flow, upon which many of these factors rely.

2.5 Summary

The composition and structure of riparian communities are influenced primarily by river channel shape and water flow (Naiman et al. 2008). Rivers adjust their morphology (width, depth, slope and planform) to transport the water and sediment supplied from the drainage basin (Newson and Newson 2000). River channels and floodplains increase in width and complexity down the rivers length as the balance between sediment supply and transport shifts from supply limited channels upstream to transport limited channels downstream. Channels in the upper reaches of river basins are laterally constrained with limited capacity to store sediment and other organic matter. Upland rivers and floodplain systems operate under different hydrological regimes and as such exhibit different physical structure/habitat availability. Aside from creating and maintaining physical habitat, the flow regime of a river also has a direct influence on the riverine biota. The conceptual understanding of this influence has been captured in the Natural Flow Regime paradigm (Poff et al. 1997) based on the principle that the integrity of lotic (flowing) ecosystems depends upon their natural dynamic character.

The flow regimes of southern African rivers differ considerably from rivers in the temperate climates where many of the studies of riparian ecology have taken place. South African river flow is ‘predictably unpredictable’ and apart from some coastal regions, the country is semi-arid, and only very few of the rivers are associated with extensive floodplains (Davies et al. 1995), unlike Northern hemisphere rivers. Much of the country experiences summer rainfall and a dry winter. The Western Cape with its Mediterranean climate, i.e., winter rainfall and a dry summer is the exception, although rainfall in the mesic southern coastal region tends to be aseasonal. Almost all the rivers in South Africa exhibit a ‘flashy’ runoff response which is considered to be fairly typical of arid or semi-arid countries (Gordon et al. 2002). This means flood events have short lag times relative to rainfall events in the basin, and steep ascending and receding limbs. Although the wet and dry seasons occur with some regularity, the frequency and magnitude of floods in the wet season is unpredictable relative to Northern Hemisphere rivers. Joubert and Hurly (1994) made use of daily flow data to classify South African rivers. Their analyses of seasonal and the flood characteristics revealed general patterns as follows. The pattern of flow along the subtropical coast and the plateau slopes of the Transkei, KwaZulu-Natal and Mpumalanga were similar. The seasonal groups in these areas were moderate mid-late summer with perennial flow. The southern and eastern Cape coastal belt was clearly distinct in both groupings and characterised by aseasonal flow or a slight early spring peak; a flow regime not commonly found elsewhere in the country. Overall predictability was very low, with a fairly high flood frequency and the lowest flood predictability of all groups. The Western Cape recorded winter peak flow with low overall predictability and high seasonal predictability.

Riparian vegetation communities are dynamic and the proportions of dominant species change down the length of a river. The likelihood of a species growing and persisting at a particular location depends upon the stability of the site for germination and establishment, and the ambient environmental conditions at the site that permit persistence until age of reproduction (Hupp and Osterkamp 1996). Sufficient flows are required seasonally to recharge ground water levels at the end of the dry season and also to facilitate vegetation recruitment (dispersal, germination and growth of seedlings), often toward the end of the flood season. The life histories of some species on large floodplain rivers of the northern hemisphere are intimately linked with the annual flood peak. Flowering and seed set are cued such that seed dispersal takes place as flood waters recede (Mahoney and Rood 1998). Hughes (1988; Tana River floodplain in Kenya) and van Coller (1992; Sabie River in the Kruger National Park) presented empirical evidence for the existence of plant communities in lateral zones and sought links to link community descriptions with indirect gradients, such as elevation and distance from the active channel. Both authors introduced lateral zonation in their categorisations of riparian communities describing a combination of hydraulic and geomorphic factors for the patterns described. These studies differed to ours as they:

- were on large rivers lower down the longitudinal profile, and
- dealt with seral succession of floodplain communities in lateral zones; much like the studies of northern hemisphere floodplain forests.

Both experienced difficulties in linking flow components to exact floodplain positions (elevation and distance vectors). This was attributed to a combination of the complexity of the floodplain geomorphic mosaic and inaccurate/incomplete hydrological data.

In this report we have assumed the naming convention of Kleynhans et al. (2007a) as a starting point to avoid confusion since many practitioners are already using the VEGRAI method and it represents the most current, and possibly the first, naming convention consensus by South African botanists for lateral zones. A hypothetical riparian zone (Table 2.3) consists of three lateral zones (Figure 2.2) bounded by a freshwater and terrestrial ecosystem on either side. In general, water availability decreases laterally away from the river channel as the depth to groundwater increases and the frequency of flooding decreases. The probability of being flooded and the duration of inundation decrease laterally with increasing distance and elevation away from the active channel. Inundation duration also influences vegetation structure, with permanent to frequently inundated areas dominated by herbaceous perennials and graminoids, and less frequently inundated areas by shrubs and trees, with an understory of herbaceous perennials and graminoids. The combination of a decrease in water availability and frequency of being flooded equate to a higher probability of experiencing drought conditions. As such, there is a lateral gradation from the river channel as communities continually adapt to the seasonally recurring conditions, which characterise different hydrogeomorphic habitats. Thus, life history strategies between marginal, lower and upper zones are expected to differ.

3 CHARACTERISTICS OF LATERAL ZONES

3.1 Introduction

Riparian zones are ecotones (Swanson et al. 1992) that occupy a three-dimensional (Wilson and Imhoff 1998), transitional area between aquatic and terrestrial ecosystems. Typically, the biotic communities that occupy the banks of rivers and floodplains occur as a mosaic of vegetation communities associated with variation in soil type and moisture (Naiman and Decamps 1997), and are thus distinct, in terms of species richness and composition (Corbacho et al. 2003), from adjacent terrestrial communities (Naiman et al. 2005). Headwaters are characterized by single thread channels, limited floodplain development and storage capacity, vertical exchange with the hyporheos, steeper longitudinal and lateral gradients and coarser substrata (Gomi et al. 2002) than rivers further downstream. Undisturbed headwaters are well-suited to the study of zonation patterns as the riparian communities are laterally constrained and are characterised by steep lateral gradients. This means the entire riparian width may be studied over a relatively short distance as changes between communities occur sharply. Thus, the headwaters of the Fynbos biome of the Western Cape (South Africa) were considered ideal for the purposes of investigating lateral zonation patterns.

Despite extensive research in the Fynbos biome of the Western Cape, a Mediterranean Type Ecosystem, its riparian vegetation has not been intensively studied until recently and there is no formal classification of riparian vegetation communities for the Western Cape (Prins et al. 2004) or for the rest of Southern Africa. The riparian zones of perennial Western Cape headwaters are inhabited by members of the Fynbos Riparian Vegetation community (Mucina and Rutherford 2006). Fynbos Riparian Vegetation is easily distinguished from the surrounding vegetation (Boucher 1978) and has been alternately described as hygrophilous mountain fynbos (Taylor 1978), closed-scrub fynbos (Campbell 1985, Cowling and Holmes 1992) or broad sclerophyllous closed scrub (Cowling et al. 1997). Cowling and Holmes (1992) describe the vegetation as being similar to forest and thicket, with a relatively high cover of mesophyllous non-proteoid woody plants, but dissimilar in its high cover of Restionaceae and the presence of Ericaceae. Fynbos Riparian Vegetation dominates rivers in valleys with fire cycles shorter than 50 years and is typified by the small trees *Brabejum stellatifolium, Metrosideros angustifolia* and *Brachylaena neriifolia* (Holmes et al. 2005). Other shade tolerant species may establish as the canopy closes and Southern Afrotemperate Forest (Mucina and Rutherford 2006) may develop with protection from fire longer than 50 years (Taylor 1978).

Although less studied than floodplain systems, some attention has been paid to the zonation patterns of Fynbos Riparian Vegetation. Boucher (2002) developed a seven-zone classification system that distinguishes zones on the basis of their species composition, which was thoroughly investigated by Sieben (2002) on Western Cape rivers and updated by Sieben and Reinecke (2008). These authors used the Braun-Blanquet (phytosociological) classification system to describe lateral zones. This method relies on specialist knowledge to delineate communities within the riparian area *a priori* purposefully avoiding transitions between different communities. Reinecke et al. (2007) explored patterns of zonation in

Modified-Whittaker nested vegetation sample plots (Stohlgren et al. 1995) system and found evidence for four lateral zones. However, the data included canopy cover of species rooted outside of the sample area, which may have skewed the results as riparian species do not always grow upwards; a plant may be rooted 5 to 10 m away from its canopy. Further, riparian zones are notoriously dense, and distinguishing the root and canopy of an individual plant from that of its neighbours is often difficult. Subsequently, Kleynhans et al. (2007a), in consultation with a number of South African botanists, produced a simplified description of three lateral zone types for rivers in South Africa: marginal, lower and upper zones.

The various descriptions underpin the belief that lateral zones exist and postulate links between the zones and changes in bank topography, aspects of the flow regime, or a combination thereof, albeit that there are discrepancies between the results of different studies. We believe this uncertainty stems from different interpretations of the pattern and the application of different methods for collection and analysis of the data, which make it difficult to discern whether the patterns are real and if so, the number of lateral zones that occur. Most studies have assumed the patterns exist and accommodated this assumption within the sampling protocol, usually by delineating *a priori* sample plots within community types. This is a standard protocol of the phytosociological (Braun-Banquet) approach based on an assumption of community stability at larger scales and may be unsuitable for use in highly variable, narrowly-linear environments (Kent and Coker 1992), such as riparian areas. The main confounding issue with phytosociological data is that different practitioners who collect the same data at the same site may produce different classifications because the boundaries between lateral zones are selected upfront, and then determine the location of sample plots. A further problem arises during data processing if sample plots assigned to one lateral zone, group with those of a different lateral zone based on their species complement.

For this study, we used methods of data collection and analysis that would identify patterns independently of user decisions. The idea being that, if the patterns exist, then it will be possible to generate data from other hydrogeomorphic settings and in other vegetation communities (see Chapter 4) that can contribute toward and refine a framework of zone types.

The key question was “Can characteristic taxa be used to identify lateral zones?”

Three hypotheses were tested:

- Riparian plants are distributed in a repetitive and predictable manner.
- Groundcovers and canopy species contribute in different ways to the pattern.
- Characteristic taxa are restricted to specific lateral zones.

The results presented expand on those in Reinecke et al. (2007). This is because the data were collected at the same sites in the same sample plot configuration. However, the Reinecke et al. (2007) data included canopy cover of species outside the sample area, while those presented here are for species rooted in the sample area only**.** This was considered to be more accurate toward formulating links between species distributions and flow.

3.2 Method statement

3.2.1 Data collection

Data were collected from 16 sites on five undisturbed rivers. A geomorphological hierarchy (Rowntree et al. 2000) was used to classify the longitudinal zone in which each site was located based upon river slope and valley shape (Table 3.1). Slope was calculated from electronic 1:50 000 maps in ARCVIEW. Headwater sites, in the mountain stream, transitional and upper foothill (longitudinal) zones, were chosen on single thread rivers with restricted floodplain development and predominantly longitudinal river flow. This was done to reduce the topographic complexity of the riparian area laterally; lowland rivers with expanding floodplains are typically more hydro-geomorphologically complex and were not considered in this study.

At each site four contiguous belt transects were laid out (Figure 3.1). Cover abundance data, estimated visually as a percentage of each plant species in each sample plot, were collected for all canopy layers and groundcovers rooted in the sample plots. The occurrence of each species at each study site is shown in Appendix Table 1 (nomenclature follows Goldblatt and Manning 2000). Overhanging species rooted outside of sample plots were excluded. Transects comprised contiguous 5x1 m sample plots, positioned from the water's edge to the outer edge of the riparian zone, indicated by the presence of terrestrial vegetation. The density and distribution of trees and shrubs was recorded to 1 m accuracy within each sample plot. Trees were separated into three life history stages; seedlings (height <0.3 m), saplings (0.3 < height < 2 m) and adults (height > 2 m).

Table 3.1 Location and description of study sites. Masl = metres above sea level. Zones as per Rowntree et al. (2000, Table 2.1).

Basin	River	Code	Longitudinal zone	Gradient	Altitude (masl)	Co-ordinates
Olifants	Rondegat	R1	Mountain stream	0.085	624	S 32.396067°, E 19.089733°
		R2	Mountain stream	0.085	624	S 32.396033°, E 19.089467°
		R3	Transitional	0.029	501	S 32.376825°, E 19.067119°
		R4	Transitional	0.029	497	S 32.376325°, E 19.066775°
	Heks	H1	Transitional	0.023	245	S 32.435379°, E 19.008838°
		H2	Transitional	0.023	244	S 32.435269°, E 19.008638°
		H3	Upper Foothills	0.018	175	S 32.436450°, E 18.981384°
		H4	Upper Foothills	0.018	167	S 32.436533°, E 18.981342°
Breede	Witte	W1	Transitional	0.027	285	S 33.571850°, E 19.138617°
		W2	Transitional	0.027	281	S 33.571550°, E 19.138717°
	Elands	E1	Mountain stream	0.054	519	S 33.760900°, E 19.128417°
		E2	Mountain stream	0.054	505	S 33.760753°, E 19.128325°
		E3	Transitional	0.017	450	S 33.740167°, E 19.113183°
		E4	Transitional	0.017	446	S 33.739756°, E 19.113142°
Berg	Jonkershoek	J1	Mountain stream	0.040	360	S 33.993750°, E 18.975517°
		J2	Mountain stream	0.040	314	S 33.987075°, E 18.956507°

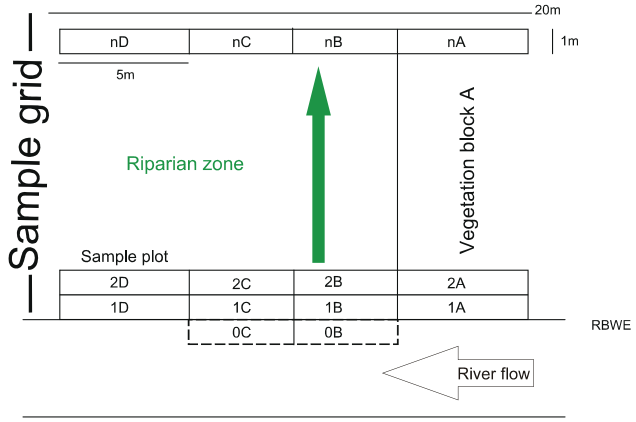


Figure 3.1 Sample grid of belt transects. RBWE = right bank water's edge.

The location (elevation and distance from the water's edge) of each sample plot was surveyed with a total station (Leica TC307 model). Thus four cross-sections were surveyed across the macro-channel on both banks; each through the middle of a belt transect. Proportions of soil texture were recorded for each sample plot (Wentworth scale, Gordon et al. 2002). Collected specimens were submitted to the Compton Herbarium, located at the Kirstenbosch National Botanical Gardens, Cape Town, South Africa, for identification.

3.2.2 Data analyses

Relationships were investigated at two scales: *between* rivers at the site scale and *within* sites at the sample-plot scale.

3.2.2.1 Comparison between rivers

Cover abundance data from all sample plots were lumped together by summing cover values into a single species list for each site. ANOSIM (analysis of similarities Clarke and Warwick 2001), a non-parametric permutation procedure analogous to ANOVA was used to determine significance of separation between site and river groups. Differences between groups were explored at three taxon levels: growth form, family and species as follows.

The cover recorded for each species at a site was lumped together into ten growth form categories (Table 3.2). Average cover of each growth form in each sample group was compared. The cover recorded for each species at each site was sorted into families. An average cover was calculated for each family and the frequency of occurrence between sample groups was compared.

Multivariate analyses (PRIMER V6, Clarke and Warwick 2006) were used to discern patterns of zonation based on species-level similarities between river groups. Data were 4^{th} root transformed in order to boost the presence of smaller species at lower covers. Bray-Curtis similarity coefficients were calculated between rivers and the results were displayed using Multidimensional Scaling ordinations (MDS) and CLUSTER analyses (Clarke and Gorley

2006). The SIMPER (similarity percentages) routine in PRIMER (V6, Clarke and Warwick 2006) was used to discern typical and differentiating species between river groups.

Table 3.2 Growth form definitions (Goldblatt and manning 2000).

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

3.2.2.2 Comparison within sites

Cover abundance data from all sample plots were separated into sites. Data were separated into three sets: groundcovers, trees and trees/groundcovers combined. Trees were separated into three life history stages: seedlings (height < 0.3m), saplings (0.3 < height < 2.0 m) and adults (height > 2.0 m). Each data set was analysed independently.

COMPARING PATTERNS OF ZONATION

Multivariate analyses (PRIMER V6, Clarke and Warwick 2006) were used to discern patterns of zonation based on species-level similarities between sample plots for ground covers, trees and trees/groundcovers separately. The different ways that groundcovers and trees contribute to the pattern were explored using the Rondegat River sites (R1-R4). Based on the results of this initial analysis it was decided to pursue the pattern using a combination of trees/groundcovers only at all the rivers. In each case the data were 4th root transformed in order to boost the presence of smaller species at lower covers. Bray-Curtis similarity coefficients were calculated between samples and the results were displayed using Multidimensional Scaling ordinations (MDS) and CLUSTER analyses (Clarke and Gorley 2006).

Lateral zones were assigned to species groups of trees/groundcovers data for each site. Groups of sample plots with greater than 40% similarity were tentatively recognised, along with a few clusters of plots with lower similarity but obvious cohesion as a group. Groups of sample plots were numbered from 1, closest to the water's edge, and in ascending order laterally outwards. Each site produced several groups numbered from 1 upwards. A group was designated to a lateral zone based on the habitat characteristics of dominant species. Goldblatt and Manning (2000) provided habitat preference data and plants were assigned to one of three categories as follows:

- species common on or near streamsides, seeps, rivers and watercourses were deemed **obligate** riparian (wet) species;

- those occurring on rocky slopes and outcrops or mountain slopes were deemed **incidental** terrestrial (dry) species; and
- species described as occurring in bush, woodland or forests and/or associated with water courses were deemed **facultative** riparian (wet/dry) species.

These designations are listed in Appendix Table 2. To avoid confusion, we adopted the Kleynhans et al. (2007a) naming convention for the lateral zones. The following logic was used to designate groups into lateral zones based on which of the three categories of plants were dominant in a group:

- groups that contained only incidental species were designated terrestrial and were not considered further;
- groups containing a mixture of incidental and facultative species, and most closely related to terrestrial groups were designated upper;
- groups with facultative species were designated lower;
- groups with a mixture of facultative and obligate and most closely related to lower or marginal were designated lower dynamic; and
- groups with obligate species were designated marginal.

DETERMINING INDICATORS FOR EACH LATERAL ZONE

Two different analyses were used to discern indicators for lateral zones. Firstly, the SIMPER (similarity percentages) routine in PRIMER (V6, Clarke and Warwick 2006) was used to discern typical and differentiating species for lateral zones and, from this, similarity coefficients for typical species and dissimilarity coefficients for differentiating species were tabulated per river using the trees/groundcovers data set. Secondly, General Discriminant Models (GDA, StatSoft 2012) were computed between the species composition of lateral zones for all rivers by combining the data from all sites but separating them into for groundcovers, trees and trees/groundcovers separately. The first analysis seeks to identify river based differences in species composition while the second seeks to provide indicators for Fynbos Riparian Vegetation overall.

3.3 Results

3.3.1 Comparison between rivers

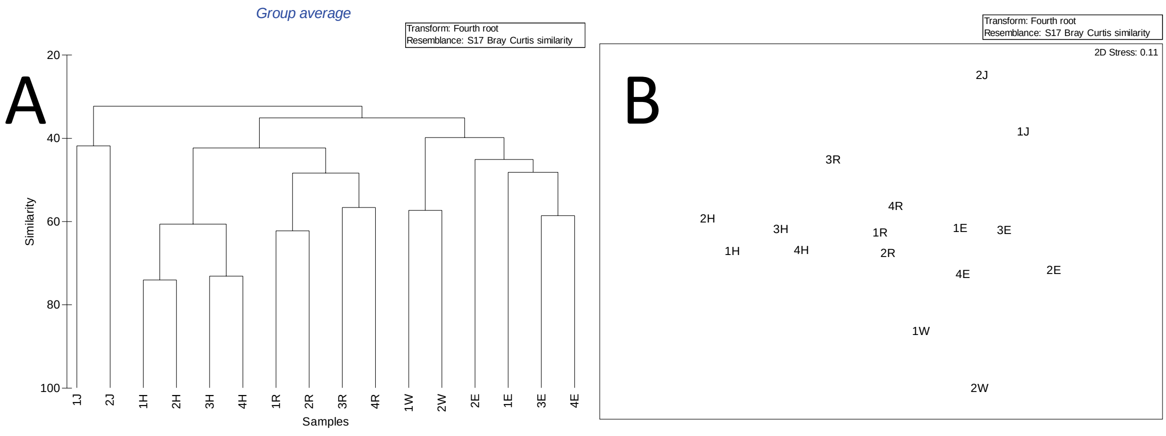


Figure 3.2 (A) CLUSTER and (B) MDS ordination of Bray Curtis similarity between species composition of sites. Site codes as per Table 3.1.

The 16 sites grouped by river basin first. The Hex and Rondegat Rivers of the Olifants basin separated from the Witte and Elands Rivers of the Breede Basin, while the Jonkershoek River formed a third group of the Berg Basin. Within each basin group, the rivers separated from one another and replicate sites separated into longitudinal zones. For example, the two transitional sites on the Hex River (H1 and H2) separated from those in the upper foothills (H3 and H4). This was true for all sites, rivers and basins. A global nested pair-wise ANOSIM test of differences between the species composition of rivers within basins were different (R = 0.869, p < 0.01) while no such differences were significant between basins. Thus, interpretations of patterns within the data were focussed at a river-scale.

Within river groups, forbs, grasses, shrubs and small trees were generally well represented (Table 3.3). A Kruskal-Wallis ANOVA by ranks for multiple independent samples performed on mean abundances in growth form groups did not reveal significant differences.

Table 3.3 The mean and standard deviation about average abundance of growth forms per river basin. Growth form categories as per Table 3.2. (n) = number of sites while (N) = number of observations.

Growth form	Forb	Geophyte	Rush	Sedge	Grass	Restio	Small shrub	Shrub	Small tree	Large tree	Unknown
Olifants n=8											
Mean	10.98	0.02	2.37	4.79	9.32	15.69	0.20	12.26	36.67	7.42	0.34
SD	11.9	0.1	4.3	3.5	9.3	6.7	0.4	3.5	16.3	4.8	
N	8	1	3	8	8	8	3	8	8	8	
Breede n=6							^				
Mean	8.78	0.00	0.02	3.61	11.45	15.64	2.47	25.93	24.25	7.86	0.10
SD	7.92	0.0	0.1	2.7	6.9	3.3	2.4	13.9	6.1	5.0	
N	6	0	1	6	6	6	5	6	6	6	
Berg n=2											
Mean	11.57	0.40	0.00	7.44	6.37	17.08	0.40	13.90	22.03	10.70	9.71
SD	13.6	0.6	0.0	2.5	2.5	11.4	0.6	8.2	2.9	6.0	
N	2	1	0	2	2	2	1	2	2	2	

Restionaceae, Myrtaceae, Poaceae, Ericaceae, Myricaceae, Cyperaceae, Asteraceae and Proteaceae were the best represented families (Table 3.4) and are among the top ten most speciose families in Fynbos Riparian Vegetation (Cowling and Holmes 1992). The following species were typically found (Table 3.5):

- Restionaceae, *Calopsis paniculata* and *Elegia capensis*;
- Mrytaceae, *Metrosideros angustifolia*;
- Poaceae, *Pennesetum macrourum* and various *Ehrharta* species;
- Ericaceae, *Erica caffra*;
- Myricaceae, *Morella serrata*;
- Juncaceae, various *Juncus* spp.;
- Asteraceae, various asters but notably *Brachylaena neriifolia*; and
- Proteaceae, *Brabejum stellatifolium*.

Differentiating species were either incidental or obligate riparian species (Table 3.6). The Hex River was distinguished from the Rondegat, Elands and Witte rivers by the presence of *Ehrharta rehmannii.* The Jonkershoek Rivers was distinguished from the Rondegat, Elands and Witte Rivers by the presence of *Cliffortia cuneata* and *Erica sphaeroidea*. Within the Olifants Basin *Pteridium aquilinum* and *Freylinia lanceolata* differentiated the Heks from the Rondegat. Within the Breede basin *Metrosideros angustifolia* trees, *Erica hispidula* and *Prionium serratum* differentiated the Elands from the Witte River.

Table 3.4 Mean abundance of families per river basin. (n) = number of sites, (N) = number of observations.

	Breede (n=6)			Olifants (n=8)			Berg (n=2)		
	mean	SD	N	mean	SD	N	mean	SD	N
Restionaceae	15.6	3.3	6	15.1	6.6	8	17.1	11.4	2
Myrtaceae	11.6	3	6	22.3	9.6	8	11.6	0.6	2
Poaceae	11.3	6.8	6	9.3	9.6	8	6.4	2.4	2
Ericaceae	7.4	3.6	6	3.1	4.7	4	10.4	4.7	2
Myricaceae	4.9	4.3	6	9.1	7.6	8	5.4	6.2	2
Cyperaceae	3.6	2.7	6	4.6	3.4	8	11	7.5	2
Asteraceae	6.9	4.2	6	6.4	4.8	8	4.1	5.7	2
Proteaceae	4.6	3.3	6	6	6.5	8	5.8	5	2
Dennstaedtiaceae	2.3	2.6	4	6.9	9.3	4	5	2.8	2
Prioniaceae	10.1	15.2	4	1	2.2	4	1.7	2.1	2
Ebenaceae	1.5	0.8	6	3.3	3.1	7	1.8	0.9	2
Anacardiaceae	0.2	0.4	1	3.1	2.8	7	2.6	2.1	2
Osmundaceae	1.8	2.4	6	2.1	4.9	5	0.4	0.6	2
Rubiaceae	3	4.6	3	0.2	0.3	3			
Scrophulariaceae	0	0	1	1.8	2.1	6	1.3	1	2
Celastraceae	1.8	1.8	5	0.8	1.6	4	0.3	0.4	2
Bruniaceae	2.4	4.3	4				0.1	0.1	2
Blechnaceae	1.1	1.7	4	0.7	1.8	3	0.4	0.3	2
Cunoniaceae	1.7	2.9	4				0.3	0.4	2
Fabaceae	0.4	0.3	5	0	0.1	2	0.4	0.5	2
Juncaceae	0	0.1	1	0.7	1.9	2			
Salicaceae	0.6	1.5	1	0	0.1	1			
Thymeleaceae	0.1	0.2	1				0.1	0.1	2
Asparagaceae	0	0.1	1				0.1	0.1	2
Myrsinacaea				0.1	0.2	1			
Campanulaceae				0.1	0.2	4			
Podocarpaceae	0.1	0.2	1						
Haloragaceae				0	0	1			
Aizoaceae				0	0.1	2			

Table 3.5 Typical species at each river. Sim = similarity coefficient. S = seedling, J = sapling and T = tree.

River	Sim. (%)	Species
Rondegat	52	*Calopsis paniculata* *Brabejum stellatifolium J* *Metrosideros angustifolia J*
Heks	65	*Morella serrata J* *Ehrharta rehmannii* *Calopsis paniculata*
Witte	57	*Prionium serratum* *Morella serrata J* *Erica caffra*
Elands	48	*Brabejum stellatifolium S* *Brachylaena neriifolia T* *Metrosideros angustifolia T*
Jonkershoek	42	*Erica caffra* *Metrosideros angustifolia T* *Elegia capensis*

Table 3.6 Differentiating species between rivers. Diss = dissimilarity coefficient. I = *Ischyrolepis*, M = *Metrosideros* and P = *Pentameris*. J = sapling, T = tree. Bolded species are riparian obligates, others are incidental.

	Rondegat	Heks	Witte	Elands	Jonkershoek
Rondegat		Diss. = 58 % *Ehrharta rehmannii* *Pteridium aquilinum* ***Freylinia lanceolata* C**	Diss. = 63 % *I. fraterna* ***Berzelia lanuginosa*** *P. distichophylla*	Diss. = 59 % *P. disctichophylla* ***Ilex mitis T*** ***Isolepis prolifera***	Diss. = 64 % *Cliffortia cuneata* *Erica sphaeroidea* ***I. subverticulata***
Heks			Diss. = 70 % *Ehrharta rehmannii* *I. fraterna* ***Erica caffra***	Diss. = 69 % *Ehrharta rehmannii* *P. disctichophylla* ***Cyperus denudatus***	Diss. = 74 % *Aristea capitata* *Cliffortia cuneata* *Erica sphaeroidea*
Witte				Diss. = 60 % ***M. angustifolia J*** *Erica hispidula* ***Prionium serratum***	Diss. = 71 % *Aristea capitata* *Cliffortia cuneata* ***I. subverticulata***
Elands					Diss. = 63 % *Erica sphaeroidea* *Cliffortia cuneata* ***I. subverticulata***

3.3.2 Comparison within sites

The patterns of groundcovers versus trees alone differed at the Rondegat River (Figure 3.3-Figure 3.6). In most cases this was due to the absence of trees from some sample plots, these outliers would thus not contribute toward the pattern. Patterns of trees showed that in some cases, sample plots situated some distance apart contained similar species. For example, a water's edge sample plot grouped closely with a sample plot 5 m up the bank. Ground covers on the other hand were generally abundant and at each river a clear pattern of separation was evident with few outliers. Sample plots in close proximity to one another grouped strongly and in a chronological order in line with their position to the active channel.

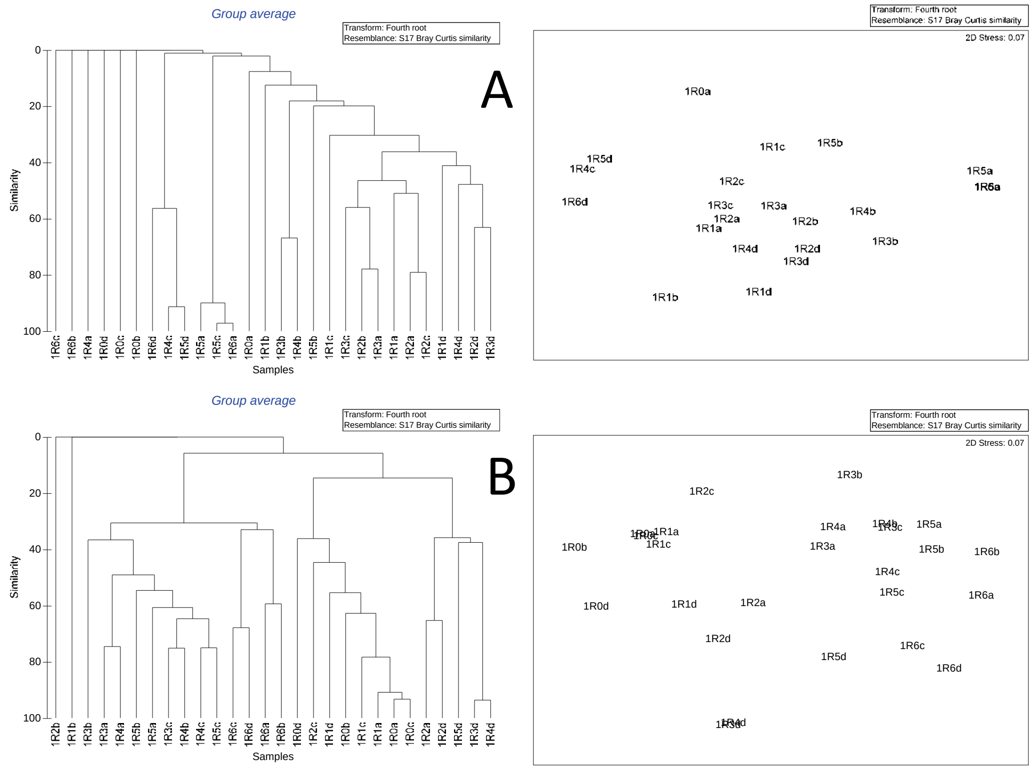


Figure 3.3 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots at R1. Site codes as per Table 3.1. A = canopy, B = groundcover.**

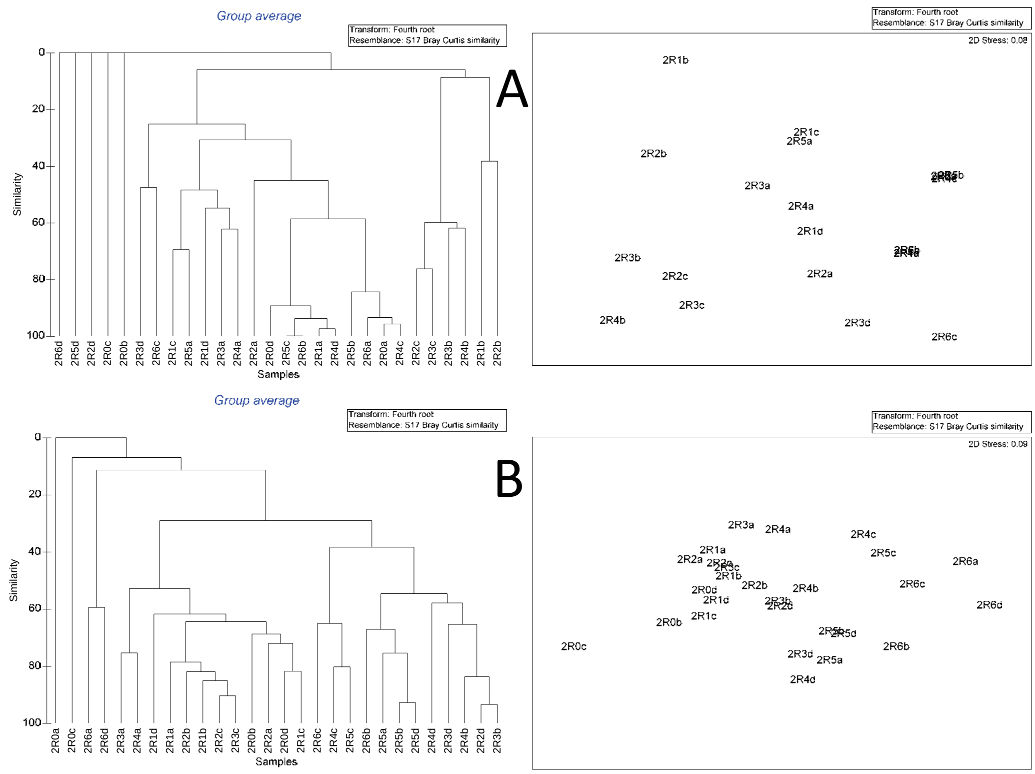


Figure 3.4 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots at R2. Site codes as per Table 3.1. A = canopy, B = groundcover.**

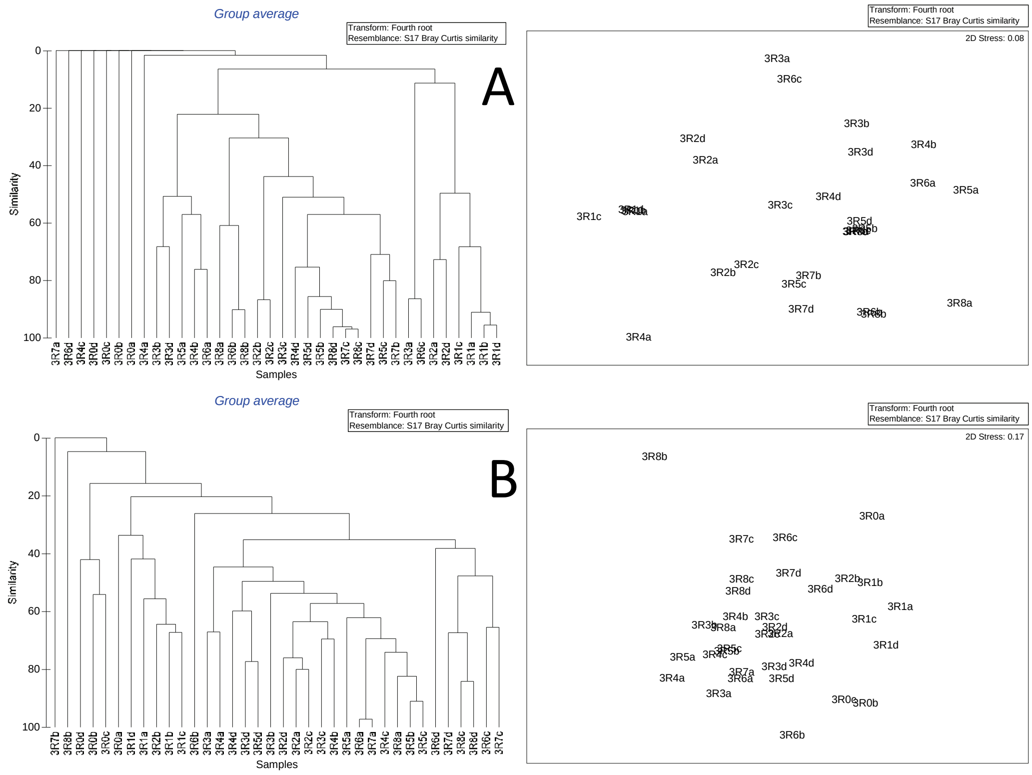


Figure 3.5 CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots at R3. Site codes as per Table 3.1. A = canopy, B = groundcover.

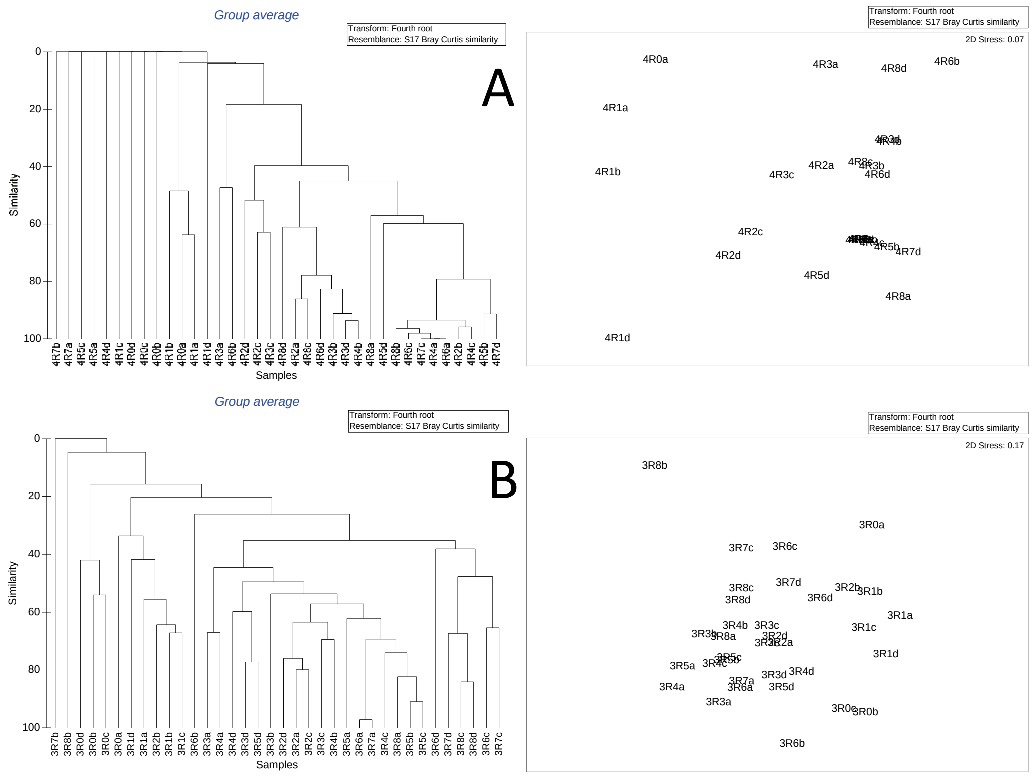


Figure 3.6 CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots at R4. Site codes as per Table 3.1. A = canopy, B = groundcover.

Patterns of lateral zones at all sites showed there were four kinds of lateral zones (Figure 3.7 -Figure 3.11). As expected, a marginal zone, a lower zone and upper zone were present. The marginal was situated at the active channel edge for a short distance up the bank. The majority of the riparian area comprised the lower and upper zones. The lower zone formed the body of the riparian area being situated in the middle and the upper zone formed the boundary with the adjacent terrestrial community. The fourth lateral zone, the lower dynamic, was transitional between the marginal and lower and could be most similar to either, depending upon whether it comprised obligate or facultative riparian species.

In some cases a lateral zone was absent. For example, the marginal zone was absent alongside pools, such as at 2R, 4R, 4E and 1J. The upper zone was absent at 4R as the site was to laterally extensive to reach the adjacent terrestrial community using a contiguous sample plot layout. In all other cases there were four zones. The outputs of the CLUSTER and MDS ordinations concur on the pattern and this was taken to strengthen the relationships presented (Clarke and Warwick 2006).

The SIMPER analyses showed the marginal zone at the Hex and Rondegat rivers consisted of *Isolepis prolifera,* while at the Elands River *Salix mucronata* and *Prionium serratum* were more common (Table 3.7). The marginal at the Witte River comprised recruiting saplings of *Morella serrata* and *Brachylaena neriifolia.* The most common plants in the lower dynamic were *Calopsis paniculata,* at the Rondegat and Hex rivers, and trees and saplings of *Morella serrata,* at the Elands, Witte and Jonkershoek Rivers. *Erica caffra* was also typically found in the lower dynamic of the Rondegat and the Jonkershoek Rivers. *Metrosideros angustifolia* trees were the most common lower zone plant at the Rondegat, Hex, Witte and Elands Rivers but not at the Jonkershoek River. Some plants typically found in the lower dynamic were also present here, including *Morella serrata, Erica caffra* and *Elegia capensis.* The upper zone was typified by disturbance favoured species, such as *Pteridium aquilinum* or incidental species, such as *Ehrharta ramosa, Ehrharta rehmannii, Pentameris distichophylla* and *Diospyros glabra.* The degree of similarity ranged from 9-60% reflecting a wide variance in the distribution of plants between lateral zones and between sites.

SIMPER showed *Isolepis prolifera* to be a good differentiating species for the marginal zone at the Rondegat and Hex Rivers (Table 3.8). Recruiting saplings of *Morella serrata* and *Salix mucronata* were good differentiators for the Witte and the Elands River respectively. There was no marginal zone at the Jonkershoek River. *Calopsis paniculata* was a good differentiating species for the lower dynamic at the Rondegat and Hex Rivers while *Elegia capensis,* another obligate restio, was situated in this position on the Elands River. Recruiting saplings of *Metrosideros angustifolia* and *Brabejum stellatifolium* were good differentiators for the lower zone Witte and Jonkershoek Rivers respectively. *Metrosideros angustifolia* trees were good differentiators for the lower zones of Rondegat, Hex, Witte and Elands Rivers, along with *Brabejum stellatifolium* trees at the Rondegat and Jonkershoek Rivers. Incidental grasses, such as *Ehrharta ramosa, Ehrharta rehmannii* and *Pentameris distichophylla* were good differentiators for the upper zone, as were incidental trees *Maytenus oleoides* and *Hartogiella schinoides* on the Witte as well as the shrub *Diospyros glabra* on the Heks River. In some cases a plant, for example *Morella serrata* trees, was a good differentiating species for two different zones; the lower zone at the Hex River and the lower dynamic at the Jonkershoek River.

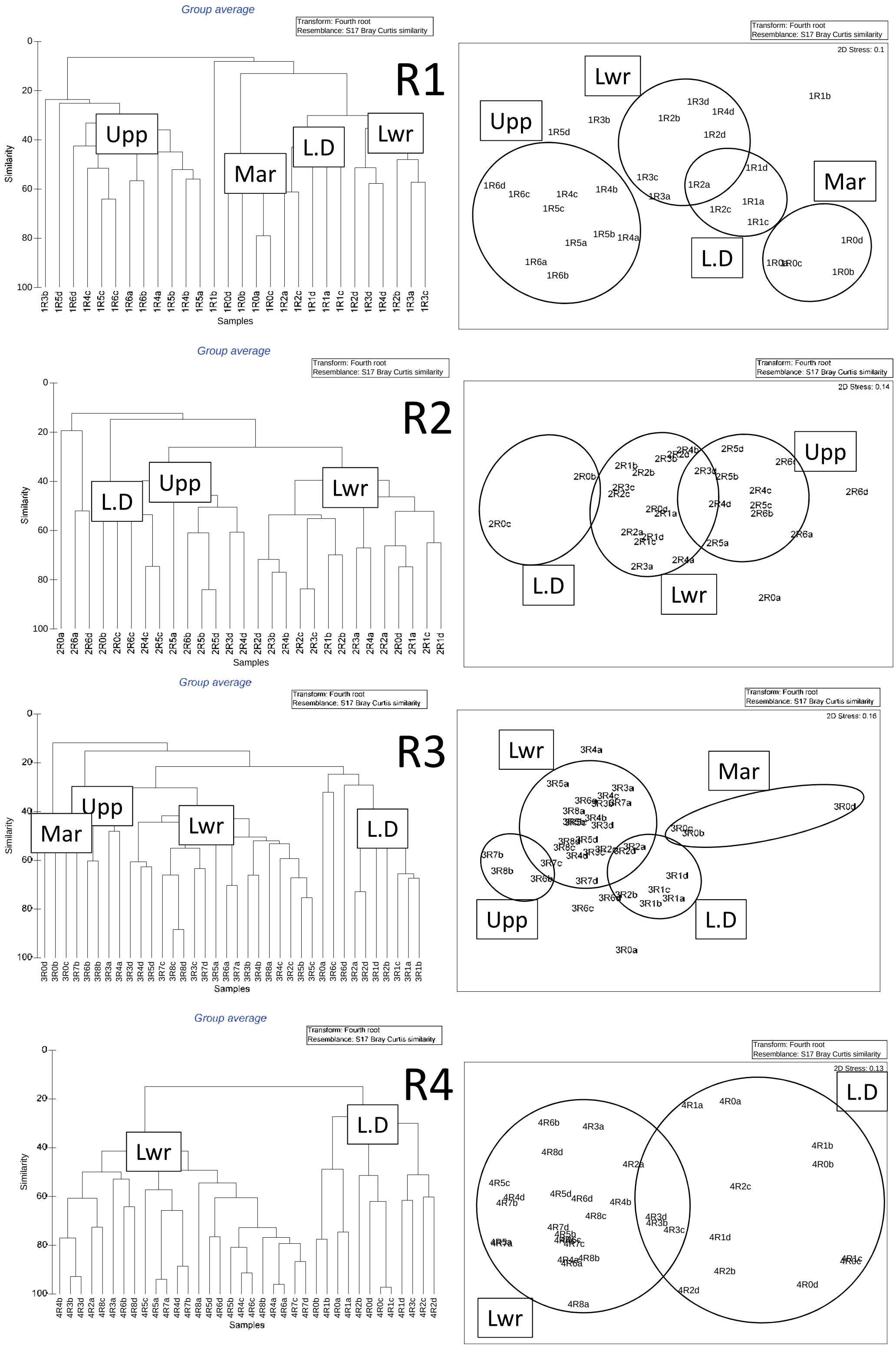


Figure 3.7 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on the Rondegat River. Site codes as per Table 3.1. Mar = marginal, L.D. = lower dynamic, Low = lower and Upp = upper.**

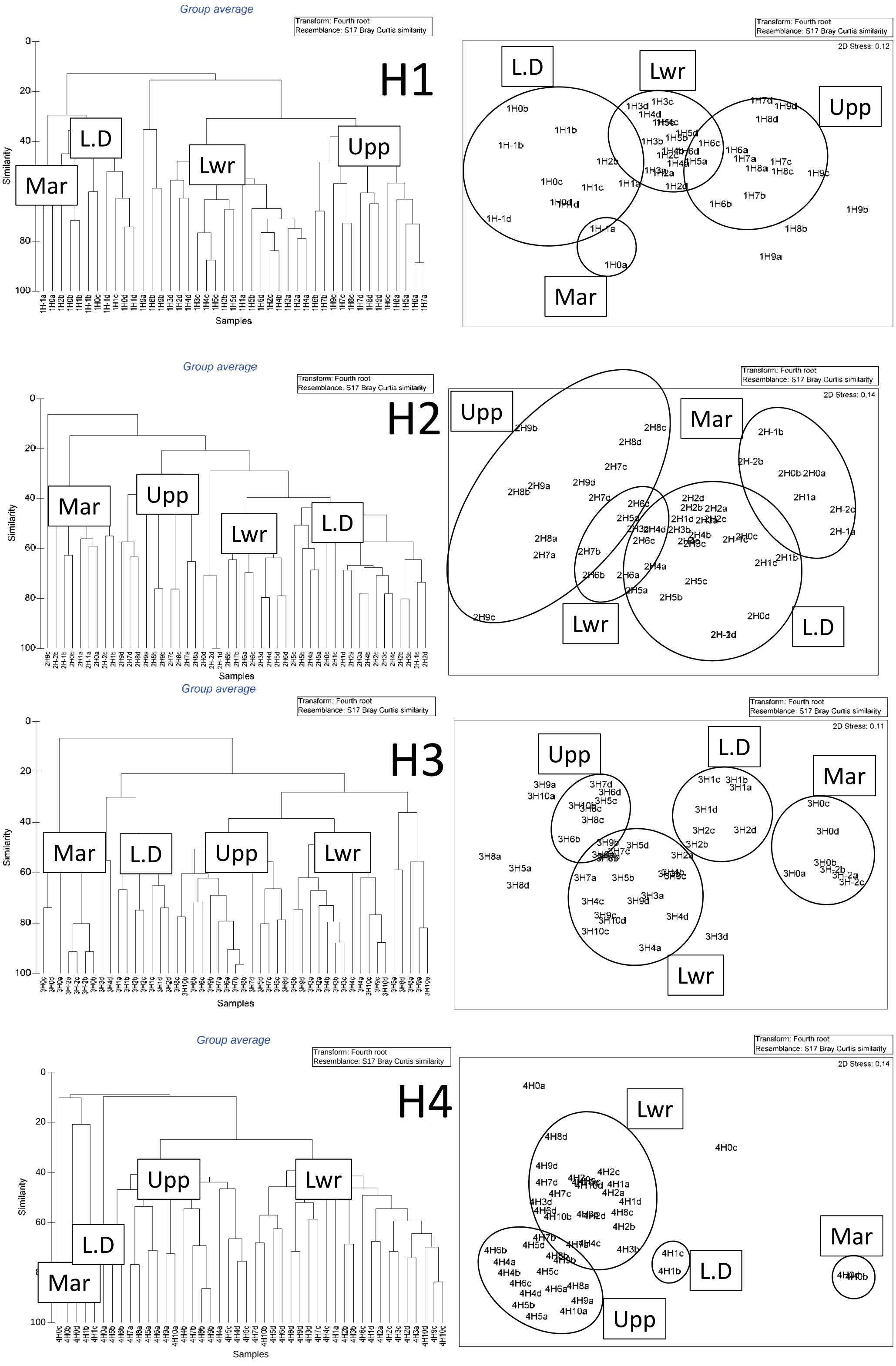


Figure 3.8 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on the Hex River. Site codes as per Table 3.1. Mar = marginal, L.D. = lower dynamic, Low = lower and Upp = upper.**

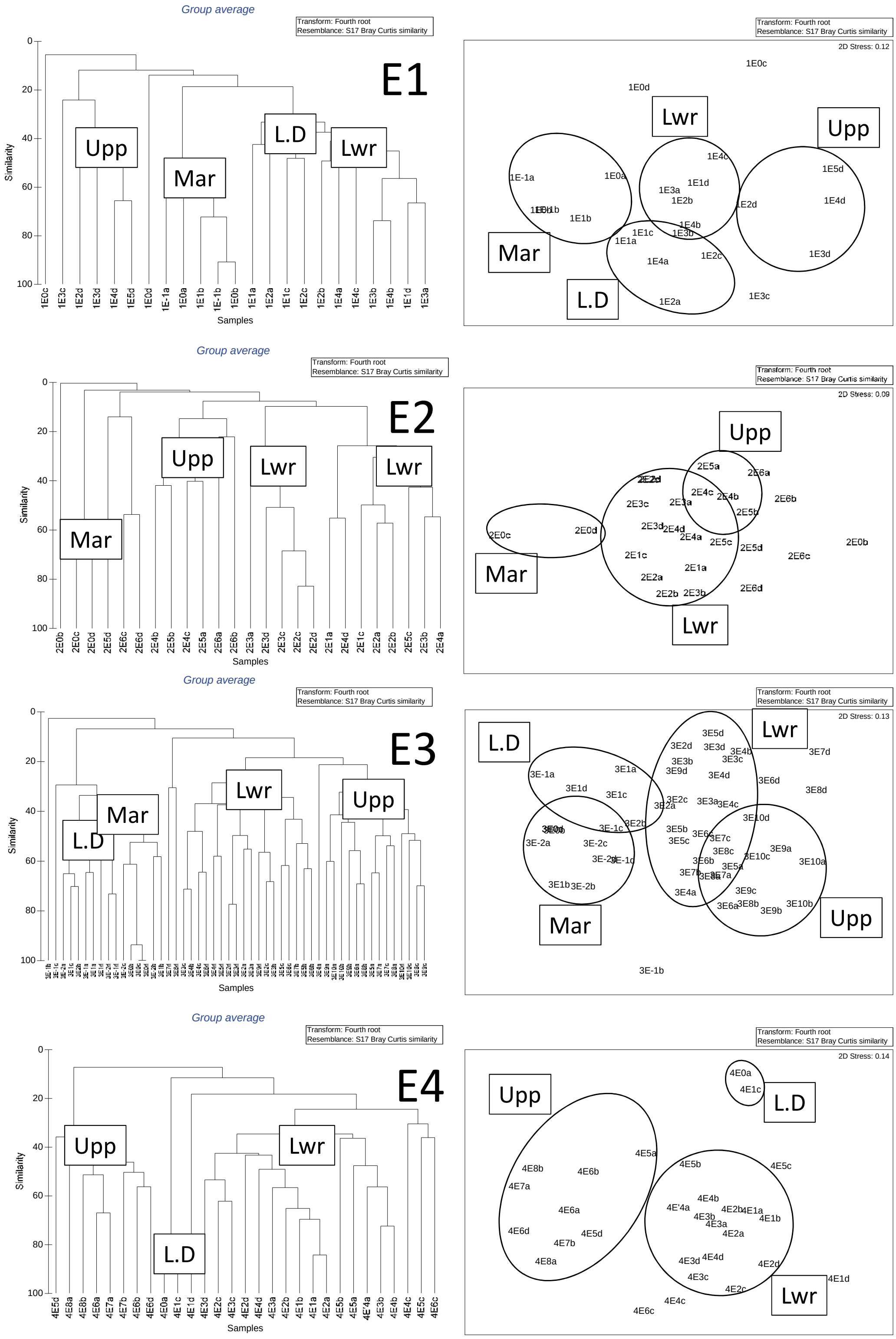


Figure 3.9 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on the Elands River. Site codes as per Table 3.1. Mar = marginal, L.D. = lower dynamic, Low = lower and Upp = upper.**

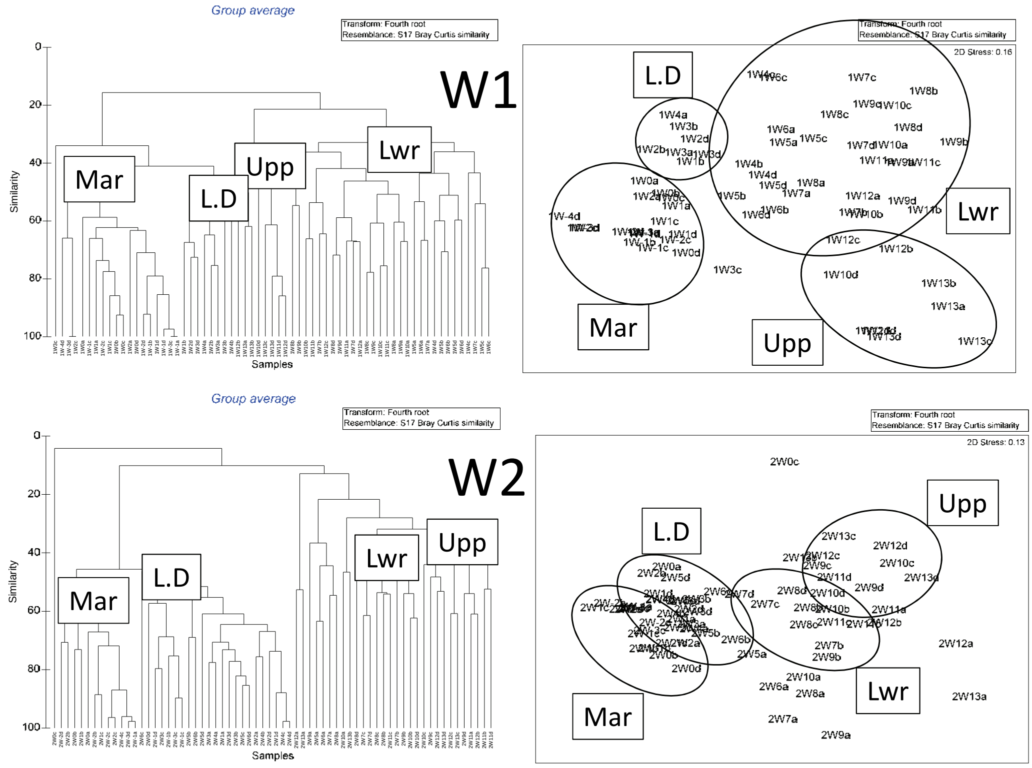


Figure 3.10 CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on the Witte River. Site codes as per Table 3.1. Mar = marginal, L.D. = lower dynamic, Low = lower and Upp = upper.

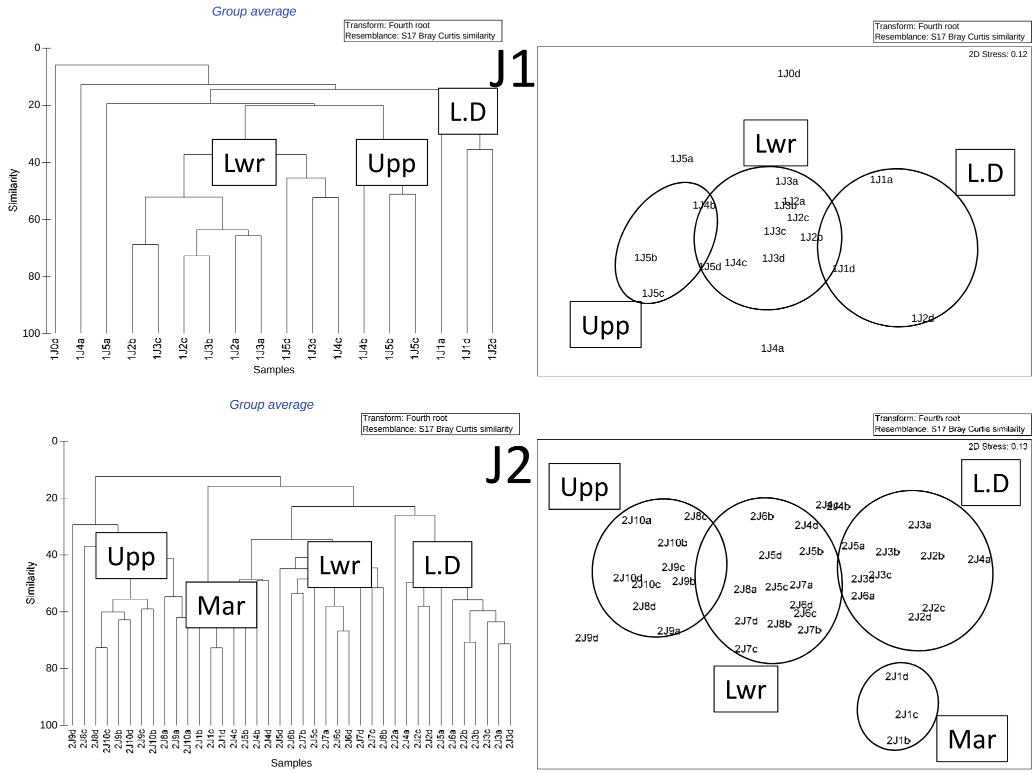


Figure 3.11 CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on the Jonkershoek River. Site codes as per Table 3.1. Mar = marginal, L.D. = lower dynamic, Low = lower and Upp = upper.

Table 3.7 **Typical species for lateral zones per river. Sim = similarity coefficient. S = seedling, J = sapling and T = tree. *Br. = Brachylaena, B. = Brabejum, M = Metrosideros, P. = Pentameris.***

	Rondegat	Heks	Witte	Elands	Jonkershoek
Marginal	Sim = 51% *Isolepis prolifera*	Sim = 36% *Calopsis paniculata* *Isolepis prolifera*	Sim = 21% *Morella serrata J* *Br. neriifolia J*	Sim = 24% *Salix mucronata J, S* *Prionium serratum*	Sim = 60% *Sphagnum sp.*
Lower dynamic	Sim = 28% *Calopsis paniculata* *Erica caffra*	Sim = 34% *Calopsis paniculata* *Morella serrata T*	Sim = 52% *Morella serrata J* *M. angustifolia J*	Sim = 25% *Elegia capensis* *Morella serrata S*	Sim = 35% *Erica caffra* *Morella serrata T*
Lower	Sim = 35% *M. angustifolia T* *B. stellatifolium T*	Sim = 35% *M. angustifolia T* *Morella serrata T*	Sim = 30% *M. angustifolia T* *Morella serrata J*	Sim = 22% *Elegia capensis* *M. angustifolia T*	Sim = 32% *Erica caffra* *Sphagnum sp.*
Upper	Sim = 24% *Pteridium aquilinum* *Ehrharta ramosa*	Sim = 35% *Diospyros glabra* *Ehrharta rehmannii*	Sim = 9% *Br. neriifolia J*	Sim = 20% *P. distichophylla* *Pteridium aquilinum*	Sim = 36% *Pteridium aquilinum* *Calopsis paniculata*

Table 3.8 **Differentiating species for lateral zones per river. J = sapling and T = tree. B. = *Brabejum*, M = *Metrosideros*, P. = *Pentameris*.**

	Rondegat	Heks	Witte	Elands	Jonkershoek
Marginal	*Isolepis prolifera*	*Isolepis prolifera*	*Morella serrata J*	*Salix mucronata J*	
Lower dynamic	*Erica caffra* *Calopsis paniculata*	*Panicum schinzii* *Calopsis paniculata*	*Metrosideros angustifolia J* *Morella serrata J*	*Elegia capensis*	*B. stellatifolium J* *Morella serrata T*
Lower	*M. angustifolia T* *B. stellatifolium T*	*M. angustifolia T* *Morella serrata T*	*Metrosideros angustifolia T*	*M. angustifolia T*	*B. stellatifolium T* *Elegia capensis*
Upper	*Pteridium aquilinum* *Ehrharta ramosa*	*Diospyros glabra* *Ehrharta rehmannii*	*Maytenus oleoides* *Hartogiella schinoides*	*P. distichophylla*	*Pteridium aquilinum* *Pellaea pteroides*

The General Discriminant Analyses confirmed that some of these species were indeed useful indicators for lateral zones overall. Groundcovers (Figure 3.12) and trees (Figure 3.13) are taken in turn followed by trees/groundcovers combined (Figure 3.14).

Prionium serratum and *Isolepis prolifera* were good groundcover indicators for the marginal zone (Figure 3.12). *Calopsis paniculata* and *Panicum schinzii* were good indicators for the lower dynamic. *Elegia capensis* and *Todea barbara* were good indicators for the lower zone. *Ehrharta ramosa, Pteridium aquilinum* and *Diospyros glabra* were good indicators for the upper zone.

Seedlings of the four most common trees, *Metrosideros angustifolia, Morella serrata, Brabejum stellatifolium* and *Brachylaena neriifolia* were prominent across the whole width of the riparian zone, so only trees and saplings were considered further. The abundance of saplings and trees did not coincide with each other (Figure 3.13). *Metrosideros angustifolia* trees were the most abundant riparian tree across sites and were most common to the lower zone, while saplings were to be found in all four lateral zones although they were most common in the lower dynamic. Two of the other trees, *Brabejum stellatifolium* and *Brachylaena neriifolia* were also most common in the lower zone, while saplings of both were also found in the other four zones but again were most common in the lower dynamic.

Morella serrata was most common the lower dynamic and preferentially recruited here, although saplings were found throughout.

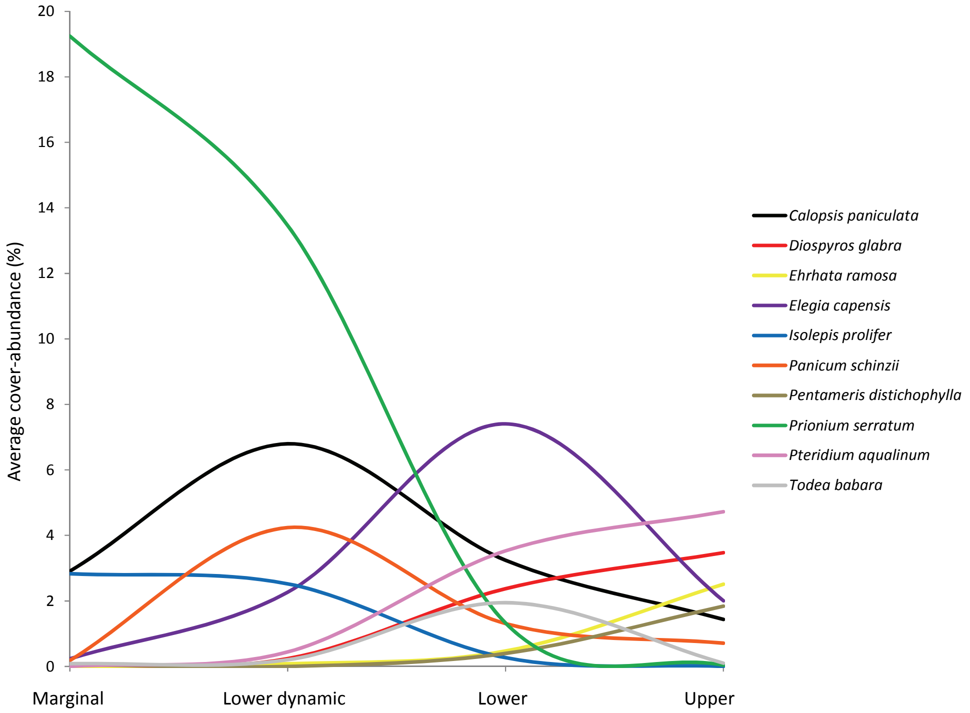


Figure 3.12 Average abundance (% cover) of differentiating ground covers for lateral zones.

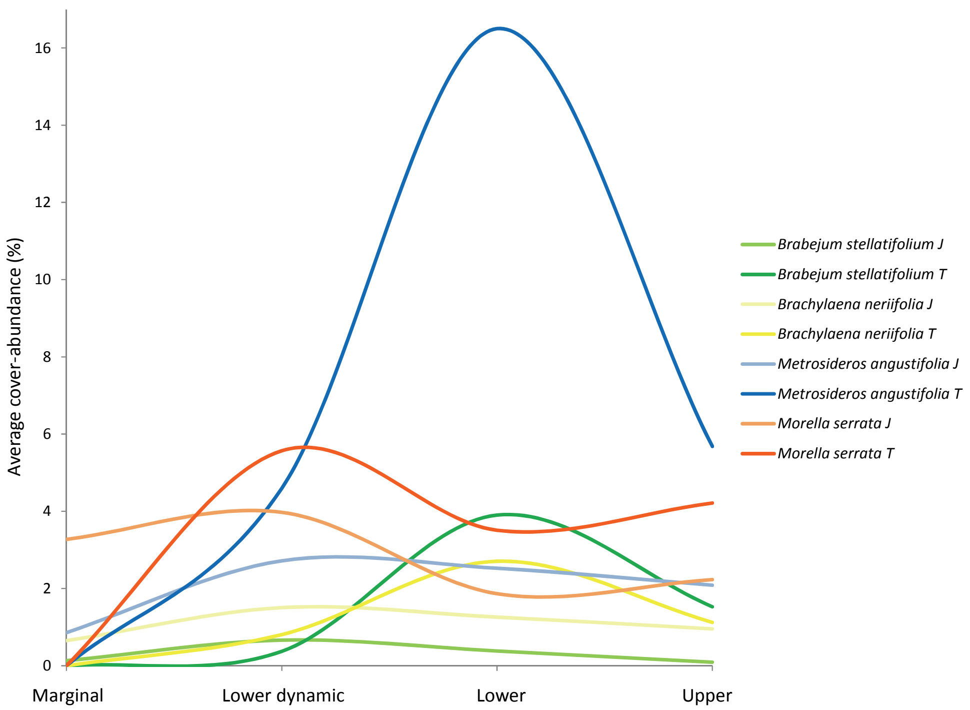


Figure 3.13 Average abundance (% cover) of differentiating canopy species for lateral zones. T = tree, J = sapling.

Overall, the best indicators for the four lateral zones were (Figure 3.14):

- *Prionium serratum* and *Isolepis prolifera* for the marginal zone;
- *Calopsis paniculata* and *Morella serrata* trees for the lower dynamic zone;
- *Metrosideros angustifolia* trees and *Elegia capensis* for the lower zone; and
- *Diospyros glabra* and *Pteridium aquilinum* for the upper zone.

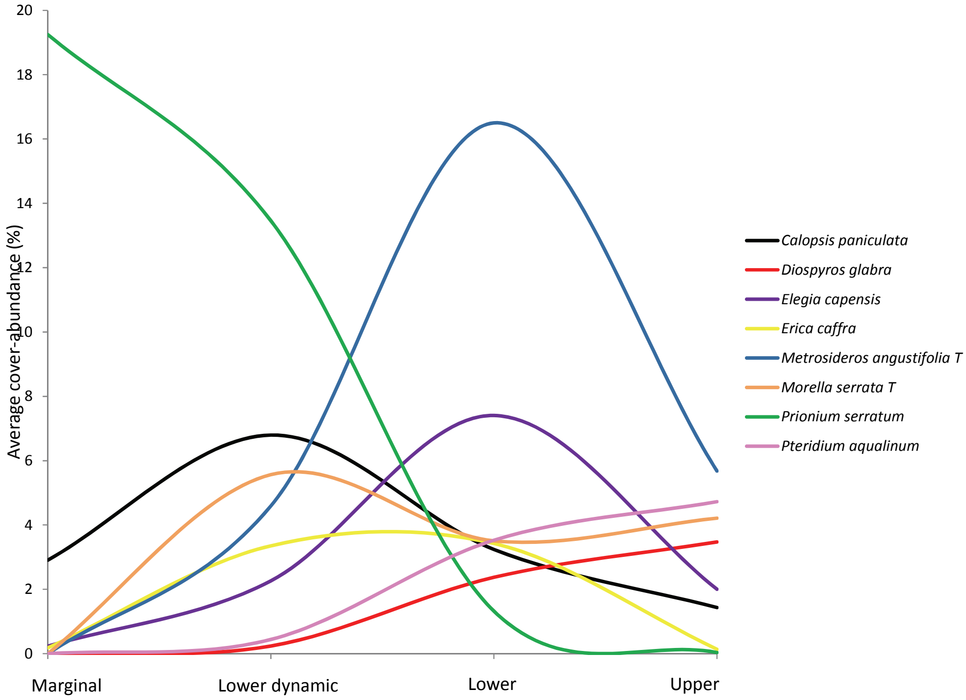


Figure 3.14 Average abundance (% cover) of indicator species for lateral zones. T = tree.

3.4 Discussion

Patterns of zonation were explored in Fynbos Riparian Vegetation. Four lateral zones were identified and the arrangement of lateral zones at any one river was shown to be repetitive and predictable. These patterns confirm the consensus presented by Kleynhans et al. (2007a); there are two main lateral zones, a marginal and lower comprised of riparian species, and a third, the upper, comprised of a mixture of riparian and terrestrial species. The naming convention proposed by Kleynhans et al. (2007a) was found to be generally useful, although a fourth zone was identified, which comprised species from the two neighbouring zones, the marginal and lower. This lateral zone appeared to be an area of active tree recruitment and would thus be useful for assessing riparian community health. We named this the lower dynamic zone after Boucher (2002) who hypothesized that such a transitional zone would be situated in this position. The results clearly demonstrated that the pattern was repetitive and rules to predict the location of a lateral zone in Fynbos Riparian Vegetation were developed. These are presented in Chapter 5.

Rivers were shown to differ in species composition but river groups between basins contain many similar species. This alludes to a riparian-based river signature *sensu* King and Schael (2001). The notion of river signatures was incorporated into the methods of analysis as we sought to identify differentiating species between rivers and their zones. When rivers were analysed separately, many of the typical and differentiating species were the same on the different rivers although they may have been assigned to different lateral zones on any one river. This means that the ratios of abundance of a core set of species differs between rivers more than the species composition itself. This is not surprising since all the rivers were inhabited by the same community, Fynbos Riparian Vegetation. A cross-community comparison may be more successful in determining typical and differentiating species for rivers (see Table 4.2).

Groundcovers and trees were shown to contribute in different ways to the pattern of zonation. Trees were not present in all samples and so on their own are not useful to establish how lateral zones are structured. Additionally, the distribution of trees, their seedlings and saplings differed between zones. Trees were shown to be more specific to a particular zone while saplings were less restricted and seedlings were not restricted. Groundcovers were more robust and, when analysed alone, presented a clear pattern. This is probably because the shallow roots of groundcovers means they are less able to withstand the abrasive force of floods and more vulnerable to drought. As such, the transition from obligate-facultative-incidental up the bank occurs with sharp boundaries as water availability and flooding frequency decreases. Since trees and groundcovers produced different patterns so it was decided that the combined data set would best represent the true pattern. It is also likely that most practitioners would collect a combined sample so this was an obvious choice for our analyses. Groundcovers were the strongest contributor to the pattern so it is not recommended that studies of lateral zones exclude groundcovers. A combination of tree and groundcover data presented the best patterns.

When the entire data set from all rivers were combined indicators for the four lateral zones were apparent. These were incorporated into the guidelines of Chapter 5.

3.5 Summary

Undisturbed headwaters are well suited to study zonation patterns as the riparian communities are laterally constrained and are characterised by steep lateral gradients. Despite extensive research in the Fynbos biome of the Western Cape, a Mediterranean Type Ecosystem, its riparian vegetation has not been intensively studied until recently and there is no formal classification of riparian vegetation communities for the Western Cape (Prins *et al*. 2004) or the rest of Southern Africa. Despite the seemingly obvious lateral patterning within riparian areas and the contention that different communities may be distinguished floristically *in situ* there are discrepancies between the results of different studies. To date, most studies have assumed the pattern exists and accommodated this assumption within the sampling protocol, usually by delineating sample plots within community types *a priori.* The three alateral zones of Kleynhans et al. (2007b) were adopted and tested: marginal, lower and upper zones. The key question was "Can characteristic species/taxa be used to identify lateral zones?" Three hypotheses were tested:

- Riparian plants are distributed in a repetitive and predictable manner.
- Groundcovers and canopy species contribute in different ways to the pattern.
- Characteristic taxa are restricted to specific lateral zones.

There were four lateral zones, which confirm the consensus presented by Kleynhans et al. (2007a); that there are two main lateral zones, a marginal and lower comprised of riparian species, and a third, the upper, comprised of a mixture of riparian and terrestrial species. The fourth lateral zone was transitional between the marginal and lower and could be most similar to either, depending upon whether it comprised obligate or facultative riparian species. Some species were considered to be useful indicators for the lateral zones: (Figure 3.14):

- *Prionium serratum* and *Isolepis prolifera* for the marginal;
- *Calopsis paniculata* and *Morella serrata* for the lower dynamic;
- *Erica caffra* for the body of the riparian area, being equally distributed across the lower dynamic and lower zones, and at low abundance in the marginal and upper zones;
- *Metrosideros angustifolia* trees and *Elegia capensis* for the lower; and
- *Diospyros glabra* and *Pteridium aquilinum* for the upper zone.

4 LINKS BETWEEN LATERAL ZONES AND FLOW

This chapter was written in collaboration with Martin Kleynhans, Aurecon Group, and Martin Kidd, Center for Statistical Consultation, University of Stellenbosch. Martin Kleynhans modelled the hydrology and hydraulics and Martin Kidd processed the univariate statistics.

In this Chapter, the lateral zones distinguished for Western Cape rivers (Chapter 3) were tested at rivers with different riparian communities in other parts of South Africa, using the same methods of data collection and analysis.

4.1 Introduction

The flow regime is considered to be the master variable responsible for the occurrence of lateral zones (Poff et al. 1997) as it directs, *inter alia*, river channel structure, water availability and the life histories of plants, which also interact and influence one another. As such, the nature and extent of riparian vegetation is intimately linked to river channel structure (Hupp and Osternkamp 1996). Changes in the flow regime have been shown to illicit a response in the nature and extent of riparian vegetation in numerous studies downstream of new dams or where dams were removed (Carter et al. 1995; Rood et al. 1999, Nilsson and Berggren 2000, Howell and Benson 2000, Shafroth et al. 2002, Rood et al. 2005, Dewson et al. 2007; Richter and Thomas 2007; Poff and Zimmerman 2010 and Renofalt et al. 2010). This response, and its knock-on effects on other aspects of the riverine ecosystem, is fundamental to the science of Environmental Flows, as is understanding the commonalities between river systems, so that knowledge developed on one system can be transferred to other, lesser known but similar, systems.

Assessments of riparian community health in Environmental Flow studies have been based on the assumption that the onset of flowering, seed dispersal and thus recruitment success are driven by floods, a concept best described by the recruitment box model of Mahoney and Rood (1998) for the riparian cottonwoods (*Populus* sp.) of North American rivers and floodplains. Mahoney and Rood (1998) demonstrated that the life history of cottonwoods was intimately linked to onset of the annual flood; that flowering and seed set were cued so that seed dispersal took place during flood recession (Mahoney and Rood 1998), and; that the hydrochorous (water-dispersed) seeds were dispersed to, and preferentially germinated in, new sandy alluvial deposits, called nursery sites. Cottonwoods were thus said to be floodplain specialists and alterations to the flow regime, particularly high flows, were predicted to result in recruitment failure. This was the reason behind attempts to reverse the negative impacts of development-linked flow changes on riparian communities by reinstating the timing and magnitude of natural high and low flow periods into altered flow regimes (Rood et al. 1999, 2003).

Several authors have proposed links between inundation of a river bank and the plant communities that occur there, mostly along northern hemisphere rivers with flood plains. The number of communities described in studies differ, for instance, Harris (1988) described two, Hughes (1990) three, and Hupp and Osterkamp (1992) four. However, they all located at least one of the separation lines at the elevation reached by the annual or channel-forming flood (Gordon et al. 2002). Hupp and Osterkamp (2002) described two communities that were inundated *ca* 40 % and 5-25% of the year and another two that were only flooded every two-three years or less frequently than every three years, respectively. Nilsson and Svedmark (2002) also divided the riparian area into two main communities with an intra-annual community of graminoids and an inter-annual community of woody shrubs and trees. Silvertown et al. (1999) sought a mechanistic explanation for hydrological niche separation and demonstrated experimentally that coexisting species were distributed along a lateral gradient controlled by water availability and that niche overlap was reduced when competition for water resources was intensified. From this it was expected that life history strategies would differ between occupants at different bank positions in response to prevailing conditions since these change along the lateral gradient. Francis (2006) picked up on this and stated that populations situated closest to the active channel were inundated more frequently thus should be driven by predominantly allogenic (hydrogeomorphic) factors when compared to those situated higher up and inundated less frequently, which should be driven by predominantly autogenic (plant-induced) factors. Thus, the conceptual framework for this chapter was based on the general understanding that water availability decreases laterally away from the river channel. Similarly, depth to groundwater, the probability of being flooded and the duration of inundation when flooded also decrease. Finally, there should be two main lateral zones, one flooded intra-annually and the other inter-annually.

For the most part, hypotheses concerning riparian vegetation community dynamics were developed on Northern Hemisphere floodplain forests (Bendix 1994, 1997; Rood et al. 1999; Bendix and Hupp 2000; Richter and Richter 2000; Hughes and Rood 2002, 2003; Rood et al. 2003; Baker and Wiley 2004; Lytle and Poff 2004; Rood et al. 2005; Richter et al. 2006; Naiman et al. 2008 and Baker and Wiley 2009). However, well-developed floodplains are an unusual feature of South African river systems and these are mainly confined to the “older” rivers in north-eastern parts of the country, such as the Zambezi, Limpopo and Orange-Vaal systems. The “younger” rivers of the east and south coast cut deeply into the coastal margins and lack the floodplains of their northern neighbours (Davies et al. 1995).

There is some evidence that the rivers of north-eastern South Africa display similar links between the flow regime and riparian community structure as those reported for the Northern Hemisphere floodplain systems (Hughes 1988 and 1990, van Coller 1992, van Coller et al. 1997, Mackenzie 1999, van Coller et al. 2000 and Botha 2001). However, these studies were unable to relate flow components to specific floodplain positions (elevation and distance vectors) either due to the complexity of the floodplain mosaic or inaccurate/incomplete hydrological records. Each study proposed that lateral zones may be usefully categorized by combining hydraulic and geomorphic factors against lateral plant distributions and that flood events drove changes in riparian community structure and geomorphic channel structure. Similar studies on the rivers of the Western Cape have yielded even more mixed results. Boucher (2002) hypothesized that the boundary between two main communities, which he called wet and dry banks, was correlated with the position of the 1:2 flood recurrence interval on a the channel cross-section and that the outer edge of the dry bank was inundated every 20 years. These two communities thus aligned with two geomorphologically relevant flow events: the channel forming discharge said to have a return period of 1 to 2 years (Gordon et al. 2002), and the so-called catastrophic floods that reset riverine ecosystems. The appropriateness of channel forming discharge as the primary determinant of channel shape was tested at selected South African rivers by Dollar and Rowntree (2003) who failed to find compelling evidence that flood events with a return period of 1 to 2 years were responsible for maintaining channel form. Instead they suggested that a range of flows, with different return periods, was responsible for the bulk of bed material transport and morphological adjustment of the active channel and that larger ‘reset’ discharges, which occurred on average every 20 years, maintained the macro-channel and mobilised the entire bed. Galatowitsch and Richardson (2005) presented evidence that suggested disturbance-driven seedling recruitment, as described for riparian floodplain specialists, was not an adaptive advantage for Fynbos Riparian Vegetation along headwater reaches based on the observation that seedlings germinated preferentially on stable banks and rock fractures rather than on recent alluvial deposits. Vosse et al. (2008) showed that the seeds of these same species were absent from the seedbank of headwaters soils and concluded that Fynbos Riparian Vegetation may be dominated by resprouters and not reseeders.

Nonetheless, the fact that various categorisations of riparian communities based on inundation compare so well with one another despite differences in data collection and analysis, provides anecdotal evidence that lateral zones correlate with flow events. The Western Cape data presented in Chapter 3 supported the three lateral zones of Kleynhans et al. (2007a) but added a fourth, the lower dynamic zone that was transitional between the marginal and lower zones. The marginal and lower zones consisted of riparian species said to be inundated intra-annually and every one to three years respectively; the lower dynamic zone was composed from occupants of both the marginal and lower zones so should be inundated between one and three years, while the upper zone comprised a mixture of riparian and terrestrial species and was inundated at intervals greater than three years.

If the nature and mechanism of these links can be established for different riparian communities and/or flow regimes in South Africa, then they can be used to predict changes in river ecosystems with changes in flow driven by climate change and/or anthropogenic use of rivers, such as impoundments, abstractions and power generation.

Almost all the rivers in the country exhibit a ‘flashy’ runoff response, which is considered fairly typical of arid or semi-arid countries (Gordon et al. 2002). Flood events tend to have short lag times relative to rainfall events in the basin, and steep ascending and receding limbs. Although the wet and dry seasons occur with some regularity, the frequency and magnitude of floods in the wet season are unpredictable relative to Northern Hemisphere rivers. This led Davies et al. (1995) to describe the flow regimes of South African rivers as ‘predictably unpredictable’. Joubert and Hurly (1994) analysed daily flow records from 352 gauging weirs with records in excess of 20 years and fairly natural flow regimes using seasonal flow type characteristics, such as temporal predictability and variability; and flood characteristics, such as the number of floods per year, the median number of day intervals between floods, the median duration of floods, flood predictability, and the median day of the year on which floods occurred. The patterns of flow along the subtropical coast and the plateau slopes of the Transkei, KwaZulu-Natal and Mpumalanga were similar, with perennial flow and moderate mid- and late summer floods. The southern and eastern Cape coastal belts were characterised by aseasonal flow or a slight early spring peak; a flow regime not commonly found elsewhere in the country. Overall predictability was very low, with a fairly high flood frequency and the lowest flood predictability of all groups. The Western Cape had winter peak flow with low overall predictability and high seasonal predictability.

Thus the objectives of this Chapter were to test whether the four lateral zones identified for Fynbos Riparian Vegetation were valid on other South African rivers inhabited by different riparian communities, and to quantify the links between flood recurrence and inundation duration, and the occurrence of riparian plants in lateral zones.

The hypotheses for this study were:

- If vegetation zones result from differential species responses to a combination of abiotic factors that vary in space and time then the same pattern should be repeated on different rivers even though the species composition of the communities may differ. There should be two main lateral zones: a wet bank comprising the marginal and lower dynamic lateral zone, and; the dry bank comprising the lower and upper lateral zone.
- If there is a separation between the wet and dry bank zones, inundation duration should be a good predictor of the wet bank communities as the life histories of the plants must have evolved in response to regular inundation. The boundary between the wet and dry bank should thus be located at the limit of where intra-annual floods inundate the bank.
- If the dry bank is inundated inter-annually, the lower and upper zones will be subject to disturbance associated with large flood events, and it should be possible to demonstrate significant differences in flood recurrence within the ranges of these two communities along an inundation gradient.

Perennial rivers were selected in three regions with distinctly difference flow hydrographs: summer peak flow in Mpumalanga; the aseasonal or early spring peak in the Southern Cape; and winter peak flow in the Western Cape. Not coincidently, distinct vegetation communities occur in each region (Mucina and Rutherford 2006): Lowveld Riverine Forest and Northern Mistbelt Forest in Mpumalanga; Southern Afrotemperate Forest in the Southern Cape and Fynbos Riparian Vegetation in the Western Cape. In each area, the study focussed on upland rivers (transitional and upper foothill reaches, Rowntree et al*.* 2000) that were laterally constrained so surface flow was concentrated in a longitudinal direction (Gomi et al. 2002).

4.2 Methods

4.2.1 Site selection

Study sites were selected using criteria designed to maximise the accuracy of hypothesized links between vegetation communities and flow. Department of Water Affairs (DWA) Reserve determination sites (King and Pienaar 2011) provided a useful starting point as they are selected for their suitability for modelling links between biota and flow. They also generate useful secondary information such as general ecological condition and extent of anthropogenic disturbance. The hydrological and hydraulic data from several of these studies were also collated by Birkhead and Desai (2006). These data were interrogated to select sites with reasonably accurate hydrological records of longer than 30 years. Assessments of general ecological condition (EcoStatus; Kleynhans et al. 2007b) were used to rank potential sites in terms of hydrology, geomorphology, riparian vegetation and overall condition. The scores vary from A = near natural, to F = completely degraded. Only sites that scored ≥C overall, and ≥C for riparian vegetation, accuracy of hydrological data and geomorphological condition were selected. Thereafter only sites on transitional or upper foothill zones, and where the hydrological data were measured rather than simulated were retained. Thereafter on-site assessments were done to arrive at a final list of 18 sites in three different regions of South Africa, two replicates on each river listed (Table 4.1).

Table 4.1 Biophysical data and location of study sites. Zonation after Rowntree et al. (2000), vegetation community type from Mucina and Rutherford (2006).

Region	River (Site code)	Latitude	Longitude	Gauge	Flow record	Geomorphic zone	Vegetation Community
Western Cape (Winter high flow, summer low flow)	Molenaars (Mol1)	-33.7233	19.17179	H1H018	1969-	Upper foothills	Fynbos Riparian Vegetation
	Elands (Ela1)	-33.7392	19.1132	H1H033	1991-	Transitional	Fynbos Riparian Vegetation
	Elands (Ela2)	-33.7394	19.1131	H1H033	1991-	Transitional	Fynbos Riparian Vegetation
Southern Cape (Aseasonal flow, early spring peak)	Karatara (Kar1)	-33.8824	22.8385	K4H002	1961-	Transitional	Southern Afrotemperate Forest
	Kaaimans (Kaa1)	-33.9711	22.5478	K3H001	1961-	Transitional	Southern Afrotemperate Forest
	Diep (Die1)	-33.9136	22.7081	K4H003	1961-	Upper foothills	Southern Afrotemperate Forest
Mpumalanga (Summer high flow, winter low flow)	Crocodile (Cro1)	-25.5024	31.1820	X2H032	1968-	Lower foothills[7]	Lowveld Riverine Forest
	Mac Mac (Mac1)	-24.9999	30.8146	X3H003	1963-	Upper foothills	Northern Mistbelt Forest
	Mac Mac (Mac2)	-24.9999	30.8147	X3H003	1963-	Upper foothills	Northern Mistbelt Forest

4.2.2 Vegetation data collection and analysis

For the most part, methods were the same as those presented in Chapter 3. However, there were some changes to the study design necessitated by the scale of Lowveld Riverine Forest rivers where systematic samples were employed to cross the much wider riparian width. Also, for this chapter, replicate samples were positioned on opposing banks as this reduced the number of cross-sections needed to quantify the hydraulic relationships. The total riparian area sampled was the same for both chapters.

Vegetation data were collected in 10 m wide belt transects positioned perpendicular to the direction of flow and with the centre point (5 m) of each located along a hydraulic cross-section (Figure 4.1, Section 4.2.4).

Transects encompassed the active and macrochannel up to the riparian edge, which was located at the transition between the riparian zone and the adjacent terrestrial community by the presence of terrestrial species.

[7] This site on the Crocodile River did not meet the geomorphological criteria as it was lower down the longitudinal profile but was selected as the vegetation and hydraulic criteria surpassed all other sites visited in Mpumalanga.

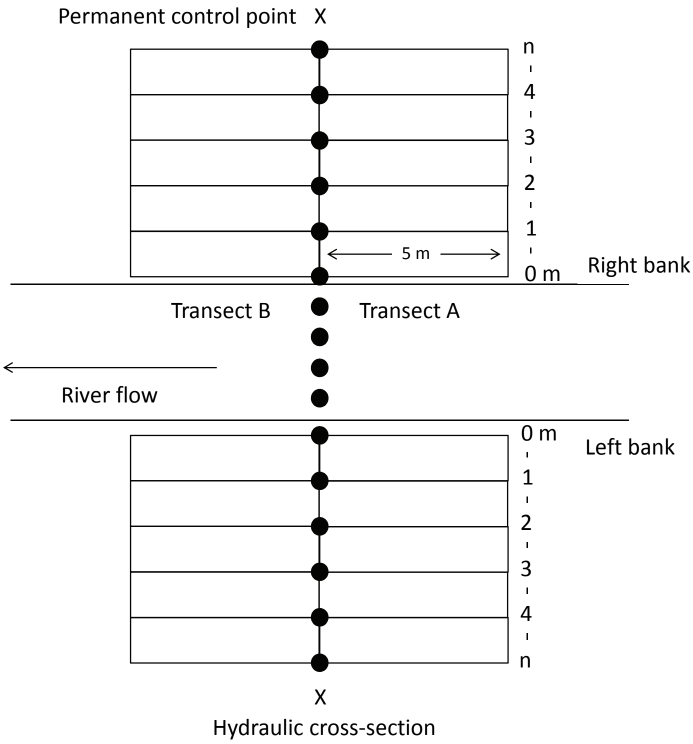


Figure 4.1 Vegetation transects aligned adjacent to hydraulic cross-sections on both river banks.

Each belt transect was divided laterally into contiguous 1x5 m sample plots at all sites except Cro1, where the total length across the macrochannel exceeded 100 m. At Cro1, plots were systematically sampled every 4 m on the left bank and every 2 m on the right bank, in order to arrive at the same number of plots on each bank as at the other sites (~12). The position of each sample plot was surveyed along the cross-section and the position of each sample plot relative to water surface elevation was recorded. Opposing banks were considered to be replicates as they vary in shape, one aggrading and another eroding. All species present were recorded as percentage cover abundance estimated by eye (Kent and Coker 1992) and in three life stages for trees: seedling (height<0.3 m), sapling (0.3>h>2 m) and tree (h>2 m).

Species level cover data for all sample plots were 4^{th} root transformed to boost the presence of smaller species at lower covers. A similarity analysis of sample plots was completed using CLUSTER and Multidimensional (MDS) scaling ordinations. Groups of sample plots with a greater than 40% similarity were recognized. In most cases there were four main groups that ran laterally up the bank from the active channel edge. These were assigned as marginal, lower dynamic, lower or upper zones first on the basis of their proximity to the active channel and secondly the species present (Section 3.2.2.2). The width of each zone was plotted onto the hydraulic cross-sections. Differentiating species for each lateral zone at each site were generated using the SIMPER routine in PRIMER (V6, Clarke and Warwick 2006). Species that discriminated lateral zones for each site within a plant community were tabulated.

4.2.3 Hydrological data collection and analysis

Time series of daily average flows were obtained from DWA (2012) for the gauging stations near each site. Data flagged as either missing or unreliable were patched for up to 20 days in length where-after the entire hydrological year was disregarded and the bounding years concatenated. Records were patched using data from nearby DWA gauges situated on the same river or a river with similar flow characteristics. Mean monthly runoff ratios between patching gauging stations were derived using common complete years with good data. These ratios were applied to observed data at the nearby station and used to infill the gaps in the target station's record. The time-series of annual maximum flood peaks obtained (DWA 2012) for each site, were checked for consistency and data flagged as missing or exceeded were checked against the daily discharges to decide whether the peaks should be incorporated or not. Where flood peaks were missing or considered as bad data after being checked, they were ignored. The annual maxima were then ranked and the Log Pearson III probability distribution fitted. Inter-annual flood peaks at 2, 5, 10 and 20 years were then extracted for each of the sites. Considering that all the sites had more than 20 years of good flood peak data, the estimates of the return period floods were considered to be reasonable. Daily average flow peaks were plotted on the cross-sections of each site using the rating curves (Section 4.2.4). Four intra-annual flood classes were calculated using the DRIFT[8] guidelines (Brown et al. 2006). The top of the Class 4 flood class was calculated by subtracting 10% from the 1:2 year flood discharge. The top of the Classes 3, 2 and 1 were calculated as successive halves of this value. The flow duration curve was then converted to a stage duration curve using the rating curve. The floods were converted to stage using the rating curves and were plotted on the stage-duration curve and the cross-sections.

4.2.4 Hydraulic data

Water surface elevations (stage) were surveyed in at each cross-section, for high and low flows. Surveys were done in September and November 2011, and March 2012 at the Western Cape sites; in November 2011, and April and June 2012 at the Southern Cape sites, and; in April, June and July 2012 at the Mpumalanga sites. A rating curve was derived for each cross-section based on the surveyed stages and discharges observed at the relevant gauging station, which were cross checked against primary verified sub-daily data accessed from the DWA database (DWA 2012); the stage of zero flow that was surveyed in, and; one or two modelled high flows to extend the rating curve beyond the observed data. The high flows used to extend the rating curve beyond the measured points were modelled using:

- Manning's equation based on a single cross-section and representative high flow energy slope at Ela1, Ela2, Kaa1, Kar1, Mac1 and Mac2. Manning's n values were estimated using photographs from various references (Barnes 1967, Arcement and Schneider 1989, Hicks and Mason, 1998; Birkhead and Desai, 2009) and experience. In addition, the variation of Manning's resistance with stage was determined by plotting the Manning's resistances back-calculated from the observed stages, discharges and slopes. The energy slope was estimated based on the general channel slope for the reach measured off a 1:50 000 scale topographical map with 20 m contours and where available a survey of the channel bed over a reasonable distance.

[8] The DRIFT (Downstream Response to Imposed Flow Transformation) methodology is an interactive scenario based method for calculating river ecosystem responses to manipulated flow regimes.

- A one-dimensional hydraulic model (HEC-RAS) consisting of at least three cross-sections and a downstream boundary condition consisting of:
    - o a surveyed downstream normal depth (slope) at Mol1.
    - o a known rating curve for Die1 (DWA 2012).
- The existing cross-section and rating curve (Birkhead and Desai 2009) derived for the EWR study (DWA 2010) at Cro1 – since the original cross-section was re-surveyed from the existing benchmarks and had not changed since the Reserve study.

The rating curve was determined by fitting equation 1 to the rating points:

$y = aQ^b$+c   Equation 1[9]

Each time-series of daily average flows was translated to a time-series of stage via the rating curve in order to generate an (1) annual and (2) monthly time-series of daily averaged inundation durations and standard deviations about these means at 0.1 m intervals along the hydraulic cross-sections. These statistics were generated for the median year, the minimum year (year with lowest annual runoff), the maximum year (year with highest annual runoff) and most recent years since a significant disturbance event, the timing of which varied per river. The rivers in Mpumalanga experienced catastrophic flooding in February 2000 and so the hydrological years from October 2000 to September 2011 were used. The rivers in the Southern Cape experienced large floods in November 2007 and so the hydrological years from October 2008 to September 2011 were used. The Western Cape rivers experienced a large flood in June 1996 so the most recent 11 years available were used, from October 2000 to September 2011.

4.2.5 Relating plant distribution to hydraulic variables

The distribution of plants along each hydraulic cross-section was related to elevation, distance, flow exceedence probability, number of days inundated during a year (inundation duration) and the standard deviation about the inundation period using the BEST routine in PRIMER (V6, Clarke and Warwick 2006). The recurrence interval (the inverse of the exceedence probability at a particular bank position) and inundation duration associated with the mid-point of each lateral zone at all sites were tabulated. The relationship between exceedence probability and inundation duration was tested using a range of univariate statistics in STATISTICA (V11, StaSoft 2012). Since each vegetation transect comprised a different number of sample plots with different lengths it was necessary to use a sub-sample. Five distance groups were assigned systematically along the vegetation transects to overcome the bias of more sample plots being present in each lateral zone along longer versus shorter transects. At each point a sample plot was selected along the hydraulic cross-sections and Least Squares Differential (LSD) tests were used to test the significance of the relationship between the lateral zone assigned to this sample plot, the probability that it was inundated (exceedence probability) and the duration of inundation.

[9] Where: (y) is stage, (Q) is discharge and (a), (b) and (c) are constants. (c) Denotes the depth of zero discharge and thus is often zero in riffles where zero discharge occurs at zero depth.

4.3 Results

4.3.1 Patterns of lateral zonation

4.3.1.1 Fynbos Riparian Vegetation in the Western Cape

The marginal, lower dynamic, lower and upper zones were present at five of the six Fynbos sites (Figure 4.2 -Figure 4.4): on both banks of Mol1 and Ela1 and on the left bank of Ela2. There was no marginal zone on the right bank of Ela2, a pool site. There were however marginal-zone species scattered along the steep active channel edge, which comprised large cobbles and boulders that were mostly not suited to colonising graminoids, the fine rooted plants that constitute a large proportion of marginal zone flora (Table 4.2). The distribution and similarity of samples within lateral zones were less distinct on the right bank at Ela1 than at the other five sites. The outer edges of this riparian area were burnt two months before data collection and it is possible that this resulted in an influx of annuals and transient terrestrial species, which distorted the pattern.

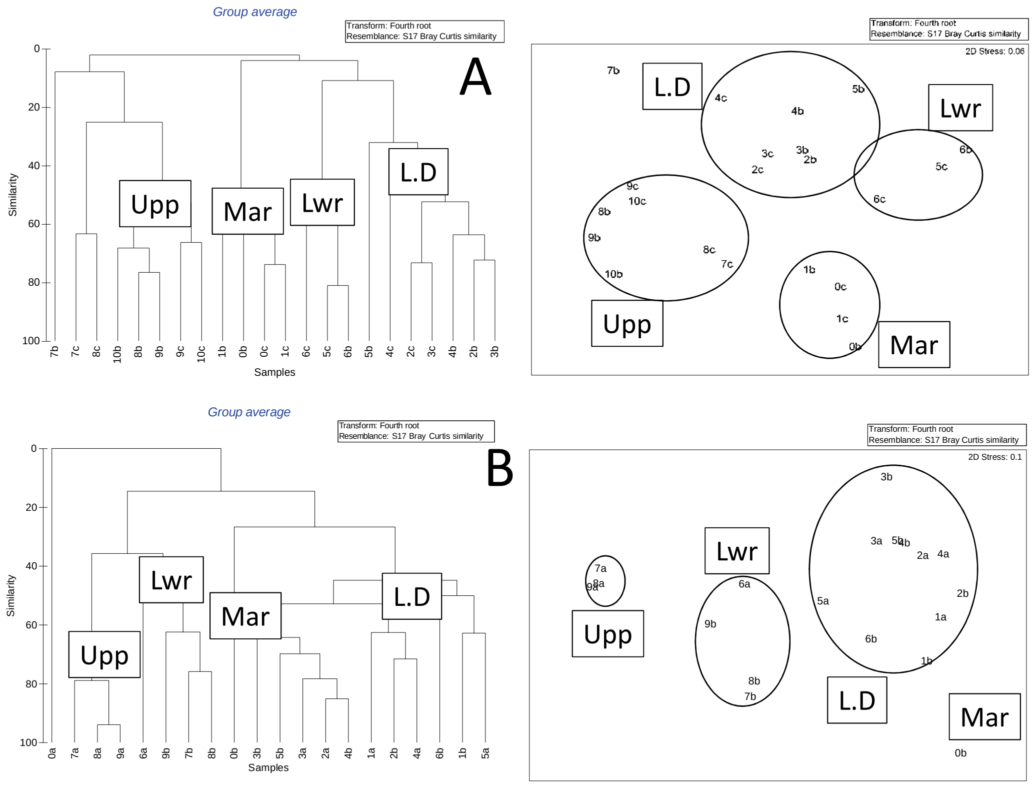


Figure 4.2 CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right banks at Mol1. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.

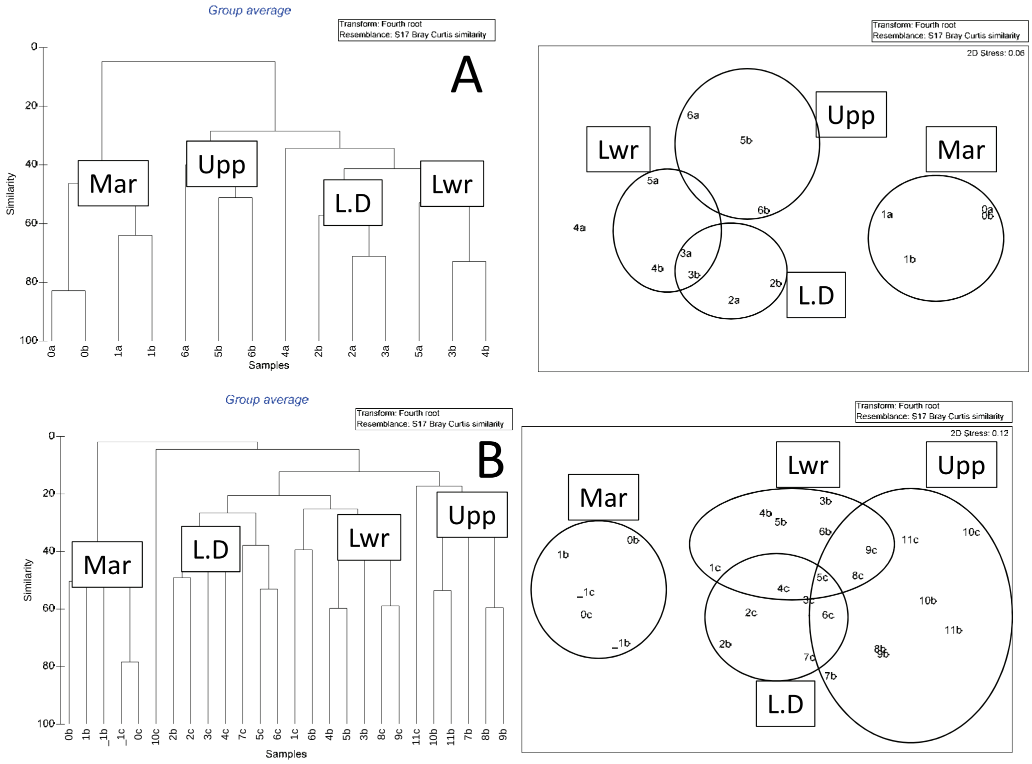


Figure 4.3 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right bank at Ela1. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.**

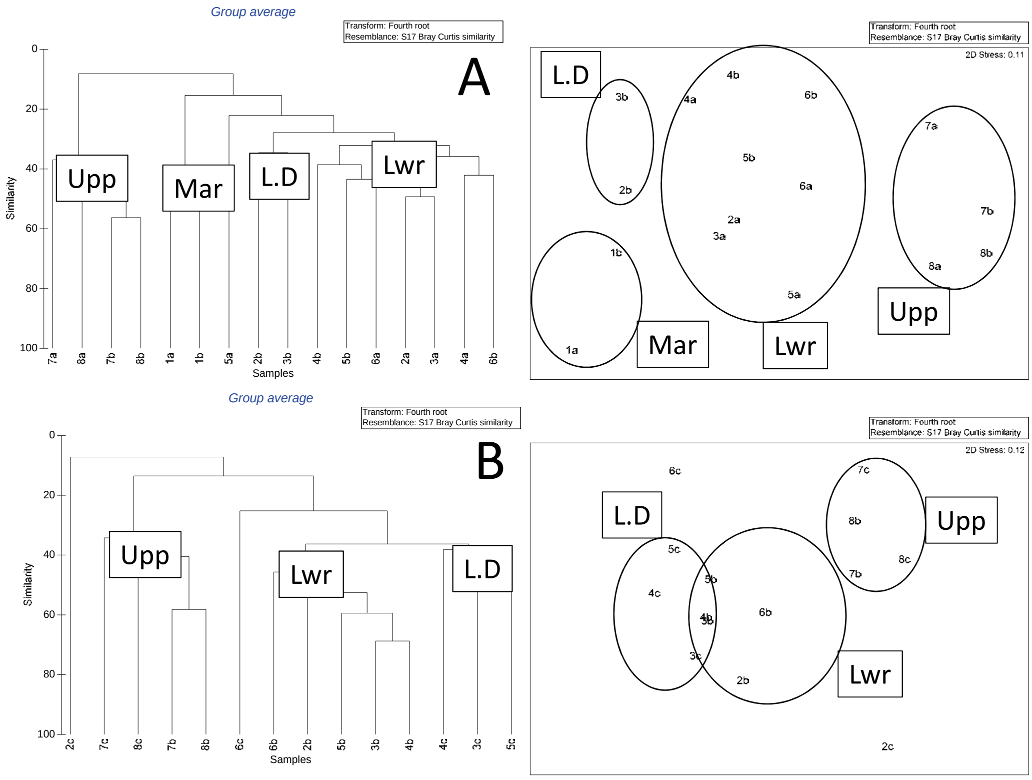


Figure 4.4 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right bank at Ela2. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.**

4.3.1.2 Southern Afrotemperate Forest in the Southern Cape

There was no marginal zone on either bank at Kar1 where the active channel was bedrock controlled and consisted of large boulders and cobbles (Figure 4.5). The marginal, lower dynamic, lower and upper zones were present on both banks of Kaa1 (Figure 4.6) and Die1 (Figure 4.7). The distribution and similarity of samples within lateral zones on the left bank at Die1 were less distinct than at the other five sites. A large flood scoured the lower dynamic and lower zones in 2007 and four years may be insufficient for the plants to have distributed into their zones.

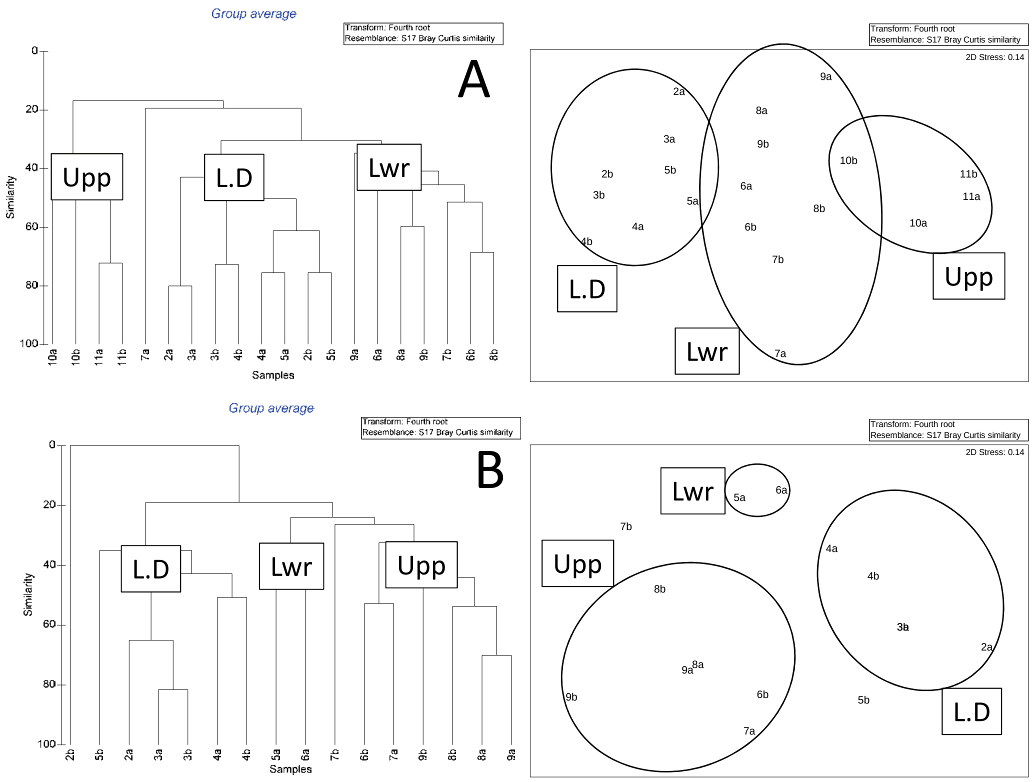


Figure 4.5 CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right bank at Kar1. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.

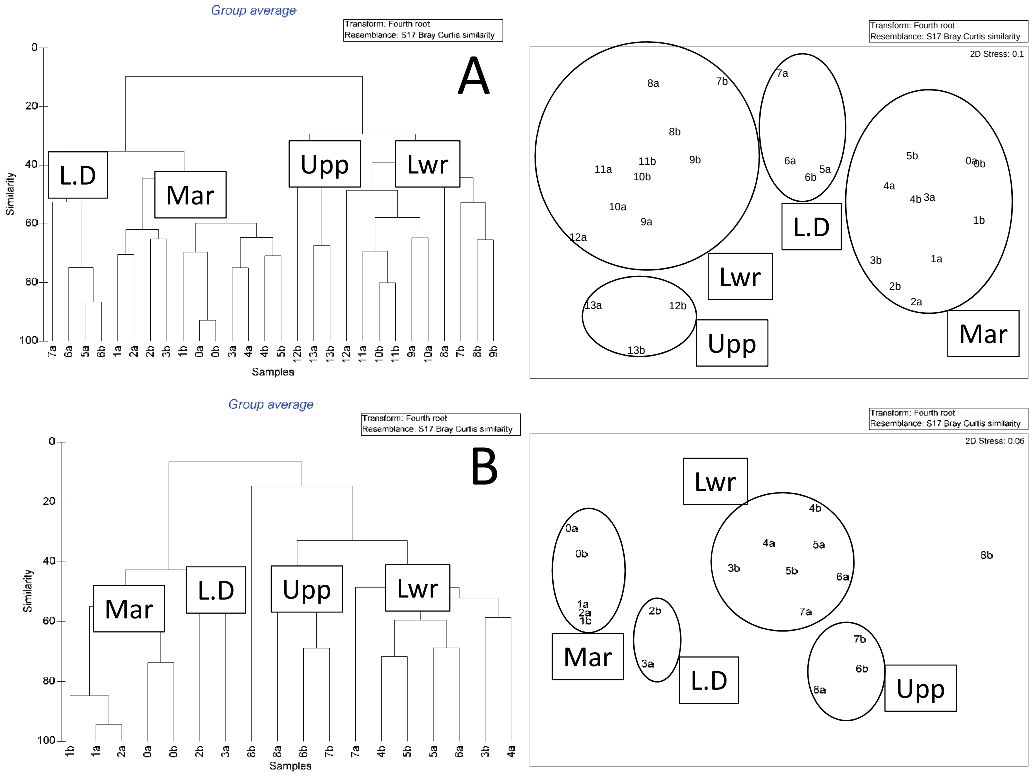


Figure 4.6 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right bank at Kaa1. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.**

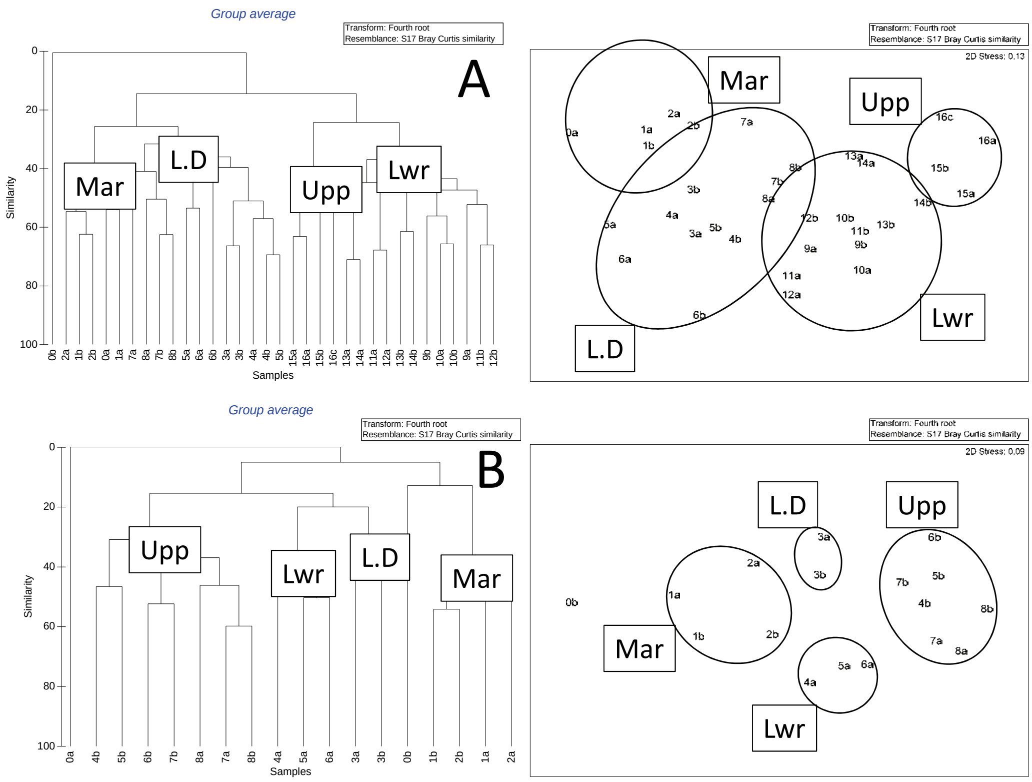


Figure 4.7 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right bank at Die1. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.**

4.3.1.3 Lowveld Riverine Forest and Northern Mistbelt Forest in Mpumalanga

The marginal, lower dynamic, lower and upper zones were present on both banks at Cro1 (Figure 4.8). However, the positions of the lower dynamic and lower zones were swopped on the right bank where the order of zones was marginal, lower, lower dynamic and upper, from the active channel upwards. This was probably due to a flood channel that flowed along the vegetation transects perpendicular to river flow and distorted the lateral arrangement of plants. There was no marginal zone at Mac1 (Figure 4.9) or Mac 2 (Figure 4.10) where the active channel edge was steep and comprised large cobbles and boulders unsuitable for the establishment of graminoids. The lower zone was also missing from the left bank at Mac1, which was near vertical. Here, there was only a lower dynamic at the water's edge and an upper zone located at the cliff ledge and beyond.

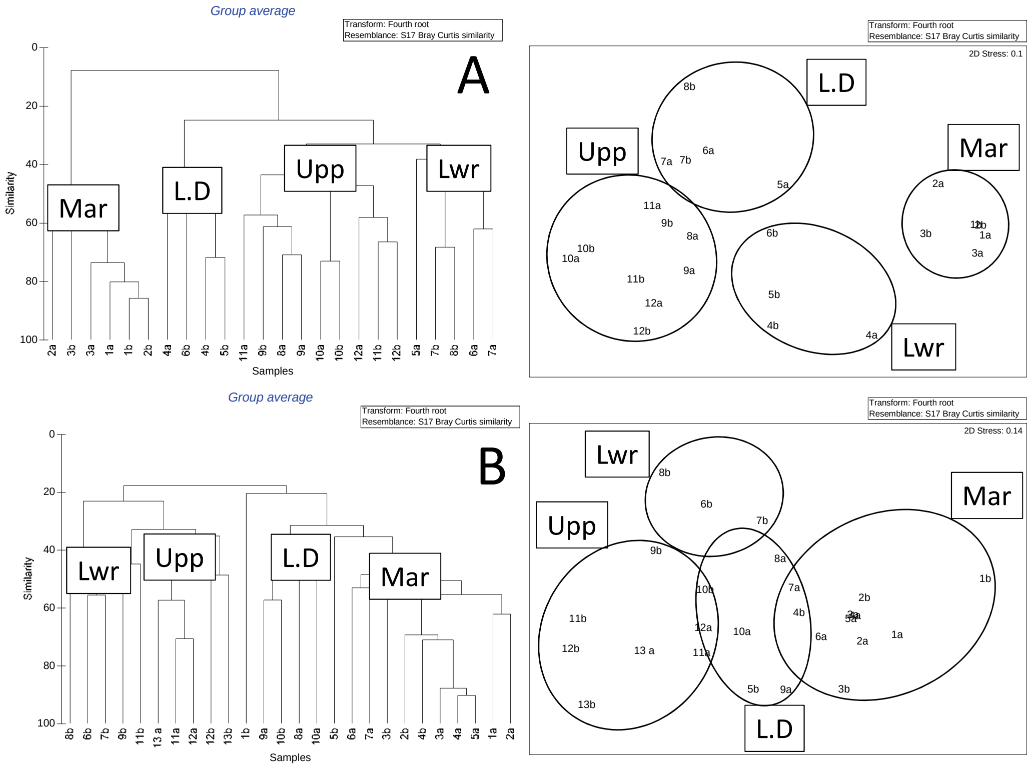


Figure 4.8 CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right bank at Cro1. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.

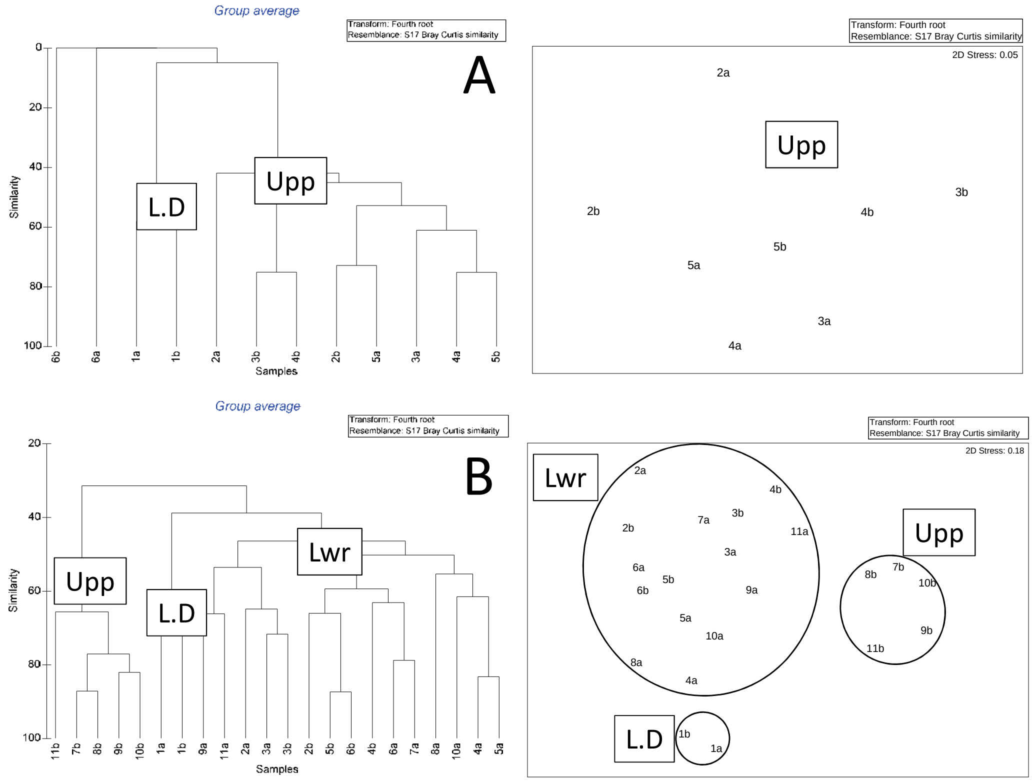


Figure 4.9 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right bank at Mac1. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.**

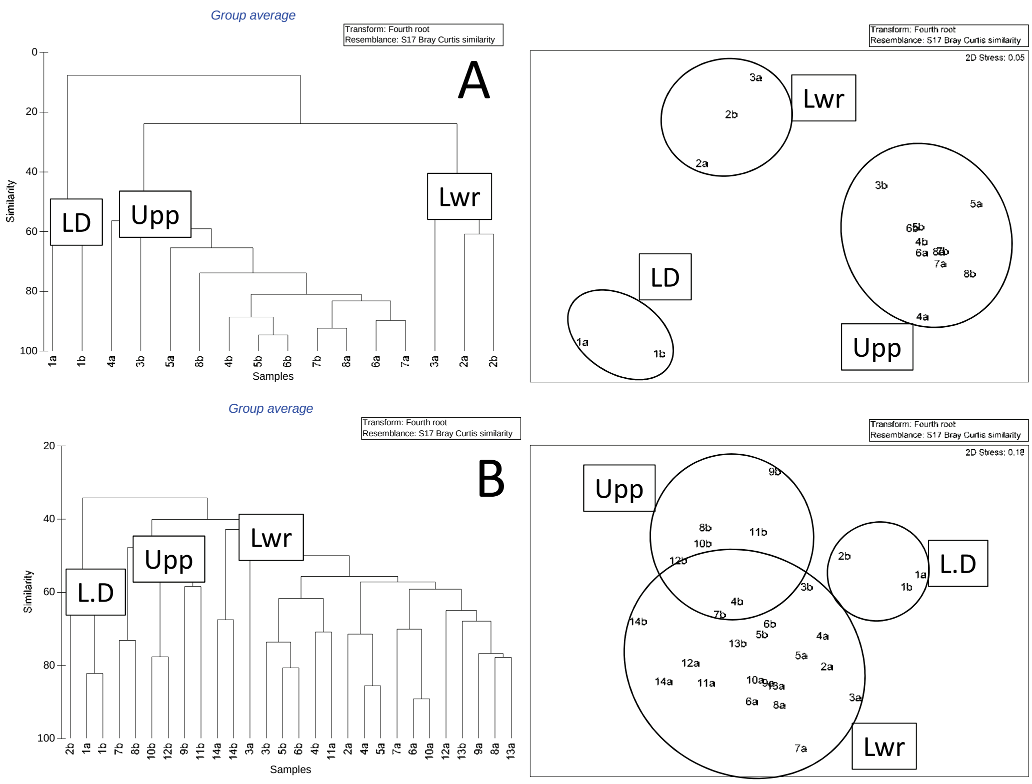


Figure 4.10 **CLUSTER analysis and MDS ordination of Bray Curtis similarity between sample plots on (A) the left and (B) right bank at Mac2. Mar = marginal, L.D. = lower dynamic, Lwr = lower and Upp = upper.**

4.3.1.4 Differentiating species for each lateral zone

The marginal zone was distinguished by a high cover of graminoids (sedges, rushes, reeds and grasses, Table 4.2) and rhizomatous perennials; mostly ferns but also palmiet, *Prionium serratum*, in the Fynbos and Southern Afrotemperate communities. These coexisted with a low cover of pioneering trees, such as the Cape Willow (*Salix mucronata*) on the Fynbos rivers, and the Matumi (*Breonadia salicinia*) on the Lowveld Forest river. There was no marginal zone recorded at the Mistbelt Forest river.

The lower dynamic zone at the Fynbos rivers was distinguished by the common restio *Calopsis paniculata* that coexisted with the river heath *Erica caffra*. At the Southern Afrotemperate rivers the rhizomatous perennials *Todea barbara* and *Dietes iridioides* distinguished the lower dynamic zone. *Panicum maximum* distinguished the lower dynamic of the Lowveld Forest river, and *Searsia batophylla,* along with a mixture of rhizomatous perennials and sedges, distinguished the lower dynamic at the Mistbelt Forest river.

The lower zone of the Fynbos rivers was distinguished by the tree *Brachylaena neriifolia* and the restio *Elegia capensis.* The Southern Afrotemperate river lower zones were distinguished by the grass *Ehrharta rehmanii* and the rhizomatous perennial *Aristea ensifolia.* The lower zones on the Lowveld Forest river were distinguished by the tree *Bridelia cathartica* and the shrub *Phyllanthus reticulatus.* The Mistbelt Forest river lower zones were discriminated by the rhizomatous perennial *Chelianthes viridis* and the shrub *Leucosidea sericea*.

Terrestrial species from the neighbouring upland community adjacent to each site distinguished the upper zone and these are likely to differ between conspecific riparian communities for reasons that have nothing to do with river flow and they were excluded from this study. The mere presence of these upland terrestrial species distinguished the upper zone from the zones and indicates the outer boundary of the riparian area.

4.3.2 Hydraulics of lateral zones

The distribution of plants correlated fairly well against the two main hydraulic variables: inundation duration and exceedence probability (Table 4.3), with R^2 values for both factors ranging between 0.4 and 0.7. Approximately one fifth of the sites were weakly correlated to one or both of these variables with R^2 values < 0.4, while approximately one sixth had strong relationships, $R^2 > 0.7$. The BEST correlations were described for a combined set of variables at all sites except for Kar1, BEST against elevation and Mac1, BEST against inundation duration, alone. Ten of the combined relationships were strong, six were fair and two were weak and included distance and elevation vectors as well as the standard deviation about the mean inundation period.

Table 4.2 Differentiating species for each zone type in each community. Mar = marginal, L.D = lower dynamic, Lwr = lower and Upp = upper.

Community	Site	Mar	L.D	Lwr	Upp	Growth form	Flow dependency
Fynbos Riparian Vegetation	*Juncus lomatophyllus*	■				Sedge	Obligate
	Isolepis prolifera	■				Sedge	Obligate
	Prionium serratum	■				Rhizomatous perennial	Obligate
	Salix mucronata	■				Tree	Obligate
	Erica caffra		■			Shrub	Facultative
	Calopsis paniculata		■			Restiod	Obligate
	Metrosideros angustifolia		■	■		Tree	Facultative
	Brachylaena neriifolia			■		Tree	Facultative
	Elegia capensis			■		Restiod	Obligate
	Searsia angustifolia			■	■	Shrub	Incidental
	Diospyros glabra			■	■	Shrub	Incidental
	Restio perplexus				■	Restiod	Incidental
	Pteridium aquilinum				■	Rhizomatous perennial	Incidental
	Tribolium uniolae				■	Grass	Incidental
	Erica pinea				■	Shrub	Incidental
Southern Afrotemperate Forest	*Juncus lomatophyllus*	■				Sedge	Obligate
	Juncus effusus	■				Sedge	Obligate
	Prionium serratum	■				Rhizomatous perennial	Obligate
	Calopsis paniculata		■			Restiod	Obligate
	Hippia frutescens		■			Shrub	Facultative
	Todea barbara		■			Rhizomatous perennial	Obligate
	Dietes iridioides		■			Rhizomatous perennial	Incidental
	Ehrharta rehmanii			■		Grass	Incidental
	Aristea ensifolia			■		Rhizomatous perennial	Incidental
	Blechnum punctulatum				■	Rhizomatous perennial	Incidental
	Histiopteris incisa				■	Rhizomatous perennial	Incidental
	Searsia chirendensis				■	Tree	Incidental
	Canthium ventosum				■	Tree	Incidental
Lowveld Riverine Forest	*Cynodon dactylon*	■				Grass	Facultative
	Phragmites mauritianus	■				Reed	Obligate
	Breonadia salicinia	■				Tree	Obligate
	Conyza scabrida	■	■			Shrub	Facultative
	Panicum maximum		■			Grass	Obligate
	Ischaemum fasciculatum		■	■		Grass	Facultative

Community	Site	Mar	L.D	Lwr	Upp	Growth form	Flow dependency
	Bridelia cathartica					Tree	Facultative
	Phyllanthus reticulatus					Shrub	Facultative
	Gymnosporia senagalensis					Tree	Incidental
	Tagetes minuta					Shrub	Incidental
	Baleria elegans					Shrub	Incidental
Northern Mistbelt Forest	*Lunularia sp.*					Rhizomatous perennial	Obligate
	Searsia batophylla					Tree	Obligate
	Juncus effusus					Sedge	Obligate
	Cliffortia linearifolia					Shrub	Incidental
	Carex spicata					Sedge	Facultative
	Cyathea capensis					Rhizomatous perennial	Facultative
	Chelianthes viridis					Rhizomatous perennial	Facultative
	Ehrharta sp.					Grass	Incidental
	Leucosidea sericea					Shrub	Facultative
	Setaria megaphylla					Grass	Facultative
	Buddleja salvifolia					Tree	Facultative
	Pteridium aquilinum					Rhizomatous perennial	Incidental

Table 4.3 **Correlations between plant distribution and inundation duration (I-D), standard deviation about this mean (δI-D) and probability of being inundated (Ex.P).**

Community	Site	BEST	Factors	I-D	Ex.P
Fynbos Riparian Vegetation	Mol1 LB	0.537 (1%)	Distance, δI-D	0.398	0.296
	Mol1 RB	0.631 (1%)	Distance, Ex.P	0.566	0.525
	Ela1 LB	0.825 (1%)	I-D, δI-D	0.716	0.440
	Ela1 RB	0.639 (1%)	Distance, elevation, δI-D	0.458	0.394
	Ela2 LB	0.707 (1%)	Elevation, Ex.P, I-D	0.428	0.529
	Ela2 RB	0.612 (1%)	Distance, elevation, Ex.P, δI-D	0.402	0.399
Southern Afrotemperate Forest	Kar1 LB	0.698 (1%)	Elevation	0.443	0.270
	Kar1 RB	0.582 (1%)	Distance, Ex.P	0.536	-0.090
	Kaa1 LB	0.846 (1%)	Distance, Ex.P	0.443	0.816
	Kaa1 RB	0.784 (1%)	Distance, Ex.P	0.642	0.737
	Die1 LB	0.777 (1%)	Distance, elevation, I-D, δI-D	0.499	0.623
	Die1 RB	0.733 (1%)	Distance, elevation, I-D	0.662	0.716
Lowveld Riverine Forest	Cro1 LB	0.793 (1%)	Distance, Ex.P, δI-D	0.677	0.748
	Cro1 RB	0.609 (1%)	Distance, elevation, Ex.P	0.208	0.503
Northern Mistbelt Forest	Mac1 LB	0.887 (1%)	I-D	0.887	0.830
	Mac1 RB	0.383 (1%)	Distance, I-D	0.293	0.298
	Mac2 LB	0.870 (1%)	Ex.P	0.660	0.870
	Mac2 RB	0.369 (2%)	I-D	0.369	0.262

Inundation duration of the marginal zone ranged from 19 to 234 days a year about a mean value of 110 ± 21 days, every 1.0 years on average (Table 4.4). The lower dynamic zone was inundated between 0.7 and 109 days a year about an average of 24 ± 11 days, every 1.9 years on average. The lower zone was inundated between 0.1 and 10 days a year about an average of 2 ± 1 days, every 15.3 years on average. The upper zone was inundated between 0.1 and 3 days a year about an average of 0.3 ± 0.2 days, every 66.3 years on average.

Table 4.4 **Number of days inundated annually (I-D) and recurrence intervals (RI) associated with lateral zones. Codes as per Table 4.1.**

Community	Site	Mar		L.D		Lwr		Upp	
		I-D	RI	I-D	RI	I-D	RI	I-D	RI
Fynbos Riparian Vegetation	Mol1 LB	216 ± 23	<1	42 ± 14	<1	10 ± 5	1.0	3 ± 2	1.1
	Mol1 RB	216 ± 23	<1	35 ± 13	<1	3 ± 2	1.1	0.3 ± 0.4	3.5
	Ela1 LB	225 ± 20	<1	37 ± 10	<1	<0.1	8.5	<0.1	72.7
	Ela1 RB	173 ± 6	<1	11 ± 5	1.0	0.1 ± 0.3	5.5	<0.1	>100
	Ela2 LB	234 ± 20	<1	109 ± 19	<1	15 ± 6	<1	<0.1	2
	Ela2 RB	-	-	28 ± 9	<1	1 ± 0.9	1.5	<0.1	33
Southern Afrotemperate Forest	Kar1 LB	-	-	9 ± 8	1.0	0.3 ± 0.5	12.9	<0.1	>100
	Kar1 RB	-	-	12 ± 9	1.0	1 ± 0.8	2.9	<0.1	>100
	Kaa1 LB	22 ± 22	1.0	4 ± 4	1.3	<0.1	>100	<0.1	>100
	Kaa1 RB	36 ± 34	1.0	13 ± 13	1.0	2 ± 2	1.8	<0.1	>100
	Die1 LB	42 ± 40	1.0	0.7 ± 0.9	3.3	<0.1	20.1	<0.1	>100
	Die1 RB	19 ± 20	1.1	0.7 ± 0.6	2.8	<0.1	15.0	<0.1	66.0
Lowveld Riverine Forest	Cro1 LB	18 ± 13	1.0	0.8 ± 1	3.1	0.3 ± 0.7	4.2	<0.1	>100
	Cro1 RB	18 ± 13	1.0	6 ± 7	1.7	<0.1	8.7	<0.1	47.3
Northern Mistbelt Forest	Mac1 LB	-	-	5 ± 6	3.4	-	-	<0.1	>100
	Mac1 RB	-	-	108 ± 66	1.0	<0.1	22.3	<0.1	27.9
	Mac2 LB	-	-	4 ± 1	6.6	0.1 ± 0.0	32.4	<0.1	84.0
	Mac2 RB	-	-	12 ± 5	3.7	0.2 ± 0.0	21.3	<0.1	55.8
AVERAGE		110 ± 21	1.0	24 ± 11	1.9	2 ± 1	15.3	0.3 ± 0.2	66.3

The variance about the relationships between the inter-annual (2, 5, 10 and 20 year) and inter-annual (DRIFT, Brown et al. 2006, class 1 to 4) floods are illustrated on the hydraulic cross-sections (Figure 4.11-Figure 4.19) for each site.

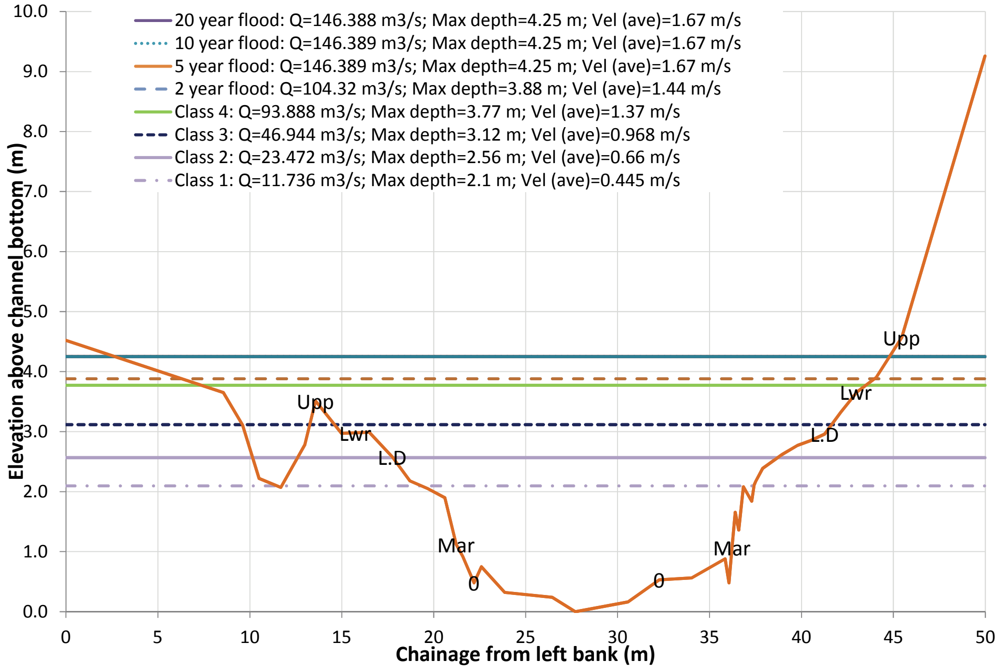


Figure 4.11 **Hydraulic cross-sections with intra- and inter annual floods that inundate each lateral zone at Mol1. 0 = lowest surveyed water level. Codes as per Table 4.1.**

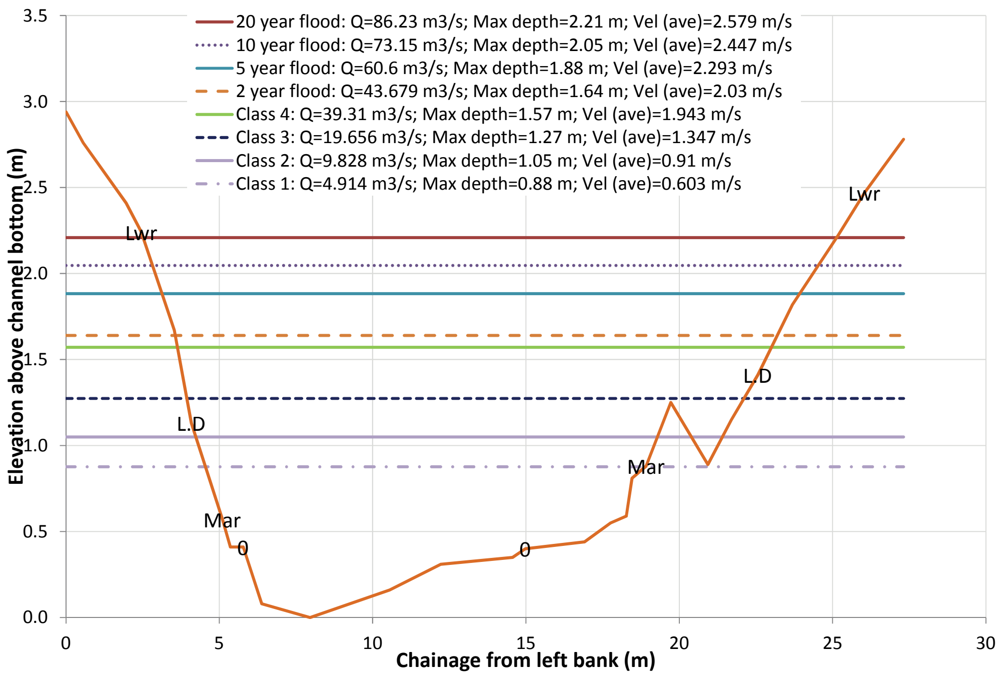


Figure 4.12 **Hydraulic cross-sections and intra- and inter annual floods that inundate each lateral zone at Ela1. 0 = lowest surveyed water level. Codes as per Table 4.1.**

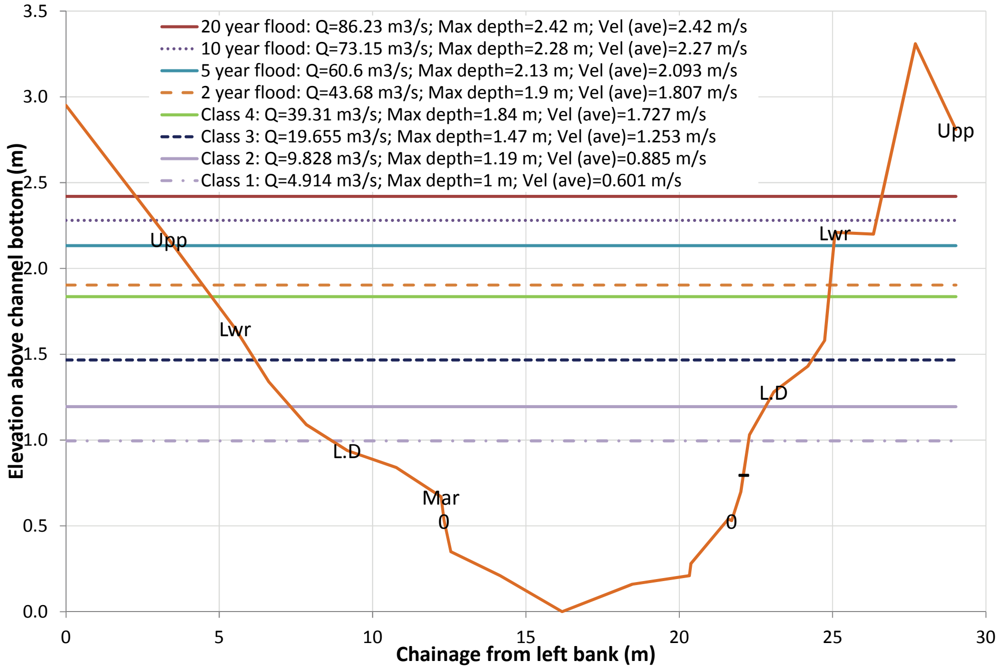


Figure 4.13 **Hydraulic cross-sections and intra- and inter annual floods that inundate each lateral zone at Ela2. 0 = lowest surveyed water level. Codes as per Table 4.1.**

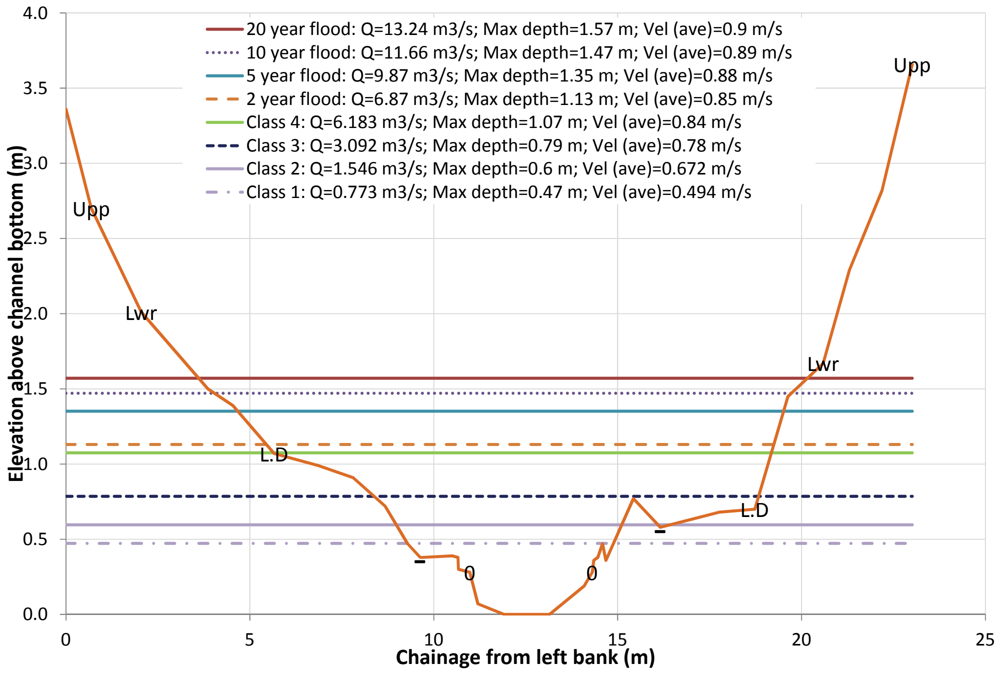


Figure 4.14 **Hydraulic cross-sections and intra- and inter annual floods that inundate each lateral zone at Kar1. 0 = lowest surveyed water level. Codes as per Table 4.1.**

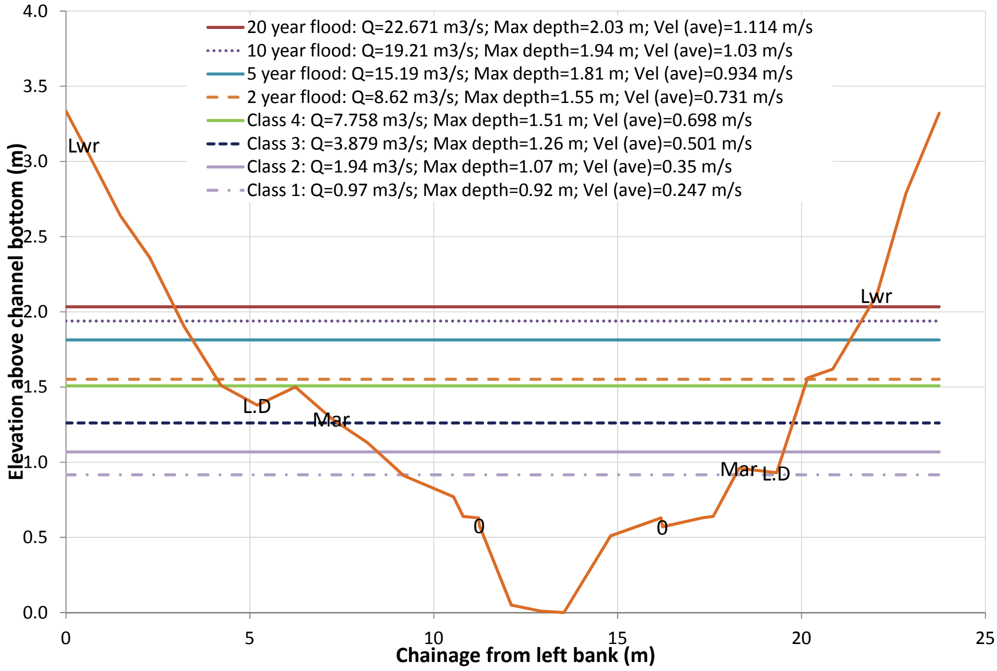


Figure 4.15 **Hydraulic cross-sections and intra- and inter annual floods that inundate each lateral zone at Kaa1. 0 = lowest surveyed water level. Codes as per Table 4.1.**

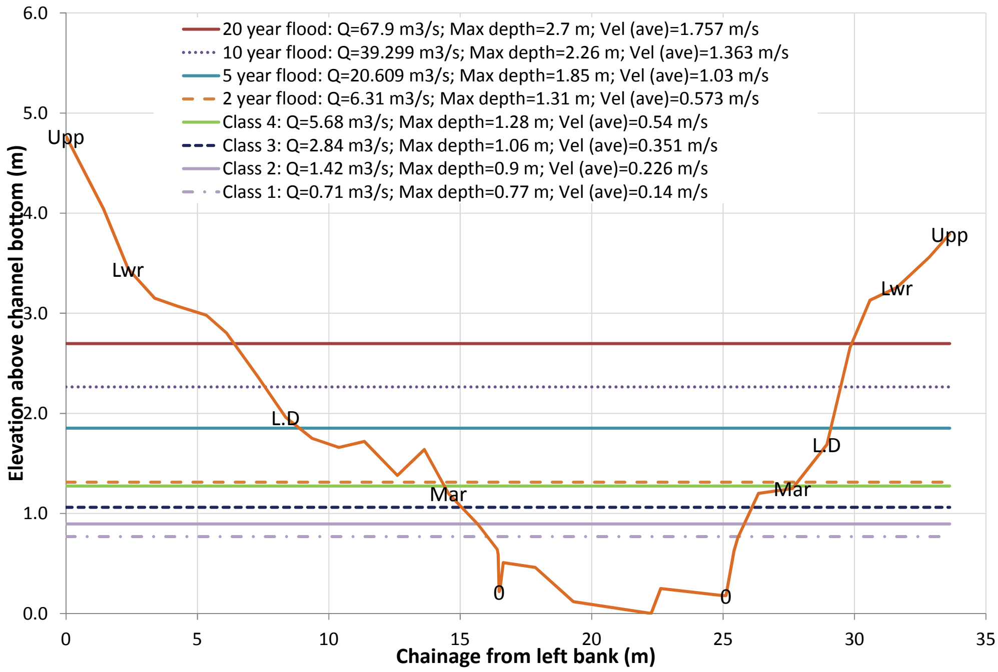


Figure 4.16 **Hydraulic cross-sections and intra- and inter annual floods that inundate each lateral zone at Die1. 0 = lowest surveyed water level. Codes as per Table 4.1.**

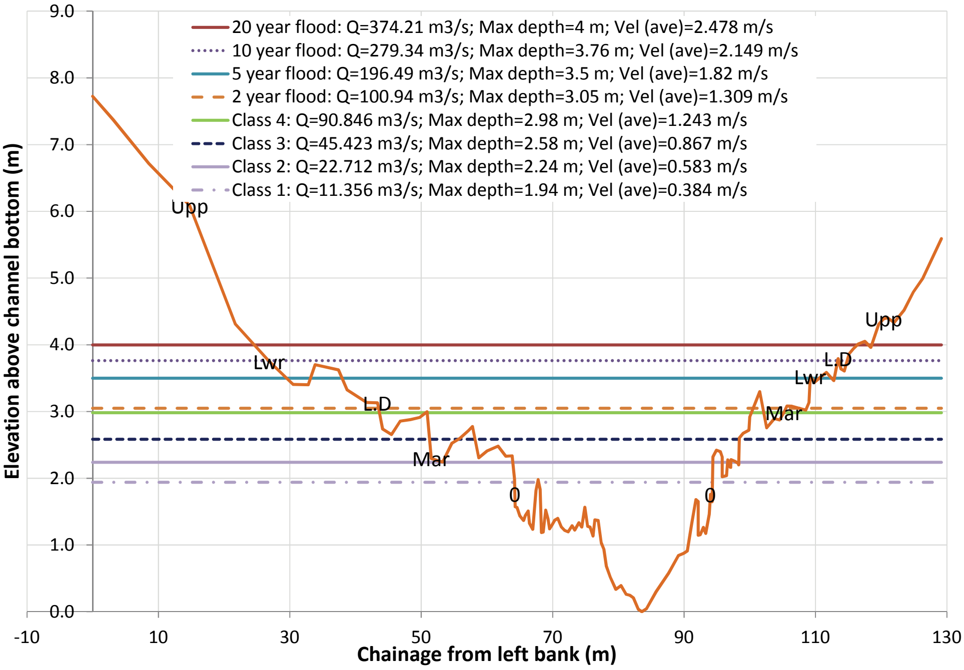


Figure 4.17 **Hydraulic cross-sections and intra- and inter annual floods that inundate each lateral zone at Cro1. 0 = lowest surveyed water level. Codes as per Table 4.1.**

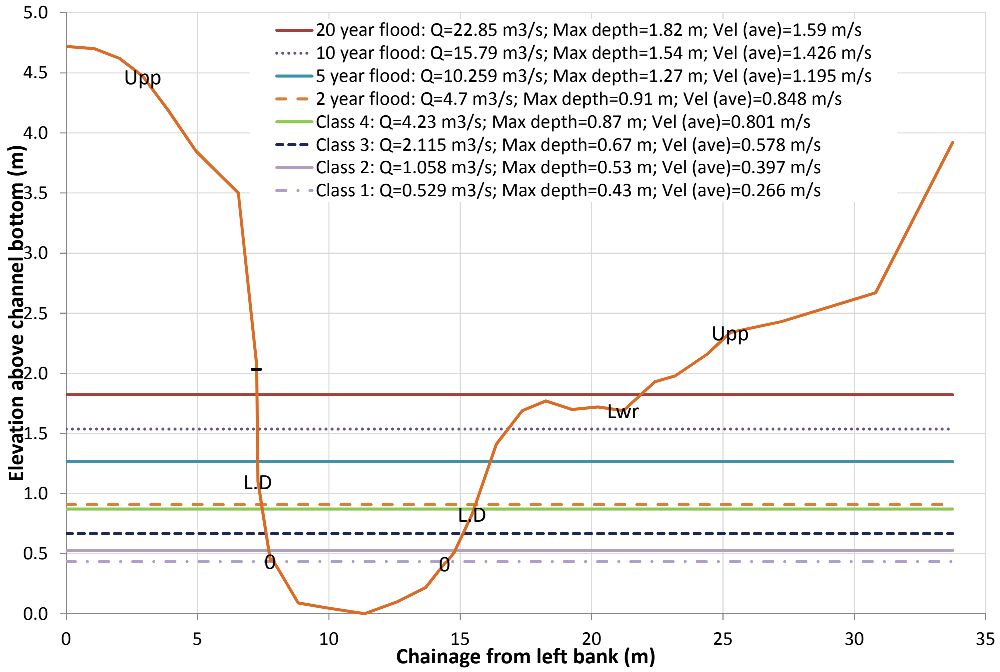


Figure 4.18 **Hydraulic cross-sections and intra- and inter annual floods that inundate each lateral zone at Mac1. 0 = lowest surveyed water level. Codes as per Table 4.1.**

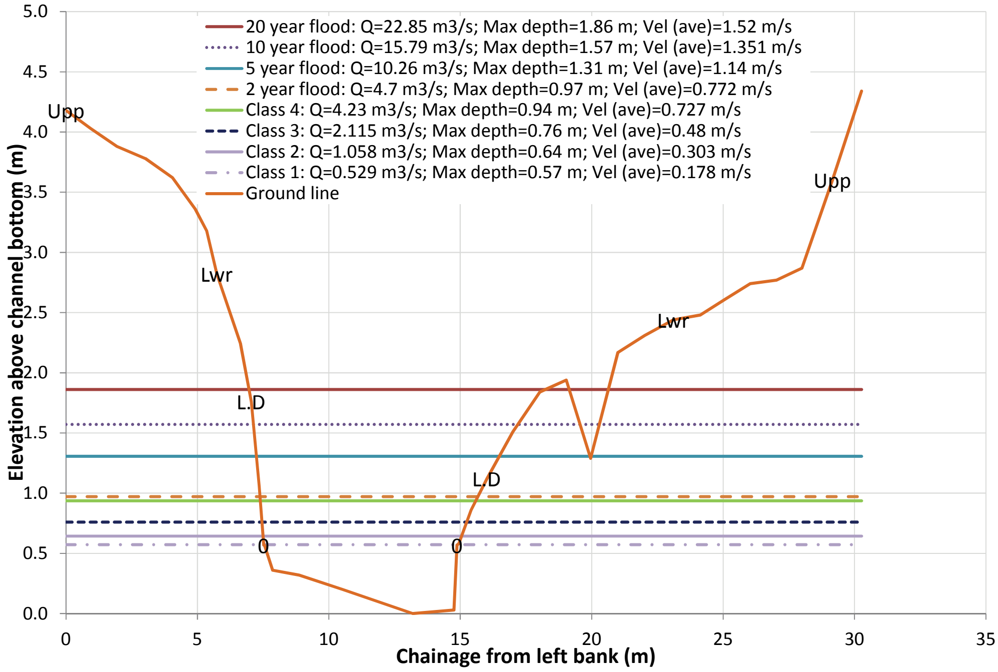


Figure 4.19 **Hydraulic cross-sections and intra- and inter annual floods that inundate each lateral zone at Mac2. 0 = lowest surveyed water level. Codes as per Table 4.1.**

The upper boundary between intra- and inter-annual floods, the Class 4 (green) and 1:2 year flood respectively (orange dashed), are adjacent to one another. Ten of the 18 sites demonstrated the expected relationship: that the marginal and lower dynamic were inundated by intra-annual floods and the lower and upper zone were inundated by inter-annual floods.

Tests of the relationship between inundation duration, exceedence probability and lateral zone type (Table 4.5) showed the ranges of exceedence for the marginal and lower zones overlapped. This was because the lower dynamic was situated at the edge of active channel if the marginal was absent. The marginal zone was inundated every 1.1-1.6 years, while the lower was inundated every 1.3-1.6 years. Since both these recur intra-annually it was not possible to separate them using the stage of different flood events on a cross-section. It was however possible to separate them using the duration of inundation since the marginal was inundated for longer (12 to152 days each year), compared with the lower dynamic (8 to 12 days a year).

Table 4.5 **Relationships between lateral zones and exceedence probability and inundation duration. Asterisked values are significant at the 5% level.**

Distance Group	Lateral zone	Exceedence Probability	Inundation duration (days)	Recurrence interval (years)
1	Mar	0.92 ± 0.04*	152.3 ± 21.5*	1.1*
1	L.D	0.75 ± 0.05*	8.5 ± 28.9*	1.3*
2	Mar, L.D	0.62 ± 0.08*	11.9 ± 3.7*	1.6*
3	Lwr, Upp	0.41 ± 0.08*	4.4 ± 3.3*	2.4*
4	Upp	0.19 ± 0.06	0.7 ± 0.3	5.3

Further, if the standard deviation about these inundation periods is taken into account, a major difference emerges as the marginal zone is inundated every year while the lower dynamic is not inundated in drier years, since the variance about inundation of the lower limit of the lower dynamic is greater than the mean value. This is an important distinguishing feature and may help to explain the transitional nature of the plants that occupy this zone, being the transitional zone for marginal and lower zone species. The lower dynamic is separated from the two higher zones at the position of the 1:2 year flood on a cross-section.

The marginal and lower dynamic collectively form the wet bank and the lower and upper zone collectively form the Dry bank and thus a wet bank/dry bank separation occurs at the point where the 1:2 flood recurs. The lower and upper zones were separable from the wet bank hydraulically but not from one another since their distributions overlapped; the lower zone and the lower limit of the upper zone were inundated for 1-7 days every 2.4 years. There was no relationship between the upper zone and these variables.

4.4 Discussion

There were two main lateral divisions on each river bank: the wet and the dry bank (Boucher 2002); which are separated at the point reached by the 1:2 year flood. The wet and dry banks could be separated from one another on the basis of obligate riparian graminoids, as these are present in the wet bank but not in the dry bank. The dry bank is characterised by a mixed population of adult trees and shrubs and in some cases terrestrial graminoids and forbs.

Each main lateral division is comprised of two lateral zones. The wet bank has the marginal and lower dynamic zones, and the dry the lower and upper zones. The occurrence of these four zones was similar across the four riparian communities: 61% of sites had four lateral zones, 33% had three zones and 6% had two. Of those with fewer than four; the lower zone was absent in one case because the river bank was a near vertical cliff, which was unusual, and the marginal zone was absent in the remaining cases.

Substratum particle size most likely accounted for the absence of the marginal zones since the zone is typically comprised of a mixture of graminoids, which are do not occur when the active channel is bedrock-controlled or dominated by boulder and cobbles. Graminoids exhibit root dimorphism in response to waterlogging; the plants form soil roots that are thick and poorly branched in order to anchor into soft, wet and anaerobic soil, while aquatic roots are finely branched laterally and function mainly for nutrient uptake (Koncalova 1990). Presumably this rooting structure is not suited to larger-calibre sediments. Specialist riparian trees with pioneering attributes (Rood et al. 2005) that were present in some marginal zones, such as *Salix mucronata* and *Breonadia salicinia,* are however able to take root on substrata of a larger calibre; *S. mucronata* roots into lateral cobble bars and downstream of boulders while *B. salicinia* roots specifically onto bedrock (van Coller et al. 1997).

Prionium serratum and *Calopsis paniculata,* respectively, distinguished the marginal and lower dynamic zones of Fynbos Riparian Vegetation and Southern Afrotemperate Forest. In all other cases the discriminating species were community specific so may not be used as indicators of zone type in other riparian communities. Although the marginal and lower dynamic zones were both inundated intra-annually, they could be separated on the basis of the duration of inundation; on average the marginal zone was inundated for three to four months a year, while the lower dynamic was inundated for about a month. Furthermore, the timing of inundation did not seem to make any significant difference.

The lower dynamic zone comprised a mixture of marginal and lower zone species; largely seedlings and saplings of facultative riparian trees and shrubs, and recruiting individuals of the shrubs. Facultative riparian species are favoured by their close proximity to water but are not dependent on regular (intra-annual) inundation. Indeed, although usually associated with perennial rivers, these species are more tolerant of dry conditions than marginal species and so may persist during drier years. They may also occur outside of riparian environments provided conditions are reasonably moist.

Many of the lower zone species (facultative riparian trees and shrubs) were present in the lower dynamic as recruiting individuals, thus species complement alone did not distinguish the lower dynamic from the lower zone. However, they could be distinguished if population structure and life stages of trees and shrubs were used. This makes intuitive sense because juveniles often have different water requirements compared to conspecific adults (Carter Johnson 2000). The upper zone is distinguished from the lower by the presence of terrestrial species. The lower and upper zone differed in the degree to which they were inundated inter-annually: on average the lower zone was inundated every 15 years for a day or two while the upper zone was inundated every 66 years for a few hours.

The distinguishing species provide a useful step towards a list of indicators for South African lateral zones. Replicated data are required from other rivers to extend these results. Such a study would contribute towards the formulation of *riparian response guilds* since further quantifiable links can contribute to the defensibility of flow prescriptions (Merrit et al. 2010). They proposed guilds in five categories: life history, reproductive strategy, morphology, fluvial disturbance and water balance. Their idea was based upon grouping plants according to characteristics that were sensitive to changes in the flow regime and were suited to the appropriate temporal and spatial scale of the investigation. Many techniques are limited and describe relationships that are river or site specific. This limits their transferability between rivers and between different hydroclimatic regions. Our study provides a framework in which to begin disaggregating riparian response guilds (Chapter 5) but at this stage is only applicable to upper reach rivers (mountain streams, transitional and upper foothills, Rowntree et al. 2000) with limited or no floodplain development only. It is not certain how the pattern of zonation may differ in lower reaches and how the hydraulics associated with lower reach channels may change. Both avenues of investigation are necessary for this concept to be taken further and tested. We have linked regionally calibrated flow patterns to that of plant zonation statistically. Further research in this area may lead to guidelines within particular flow classes that could obviate the need to prescribe river/site specific recommendations of flow. It may even be possible to use patterns of lateral zonation to account for decisions on flow management in the absence of hydraulic modelling. Tools like this would need to be backed by a large baseline data set for a range of river types and riparian communities.

4.5 Summary

The flow regime is considered to be the master variable responsible for the occurrence of lateral zones (Poff et al. 1997) as it directs, *inter alia*, river channel structure, water availability and the life histories of plants, which also interact and influence one another. Several authors have proposed links between inundation of a river bank and the plant communities that occur there, mostly along northern hemisphere rivers with flood plains. Thus, the conceptual framework for this Chapter was based on the general understanding that water availability decreases laterally away from the river channel. Similarly, depth to groundwater, the probability of being flooded and the duration of inundation when flooded also decrease. Finally, we proposed there would be two main lateral zones, one flooded intra-annually and the other inter-annually. The marginal and lower zones consisted of riparian species said to be inundated intra-annually and every one to three years respectively, while the upper zone consisted of a mixture of riparian and terrestrial species and was said to be inundated at intervals greater than three years. The first objective of this chapter was to test whether the proposed naming convention of four lateral zones for Fynbos Riparian Vegetation was valid on other South African rivers inhabited by different riparian communities.

Perennial rivers were selected in three regions that differ in flow season: summer peak flow in Mpumalanga; the aseasonal or early spring peak in the Southern Cape; and winter peak flow in the Western Cape. Not coincidently, distinct vegetation communities occur in each region (Mucina and Rutherford 2006): Lowveld Riverine Forest and Northern Mistbelt Forest in Mpumalanga; Southern Afrotemperate Forest in the Southern Cape and Fynbos Riparian Vegetation in the Western Cape.

The hypotheses tested were:

- If vegetation zones result from differential species responses to a combination of <u>abiotic factors</u> that vary in space and time then the same pattern should be repeated on different rivers even though the species composition of the communities may differ. There should be two main lateral zones: a wet bank comprising the marginal and lower dynamic lateral zone, and; the dry bank comprising the lower and upper lateral zone.
- If there is a separation between the wet and dry bank zones, inundation duration should be a good predictor of the wet bank communities as the life histories of the plants must have evolved in response to regular inundation. The boundary between the wet and dry bank should thus be located at the limit of where intra-annual floods inundate the bank.
- If the dry bank is inundated inter-annually, the lower and upper zones will be subject to disturbance associated with large flood events, and it should be possible to demonstrate significant differences in flood recurrence within the ranges of these two communities along an inundation gradient.

Eleven of the 18 sites had four lateral zones, six sites had three zones and one site had two zones. The marginal zone was missing from seven of the 18 sites, which were either bedrock controlled or where the active channel comprised boulders and large cobble. The lower zone was missing at one site, where the bank was near vertical. The order of lateral zones did not follow the expected pattern at one site due to a flood channel. Thus, although the basic pattern can be discerned using the methods described, site specific factors resulted in some variations. Ten of the 18 sites demonstrated the expected relationship: that the marginal and lower dynamic were inundated by intra-annual floods and the lower and upper zone were inundated by inter-annual floods. The marginal zone was inundated every 1.1-1.6 years, while the lower was inundated every 1.3-1.6 years. Since both these recur intra-annually it was not possible to separate them using the stage of different flood events on a cross-section. It was however possible to separate them using the duration of inundation since the marginal was inundated for longer (12 to152 days each year), compared with the lower dynamic (8 to 12 days a year). The lower dynamic was separated from the two higher zones at the position of the 1:2 year flood on a cross-section. The marginal and lower dynamic collectively form the wet bank and the lower and upper zone collectively form the Dry bank and thus a wet bank/dry bank separation occurs at the point where the 1:2 flood recurs. The lower and upper zones were separable from the wet bank hydraulically but not from one another since their distributions overlapped; the lower zone and the lower limit of the upper zone were inundated for 1-7 days every 2.4 years. There was no relationship between the upper zone and these variables.

5 GUIDELINES TO IDENTIFY LATERAL ZONES

This Chapter addresses the project aim:

- to produce guidelines on the identification of lateral vegetation zones, and their links to flow, for use in South Africa.

Note:

- To facilitate a stand-alone chapter some of the referenced material and results from the other chapters are repeated.
- The guidelines exclude rivers with floodplains. The complexity of river habitat increases when a floodplain is present, which makes identification of the links between riparian communities and flow significantly more difficult.

5.1 Introduction

The guidelines aim to provide sufficient information to identify lateral zones. To do this they provide rules to identify lateral zones in Fynbos Riparian Vegetation produced from data on community structure of undisturbed rivers (Section 5.2). Construction of similar rules for other riparian communities was not possible as there were insufficient data. However, step-by-step instructions for the collection (Section 5.3) and analysis (Section 5.4) of riparian vegetation data are provided so these can be used to generate similar rules for other South African rivers.

Guidance is also provided on how to collect the associated hydraulic data, but not how to synthesize and interpret these data, as this should be completed by a qualified hydraulician.

5.2 Rules to identify lateral zones in Fynbos Riparian Vegetation

The rules presented here were generated using the vegetation and physical site data collected in Fynbos Riparian Vegetation on Western Cape headwaters (mountain streams, transitional and upper foothill rivers, Table 5.1). The rivers were all laterally constrained in narrow valleys such that the entire riparian area was spread over a distance of 5 to 13 m. These rules are thus suitable for Fynbos Riparian Vegetation along perennial headwaters.

5.2.1 How the rules were developed

The BIOENV routine in PRIMER (V6, Clarke and Warwick 2006) was used to determine which biophysical data (elevation, distance, depth, proportion of different particle sizes and proximity to water in active channel) best explained the variation in lateral species composition.

Table 5.1 Undisturbed study sites. Masl = metres above sea level. Zones as per Rowntree et al. (2000, Table 5.3).

Basin	River	Code	Longitudinal zone	Gradient	Altitude (masl)	Co-ordinates
Olifants	Rondegat	R1	Mountain stream	0.085	624	S 32.396067°, E 19.089733°
		R2	Mountain stream	0.085	624	S 32.396033°, E 19.089467°
		R3	Transitional	0.029	501	S 32.376825°, E 19.067119°
		R4	Transitional	0.029	497	S 32.376325°, E 19.066775°
	Heks	H1	Transitional	0.023	245	S 32.435379°, E 19.008838°
		H2	Transitional	0.023	244	S 32.435269°, E 19.008638°
		H3	Upper Foothills	0.018	175	S 32.436450°, E 18.981384°
		H4	Upper Foothills	0.018	167	S 32.436533°, E 18.981342°
Breede	Witte	W1	Transitional	0.027	285	S 33.571850°, E 19.138617°
		W2	Transitional	0.027	281	S 33.571550°, E 19.138717°
	Elands	E1	Mountain stream	0.054	519	S 33.760900°, E 19.128417°
		E2	Mountain stream	0.054	505	S 33.760753°, E 19.128325°
		E3	Transitional	0.017	450	S 33.740167°, E 19.113183°
		E4	Transitional	0.017	446	S 33.739756°, E 19.113142°
Berg	Jonkershoek	J1	Mountain stream	0.040	360	S 33.993750°, E 18.975517°
		J2	Mountain stream	0.040	314	S 33.987075°, E 18.956507°

A Classification and Regression Tree (CART, STATISTICA 11, StatSoft 2012) was employed (Breiman *et al.* 1984) to determine physical rules for locating assemblage types. A number of potential predictor variables were investigated:

- distance from summer low-flow water's edge;
- elevation from summer low-flow water's edge;
- wet Bank (WB) gradient 1, over the first three sample plots (from water's edge upwards);
- dry Bank (DB) gradient 2, covering sample plots four to six (4-6 m distance from water's edge up the bank);
- bank shape, the difference between gradients 1 and 2 (a negative value indicated a concave bank and positive value a convex bank);
- whether the river bank overall was convex or concave;
- gradient 3, over the last three sample plots (the steeper this gradient the narrower the valley);
- percentage of sand per sample plot; and
- percentage of water per sample plot.

A CART creates a decision tree that designates a dependent variable, in this case the lateral zone, to a sample plot based on the best fit about a range of independent variables; in this case the predictors listed above. 70% of the sample data were randomly selected for model development (*observed* in Table 5.2) the remaining 30% were used to test the predictive accuracy of the rules (*test* in Table 5.2).

5.2.2 Rules based on bank shape

BIOENV revealed that first distance and then elevation from the water's edge[10] were the factors most strongly associated with species distributions on the river bank.

The CART decision tree confirmed that distance and elevation were good predictors of lateral zones along with bank gradient. The primary split occurred at a distance of 1.5 m, with the marginal and lower dynamic being located closer, while the lower and upper were further away, than this from the active channel (Table 5.2).

Table 5.2 Physical rules for identifying lateral zones in Fynbos Riparian Vegetation.

Bank type	Lateral zone	Physical rule	Observed	Test
Wet bank	Marginal	Distance <= 1.5 m and elevation <= 0.12 m	70%	96%
Wet bank / Dry bank	Lower dynamic	Distance <= 1.5 m and elevation > 0.12 m	34%	26%
Dry bank	Lower	Distance > 1.5 m and elevation <= 1.29 m	86%	70%
Dry bank	Lower / Upper	Distance > 1.5 m and elevation > 1.29 m and WB-DB grad > 0.23	-	-
Terrestrial	Upper	Distance > 1.5 m and elevation > 1.29 m and WB-DB grad <= 0.23	65%	54%

Thus, a sample plot placed within 1.5 m of the water's edge will either be in the marginal or lower dynamic zones. Of these, those positioned at elevations less than 0.12 m above the water's surface will be in the marginal zone. Those situated higher than 0.12 m will be in the lower dynamic zone.

Plots located at a distance greater than 1.5 m from the water's edge will be in the lower or upper zones. Of these, those lower than 1.29 m in elevation will be in the lower zone. Those higher than 1.29 m in elevation could either be in the lower or upper zones based upon the difference in gradient. Those on a convex bank (WB-DB > 0.23) will be in the lower zone, while those on a concave bank (WB-DB <=0.23) will be in the upper zone. An example of the latter case is where the riparian area extends for some distance before the slope steepens at the adjacent terrestrial community.

These rules were extremely good in predicting the location of the marginal zone and very good in predicting the location of the lower zone. They were less accurate in predicting the location of the upper and least accurate for the lower dynamic zones. The poor scores for the lower dynamic and upper zone (*test* in Table 5.2) result from the transitional nature of these zones: the lower dynamic consists of a mixture of marginal and lower species while the upper zone consists of a mixture of lower and terrestrial species. Further, the lower dynamic is an area of active recruitment that experiences a high turnover in species composition while the upper zone is subject to a continual influx of transient terrestrial species.

[10] Please note, the data used to develop these rules was collected during summer low flow. As such, the term *water's edge* refers to the summer base flow level of the active channel.

5.2.3 Indicator species for lateral zones

Zone identity is partly based upon species composition, which varies considerably. However, there are some species that are particularly abundant in one or the other lateral zone, which can be used to verify/adjust the delineation of zones in the field (Figure 5.1). The shrub *Prionium serratum* (Figure 5.3) and the sedge *Isolepis prolifera* are most abundant in the marginal zone. The restio *Calopsis paniculata* and the tree *Morella serrata* are most abundant in the lower dynamic zone. The restio *Elegia capensis* and the tree *Metrosideros angustifolia* are most abundant in the lower zone. The fern *Pteridium aquilinum* and the shrub *Diospyros glabra* are most abundant in the upper zone.

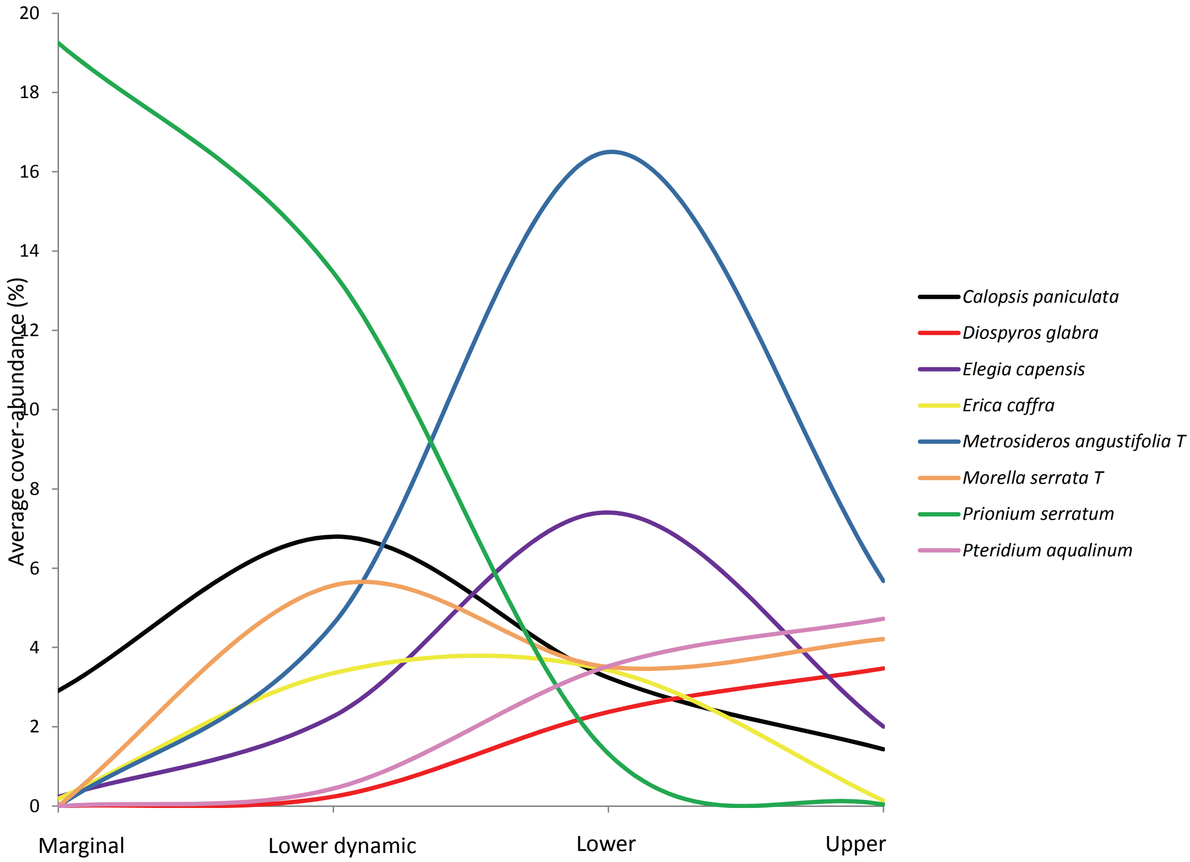


Figure 5.1 Indicators of lateral zones in Fynbos Riparian Vegetation. T = tree.

5.2.4 Procedure for delineating lateral zones using bank shape and indicators species

The procedure for delineating lateral zones (Figure 5.2) using a combination of the rules (Table 5.2) and indicators (Figure 5.3) is to:

- measure out a distance of 1.50 m from the water's edge to separate the wet bank from the dry bank;
- in the wet bank, mark the vertical elevation of 0.12 m above the water's surface to separate the marginal from the lower dynamic zone;
    - look for *Prionium serratum* and *Isolepis prolifera* in the marginal zone;
    - look for *Calopsis paniculata* and *Morella serrata* in the lower dynamic zone;

        - if present use their **<u>rooted</u>** position to adjust the boundary between the marginal and the lower dynamic zone;

- in the dry bank mark the vertical elevation of 1.29 m above the water's surface to separate the lower from the upper zone;
    - look for *Calopsis paniculata* and *Morella serrata* in the lower dynamic zone;
    - look for *Metrosideros angustifolia* and *Elegia capensis* in the lower zone;
        - if present use their **<u>rooted</u>** position to adjust the boundary between the lower dynamic and the lower zone;
    - look for *Metrosideros angustifolia* and *Elegia capensis* in the lower zone;
    - look for *Pteridium aquilinum* and *Diospyros glabra* in the upper zone;
        - if present use their **<u>rooted</u>** position to adjust the boundary between the lower and upper zone;
- in the upper zone, look for terrestrial plants that may be drier in texture and situated on soil that is different in colour and texture; and
    - use these to guide the location of the outer riparian boundary.

5.2.5 Decision tree for Fynbos Riparian Vegetation

A decision tree describes the process for locating lateral zones (Figure 5.2).

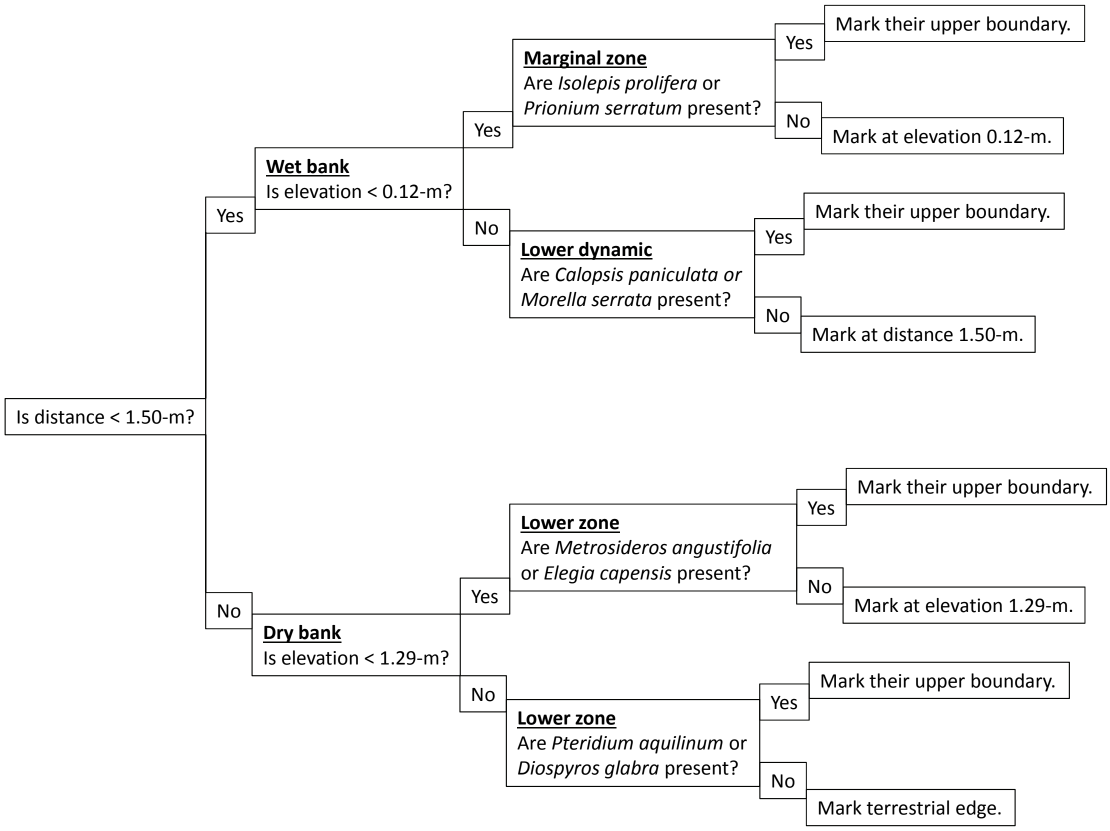


Figure 5.2 A decision tree for locating lateral zones in Fynbos Riparian Vegetation.

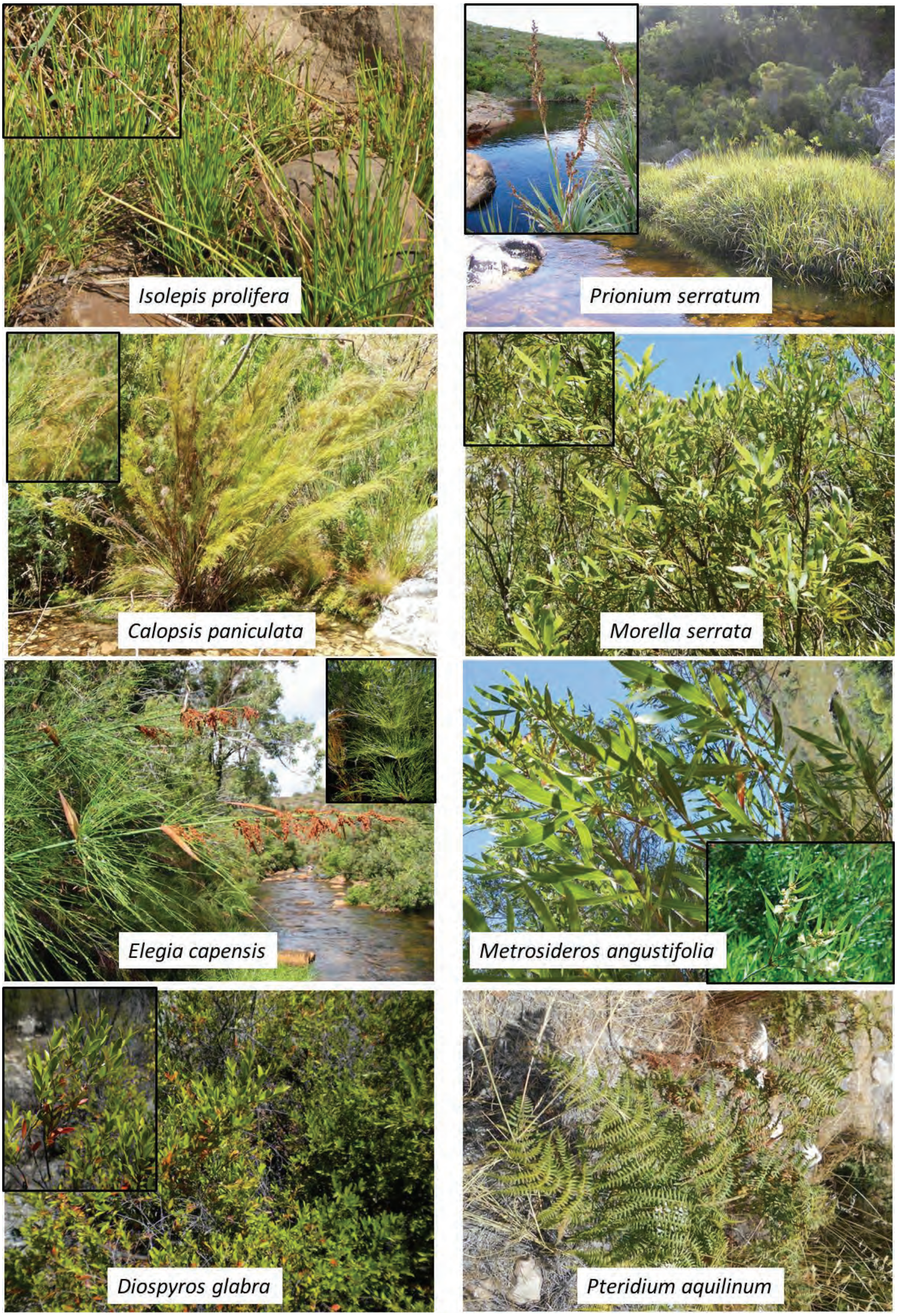


Figure 5.3 Photographs of the indicator species

5.3 Site choice and data collection

5.3.1 Study site selection

Study sites should:

- be in headwaters, e.g., mountain streams, transition and upper foothills (Figure 5.4 and Table 5.3 refer);
- have naturally shaped banks with undisturbed riparian vegetation, as noted by the dominance of a variety of different indigenous growth forms and few alien species;
- be located along a relatively straight reach, and the active channel should contain the full volume of water flowing past the site, i.e., no side channels or mid-channel bars;
- be accurately gauged;
- have some hydraulic controls (rapids, riffles, plane beds) as these are better suited to accurate hydraulic modelling and present better riparian zonation patterns;
- have low human or animal traffic, as footpaths trample groundcovers (and curious people move/remove survey pins and plot-layout strings);
- be located on reaches with few/no changes to the hydrology;
- not have been burnt or cleared, nor been subject to catastrophic flooding, for at least 15 years, since there will have been insufficient time for the riparian flora to have re-established; and
- not be used for subsistence activities, such as grazing, clearing for pastoral lands, or the felling of trees for wood or the collection of reeds for dwellings or craft making.

In is important that the hydrological, hydraulic, geomorphological and botanical conditions of each site are carefully evaluated before inclusion. Currently, Birkhead and Desai (2009) is one of the simplest ways to evaluate physical parameters, as it provides synthesized hydraulic data (as at 2007) from South African Ecological Reserve studies. This information is also available for Reserve studies completed after 2007 (www.dwa.gov.za). Typically, the documentation from Reserve studies describes the accuracy of available hydrological data, the hydraulic and geomorphological characteristics of the river channel, and the condition of the riparian and aquatic communities[11]. The condition of each discipline is scored in Ecological Categories (EC), A through F (Kleynhans et al. 2007b), where A is natural, C is largely natural and F completely modified. The best sites from these reports and Birkhead and Desai (2009) are shown in Table 5.4 based on:

- the accuracy of the hydrological data and data record longer than 30 years being available for download;
- their being a gauge at/near the site i.e. on the same channel in order to provide observed data; and
- the geomorphological and riparian condition being in a class C or higher.

[11] Water quality, fish and invertebrate data are also synthesized but are not considered here.

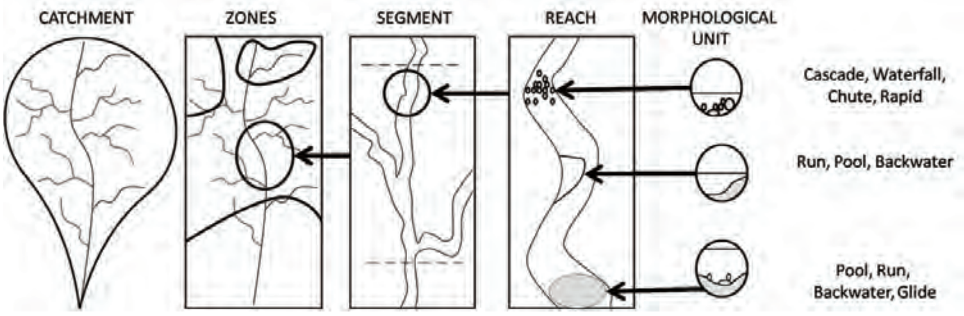


Figure 5.4 A geomorphological classification system (Rowntree et al. 2000).

Table 5.3 Longitudinal zones along South African Rivers (Rowntree et al. 2000).

Longitudinal zone	Range of slope	River characteristics
Source zone	Not specified	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	>0.1	A very steep gradient river dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain stream	0.04-0.099	Steep gradient river dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool. Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Transitional	0.02-0.039	Moderately steep river dominated by bedrock or boulder. Reach types include plane-bed, pool-rapid or pool-riffle. Confined or semi-confined valley floor with limited flood plain development.
Upper foothills	0.005-0.0019	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plane-bed, pool-riffle, or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain or sand, gravel or cobble often present.
Lower foothills	0.001-0.005	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types include pool-riffle or pool rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Flood plain often present.
Lowland river	0.0001-0.0009	Low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.
Additional zones associated with a rejuvenated longitudinal profile		
Rejuvenated bedrock fall/cascades	>0.02	Moderate to steep gradient, often confined channel (gorge) resulting from uplift in the middle to lower reaches of the long profile, limited lateral development of alluvial features, reach types include bedrock fall, cascades and pool-rapid.
Rejuvenated foothills	0.001-0.0019	Steepened section within middle reaches of the river caused by uplift, often within or downstream of gorge; characteristics similar to foothills (gravel/cobble bed rivers with pool-riffle/ pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro-channel activated only during infrequent flood events. A flood plain may be present between the active and macro-channel.
Upland flood plain	>0.005	An upland low gradient channel often associated with uplifted plateau areas as occur beneath the eastern escarpment.

Table 5.4 **Short list of South African rivers suitable for modelling riparian vegetation-flow links (data from Birkhead and Desai 2009). Missing data were not provided or are non-reserve sites. PES = present ecological status; A = natural, B = near natural, C = largely natural. Bolded sites were used in Chapter 4.**

Region	Environmental Flow study site	River	Latitude	Longitude	Gauging weir	Overall	Hydrology	Geomorphology	Riparian	Channel width (m)
						Ecological Category				
Western Cape	**Breede 2**	**Molenaars**	-33.7233	19.17179	H1H018	B	AB	B	BC	40
	Non reserve	**Elands**	-33.7394	19.1131	H1H033					25
	Non reserve	Jonkershoek	-33.9889	18.96694	G2H037					20
	Palmiet 4	Palmiet	-34.3303	18.98937	G4H011	C		B	B	60
	Hex River 2	Sanddrifskloof	-33.4883	19.52039	H2H004	C	E	BC	BC	35
	Non reserve	Rooielskloof	-33.4611	19.61786	H2H005					20
Southern Cape	Outeniqua	Knysna	-33.8911	23.03253	K5H002	B	B	AB	B	30
	Outeniqua	**Karatara**	-33.8824	22.83853	K4H002	A/B	B	A	AB	25
	Outeniqua	Malgas	-33.9375	22.4213	K3H004	C	C	BC	D	30
	Outeniqua	**Kaaimans**	-33.9711	22.54773	K3H001	B	B	BC	A	25
	Outeniqua	**Diep**	-33.9136	22.70806	K4H003	B	C	B	AB	40
Limpopo province	Mokolo 1B	Mokolo	-24.1783	27.97768	A4H002	B/C	D	C	BC	70
	Mokolo 2	Mokolo	-24.065	27.78716	A4H005	B/C	C	BC	AB	60
Mpumalanga	Crocodile 3	Crocodile	-25.4521	30.68108	X2H013	B/C	C	C	C	60
	Crocodile 4	**Crocodile**	-25.5024	31.18198	X2H032	C	C	BC	C	140
	Crocodile 5	Crocodile	-25.4829	31.50773	S2H046	C	C	CD	C	140
	Crocodile 6	Crocodile	-25.3905	31.97444	X2H016	C	D	C	C	300
	Sabie/Sand 2	Sabie	-25.0279	31.05166	X3h023	C				
	Dwars 1	Dwars	-24.8439	30.09189	B4H009	BC	C	B	C	60
	Olifants 12	Blyde	-24.4144	30.83111	B6H001	B				
	Elands 1	Elands	-25.631	30.32625	X2H011	B	B	B	B	50
Vaal	Upper Vaal 1	Vaal 1	-26.8728	29.61384	C1H007	B/C	C	BC	AB	120
	Upper Vaal 2	Vaal 2	-26.9211	29.27929	C1H019	C	D	D	BC	60
	Upper Vaal 3	Vaal 3	-26.9909	28.72971	C1H012	C	C	C	C	100
KwaZulu-Natal	Thukela 7	Sundays	-28.4605	30.04288	V6H004	BC		BC	BC	140
	Thukela 11	Mooi	-29.054	30.30067	V2H004	B/C		C	C	80

There may be many other sites on other rivers that are also suitable. Guidelines for evaluating site suitability are provided in King et al. (2008).

5.3.1.1 Field verification

Once a list of potential sites is identified, each one should be visited to verify their condition and suitability for modelling flow and vegetation links. Fire, invasion and/or clearing of alien vegetation, abstraction, sand mining or bulldozing of the river banks and channel and many other kinds of anthropogenic disturbances may impact upon the condition of the river channel or the riparian community between site visits.

5.3.2 Site set-up

5.3.2.1 Cross-section establishment

At each site one cross-section is established across both banks of the macrochannel through the riparian area (Figure 5.5). Hydraulics are modelled along the cross-section (section 5.3.2.2) and related to the distribution of riparian plants in two belt transects located up- and downstream of the hydraulic cross-section (section 5.3.2.3).

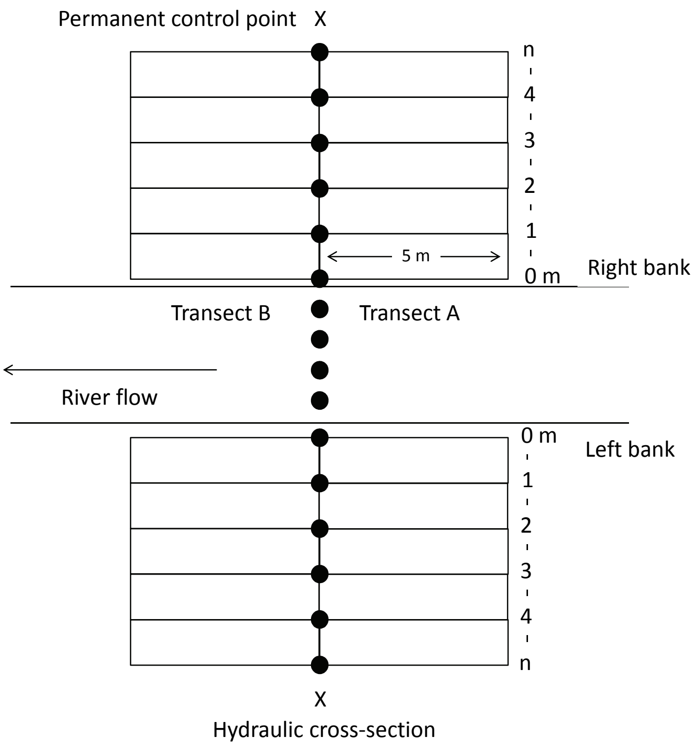


Figure 5.5 Layout of hydraulic cross-section and vegetation transects. Black circles are points surveyed along the cross-section at marked boundaries between sample plots and the active channel.

At each cross-section a line-of-site should be established through the riparian vegetation on both banks perpendicular to river flow (Figure 5.6). It is often necessary to hack/cut a line through dense vegetation. The line-of-site provides a path along to survey the cross-section and from which the two vegetation transects (A and B) can be surveyed (Figure 5.5). Opposing banks will provide replicate samples.

Figure 5.6 A line of site along a cross-section through riparian vegetation.

5.3.2.2 Hydraulic cross-sections

The procedure used here is identical to that for many environmental flow assessments. Please see King (2008) for detailed instructions.

In general, water surface elevations (stage) are surveyed in at each cross-section, for high and low flows. A rating curve is derived for each cross-section based on the surveyed stages and discharges observed at the relevant gauging station, which are cross checked against primary verified sub-daily data accessed from the DWA database (http://www.dwaf.gov.za/Hydrology/). The stage of zero flow that is surveyed in, and; one or two modelled high flows are used to extend the rating curve beyond the observed data using Manning's equation based on a single cross-section and representative high flow energy slope recorded at the site. Manning's n values are estimated using photographs from various references (Barnes 1967, Arcement and Schneider 1989, Hicks and Mason, 1998; Birkhead and Desai, 2009) and experience. In addition, the variation of Manning's resistance with stage is determined by plotting the Manning's resistances back-calculated from the observed stages, discharges and slopes. The energy slope is estimated based on the general channel slope for the reach measured off a 1:50 000 scale topographical map with 20 m contours and where available a survey of the channel bed over a reasonable distance. Each time-series of daily average flows is translated to a time-series of stage via the rating curve in order to generate an (1) annual and (2) monthly time-series of daily averaged inundation durations and standard deviations about these means at 0.1 m intervals along the hydraulic cross-sections. These statistics may be generated for the median year, the minimum year (year with lowest annual runoff), the maximum year (year with highest annual runoff) and most recent years since a significant disturbance event, the timing of which varied per river. It is important to take note when a catastrophic flood last occurred as the channel shape and distribution of plants is likely to change during such events.

The hydraulic cross-section must be established where the river channel shape is likely to remain stable over the course of the study. The same cross-section is surveyed three times at different flows so that the stage (water surface height on the cross-section) is recorded during a low, medium and, if possible, a high flow event. If the cross-section shape changes during the course of the study any data prior to the change cannot be used. To ensure that the cross-section is re-surveyed accurately each time, three permanent control points should established at the site, by painting a mark on a rock or by cementing a short metal stake into the ground (Figure 5.7). These permanent controls must be located where they are accessible during floods and where they will remain stable over the course of the study. One control should be at the setup point where the tripod for the total station is placed (Figure 5.8).

Figure 5.7 A permanent control point in a rock or as a metal stake cemented into the ground surrounded by a pyramid of rocks.

Figure 5.8 A total station over the setup point.

5.3.2.3 Vegetation transects

Two vegetation transects are aligned 5 m upstream and downstream of the hydraulic cross-section (Figure 5.5). Each transect consists of sample plots that are 5x1 m placed back to back through the riparian area. If the riparian area is wider than 20 m, it is advisable to sample plots systematically, for example every 2 m for a 20 m wide riparian area, every 3 m for a 30 m wide riparian area and so on. Approximately 10 sample plots along each transect on each bank is sufficient. If the riparian area is narrower than 20 m, every adjacent sample plots must be sampled. The position of every meter along each transect is marked with a tag made from a cable tie and key tag (Figure 5.9).

Figure 5.9 Tags to mark the boundaries between sample plots.

5.3.3 Data collection

5.3.3.1 Hydrological data

Hydrological data for river gauges can be downloaded from Department of Water Affairs (DWA) website (http://www.dwaf.gov.za/Hydrology/) as follows:

- access website;
- click on 'Verified data' at the top left of the screen;
- select the drainage region, for example 'H Breede' and press the 'SEARCH' button;
    - alternately enter the gauge number if you have it, or search for it by river name;
- a list of gauging stations is shown that are hyperlinks, click on the one you are interested in, for example 'H1R001';
- beneath the bright green headers, enter the dates of interest and select either 'average daily flow', or 'time series' for sub-daily flow readings;
- in each case a web page with the data is shown that can be saved as a note pad file and then can be imported into EXCEL for easy manipulation; and
    - in the file menu click File, Save as, and choose Text File (*.txt) from the drop down menu, and input the file destination.

The hydraulician may base his modelling on either the daily or sub-daily data depending on the reliability of the data, accuracy required for the study and the flow regime of the river.

5.3.3.2 Hydraulic data

On the first data collection trip the entire cross-section is surveyed from a control point on one bank, through the active channel to end on the control point on the other bank. The following should be captured:

- all changes in bank and channel topography;
- the boundary of each sample plot, i.e. every meter;
- the height and distance from the water's edge of each sample plot;
- the left and right bank water's edge; and
- the position and elevation of the permanent control points.

The water level at each cross-section (stage) must be recorded during three different flow events, preferably a low, medium and high flow. On subsequent trips it is not necessary to resurvey the entire cross-section. All that is required is to record the left and right bank water's edge along with the two permanent control points. The distance and elevation from the setup point to the control points allows the user to orientate about the site and cross-check the values recorded for these against the other surveys. The data for these points should be within a 1-cm error. Anything greater is unacceptable and can mean either that the total station was set up differently to previous trips, which can be corrected, or that the permanent control points have moved, which may or may not indicate the river channel shape has changed. Ideally, repeat surveys should show exactly the same values for control points.

The stage data, surveyed in at the cross-sections, are used to create a rating curve that describes how discharge, the volume of water, varies with stage up the cross-section. The hydraulician will need the stage readings as well as the level of the water on the stage plate (Figure 5.10) at the gauging weir (Figure 5.11) as near to the time of day that the readings were surveyed. The stage plate photograph is used to cross-check the hydrological data that is downloaded from the DWA website of that day.

In summary, the hydraulic data collected and handed to the hydraulician comprises:

- hydrological data downloaded from the DWA website;
- surveyed cross-section data, either raw data sheets or electronic downloads from the total station;
- water level (stage) at three distinctly different discharges along the hydraulic cross-sections; and
- stage plate photographs from each gauge taken immediately after each survey was completed.

Figure 5.10 A stage plate photograph records the water level on the day.

Figure 5.11 Gauge No. X2H032 on the Crocodile River downstream of EWR site 4.

5.3.3.3 Vegetation data

Mark out the boundaries of the sample plots:

- lay a string along the hydraulic cross-section and mark 1 m intervals;
- attach tags to the trees/bushes at each 1 m interval and label them chronologically from the water's edge (Figure 5.9); and
- collect as many unknown plants as you can find before recording plant distribution in each transect.

Collect vegetation data:

- count and record the number of each species of tree and shrub in each plot;
    - o estimate the cover that each species contributes toward the total vegetation cover in a sample plot by eye (two-dimensional areal cover);

    - separate trees into three size-classes according to height, *viz*.: seedlings (<0.3 m), shrubs (0.3 to 2 m) and adults (>2.0 m) and record cover data for each separately;
- estimate and record the height and cover of every tree, shrub and graminoid;
- record the proportion of each sediment particle size in each sample plot as a fraction of 100 using the Wentworth scale (Table 5.5, Gordon et al. 2002):
    - as rough guide, boulders are too large to lift;
    - cobbles are soccer ball sized and can be picked up;
    - gravel is finger nail sized;
    - sand is the final category;
- focus on perennial plants that live for more than one year; and
- ignore annuals, such as weedy forbs, as they are transient and thus not likely to persist over the decades that flow is modelled.

Collect and press two specimens of each plant; one for submission to a herbarium for identification and another to be kept by the collector for future reference. Compile a species list while collecting plants and give each collected plant a temporary name and a site-specific collection number. Take two photographs of each plant collected: one of any reproductive material (flowers, seed pods), and; one close up of a branch tip showing leaf structure. The South African National Botanical Institute can be contacted to locate the nearest botanical gardens (www.sanbi.org). Once identifications are received, ensure that the retained specimen is correctly labelled.

Note: Specimens should be pressed immediately on collection, as many of the plants wilt easily and rot:

- use an A4 plant press as it is able to fit most plants collected; trees, shrubs and graminoids (grasses, reeds, rushes and sedges);
- try to collect a specimen with reproductive material (flowers, seeds) as without it the plant may not be identified;
- press each drier specimen between at least four layers of newspaper;
- press wetter specimens, such as succulents or marginal zone graminoids, between eight, or more, layers of newspaper;
- attach an identification tag to each specimen with a collection number and name;
- also write the identification particulars on the newspaper in which the plant is pressed and onto a specimen collection list for that site;
- use a waterproof pen for the newspaper and the specimen tags;
- store the plant press in a dry room and change the newspaper daily until both the specimen and the newspaper are dry as wet specimens will rot;
- for trees and shrubs:
    - cut fresh branch ends to show the branching pattern, leaf shape and arrangement, and flowers/seed pods if present;
- for graminoids and forbs:
    - for small plants, uproot and press the entire plant as roots are needed for identification; and

- o for larger plants, particularly those with long filamentous leaf shoots and flower parts, cut sections of the plant into A4 length pieces: a flower, a leaf shoot length, and a root mass.

Table 5.5 Wentworth scale categories for sediment particle size.

Sediment calibre	Size range
Boulder	>256 mm
Cobble	64 to 256 mm
Gravel	2 to 64 mm
Sand	<2 mm

In summary, the vegetation data collected includes:

- a species list, plant specimens and photographs of collected plants;
- plant distribution data recorded as percentage cover in three life stages for trees in each sample plot;
- plant distribution data recorded as percentage cover for shrubs and graminoids in each sample plot; and
- the percentage cover of different particles sizes in each sample plot.

5.4 Analysis and interpretation of site-level vegetation data

5.4.1 Data capture

PRIMER V6 (Clarke and Warwick 2006), a multivariate statistics package designed for the synthesis of biological data, should be used to analyse the data. Data sheets can be imported from MSExcel. A standard data sheet for import into PRIMER must be prepared as follows (Table 5.6):

- the first row of the spreadsheet must be empty;
    - o row 2 contains the sample headers in columns B, C, D etc.;
- species names are listed in column A from row 3 down;
    - o there is **no** species column header;
- percentage covers for each species in a sample plot are listed in columns B, C, D and so on; and
- zeroes are entered where a species was absent from a sample plot.

A data sheet like this must be created for each river bank by combining the data of both transects on one bank.

The file must be saved as a MSExcel version 2003-2007 spreadsheet as PRIMER will not accept version 2010 files. Give the worksheet a name you recognise as PRIMER asks for this during the import process.

Table 5.6 **EXCEL spreadsheet formatted for import into PRIMER. T = tree, J = sapling, S = seedling.**

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2		0a	0b	0c	0d	1a	1b	1c	1d	2a	2b	2c	2d
3	*Ehrharta ramosa subsp. aphylla*	0	0	0	0	0	0	0	0	2	0	0	0
4	*Metrocideros angustifolia T*	0	0	0	0	0	0	0	0	0	60	0	25
5	*Brabejum stellatifolium T*	0	0	0	0	0	0	0	0	0	25	0	23
6	*Pteridium aqualinum*	0	0	0	0	0	0	0	0	0	0	0	0
7	*Brachylaena neriifolia T*	0	0	0	0	0	0	10	0	0	0	0	30
8	*Calopsis paniculata*	2	0	4	0	10	0	3	5	15	0	4	4
9	*Brachylaena neriifolia J*	0	0	0	0	3	0	0	0	34	13	20	0
10	*Elegia capensis*	0	0	0	0	0	0	0	6	5	0	0	7
11	*Metrocideros angustifolia J*	0	0	0	0	15	5	0	10	13	0	0	0
12	*Elytropappus intricata*	0	0	0	0	0	0	0	0	0	0	0	0
13	*Brabejum stellatifolium S*	0	0	0	0	1	0	1	6	6	4	3	6
14	*Isolepis prolifer*	4	5	6	2	5	0	4	4	0	0	0	0
15	*Cliffortia ruscifolia*	0	0	0	0	0	0	0	0	0	0	0	0
16	*Hartogiella schinoides J*	0	0	0	0	0	0	0	0	0	0	0	0
17	*Brabejum stellatifolium J*	0	0	0	0	0	0	0	5	5	0	3	9
18	*Ficinia acuminata*	0	0	0	0	0	0	0	0	0	0	0	0
19	*Ishyrolepis sieberi*	0	0	0	0	0	0	0	0	0	0	0	0
20	*Morella serrata J*	0	0	0	0	0	0	7	8	0	0	0	4

5.4.2 Data analysis

In PRIMER:

- To import data:
    - o open the **file** menu;
        - select **open file**;
        - change file type in the drop down menu to be **EXCEL** files;
        - select the file and click **open**;
    - o select the **data sheet** you have named from the drop down menu;
        - check the **sample data** box in data type;
        - click **next**;
    - o check default data sheet characteristics:
        - **title** and **row labels** boxes must be ticked;
        - orientation must be **samples as columns**;
        - data type must be **abundance**;
        - blank must be **zero**; and
        - click **finish**.
- To analyse data with a CLUSTER analysis:
    - o open the **analyse** menu;
        - select **pre-treatment, transform (overall)**;
        - select **fourth root** from the drop down menu;
        - click **ok**;
    - o open the **analyse** menu again;
        - select **resemblance**;
        - check default resemblance characteristics:

            - analyse between must be **samples**;
            - measure must be **Bray-Curtis similarity**;
            - add dummy variable must be **unchecked**;
            - click **ok**;
    - open the **analyse** menu again;
        - select **CLUSTER**;
        - check CLUSTER default characteristics:
            - cluster mode must be **group average**;
            - SIMPROF test must be **unchecked**;
            - plot dendrogram must be **ticked**;
            - click **ok**;
    - export the dendrogram from the CLUSTER analysis:
        - open the **file** menu;
        - select **save graph as;**
        - give the file a name, select the destination folder and choose **Windows enhanced metafile** from the drop down menu;
        - click **save**;
        - select plot size output to be **screen** or specify size **inputs**; and
        - click **ok.**
- To analyse data with an MDS after completion of the CLUSTER analysis:
    - click the **Resem1** icon in the PRIMER navigation pane at the left:
    - open the **analyse** menu;
        - select MDS;
        - check MDS default settings;
            - number of restarts must be **25**;
            - minimum stress must be **0.01**;
            - Kruskal fit scheme must be **1**;
            - Shepard diagrams must be **unchecked**;
            - configuration plot must be **ticked**;
            - click ok;
    - export the ordination diagram from the MDS analysis:
        - open the **file** menu;
        - select **save graph as;**
        - give the file a name, select the destination folder and choose **Windows enhanced metafile** from the drop down menu;
        - click **save**;
        - select plot size output to be **screen** or specify size **inputs**; and
        - click **ok.**

5.4.3 Interpreting results

The two output files from Section 5.4.2 are the CLUSTER dendrogram and the MDS ordination (Figure 5.12).

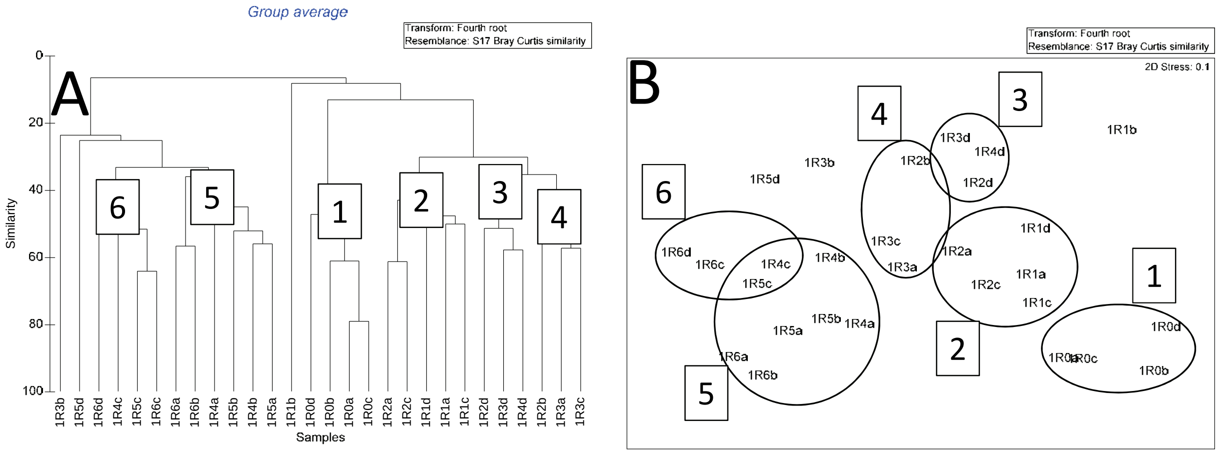


Figure 5.12 **(A) CLUSTER dendrogram and (B) MDS ordination for a site on the Rondegat River.**

If the pattern depicted in the two figures agree with one another assign samples to groups as follows:

- recognise groups with greater than 40% similarity; and
- number the groups from 1, closest to the water's edge, and in ascending order laterally outwards.

If the pattern depicted in the two figures do not agree it is not advisable to continue further.

The groups of samples are analysed further to determine which species are most abundant in a group by calculating:

- the frequency of occurrence;
    - o by dividing the number of samples a species is present in, by the total number of samples for that group; and
- cover, as a percentage of the total sampled for a group, for each species present in the group;
    - o by dividing the total cover of that species from each sample in the group, by the sum of covers for all species at the site.

An example of the outputs (Table 5.7) from this analysis is shown below for group 2 from Figure 5.12. Groups like this are assigned to a lateral zone based upon the habitat characteristics of the dominant plants. Goldblatt and Manning (2000) provide habitat preference data for Western Cape plants and there will be similar texts for plants in other parts of South Africa. An illustrative example of these data is provided in Table 5.8, used to assign plants to one of three categories as follows:

- species common on or near streamsides, seeps, rivers and watercourses are **obligate** riparian (wet) species;
- those occurring on rocky slopes and outcrops or mountain slopes are **incidental** terrestrial (dry) species; and

- species described as occurring in bush, woodland or forests and/or associated with water courses are **facultative** riparian (wet/dry) species[12].

Table 5.7 Outputs of frequency of occurrence and percentage cover abundance analysis for group 2 from Figure 5.12. S = seedling, J =juvenile, T = tree.

	TOTAL COVER	% of total cover	Number of samples	% Frequency of occurence					
Species	244	T	F	5	1a	1c	1d	2a	2c
Calopsis paniculata	37	15	5	100	10	3	5	15	4
Brabejum stellatifolium S	17	7	5	100	1	1	6	6	3
Brachylaena neriifolia J	57	23	3	60	3	0	0	34	20
Metrocideros angustifolia J	38	16	3	60	15	0	10	13	0
Isolepis prolifer	13	5	3	60	5	4	4	0	0
Brabejum stellatifolium J	13	5	3	60	0	0	5	5	3
Todea babara	6	2	3	60	0	2	2	2	0
Metrocideros angustifolia S	6	2	3	60	0	1	0	4	1
Morella serrata J	15	6	2	40	0	7	8	0	0
Elegia capensis	11	5	2	40	0	0	6	5	0
Brachylaena neriifolia S	2	1	2	40	1	1	0	0	0
Brachylaena neriifolia T	10	4	1	20	0	10	0	0	0
Morella serrata T	7	3	1	20	0	0	7	0	0
Erica caffra	6	2	1	20	0	0	0	6	0
Morella serrata S	2	1	1	20	0	0	2	0	0
Drosera capensis	2	1	1	20	0	0	2	0	0
Ehrharta ramosa subsp. aphylla	2	1	1	20	0	0	0	2	0

Once this has been done designate groups into lateral zones based on which of the three categories of plants were dominant in a group as follows:

- groups that contain only incidental species are terrestrial and are not considered further;
- groups that contain a mixture of incidental and facultative species, and that are most closely related to terrestrial groups, are upper;
- groups with only facultative species are lower;
- groups with a mixture of facultative and obligate species, and that are most closely related to lower or marginal, are lower dynamic; and
- groups with only obligate species are marginal.

[12] There are not facultative species in this example.

Table 5.8 Habitat preference data collated for species in group 2 from Figure 5.12.

SPECIES	FAMILY	GROWTH FORM	HABITAT	DESIGNATION	COMMON NAME
Brabejum stellatifolium	Proteaceae	Tree	Riverine, WET	Obligate	Wild almond
Brachylaena neriifolia	Asteraceae	Small tree	Riverine, WET	Obligate	Bitterblaar
Calopsis paniculata	Restionaceae	Restio	Riverine, WET	Obligate	
Ehrharta ramosa subsp. aphylla	Poaceae	Grass	Mountain slopes, DRY	Incidental	
Elegia capensis	Restionaceae	Restio	Riverine, WET	Obligate	
Erica caffra	Ericaceae	Shrub	Riverine, WET	Obligate	Water heath
Isolepis prolifera	Cyperaceae	Sedge	Riverine, WET	Obligate	
Metrosideros angustifolia	Myrsinaceae	Small tree	Riverine, WET	Obligate	Smalblad
Morella serrata	Myricaceae	Small tree	Coastal sandy and limestone flats, DRY	Incidental	Waterolier
Todea barbara	Osmundaceae	Forb	Riverine, WET	Obligate	

The results of this process are illustrated below (Figure 5.13). Compared with Figure 5.12 it can be seen that groups 3 and 4 were merged into the lower zone since they both consisted of facultative species, and groups 5 and 6 were merged into the upper zone since they both consisted of a mixture of incidental and facultative species.

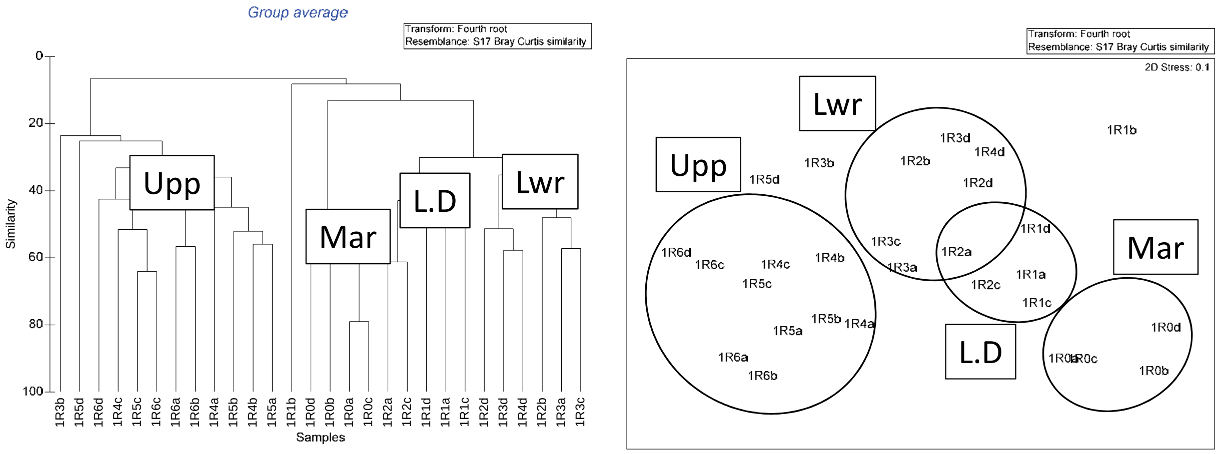


Figure 5.13 Lateral zones allocated to a site on the Rondegat River, an illustrative example.

5.5 How to develop the rules

5.5.1 Using a Classification and Regression Tree to create physical rules

Once sample plots are allocated a lateral zone type (section 5.4.3) the vegetation and physical data of each sample plot (section 5.2.1) may be combined for the Classification and Regression Tree (CART) analysis that looks for relationships between the lateral zone identity assigned to samples and their physical characteristics. STATISTCA 12 (StaSoft 2012) was used to produce the CART results from which Table 5.2 and Figure 5.2 were produced. STATISTICA is an expensive software package to acquire but the CART method should be available in other software packages. The respective user manual should be consulted in order to process the analysis. Here, we provide an overview of how to arrange the data and the logic of the process.

A single spreadsheet needs to be compiled from all the vegetation data for all sites for which the CART is to be run. This requires you to combine the species lists from each site into a MASTER species list that can be used for all every site. It is critical that the arrangement of the species list be exactly the same for each site. This allows the analysis to create a similarity matrix between sites and compare associations between groups of species against the physical data within and between sites.

Most statistics packages as that you transpose the data so that it is arranged in the opposite manner to that described for PRIMER (Table 5.6). The difference is that the sample codes run down the sheet in the first column while all the data associated with that sample plot run across the row. In the illustrative example below (Table 5.9) the site codes are listed in column B, the sample plot code for each site listed in column C, followed by the physical data (section 5.2.1), followed by the cover of each species for that sample. The final column in the spreadsheet must be the lateral zone assigned to that sample plot, here 1 referred to the marginal zone, 2 the lower dynamic, 3 the lower and 4 the upper zone, following the procedure outlined in section 5.4.3.

Table 5.9 Format of data required for import into STATISTICA for the CART analysis.

A	B	C	D	E	F	G	H	J	L	M	N	O	P
1	site	sample	Water	Sand	Height	Distance	Diff (W-B)	…other data	Asparagus scandens	Kiggelaria africana J	…	nSpecies	Latersl zone
2	J1	1J1a	50	0	0.32	1	0.634852584		0	0			2
3		1J1d	30	10	0.34	1	-0.074182284		0	0			2
4		1J2a	20	0	0.76	2	0.634852584		0	0			3
5		1J2b	0	10	1.39	2	0.681804579		0	0			3
6		1J2c	0	10	0.32	2	0.064827481		0	0			3
7		1J2d	0	20	0.60	2	-0.074182284		0	0			2
8		1J3a	0	10	1.86	3	0.634852584		0	0			3
9		1J3b	0	0	2.20	3	0.681804579		0	0			3
10		1J3c	0	40	0.83	3	0.064827481		0	0			3
11		1J3d	0	10	0.94	3	-0.074182284		0	0			3
12		1J4b	0	10	2.33	4	0.681804579		0	0			4
13		1J4c	0	30	1.29	4	0.064827481		0	0			3
14		1J5b	0	30	2.51	5	0.681804579		0	0			4
15		1J5c	0	30	1.63	5	0.064827481		0	0			4
16		1J5d	0	50	1.49	5	-0.074182284		0	0			3
17	J2	2J1b	90	0	0.11	1	0.0721835		0	0			1
18		2J1c	80	0	0.35	1	0.159442724		0	0			1
19		2J1d	100	0	0.20	1	0.108577611		0	0			1
20		2J2b	40	0	0.36	2	0.0721835		0	0			2

The analysis selects 70% of the samples randomly for preparation of the rules and then also tests the rules produced on the other 30% of the samples. It gives you percentage scores for both: a percentage of samples found within the observed data to each lateral zone, and then the percentage predicted correctly in the test data, when the rules are applied (as per Table 5.2).

5.5.2 Using a SIMPER analysis to distinguish differentiating species

The same vegetation data (Table 5.6) in PRIMER can be used to run a SIMPER analysis in order to determine which species are good indicators for the lateral zones (Figure 5.1). In PRIMER following on from the steps in 5.4.2:

- To analyse data with an SIMPER after completion of the MDS analysis:
    - click the **Data1** icon in the PRIMER navigation pane at the left:
    - open the **edit** menu;
        - select Factors;
            - click **add…**;
            - give the factor a name, in this case lateral zone;
            - enter the lateral zone number assigned to each sample plot;
            - click **ok** when done;
        - select the **analyse** menu;
            - click **SIMPER**;
                - design one way must be checked
                - measure Bray-Curtis similarity must be checked
                - factor A must indicate lateral zone
                - list only higher-contributing variables must be checked;
                - cut-off percentage must be 90; and
                - click **OK.**

The output files from the analyses list *typical* species and their contribution towards similarity between samples and *differentiating* species and their contribution towards dissimilarity between the samples. The distribution of these indicator species may be compared visually by plotting their abundances in different lateral zones against one another, as done in Figure 5.1)

5.6 Summary

Physical rules to identify lateral zones in Fynbos Riparian Vegetation were produced from data on community structure of undisturbed rivers (Section 5.2). It was not possible to provide a similar set of rules for other riparian communities as there were insufficient data. Thus, guidelines were provided to allow others to collect (Section 5.3) and analyse (Section 5.4) data to generate similar rules for other South African rivers.

A sample plot placed within 1.5 m of the water's edge will either be in the marginal or lower dynamic zones (Table 5.2). Of these, those positioned at elevations less than 0.12 m above the water's surface will be in the marginal zone. Those situated higher than 0.12 m would be in the lower dynamic zone. Plots located at a distance greater than 1.5 m from the water's edge will be in the lower or upper zones. Of these, those lower than 1.29 m in elevation will be in the lower zone. Those higher than 1.29 m in elevation could either be in the lower or upper zones based upon the difference in bank shape. Those on a convex bank (WB-DB > 0.23) will be in the lower zone, while those on a concave bank (WB-DB <=0.23) will be in the upper zone.

Some species are particularly abundant in each lateral zone and can be used to verify/adjust the delineation of zones in the field (Figure 5.1). The shrub *Prionium serratum* and the sedge *Isolepis prolifera* are most abundant in the marginal zone. The restio *Calopsis paniculata* and the tree *Morella serrata* are most abundant in the lower dynamic zone. The restio *Elegia capensis* and the tree *Metrosideros angustifolia* are most abundant in the lower zone. The fern *Pteridium aquilinum* and the shrub *Diospyros glabra* are most abundant in the upper zone.

6 CAPACITY BUILDING

Three students were trained during this project:

- Mr Michiel Karl Reinecke is registered at Stellenbosch University to read a PhD (2011-2013):
  - Thesis title: Links between riparian vegetation and flow.
  - Student Number: 16930673.
  - Department of Conservation Ecology and Entomology in the Faculty of AgriSciences, University of Stellenbosch.
  - Thesis to be submitted in August 2013, and will be available for download from the University of Stellenbosch website (http://scholar.sun.ac.za/) post-2013.
- Ms Mia Otto is registered at Stellenbosch University to read an MSc (2011-2013).
  - Thesis title: Spatial and temporal changes in Fynbos riparian vegetation in the Western Cape.
  - Student Number: 16876156.
  - Department of Conservation Ecology and Entomology in the Faculty of AgriSciences, University of Stellenbosch.
  - Thesis to be submitted in May 2013, and will be available for download from the University of Stellenbosch website (http://scholar.sun.ac.za/) post-2013.
- Ms Rozwivhona Faith Magoba is registered at the University of the Western Cape to read an MSc (2012-2014).
  - Thesis title: Effects of river flows on recruitment success of riparian vegetation along selected high gradient rivers in the Western Cape province, South Africa.
  - Student Number: 2708321.
  - Department of Environmental and Water Science in the Earth Science Faculty, University of the Western Cape.
  - Thesis to be submitted in December 2013.

The abstracts from the papers that make up Mr Reinecke's PhD are provided in Section B.1, and those from Ms Otto's MSc are provided in Section B.2. Ms Magoba's MSc research proposal is provided in Section C.

7 THE WAY FORWARD

7.1 Conclusions

Riparian plants arrange themselves into lateral zones that run parallel to river flow. Groups of plants occur together if they are able to withstand the prevailing abiotic forces acting on the bank. The conceptual framework used in this study was based upon how the availability of water drops with distance from the water's edge and how it fluctuates seasonally through a hydrological year. Lateral and seasonal water patterns were compared with the distribution of plants on rivers inhabited by different riparian communities. The biotic and abiotic variables were not linked prior to analysis *viz.* the distribution of plants and/or the variability in river flow at a site were not analysed in a way that takes each other into account.

There are four lateral zones that may be usefully grouped into (after Boucher (2002) and Kleynhans et al. (2007a)):

- two wet bank zones:
    - o the **marginal**, largely comprised of obligate riparian graminoids, trees and shrubs;
    - o the **lower dynamic**, a transitional area comprised of a mixture of marginal and lower zone species, and an area of active recruitment for these;
- two dry bank zones:
    - o the **lower zone**, largely comprised of facultative riparian graminoids, trees and shrubs; and
    - o the **upper zone**, a transitional area comprised of a mixture of lower and terrestrial species.

This arrangement was found at the vast majority of the 34 sites on all 10 rivers inhabited by the following riparian communities:

- five Fynbos Riparian Vegetation rivers;
- three Southern Afrotemperate Forest rivers;
- one Lowveld Riverine Forest river, and;
- two Northern Mistbelt Forest rivers.

The marginal zone was missing at some sites. This was because the bank:

- coincided with a pool that lacked the lateral bar inhabited by the marginal zone, or;
- was degrading under heavy scour that would flush shallow rooted marginal plants and prevent them from establishing, and/or;
- was comprised of large calibre sediment that was unsuited to their establishment.

The lower zone was absent on one bank at one site, because the bank was near vertical.

In all cases, the 'missing' zones were present elsewhere in the reach. So ultimately the reason for the zones being missing was due to the relatively short length of channel included in the sample (10 m), which was necessary for accurately modelled hydraulics. We believe that all four zones will generally be present.

The longitudinal dimension of how plants arrange themselves requires further research and is partly addressed Ms Otto's thesis (Section B.2.1). The authors have no knowledge of similar studies at lower reaches, such as lower foothills and lowlands. The understanding generated from, and the applicability of the results of, this study and the theses are confined to mountain streams, transitional zones and upper foothills. Modelling flow at rivers with floodplains, such as lower foothill and lowland reaches, will be more complicated as it is necessary to account for vertical and lateral exchanges, and for storage of surface and groundwater flows.

At present the health of a riparian community is assessed in two (marginal and non-marginal) or three (marginal, lower and upper) zones, depending upon the level of assessment, using the VEGRAI (Vegetation Response Assessment Index) method of Kleynhans et al. (2007a). This study suggests that it may be relevant to also assess the lower dynamic zone, as it appears to be an area of preferential recruitment which is an important aspect of river health. Since the lower dynamic consists of species from its neighbouring two zones, studies focussed on biodiversity could possibly omit the zone.

The two strongest relationships to plant distribution were bank elevation and distance from the water's edge, which combine to gradient, the third strongest variable. It is possible to relate plant distribution patterns to simple predictive rules using elevation and distance. This makes sense as the hydraulic relationships ultimately relate back to elevation and distance (stage). The hydraulic work supported the widely-held belief that the separation between the wet and dry bank is located at the point on a cross-section where the 1:2 year flood recurs. In addition, it showed that the mid-point of the lower dynamic zone was flooded every 1.3-1.6 years while that of the lower was every flooded every 2.4 years. It was not, however, possible to separate the lower from the upper zone using flood recurrence interval as expected, mainly because there was an overlap in plants distributed into these two zones. It was also not possible to separate the marginal from the lower dynamic statistically, using flood recurrence, even though the ranges about their flood frequency abutted one another; 1.1-1.3 years for the marginal and 1.3-1.6 years for the lower dynamic. It was possible to separate the marginal from the lower dynamic using inundation duration, in that the marginal zone was inundated every year for up to three months of the year, whereas the lower dynamic was inundated for up to one month a year or not at all, during dry years. Inundation duration clearly is an important hydraulic variable that impacts upon the life histories' of riparian plants, but is not something considered overtly in Environmental Water Requirements.

In summary, it was possible to link the occurrence of lateral zones to flood recurrence or inundation duration as follows:

- the wet bank and dry bank may be separated using the stage of the 1:2 year flood on a cross-section;
- the marginal zone will be located where the cross-section is inundated for longer than one month per annum;
- the lower dynamic zone will be located where the cross-section is inundated for shorter than one month per annum; and
- the lower zone is situated at a position on the cross-section that is inundated for shorter than one week every second year.

A simple set of rules were prescribed to identify the position of the four lateral zones on headwaters in the Western Cape, and collection and analysis procedures were presented to allow for their development elsewhere in the country. The strength of the data presented in this report rests on the systematic collection of data and analyses.

Furthermore, it was shown that a combination of groundcovers and trees produced the strongest pattern between the riparian communities. Trees did not produce a useful pattern alone, whereas the patterns produced by groundcovers alone were similar to, but less significant than, the patterns of the two combined.

The theses linked to this study provided further insight. One paper accounts for how the prescribed indicator species, which were developed at a river-scale, (Section 3.3.2) for Fynbos rivers are distributed at different headwater reaches, for example mountain streams versus upper foothills (Section B.2.1). Geomorphic setting, largely valley width and sediment calibre, were shown to be main determinants of plant distribution longitudinally. Two papers ((Sections B.1.3 and B.2.2) investigated how lateral zones establish themselves following disturbance. The first showed that recruitment of trees and shrubs takes place between two and four years after clearing and that seedlings best establish within groundcovers. The second showed that species composition of undisturbed sites remains stable for up to 10 years, but that significant differences occur in the groundcover composition after a fire or following clearing of woody exotics. Another paper (Section 0) showed that abstraction of the entire summer flows did not affect tree growth or the ability of plants to disperse seed but suggested that it hampered recruitment of the wet bank species. Wet bank species were less drought-tolerant and relied upon low flows to disperse seed, while dry bank species distributed seed during high flow events and so were less susceptible to recruitment failure as a result of the abstraction. The effects of abstraction on recruitment are currently being investigated (see Section C).

7.2 Recommended research

7.2.1 Indicators of lateral zones

There is scope to repeat aspects of this study outside of the Western Cape using the methods prescribed. Ultimately, the links between flow and species composition could be used to identify, and construct response curves for, indicators of riparian vegetation condition that can be used to predict and monitor changes in response to changes in flow. Response curves describe how the abundance of an indicator changes in response to changes in various aspects of the flow regime and are used to predict the consequences of flow alterations in environmental flow assessments.

It may also be possible to generate generic flow-linked guilds, which could assist in calibrating daily flow time series.

7.2.2 River based signatures

The data from this study indicate that riparian communities along different geomorphological zones on the same river are more similar to one another than they are to communities in the same geomorphological zone on other rivers. These 'river based signatures' were first described by King and Schael (2001) for Fynbos river macroinvertebrates, and may have profound implications for river conservation. As such it is important that they are investigated further.

7.2.3 Assessments of river health

In South Africa, river health is assessed in two (marginal and non-marginal) or three zones (marginal, lower and upper), depending upon the level of assessment, using the VEGRAI (Vegetation Response Assessment Index) method (Kleynhans et al. 2007a). However, the lower dynamic appears to be an area of preferential recruitment and, as such, its inclusion in an updated VEGRAI is worth consideration.

7.2.4 Recruitment of riparian trees

Little is known about drivers of recruitment for South African riparian trees. Examples of the kinds of questions that require answers are:

- What are the environmental cues for riparian trees to release their seeds?
- Do riparian trees increase seed production during wet years and hold back during dry years?
- Are riparian communities dominated by seeders or sprouters?
- Do riparian trees rely on soil store seedbanks or are adult populations solely responsible for their persistence?
- What triggers germination?
- Are riparian propagules long- or short-lived?
- How do life history adaptations differ between occupants of the wet and dry bank?

We are fortunate that many our rivers are relatively undisturbed and provide ideal testing grounds for many of these questions.

References

Araya. Y.N., Silvertown, J., Gowing, D.J., McConway, K.J., Linder, H.P., Midgley, G. 2010. A fundamental, eco-hydrological basis for niche segregation in plants. New Phytologist.

Arcement, G.J. Jnr., Schneider, V.R. 1989. Guide for selecting Manning's roughness coefficients for natural channels and flood plains, United States Geological Survey Water-Supply Paper 2339, Denver.

Baker, M.E, Wiley, M.J. 2004. Characterisation of woody species distribution in riparian forests of lower Michigan, USA using map-based models. Wetlands 24(3): 550-561.

Baker, M.E., Wiley, M.J. 2009. Multiscale control of flooding and riparian-forest composition in Lower Michigan, USA. Ecology, 90 (1): 145-159.

Barnes, H.H. 1967. Roughness characteristics of natural channels, United States Geological Survey Water-Supply Paper 1849, Denver.

Baterlheimer, M., Gowing, D., Silvertown, J. Explaining hydrological niches: the decisive role of below-ground competition in two closely related *Senecio* species. Journal of Ecology, 98: 126-136.

Bendix, J. 1994. Scale, direction, and pattern in riparian vegetation environment relationships. Annals of the Association of American Geographers 84(4): 652-665.

Bendix, J. 1999. Stream power influence on Southern Californian riparian vegetation. Journal of Vegetation Science, 10 (2): 243-252.

Bendix, J. and Hupp, C.R. 2000. Hydrological and geomorphological impacts on riparian plant communities. Hydrological Processes 14: 2977-2990.

Birkhead, A.L., Desai, A.Y. 2009. Collation and Synthesis of Hydraulic Information Collected Over the Past Decade in Southern Africa to Inform Environmental Flow Requirements. WRC Project K8/795.

Birkhead, A.L., Olbrich, B.W., James, C.S., Rogers, K.H. 1997. Developing an integrated approach to predicting the water use of riparian vegetation. Water Research Commission report No. 474/1/97. Water Research Commission, Pretoria, South Africa.

Botha, M. 2001. Dynamics of two South African flood plain forests. Water Research Commission, Pretoria, South Africa. WRC report No. KV 131/01.

Boucher, C. 2002. Flows as determinants of Riparian Vegetation zonation patterns in selected Southern African Rivers. Enviro Flows 2002 4th Ecohydraulics Conference, Cape Town, South Africa.

Carter Johnson, W. 2000. Tree recruitment and survival in rivers: influence of hydrological processes. Hydrological Processes, 14: 3051-3074.

Carter, W.C., Dixon, M.D., Simons, R., Jenson, S., Larson, K. 1995. Mapping the response of riparian vegetation to possible flow reductions in the Snake River, Idaho. Geomorphology 13: 159-173.

Church, M. 2002. Geomorphic thresholds in riverine landscapes. Freshwater Biology, 47: 541-557.

Clarke, K.R. and Gorley, R.N. 2006. Primer V6: user manual/tutorial. Plymouth, UK, Primer-E.

Corbacho, C., Sanchez, J.M., Costillo, E. 2003. Patterns of structural complexity and human disturbance of riparian vegetation in agricultural landscapes of a Mediterranean area. Agriculture Ecosystems and Environment, 95: 495-507.

Davies, B.R., Day, J.A. 1998. Vanishing waters. Cape Town University Press, Cape Town, South Africa.

Davies, B.R., O'Keeffe, J.H. and Snaddon, C.D. 1995. River and stream ecosystems in southern Africa: predictably unpredictable. In: Ecosystems of the world 2: river and stream ecosystems. Cushing, C.E., Cummins, K.W. and Minshall, G.W. (Eds.). Elsevier Academic Press, New York.

Department of Water Affairs, 2010. Comprehensive reserve determination study for selected water resources (rivers, groundwater and wetlands) in the Inkomati water management area, Mpumalanga. Sabie and Crocodile systems, Main report. Department of Water Affairs Report No. 26/8/3/10/12/005. Prepared by Rivers for Africa eFlows Consulting. Pretoria, South Africa.

Department of Water Affairs, 2012. Hydrological services – surface water (data, dams, floods and flows). http://www.dwaf.gov.za/Hydrology/, accessed 2011 2012.

Dewson, Z.S., James, A.B.W., Death, R.G. 2007. Stream ecosystem functioning under reduced flow conditions. Ecological Applications 17(6): 1797-1808.

Dollar, E.J.S., Rowntree, K.M. 2003. Geomorphological research for the conservation and management of southern African rivers. Volume 2: managing flow variability: the Geomorphological response. Water Research Commission, Pretoria, South Africa. WRC Report no. 849/2/02. 283pp.

Dwire, K.A., Kauffman, J.B., Baham, J.E. 2006. Plant species distribution in relation to water-table depth and soil redox potential in montane riparian meadows. Wetlands, 26, No.1, 131-146.

Francis, R.A. 2006. Allogenic and autogenic influences upon riparian vegetation dynamics. Area, 38 (4): 453-464.

Galatowitsch, S., Richardson, D.M. 2004. Riparian scrub recovery after clearing of invasive alien trees in headwater streams of the Western Cape, South Africa. Biological Conservation, 122: 509-521.

Godfrey, L. 2000. Intermediate Ecological Reserve Determination for Elands River Catchment, Inkomati System, Mpumalanga. Quaternary Catchments X21F, X21G, X21H, X21J, X21K. Technical Report for the Department of Water Affairs and Forestry, by the Division of Water Environment and Forestry Technology, CSIR, Pretoria. Report No. ENV-P-C2000-090.

Gomi, T., Sidle, R.C., Richardson, J.S. 2002. Understanding processes and downstream linkeages of headwater streams. BioScience, 52(10): 905-916.

Gooderham, J.P.R., Barmuta, L.A. 2007. Upstream heterogenous zones: small stream systems structured by a lack of competence? Journal of the North America Benthological Society, 26 (3): 365-374.

Gordon, N.D., McMahon, T.A. and Finlayson, B.L. 1992. Stream hydrology: an introduction for ecologists. John Wiley and Sons, West Sussex, England.

Gorgens, A., Hughes, D.A. 1982. Synthesis of streamflow information relating to the semi-arid Karoo biome of South Africa, South African Journal of Science, 78:56-68. groundwater ecology. Freshwater Biology 40: 402-406.

Harris, L.D. 1988. Edge effects and conservation of biotic diversity. Conservation Biology, 2: 330-332.

Hicks, D.M., Mason, P.D. 1998. Roughness characteristics of New Zealand Rivers: A handbook for assigning hydraulic roughness coefficients to river reaches by the "visual comparison" approach, Water Resources Survey, DSIR Marine and Freshwater, Wellington.

Howell, J., Benson, D. 2000. Predicting potential impacts of environmental flows on weedy riparian vegetation on the Hawkesbury-Nepan River, south-eastern Australia. Austral Ecology 25:463-475.

Hughes, F.M. 1988. The ecology of African floodplain forests in semi-arid and arid zones: a review. Journal of Biogeography, 15 (1): 127-140.

Hughes, F.M. 1990. The influence of flooding regimes on forest distribution and composition in the Tana River floodplain, Kenya. Journal of Applied Ecology, 17: 475-491.

Hughes, F.M., Rood, S.B. 2003. Allocation of river flows for restoration of floodplain forest ecosystems: A review of approaches and their applicability in Europe. Environmental Management: 32(1): 12-33.

Hupp, C.R. 1992. Riparian vegetation recovery following stream channelization: a geomorphic perspective. Ecology 73(4): 1209-1226.

Hupp, C.R. and Osterkamp W.R. 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology, 14: 277-295.

Innis, S.A., Naiman, R.J., Elliot, S.R. 2000. Indicators and assessment methods for measuring the ecological integrity of semi-aquatic terrestrial environments. Hydrobiologia, 422/423: 111-131.

Joubert, A.R. and Hurly, P.R. 1994. The use of daily flow data to classify South African Rivers. In: Assessment of the instream flow incremental methodology and initial development of alternative instream flow methodologies for South Africa. King, J.M. and Tharme, R.E. (Eds.). Water Research Commission report No. 295/1/94. Water Research Commission, Pretoria, South Africa.

Junk, W.J., Bayley, P.B., Sparks, R.E. 1989. The flood pulse concept in river-flood plain systems. Canadian Special Publication of Fisheries and Aquatic Sciences, 106: 110-127.

Kent, M., Coker, P. 1992. Vegetation description and analysis. Wiley and Sons, UK. 363pp.

King, J.M., Schael, D.M. 2001. Assessing the ecological relevance of a spatially-nested geomorphological hierarchy for river management. WRC Report No. 754/1/01. Water Research Commission, Pretoria. 276 p.

King, JM, Brown, CA, Sabet, H. 2003. A scenario-based approach to environmental flow assessments for rivers. River Research and Applications, 19: 619-639.

King, J.M., Tharme, R.E., de Villiers, M.S. 2008. Environmental Flow Assessments for rivers: manual for the building block methodology (updated edition). Water Research Commission report TT 354/08, Pretoria, South Africa. 339pp.

King, J.M., Pienaar, H. 2011. Sustainable use of South Africa's inland waters. Water Research Commission technical transfer report, TT 481/11, 245 pp.

Kleynhans, C.J., Mackenzie, J., Louw, D.A. 2007a. Module F: Riparian vegetation response assessment index in River EcoClassification: Manual for EcoStatus determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry. WRC report No. 329/08.

Kleynhans, C.J., Louw, M.D. 2007b. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC report No. TT 333/08.

Koncalova, H. 1990. Anatomical adaptations to waterlogging in roots of wetland graminoids: limitations and drawbacks. Aquatic Botany, 38: 127-134.

Lite, S.J., Bagstad, K.J., Stromberg, J.C. 2005. Riparian plant species richness along lateral and longitudinal gradients of water stress and flood disturbance, San Pedro River, Arizona, USA. Journal of Arid Environments, 63: 785-813.

Lytle, D.A., Poff, N.L. 2006. Adaptation to natural flow regimes. Trends in Ecology and Evolution 19(2): 94-100.

Mackenzie, J.A., van Coller, A.L., Rogers, K.H. 1999. Rule based modeling for management of riparian systems. Water Research Commission, Pretoria, South Africa. WRC report no. 813/1/99. 156pp.

Mahoney, J.M., Rood, S.B. 1998. Streamflow requirements for cottonwood seedling recruitment – an integrative model. Wetlands 18: 634-6 45.

Merrit, D.M., Scott, M.L., Poff, N.L., Auble, G.T., Lytle, D.A. 2010. Theory, methods and tools for determining environmental flows for riparian vegetation: riparian vegetation-flow response guilds. Freshwater Biology, 55: 206-225.

Moon, B.P., van Niekerk, A.W., Heritage, G.L., Rogers, K.H., James, C.S. 1997. A geomorphological approach to the ecological management of rivers in the Kruger National Park: the case of the Sabie River. Transactions of the Institute of British Geographers, NS 22: 31-48.

Mucina, L., Rutherford, C. 2006. The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

Naiman, R.J., Decamps, H. 1997. The Ecology of Interfaces: Riparian Zones. Annual Review of Ecological Systems 28: 621-658.

Naiman, R.J., Decamps, H., McClain, M.E. 2005. Riparia. Ecology, conservation and management of streamside communities. Elsevier Academic Press, MA, USA. 430pp.

Naiman, R.J., Latterell, J.J., Pettit, N.E., Older, J.D. 2008. Flow variability and the biophysical vitality of river systems. C.R. Geoscience, 340: 629-643.

Nilsson, C., Bergren, K. 2000. Alterations of riparian ecosystems caused by river regulation. BioScience 50(9): 783-7

Nilsson, C., Svedmark, M. 2002. Basic principles and ecological consequences of changing water regimes: riparian plant communities. Environmental Management, 30: 468-480.

Poff, N.L., Allan, M.B., Bain, J.R., Karr, K.L., Prestegaard, B.D., Richter, R.E., Sparks, R.E., Stromberg, J.C. 1997. The natural flow regime concept: a paradigm for river conservation and restoration. Bioscience, 47: 769-784.

Poff, N.L., Zimmerman, J.K.H. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55: 194-205.

Poole, G.C. 2002. Fluvial landscape ecology: addressing uniqueness within the river discontinuum. Freshwater Biology, 47: 641-660.

Prosser, I.P. 1999. Identifying priorities for riparian restoration aimed at sediment control. Second Australian stream management conference, 8-11 February. Adelaide, South Australia, pp 511-516.

Reinecke, M. K., King, J.M., Holmes, P.M., Blanchard, R., Malan, H. 2007. The nature and invasion of riparian vegetation zones in the south western Cape. Water Research Commission, Pretoria. South Africa. WRC Report No. 1407/1/07. 284pp.

Renofalt, B.M., Jansson, R., Nilsson, C. 2010. Effects of hydropower generation and opportunities for environmental flow management in Swedish riverine ecosystems. Freshwater Biology 55: 49-67.

Resh, V.H., Brown, A.V., Covich, A.P., Gurtz, M.E., Li, H.W., Minshall, G.W., Reice, S.R., Sheldon, A.L., Wallace, B., Wissmar, R.C. 1998. The role of disturbance in stream ecology. Journal of the North American Benthological Society 7(4): 433-455.

Richardson, D.M., Macdonald, I.A.W., Hoffman, J.H. and Henderson, L. 1997. Alien plant invasions. In: R. Cowling & D. Richardson (eds), pp. 535-570. Vegetation of southern Africa. Cambridge University Press, Cambridge, United Kingdom.

Richter, B.D, Thomas, G.A. 2007. Restoring environmental flows by modifying dam operations. Ecology and Society 12(1):1-12.

Richter, B.D., Richter, H.E. 2000. Prescribing Flood Regimes to Sustain Riparian Ecosystems along Meandering Rivers. Conservation Biology 14(5): 1467-1478.

Richter, B.D., Warner, A.T., Meyer, J.L., Lutz, K. 2006. A collaborative adaptive process for developing environmental flow recommendations. River Research Applications 22: 297-318.

Rogers, K.H. 1995: Riparian wetlands. In: Wetlands of South Africa. Cowan, G.I. (Ed). South African Wetlands Conservation Programme Series, Pretoria: Department of Environmental Affairs and Tourism, Pretoria, South Africa: 41-52.

Rood, S.B., Mahoney, J.M. 1995. River damming and riparian cottonwoods along the Marais River, Montana. Rivers 5(3): 195-207.

Rood, S.B., Taboulchanas, K., Bradley, C.E., Kalischuk, A.R. 1999. Influence of flow regulation on channel dynamics and riparian cottonwoods along the Bow River, Alberta. Rivers 7(1): 33-48.

Rood, S.B, Gourley, C.R, Ammon, E.A, Heki, L.G, Wagner, P.L, 2003. Flows for floodplain forests: A successful riparian restoration. Bioscience, 53(7): 647-656

Rood, S.B., Samuelson, G.M, Braatne, J.H, Gourley, C.R, Hughes, F.M.R, Mahoney, J.M, 2005. Managing river flows to restore floodplain forests. Frontiers in Ecology and the Environment, 3(4): 193-201

Rountree, M.W., Batchelor, A.L., MacKenzie, J., Hoare, D. 2008. Manual for the identification and delineation of wetlands and riparian areas. Department of Water Affairs, Stream Flow Reduction Activities, Pretoria, South Africa.

Rowntree, K. M., Wadeson, R.A., O'Keefe, J.O. 2000. The development of a geomorphological classification systems for the longitudinal zonation of South African rivers. South African Geographical Journal, 82 (3): 163-172.

Schumm, S.A. 1977. The fluvial system. Wiley, New York.

Seabloom, E.W., Moloney, K.A., van der Valk, A.G. 2001. Constraints on the establishment along a fluctuating water-depth gradient. Ecology 82: 2216-2232.

Shafroth, P.B., Auble, G.T., Stromberg, J.C., Patten, D.T. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. *Wetlands,* 18(4): 577-590.

Sidle, R.C., Onda, Y. 2004. Hydrogeomorphology: an overview of an emerging science. *Hydrological Processes* 18: 597-602.

Sieben, E.J.J. 2002. The riparian vegetation of the Hottentots Holland Mountains, Western Cape, South African. Unpublished PhD thesis, Stellenbosch University, Stellenbosch, South Africa.

Sieben, E.J.J., Reinecke, M.K. 2008. Description of reference conditions in restoration projects of riparian vegetation in the species rich fynbos. South African Journal of Botany, 74 (3): 401-412.

Silvertown, J., Dodd, M.E., Gowing, D.J.G, Mountford, J.E. 1999. Hydrologically defined niches reveal a basis for species richness in plants. Nature, 40(1): 61-63.

Shipley, B., Keddy, P.A. 1987. The individualistic and community-unit concepts as falsifiable hypotheses. Vegetatio, 69 (1/3), Theory and models in vegetation science: 47-55.

Stanford. J.A. 1998. Rivers in the landscape: introduction to the special issue on riparian and

Stanford. J.A., Ward. J.V., Liss, J.V., Frissell, C.A., Williams, R.N., Lichatowich, J.A. and Coutant, C. 1996. A General Protocol for Restoration of Regulated Rivers. Regulated Rivers: Research and Management 12: 391-413.

Stella, J.C., Battles, J.J. 2010. How do riparian woody seedlings survive seasonal drought? Oecologia 164(3): 579-590.

Stohlgren, T.J., Falkner, M.B. and Schell, L.D. 1995. A Modified-Whittaker nested vegetation sampling method. Vegetatio 117: 113-121.

Swanson, F.J., Wondzell, S.M. and Grant, G.E. 1992. Landforms, disturbance, and ecotones. In:Landscape Boundaries: Consequences for Biotic Diversity and Ecological flows. Hansen, A.J. and Centri, B.F. (Eds.). New York, Springer-Verlag

Tabacchi, E., Correll, D.L., Hauer, R., Pinay, G., Planty-Tabacchi, A., Wissmar, R.C. Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology 40: 497-516.

Taman, L. 2001. Using Rushes and Sedges in Revegetation of Wetland Areas in the South West of WA. Water and Rivers Commission, Report no. RR8: 1-14.

Terrill, D. 1999. Stream rehabilitation and co-operation of the riparian land holder, South Australia. Second Australian stream management conference, 8-11 February. Adelaide, South Australia. pp 617-627.

Thayer, G.W., McTigue, T.A., Salz, R.J., Merkeyt, D.H., Burrow, F.M., Gayaldo, P.F. 2005. Science-based restoration monitoring of coastal habitats, volume two: tools for monitoring coastal habitats. NOAA Coastal Ocean Program Decisions Analysis Series 23. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD. 628pp.

Vadas, R.L., Sanger, J.E. 1997. Lateral zonation of trees along a small Ohio stream. Ohio Journal of Science, 5: 105-112.

Van Coller, A.L. 1992. Riparian vegetation of the Sabie River: relating spatial distribution patterns to the physical environment. Unpublished M.Sc thesis, University of the Witwatersrand, Johannesburg, South Africa.

Van Coller, A.L., Rogers, K.H., Heritage, G.L. 1997. Linking riparian vegetation types and fluvial geomorphology along the Sabie River within the Kruger National Park, South Africa. African Journal of Ecology, 35: 194-212.

Van Coller, A.L., Rogers, K.H., Heritage, G.L. 2000. Riparian vegetation-environment relationships: complimentarity of gradients versus patch hierarchy approaches. Journal of Vegetation Science, 11: 337-350.

Vannote, R.L.G., Minshall, G.W., Cummins, J.R., Sedell, J.R., Cushing, C.E. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences, 37: 130-137.

Vosse, S., Esler, K.J., Richardson, D.M., Holmes, P.M. 2008. Can riparian seed banks initiate restoration after alien plant invasion? Evidence from the Western Cape, South Africa. Restoration Ecology, 74 (3): 432-445.

Walling, D.E. 1996. Hydrology and rivers. In: The physical geography of Africa. Adams, W.M., Goudie, A. S., Orme, A.R. (Eds). Oxford University Press, Oxford, pp103-121.

Ward, J.V., Stanford, J.A. 1983. The serial discontinuity concept of river ecosystems. In: dynamics of lotic ecosystems. Fontaine, T.D., Bartell, P.B. (Eds.). Science Publications, Ann Arbor Mitch, pp 22-42.

Ward, J.V., Stanford, J.A. 1995. The serial discontinuity concept: extending the model to flood plain rivers. Regulated Research and Management, 10: 159-168.

Ward, J.V., Tockner, K., Arscott, D.B., Claret, C. 2002. Riverine landscape diversity. Freshwater Biology, 47: 517-539.

Wilson, M., Imhoff, J.G. 1998. An examination of the functions of riparian zones. Riparian zone workshop, Cambridge, Ontario.

Wu, J., Loucks, O.L. 1995. From balance of nature to hierarchical patch dynamics: a paradigm shift in ecology. The Quarterly Review of Biology, 70 (4): 439-466.

A Tables

Appendix Table 1 Presence/Absence of species of Fynbos Riparian Vegetation. S = seedling, J = sapling, T = tree.

SPECIES	R1	R2	R3	R4	H1	H2	H3	H4	W1	W2	E1	E2	E3	E4	J1	J2
Acacia mearnsii S									*							
Acacia mearnsii J									*	*						
Acacia mearnsii T										*						
Agathosma crenulata J													*			
Agathosma crenulata T			*											*		
Anthospermum spathulatum	*				*	*						*				
Arctotis revoluta						*										
Aristea capitata	*										*		*	*	*	*
Aristida junciformis										*						
Arum bract restio									*							
Askidiosperma chartaceum									*	*		*				
Asparagus africanus													*			
Asparagus rubicundus					*											*
Asparagus scandens																*
Asteraceae sp.18												*				
Asteraceae sp.19												*				
Asteraceae sp.20	*	*														
Berzelia lanuginosa									*	*						*
Blechnum attenuatum																
Blechnum australe			*	*							*					*
Blechnum capense		*		*								*	*	*	*	
Brabejum stellatifolium S	*	*	*		*		*		*		*	*	*	*		*
Brabejum stellatifolium J	*	*	*	*		*		*	*	*	*	*	*	*	*	*
Brabejum stellatifolium T	*	*	*	*		*		*	*	*	*	*	*	*	*	*
Brachylaena neriifolia S	*	*		*		*		*	*	*	*	*				
Brachylaena neriifolia J	*	*	*	*	*		*	*	*	*	*	*	*	*	*	
Brachylaena neriifolia T	*	*	*	*			*	*	*	*	*	*	*	*	*	
Calopsis paniculata	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Cannomois virgata												*		*		
Carpha glomerata					*	*										
Cassytha ciliolata									*							*
Centella sp.1										*						
Chasmanthe aethiopica																
Chelianthes contracta						*						*				
Cliffortia complanata															*	
Cliffortia cuneata															*	*
Cliffortia dregeana										*						
Cliffortia pterocarpa												*				
Cliffortia ruscifolia	*	*			*	*		*			*	*		*		
Cliffortia sp.1													*			
Clutia ericoides	*	*														
Clutia sp.1														*		

SPECIES	R1	R2	R3	R4	H1	H2	H3	H4	W1	W2	E1	E2	E3	E4	J1	J2
Clutia sp.2			*													
Crassula rupestris					*	*		*								
Cullumia ciliaris												*	*			
Cunonia capensis S											*	*				
Cunonia capensis J												*		*		*
Cunonia capensis T																*
Cyclopia sp.1											*	*	*	*	*	*
Cyperaceae sp.1													*			
Cyperaceae sp.3																*
Cyperaceae sp.5															*	*
Cyperaceae sp.6																*
Cyperaceae sp.8																*
Cyperaceae sp.9															*	
Cyperus denudatus			*		*	*	*	*								
Diospyros glabra	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dodonaea viscosa S					*											
Dodonaea viscosa J	*				*	*	*									
Drosera sp.1	*		*	*			*	*			*					
Ehrharta ramosa subsp. aphylla	*								*			*				
Ehrharta rehmannii					*	*	*	*								
Ehrharta sp.4																*
Ehrhata ramosa subsp. ramosa		*	*							*	*		*			
Ehrhata sp.2									*		*	*			*	
Elegia asperiflora										*			*	*		
Elegia capensis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Elytropappus intricata	*	*			*		*	*								
Epischoenus gracilis										*	*	*	*			
Eragrostis sarmentosa					*	*	*									
Erica bergiana												*				
Erica caffra	*	*	*	*					*	*	*	*	*	*	*	*
Erica canescens												*				
Erica curvirostris										*						
Erica hispidula									*	*					*	
Erica pinea														*		
Erica sphaeroidea															*	*
Erica tenuis										*						
Euryops abrotanifolius	*					*										
Ficinia acuminata	*	*														
Ficinia capitella																*
Ficinia indica			*		*	*		*				*				
Ficinia sp.2									*	*	*					
Ficinia trichodes																*
Freylinia lanceolata J					*	*	*	*								*
Freylinia lanceolata T					*	*	*	*								*
Hackea sericia J												*				
Hackea sericia T												*				

SPECIES	R1	R2	R3	R4	H1	H2	H3	H4	W1	W2	E1	E2	E3	E4	J1	J2
Halleria elliptica			*												*	
Halleria lucida J																*
Halleria lucida T													*			
Hartogiella schinoides J	*		*						*	*	*	*		*		*
Hartogiella schinoides T	*		*							*		*		*		*
Heeria argentea J		*							*						*	
Heeria argentea T										*						
Helichrysum odoratissimum			*										*			
Helichrysum sp.2																*
Hymenolepis sp.1										*						
Hyparrhenia hirta										*						
Ilex mitis S														*		
Ilex mitis J									*		*	*	*	*		*
Ilex mitis T											*	*	*	*		*
Indigofera sp.1									*							
Ischyrolepis fraterna									*	*			*	*		
Ischyrolepis gaudichaudianus	*					*		*								
Ischyrolepis gossypina								*								
Ischyrolepis sieberi	*				*		*				*	*			*	
Ischyrolepis subverticillata											*				*	*
Ischyrolepis tenuissima										*						
Isolepis digitata			*				*	*	*	*						
Isolepis prolifer	*	*	*	*	*	*	*	*			*					
Juncus effusus			*										*			
Juncus lamatophyllus			*	*												
Kiggelaria africana S						*										
Kiggelaria africana J			*			*										
Kiggelaria africana T																*
Laurembergia repens			*													
Leucadendron salicifolium												*	*			
Mariscus thunbergii			*	*	*	*	*	*				*				
Maytenus acuminata J														*		
Maytenus acuminata T														*		
Maytenus oleoides S			*			*	*		*							*
Maytenus oleoides J			*						*							
Merxmuellera cincta										*						
Metalasia densa												*				
Metalasia dregeana	*															
Metalasia muraltiifolia										*						
Metrosideros angustifolia S	*	*	*	*	*	*	*	*	*		*	*	*			*
Metrosideros angustifolia J	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Metrosideros angustifolia T	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mohria caffrorum															*	
Morella serrata S	*	*	*	*	*	*	*	*	*		*		*	*		
Morella serrata J	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*
Morella serrata T	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*

SPECIES	R1	R2	R3	R4	H1	H2	H3	H4	W1	W2	E1	E2	E3	E4	J1	J2
Myrsine africana	*															
Neesenbeckia punctoria																*
Nivenia corymbosa									*	*						
Oftia africana		*														
Olea sp.1 T						*										
Oscularia ornata					*	*										
Osteospermum ciliatum													*	*		
Otholobium sp.1															*	
Othonna quinquidentata										*			*	*		
Oxalis pardalis															*	
Oxalis sp.1															*	
Oxalis sp.2															*	
Panicum schinzii					*	*	*									
Paspalum urvillei			*													
Pelargonium cucullatum betuli.															*	
Pelargonium scabrum	*	*			*	*		*								
Pelargonium tabulare			*													
Pellaea pteroides															*	*
Pennisetum macrourum				*	*	*			*				*	*		
Pentachistis chandelier	*															
Pentameris distichophylla									*	*	*	*	*	*		
Pentameris thuarii										*				*	*	
Pentaschistis curvifolia										*						
Pentaschistis densifolia									*							
Pentaschistis pallida											*					
Pentaschistis sp.4	*															
Peucedanum galbanum J		*														
Phylica imberbis										*		*				
Platycaulos subcompressus									*							
Platylophus trifoliatus J											*	*	*	*		
Platylophus trifoliatus T											*	*	*	*		
Poaceae sp.4															*	*
Poaceae sp.5																*
Poaceae sp.6															*	
Podalyria sp.1											*		*	*		
Podalyria sp.3															*	
Podocarpus elongatus T										*						
Poisiden trident restio										*						
Prionium serratum				*	*	*			*	*	*	*			*	*
Protea laurifolia S											*				*	
Protea laurifolia T														*		
Protea sp.1 S	*															
Protea sp.1 J	*															
Pseudobaeckia africana									*	*	*	*				
Psoralea sp.2					*	*										
Pteridium aqualinum	*	*	*	*					*		*	*	*		*	*

SPECIES	R1	R2	R3	R4	H1	H2	H3	H4	W1	W2	E1	E2	E3	E4	J1	J2
Pycreus polystachyos																*
Restio multiflorus													*			
Restio perplexus									*	*	*					
Restionaceae sp.7									*							
Restionaceae sp.8									*	*						
Restionaceae sp.9	*		*													
Rhus angustifolia			*		*	*	*	*								
Rhus crenata																*
Rhus lucida forma elliptica			*	*	*	*	*	*								
Rhus tomentosa															*	*
Rubiaceae sp.1													*	*		
Salix mucronata S					*	*							*	*		
Salix mucronata J					*								*			
Salix mucronata T													*			
Salvia sp.1						*										
Schizaea tenella	*	*									*				*	*
Species 2																*
Species 13 J														*		
Species 14															*	*
Species 15									*							
Species 16													*	*		
Species 17					*			*								
Species 18		*														
Species 19												*				
Stoebe cinerea															*	
Stoebe plumosa	*				*		*	*		*		*		*		
Stoebe spiralis													*	*		
Struthiola myrsinites																*
Taraxacum officinale															*	
Tetraria flexuosa													*			
Thamnochortus lucens														*		
Thamnochortus sp.1									*	*						
Thesium sp.1	*															
Todea babara	*	*	*	*					*	*	*	*	*	*	*	
Tribolium uniolae										*						
Ursinia abrotanifolia										*		*	*			
Ursinia pinnata										*						
Wahlenbergia rubiodes	*															
Phylica oleaefolia S	*															
Phylica oleaefolia J	*					*										
Phylica oleaefolia T					*	*		*								
Wildenowia glomerata									*	*						
Willdenowia incurvata	*	*						*								
Wimmerella arabidea			*	*		*										
Zyrphelis montana										*						

Appendix Table 2 **Habitat characteristics for species of Fynbos Riparian Vegetation.**

SPECIES	FAMILY	GROWTH FORM	HABITAT	DESIGNATION	COMMON NAME
Anthospermum spathulatum	Rubiaceae	Shrub	Clay slopes, DRY	Incidental	
Arctotis revoluta	Asteraceae	Shrub	Rocky slopes, DRY	Incidental	Krulblaargousblom
Aristea capitata	Iridaceae	Forb	Mountain slopes, DRY	Incidental	Blousuurkanol
Aristida junciformis	Poaceae	Grass	Mountain slopes, DRY	Incidental	Wire grass
Askidiosperma chartaceum	Restionaceae	Restio	Marshy mountain slopes, WET	Obligate	
Asparagus africanus	Asparagaceae	Shrub	Moist places, WET	Obligate	Katdoring
Asparagus rubicundus	Asparagaceae	Shrub	Sandy and granite slopes, DRY	Incidental	Katdoring
Asparagus scandens	Asparagaceae	Shrub	Forest	Facultative	Katdoring
Berzelia lanuginosa	Bruniaceae	Shrub	Riverine, WET	Obligate	Berzelia
Blechnum attenuatum	Blechnaceae	Forb	Forest	Facultative	Deer fern
Blechnum australe	Blechnaceae	Forb	Forest	Facultative	Southern deer fern
Blechnum capense	Blechnaceae	Forb	Riverine, WET	Obligate	Cape deer fern
Brabejum stellatifolium	Proteaceae	Tree	Riverine, WET	Obligate	Wild almond
Brachyleana neriifolia	Asteraceae	Small tree	Riverine, WET	Obligate	Bitterblaar
Calopsis paniculata	Restionaceae	Restio	Riverine, WET	Obligate	
Cannomois virgata	Restionaceae	Restio	Riverine, WET	Obligate	
Cassytha ciliolata	Lauraceae	Forb	Various trees and shrubs, DRY	Incidental	False dodder
Chasmanthe aethiopica	Iridaceae	Geophyte	Coastal, bush, forest	Facultative	Cobra lily
Cheilanthes contracta	Pteridaceae	Forb	Shady rocks, DRY	Incidental	Lip Fern
Cliffortia complanata	Rosaceae	Small shrub	Moist upper rocky slopes, WET	Obligate	Climber's Friend
Cliffortia cuneata	Rosaceae	Shrub	Lower sandstone slopes, DRY	Incidental	Climber's Friend
Cliffortia dregeana	Rosaceae	Shrub	Sandstone slopes, DRY	Incidental	Climber's Friend
Cliffortia pterocarpa	Rosaceae	Shrub	Lower mountain slopes, DRY	Incidental	Climber's Friend
Cliffortia ruscifolia	Rosaceae	Shrub	Rocky sandstone soils, DRY	Incidental	Steekbos
Cyperus denudatus	Cyperaceae	Sedge	Riverine, WET	Obligate	
Diospyros glabra	Ebenaceae	Shrub	Sandy flats and slopes, DRY	Incidental	Bloubesiebos
Diospyros whyteana	Ebenaceae	Small tree	Slopes, DRY	Incidental	Bladder-nut

SPECIES	FAMILY	GROWTH FORM	HABITAT	DESIGNATION	COMMON NAME
Dodonaea viscosa	Sapindaceae	Tree	Riverine thicket and rocky outcrops, WET	Obligate	Sand olive
Ehrharta ramosa subsp. aphylla	Poaceae	Grass	Mountain slopes, DRY	Incidental	
Ehrharta ramosa subsp. ramosa	Poaceae	Grass	Mountain slopes, DRY	Incidental	
Ehrharta rehmannii	Poaceae	Grass	Mountain slopes, forest margins, DRY	Incidental	
Elegia asperiflora	Restionaceae	Restio	Seeps on sandstone slopes, WET	Obligate	
Elegia capensis	Restionaceae	Restio	Riverine, WET	Obligate	
Elytropappus intricata	Asteraceae	Shrub	Sandstone slopes, DRY		Renosterbos
Epischoenus gracilis	Cyperaceae	Sedge	Mountain slopes, DRY	Incidental	
Eragrostis sarmentosa	Poaceae	Grass	Winter-wet sand, WET	Obligate	Love grass
Erica bergiana	Ericaceae	Small shrub	Seeps and moist slopes, WET	Obligate	Heather
Erica caffra	Ericaceae	Shrub	Riverine, WET	Obligate	Water heath
Erica canescens	Ericaceae	Small shrub	Coastal flats and lower slopes, DRY	Incidental	Heather
Erica curvirostris	Ericaceae	Small shrub	Dry stony areas, DRY	Incidental	Heuningheide
Erica hispidula	Ericaceae	Small shrub	Widespread, DRY	Incidental	Heather
Erica pinea	Ericaceae	Small shrub	Rocky slopes and plateaus, DRY	Incidental	Heather
Erica sphaeroidea	Ericaceae	?	?		Heather
Erica tenuis	Ericaceae	Small shrub	Rocky wet ledges to open slopes, DRY	Incidental	Heather
Euryops abrotanifolius	Asteraceae	Forb	Weed		Geelmagriet
Ficinia acuminata	Cyperaceae	Sedge	Riverine, WET	Obligate	
Ficinia capitella	Cyperaceae	Sedge	Flats and slopes, DRY	Incidental	
Ficinia indica	Cyperaceae	Sedge	Flats and lower slopes, DRY	Incidental	
Ficinia trichodes	Cyperaceae	Sedge	Rocky lower to middle slopes, DRY	Incidental	
Freylinia lanceolata	Scrophlariaceae	Small tree	Riverine, WET	Obligate	Heuningklokkiebos
Hakea sericea	Proteaceae	Small tree	Sandstone slopes, DRY	Incidental	Silky hakea
Halleria elliptica	Scrophlariaceae	Shrub	Riverine slopes, WET	Obligate	Fuschia
Halleria lucida	Scrophlariaceae	Small tree	Coastal bush, forest	Facultative	Tree fuschia
Hartogiella schinoides	Celastraceae	Small tree	Fynbos, forest, woodland, DRY	Incidental	Saffron
Heeria argentea	Anacardiaceae	Tree	Rocky forest and bush, DRY	Incidental	Kliphout
Helichrysum odoratissimum	Asteraceae	Small shrub	Sandy slopes in damp places, DRY	Incidental	Strooiblom

SPECIES	FAMILY	GROWTH FORM	HABITAT	DESIGNATION	COMMON NAME
Hyparrhenia hirta	Poaceae	Grass	Disturbed areas and grassland, DRY	Incidental	Thatch grass
Ilex mitis	Aquifoliaceae	Tree	Riverine Forest, WET	Obligate	African holly
Ischyrolepis fraterna	Restionaceae	Restio	?		
Ischyrolepis gaudichaudiana	Restionaceae	Restio	Dry rocky slopes, DRY	Incidental	
Ischyrolepis gossypina	Restionaceae	Restio	Light seeps and moist slopes, WET	Obligate	
Ischyrolepis sieberi	Restionaceae	Restio	Rocky slopes and flats, DRY	Incidental	
Ischyrolepis tenuissima	Restionaceae	Restio	?		
Ischyrolepis subverticulata	Restionaceae	Restio	Riverine, WET	Obligate	
Isolepis digitata	Cyperaceae	Sedge	Riverine, WET	Obligate	
Isolepis prolifer	Cyperaceae	Sedge	Riverine, WET	Obligate	
Juncus effusus	Juncaceae	Rush	Riverine, WET	Obligate	
Juncus lomatophyllus	Juncaceae	Rush	Riverine, WET	Obligate	
Kiggelaria africana	Kiggelariaceae	Tree	Forest, DRY	Incidental	Wild Peach
Laurembergia repens	Haloragaceae	Forb	Boggy, WET	Obligate	
Leucadendron salicifolium	Proteaceae	Shrub	Riverine, WET	Obligate	Cone bush
Mariscus thunbergii	Cyperaceae	Sedge	Riverine, WET	Obligate	
Maytenus acuminata	Celastraceae	Small tree	Forest margins or rocky slopes, DRY	Incidental	Sybas
Maytenus oleoides	Celastraceae	Small tree	Rocky slopes, DRY	Incidental	Klipkershout
Merxmuellera cincta	Poaceae	Grass	Riverine, WET	Obligate	
Metalasia densa	Asteraceae	Shrub	Sandy or stony flats and slopes, DRY	Incidental	Blombos
Metalasia dregeana	Asteraceae	Shrub	Sandstone and clay slopes, DRY	Incidental	Blombos
Metalasia muraltiifolia	Asteraceae	Shrub	Sandstone slopes, DRY	Incidental	Blombos
Metrosideros angustifolia	Myrsinaceae	Small tree	Riverine, WET	Obligate	Smalblad
Mohria caffrorum	Anemiaceae	Forn	Fynbos and renosterveld, DRY	Incidental	Scented fern
Morella serrata	Myricaceae	Small tree	Coastal sandy and limestone flats, DRY	Incidental	Waterolier
Myrsine africana	Myrsinaceae	Shrub	Sandy flats and slopes in scrub, DRY	Incidental	Cape myrtle
Neesenbeckia punctoria	Cyperaceae	Sedge	Riverine, WET	Obligate	
Nivenia corymbosa	Iridaceae	Shrub	Riverine, WET	Obligate	Bush iris
Oftia africana	Scrophulariaceae	Small shrub	Rocky sandstone/granite slopes, DRY	Incidental	

SPECIES	FAMILY	GROWTH FORM	HABITAT	DESIGNATION	COMMON NAME
Olea europea	Oleaceae	Tree	Forests and rocky slopes, DRY	Incidental	
Oscularia ornata	Aizoaceae	Small shrub	Rock crevices, DRY	Incidental	Sandsteenvygie
Osteospermum ciliatum	Asteraceae	Small shrub	Sandstone slopes, DRY	Incidental	Bietou
Othonna quinquidentata	Asteraceae	Shrub	Rocky sandstone slopes, DRY	Incidental	Bobbejaankool
Oxalis pardalis	Oxalidaceae	Geophyte	Heavier soils, DRY	Incidental	Sorrel
Panicum schinzii	Poaceae	Grass	Moist sites, WET	Obligate	Blousaadgras
Paspalum urvillei	Poaceae	Grass	Riverine, WET	Obligate	Dallis grass
Pelargonium scabrum	Geraniaceae	Shrub	Rocky sandstone slopes, DRY	Incidental	Hoenderbos
Pelargonium tabulare	Geraniaceae	Small shrub	Cool slopes, DRY	Incidental	Malva
Pellaea pteroides	Pteridaceae	Forb	Forest, fynbos	Facultative	Myrtle fern
Pennisetum macrourum	Poaceae	Grass	Marshes, WET	Obligate	Bedding grass
Pentameris distichophylla	Poaceae	Grass	Rocky sandstone slopes, DRY	Incidental	
Pentameris thuarii	Poaceae	Grass	Lower sandstone slopes, DRY	Incidental	
Pentaschistis curvifolia	Poaceae	Grass	Sandstones slopes, DRY	Incidental	
Pentaschistis densifolia	Poaceae	Grass	Sandstone ledges and rock cracks, DRY	Incidental	
Pentaschistis pallida	Poaceae	Grass	Slopes and flats, DRY	Incidental	
Peucedanum galbanum	Apiaceae	Small tree	Rocky slopes, forest, bush, DRY	Incidental	Blister bush
Phylica imberbis	Rhamnaceae	Shrub	Sandstone slopes and flats, DRY	Incidental	Hardebos
Phylica oleaefolia	Rhamnaceae	Shrub	Rocky slopes, DRY	Incidental	Blinkhardebos
Pinus pinaster	Pinaceae	Tree	ALIEN		Cluster pine
Pinus radiata	Pinaceae	Tree	ALIEN		
Platycaulos subcompressus	Restionaceae	Restio	?		
Platycaulus major	Restionaceae	Restio	?		
Platylophus trifoliatus	Cunoniaceae	Tree	Riverine, WET	Obligate	Witels
Prionium serratum	Prioniaceae	Shrub	Riverine, WET	Obligate	Palmiet
Protea laurifolia	Proteaceae	Tree	Sandstone slopes, DRY	Incidental	Protea
Pseudobaeckia africana	Bruniaceae	Shrub	Riverine, WET	Obligate	
Pseudoselago verbenacea	Scrophulariaceae	Forb	Riverine, WET	Obligate	Powder puff
Pteridium aquilinum	Dennstaedtiaceae	Forb	Fynbos, forest	Facultative	Bracken fern

SPECIES	FAMILY	GROWTH FORM	HABITAT	DESIGNATION	COMMON NAME
Pycreus polystachyos	Cyperaceae	Sedge	Damp, WET	Obligate	
Restio multiflorus	Restionaceae	Restio	?		
Restio perplexus	Restionaceae	Restio	?		
Rhus angustifolia	Anacardiaceae	Small tree	Riverine, WET	Obligate	Wilgerkorentebos
Rhus crenata	Anacardiaceae	Small tree	Sandy coastal flats. DRY	Incidental	Duinekraaibessie
Rhus lucida	Anacardiaceae	Small tree	Sandy flats and slopes, DRY	Incidental	Blinktaaibos
Rhus tomentosa	Anacardiaceae	Small tree	Rocky slopes, DRY	Incidental	Korentebos
Salix mucronata	Saliaceae	Small tree	Riverine, WET	Obligate	Cape willow
Schizaea tenella	Schizaeaceae	Forb	Riverine, WET	Obligate	Toothbrush fern
Stoebe cinerea	Asteraceae	Shrub	Rocky slopes, DRY	Incidental	Vaal hartebeeskaroo
Stoebe plumosa	Asteraceae	Shrub	Rocky flat and slopes, DRY	Incidental	Slangbos
Stoebe spiralis	Asteraceae	Small shrub	Damp sandstone slopes, DRY	Incidental	Hartebeeskaroo
Struthiola myrsinites	Thymelaeaceae	Shrub	Sandy soils, DRY	Incidental	Featherhead
Taraxacum officinale	Asteraceae	Forb	Weed		
Tetraria flexuosa	Cyperaceae	Sedge	Flats to middle slopes, DRY	Incidental	
Thamnochortus lucens	Restionaceae	Restio	?		
Todea barbara	Osmundaceae	Forb	Riverine, WET	Obligate	
Tribolium uniolae	Poaceae	Grass	Clay and granite flats, DRY	Incidental	Koringgras
Ursinia abrotanifolia	Asteraceae	Shrub	Sandstone slopes in damp places, DRY	Incidental	Fynkruie
Ursinia pinnata	Asteraceae	Shrub	Riverine, WET	Obligate	Bergmargriet
Wahlenbergia rubiodes	Campanulaceae	Small shrub	High rocky slopes, DRY	Incidental	African blue-bell
Willdenowia glomerata	Restionaceae	Restio	?		
Willdenowia incurvata	Restionaceae	Restio	Sandy coastal flats, DRY	Incidental	
Wimmerella arabidea	Campanulaceae	Forb	Water, WET	Obligate	
Zyrphelis montana	Asteraceae	Shrub	Sandstone slope, DRY	Incidental	Pluimastertjie

B Theses abstracts

B.1 Reinecke: PhD

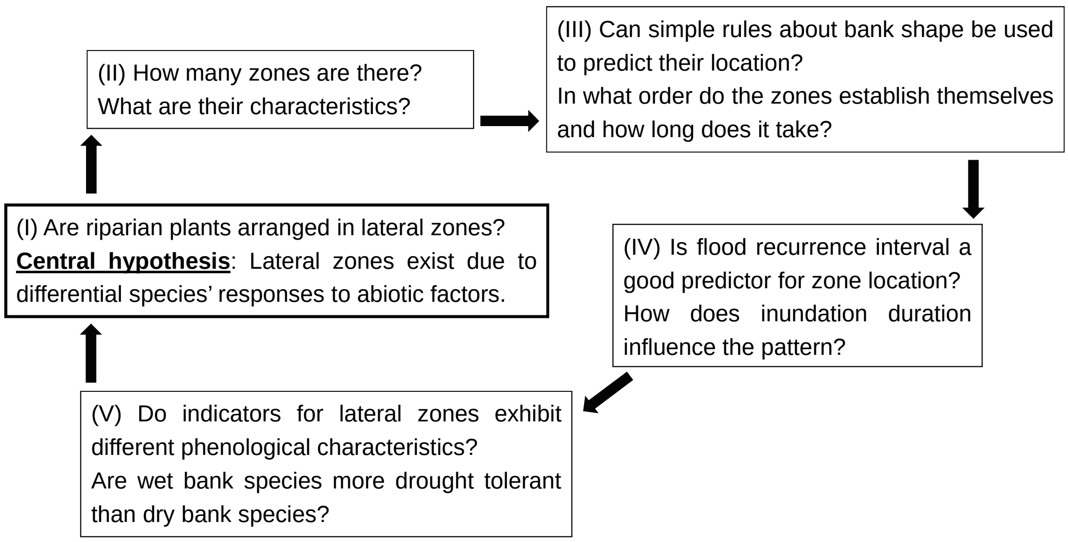
To develop a framework that explains the existence of different plant communities in different lateral zones, a mechanistic explanation for characteristic differences between the lateral zones must be established. The central hypotheses for the thesis were:

1. Vegetation zonation patterns along rivers result from differential species responses to a combination of abiotic factors that vary in space and time.
2. It is possible to identify one or two key abiotic factors that can be used to predict change in the zonation patterns in response to changes in the flow regime of rivers.

The thesis comprised five papers (Appendix Figure 1).

- Paper 1 – Links between riparian vegetation and flow: a review (Section B.1.1).
- Paper 2 –Lateral zones in Fynbos Riparian Vegetation (Section B.1.2).
- Paper 3 – A trajectory of recovery after clearing woody exotics from Fynbos Riparian Vegetation (Section B.1.3).
- Paper 4 – Links between lateral vegetation zones and flow at selected South African rivers (Section B.1.4).
- Paper 5 – Functional differences of indicators for lateral zones in Fynbos Riparian Vegetation (Section 0).

The existence of lateral zones was explored in Paper 1 and their vegetative characteristics were described. Links between the distribution of plants and physical site characteristics were explored in Paper 2 in order to account for lateral zones. Rules that describe topographic bank position were developed from Paper 2 and used to assess impacts at disturbed or recovery at cleared sites in Paper 3. Links between lateral zones and the flow regime were explored in Paper 4. Functional differences between plants that occupy different lateral zones are investigated in Paper 5. The hypotheses tested in each chapter all assumed water availability was a primary determinant of lateral zone occurrence and characteristics. Growth and reproduction are expected to have evolved in response to favourable periods of water and nutrient availability. Assessments of riparian community health in Environmental Flow studies are based on the assumption that floods drive recruitment, acting as cues to initiate flowering and subsequent seed set, and to disperse seeds to favourable nursery sites. For the most part, these hypotheses have been developed on Northern Hemisphere rivers and have not been tested locally.



Appendix Figure 1 Key questions of the five papers in Mr Reinecke's PhD

B.1.1 Links between riparian vegetation and flow: a review

Karl Reinecke, Cate Brown, Karen Esler, Jackie King

The flow regimes of southern African rivers differ considerably from rivers in the temperate climates where many of the studies of riparian ecology have taken place. Interesting advances have been made on the ecology of large floodplain forests that describe seral succession of communities in lateral zones. Few such studies exist for rivers in South Africa that differ considerably from their northern counterparts. In particular, river flow is much less predictably than in other countries and apart from the coastal regions, the country is semi-arid, and only very few of the rivers are associated with extensive floodplains (Davies et al. 1995). As such, relationships between flow and the ecology of riparian flora are expected to differ. The composition and structure of riparian communities are influenced primarily by river channel shape and water flow (Naiman et al. 2008). In addition, modelling the hydrogeomorphology of floodplains more complicated than single thread headwaters. A conceptual framework was developed for South African headwaters riparian areas that consists of three lateral zones bounded by a freshwater and terrestrial ecosystem on either side. In general, water availability decreased laterally away from the river channel as the depth to groundwater increased and the frequency of flooding decreased. The probability of being flooded and the duration of inundation decreased laterally with increasing distance and elevation away from the active channel. Inundation duration also influenced vegetation structure, with permanent to frequently inundated areas dominated by herbaceous perennials and graminoids, and less frequently inundated areas by shrubs and trees, with an understory of herbaceous perennials and graminoids. The combination of the decrease in water availability and frequency of being flooded equated to a higher probability of experiencing drought conditions. As such, there was a lateral gradation from the river channel as communities continually adapted to seasonally recurring conditions, which characterise different hydrogeomorphic habitats. On this basis, life history strategies between the three lateral zones were expected to differ.

B.1.2 The occurrence of lateral zones in Fynbos Riparian Vegetation

Karl Reinecke, Cate Brown, Karen Esler, Jackie King, David Miller, Martin Kidd

Undisturbed headwaters are well suited to the of study zonation patterns as the riparian communities are laterally constrained and are characterised by steep lateral gradients. Despite extensive research in the Fynbos biome of the Western Cape, a Mediterranean Type Ecosystem, Fynbos Riparian Vegetation has not been intensively studied until recently and there is no formal community classification, or for the rest of Southern Africa. Despite the seemingly obvious lateral patterning within riparian areas and the contention that different communities may be distinguished floristically *in situ* the difference classifications of lateral patterning have not been tested. To date, most studies have assumed the pattern exists and accommodated this assumption within the sampling protocol, usually by delineating sample plots within community types *a priori.* The distribution of plants along undisturbed Fynbos rivers were systematically sampled and analysed in order to test how many lateral zones were present and to reveal their characteristics. The key question was “Can characteristic species/taxa be used to identify lateral zones?” There were four lateral zones in two groups. The wet bank consisted of two zones, a marginal zone comprised of obligate riparian species and a lower dynamic zone situated between the marginal and the lower zone, the next one up, and comprised of a mixture of the species that characterise these two neighbours. The dry bank also consisted of two zones, a lower zone comprised of facultative riparian species and an upper zone, situated between the lower and the adjacent terrestrial community, comprised of a mixture of riparian and terrestrial species. These patterns were shown to be repetitive and predictable. Groundcovers and canopy species produced different patterns when analysed separately. The full species compliment was to describe zone characteristics and to determine indicator species that may be used to identify each lateral zone.

B.1.3 A trajectory of recovery after clearing of woody exotics from Fynbos Riparian Vegetation

Karl Reinecke, Cate Brown, Karen Esler, Jackie King

The impacts of woody exotics on, or the process of recovery following clearing in, riparian community structure are not well described. Part of the reason comes from discrepancies in how riparian communities are structured but the main reason is due to a lack of indicator species in heavily invaded riparian areas, which are normally used to orientate within the boundaries of lateral zones. A reference condition of four lateral zones was described for Fynbos Riparian Vegetation. Physical rules to identify the position of lateral zones were described. These rules were used to orientate around invaded and cleared sites that were situated downstream in order to assess the impact of the invasion or the process of clearing within each lateral zone. A chronological sequence of how riparian plants establish themselves into four lateral zones over a ten year period was described. For phases of recruitment were revealed. In phase 1, recruitment of Fynbos, scrub, and other wet and dry bank species, including exotics, pioneering annuals and transient species takes place in the first year as a flush of new growth. In phase 2, herbaceous cover of sedges, rushes, grasses and forbs establish themselves between years two and four. Restios, small shrubs and trees establish in and amongst the herbaceous cover between years four and ten of phase 3. Woody exotics also establish during this phase. Phase 4 remains open ended as sites older than 10 years were not assessed. However, some characteristic species, such as *Erica caffra* and *Elegia capensis,* were shown to be more sensitive to the presence of exotics and had failed to re-establish themselves 10 years after clearing. Areas that were not burnt were closer to reference conditions more quickly and areas where exotics were felled and removed were particularly quick to recovery.

B.1.4 Links between lateral vegetation zones and flow at selected South African River

Karl Reinecke, Cate Brown, Karen Esler, Jackie King, Martin Kleynhans, Martin Kidd

The flow regime is considered to be the master variable responsible for the occurrence of lateral zones. Several authors have proposed links between inundation of a river bank and the plant communities that occur there. The widely held belief that there two main lateral zones occur, a wet and dry bank, and that the boundary between the two is maintained by the 1:2 year flood was tested in four different riparian communities along rivers that differ in seasons of high and low flow. The same patterns of zonation were shown to occur in the four riparian communities. There were four lateral zones in two groups. The wet bank consisted of two zones, a marginal zone comprised of obligate riparian species and a lower dynamic zone situated between the marginal and the lower zone, the next one up, and comprised of a mixture of the species that characterise these two neighbours. The dry bank also consisted of two zones, a lower zone comprised of facultative riparian species and an upper zone, situated between the lower and the adjacent terrestrial community, comprised of a mixture of riparian and terrestrial species. The wet and dry bank were indeed separated by the position on a river bank where the 1:2 year flood recurs. It was not possible to discriminate the four lateral zones using flood recurrence but they were distinguished by inundation duration further as follows. The marginal was consistently inundated for longer periods of one to three months a year, every year, while the lower dynamic was inundated for up to one week a year during wet years, and was not inundated during dry years. The lower and upper zones were separable from the wet bank hydraulically but not from one another since their distributions overlapped. There was no relationship between the upper zone and flood recurrence nor inundation duration.

B.1.5 Functional differences between indicators of lateral zones in Fynbos Riparian Vegetation

Karl Reinecke, Cate Brown, Karen Esler, Jackie King, Klaudia Shachtschneider, Martin Kidd

There are few autoecological studies of South African riparian plants so little is known about their life histories. Understanding recruitment of riparian species and how flow may facilitate or retard this process is necessary for restoration, conservation planning and to inform environmental flow studies. The three species that are the focus of this study are members of Fynbos Riparian Vegetation communities. The role of flow in maintaining the pattern of lateral zones evident in these communities in terms of seed dispersal, adaptations to survive floods and tolerance to drought was questioned. Functional differences between the occupants of the three different zones were sought. It was possible to separate functional differences between willows, as representatives of the marginal zone from that of myrtles and almonds, as representatives of the non-marginal zones (lower and upper combined). Zones were distinct yet the population structure was mixed with each species present at different life stages in the same location. The structure of lateral zones appears to result from a combination of adaptations to the magnitude and frequency of occurrence of floods, which varies along the gradient along with water availability. Regular inundation of the marginal zone has led to one suite of characteristics while less regular inundation by larger magnitude floods and increased drought conditions has led to another. The life history of willows, as for cottonwoods, appeared to be linked to a preferred season of dispersal that favoured recruitment within the marginal zone. These trees were more susceptible to reduced water availability and abstraction of summer base flow as they are less drought tolerant and make use of the intra-annual floods outside of the high flow season to disperse their seed. Myrtles and almonds differ in that their distributions were less restricted to a particular zone and their seeds were distributed more widely across the riparian area. They were more drought tolerant and more resistance to stem-snap during larger floods and resprout if knocked over by really large floods.

B.2 Otto: MSc

The spatial and temporal characteristics of Fynbos Riparian Vegetation were examined. The central hypotheses for the thesis were:

- Riparian community structure is best determined at the scale of longitudinal zones.
- The species composition of undisturbed riparian communities changes over time.

The thesis comprised two papers:

- Paper 1 – Spatial character of undisturbed Fynbos Riparian Vegetation longitudinally down a Western Cape rivers (Section B.2.1).
- Paper 2 – Changes in undisturbed Fynbos Riparian Vegetation communities over time (Section B.2.2).

Comparisons were made between riparian communities of different longitudinal zones in order assess the suitability of indicators for lateral zones in Paper 1. Permanently marked plots were resampled seven years apart in order to assess changes within undisturbed riparian communities over time in Paper 2. The community descriptions provided are useful towards a description of reference conditions for Fynbos rivers.

B.2.1 Spatial character of undisturbed Fynbos Riparian Vegetation communities longitudinally down Western Cape rivers

Mia Otto, Shayne Jacobs, Cate Brown, Karl Reinecke

This study describes the lateral riparian zonation differences down the length of a Western Cape river ecosystem. Lateral zonation was identified by using Primer 6 Cluster and MDS ordination that enabled community comparisons between sites in the longitudinal dimension based on the geomorphological classification system for South African rivers. Riparian vegetation responded at a longitudinal zone scale but not at a finer scale. Mountain streams, transitional zones and upper foothills had different abundances of species present in different lateral riparian zones. Physical habitat characteristics were used to quantify the relationship between riparian vegetation and longitudinal change. Elevation and horizontal distance from the active channel were found to be the most important environmental variables. Different substrate compositions contributed to the lateral zonation pattern but did not have the same significance as combination of elevation and horizontal distance. The biodiversity of the mountain stream sites was higher than that of the upper foothills sites even though the riparian zone in the mountain stream was more constricted. The transitional zone varied in width and had the highest species diversity of all longitudinal zones. The wetbank in the mountain stream sites contained species usually considered part of the drybank (adult *Brabejum stellatifolium*), which may relate to spatial constraints in the upper reaches. Lateral zonation differences in the longitudinal dimension emphasize the use of objective analyses for the identification and assessment of riparian vegetation communities. In terms of ecological research and management practices the longitudinal dimension is an important aspect of consideration.

B.2.2 Changes in undisturbed Fynbos Riparian Vegetation communities over time

Mia Otto, Shayne Jacobs, Cate Brown, Karl Reinecke

The structural composition of riverine ecosystems are shaped by many natural disturbances such as; flood, fire and draught. These natural disturbance processes are important for nutrient cycling, primary production processes, competition and the diversity and succession within ecosystems. The changes caused by natural disturbance in undisturbed fynbos riparian communities were assessed and brought into context with sites recovering after clearing of invasive woody species. This study focused on a small temporal interval ($<10^1$ years) to examine change occurring in the fynbos riparian systems of the Western Cape, South Africa. Sites sampled by Reinecke during 2004/2005 were re-sampled by using permanent markers laid during historic vegetation sampling. This ensured a plot size level comparison to be made between two sample periods. Multivariate analyses on both sets of data showed stronger similarity based on same sampling period than on location. The total number of species recorded during 2004/2005 sampling was higher in the mountain stream sites and lower in both the transitional and upper foothill sites. Species diversity differed between the two sampling periods; biodiversity was lower at burnt sites and higher at cleared sites. Fynbos riparian vegetation community structure was shown to be very dynamic at all sites across the temporal dimension.

C Magoba MSc research proposal

Effects of river flows on recruitment success of riparian vegetation along selected high gradient streams in the Western Cape Province, South Africa

The study seeks to assess the influences of flow on the recruitment success of riparian vegetation at six high gradient streams around the Western Cape. The research is being confined to the upper reaches of rivers; mountain stream (MT), mountain stream transitional (MST) and foothill geomorphic zones (FH). Riparian zones provide many ecological benefits, including providing migratory corridors and breeding, feeding and nursery grounds that support floral/faunal communities in otherwise dry, hostile or transformed environments; act as buffers against sediments, fertilisers, pesticides and other matter draining downhill through the catchment, and provide food and shelter for people and wildlife. Different riparian zones (wet and dry banks) will be assessed along the rivers at reasonably straight sections of channel, so that a grid of sample plots can be laid out along the bank.

The type of vegetation in a riparian zone is determined by the regional climate, the regional pool of species, and the hydrological, geomorphological, and disturbance regime, with most of the world dominated by woody plants and may be classified on the basis of structures as shrubland, woodland or forest vegetation (Richardson et al. 2007). Riparian vegetation is shaped by disturbance regimes of the surrounding landscape, such as wind and fire, and by those associated with lotic and lentic systems, such as flooding, debris flows and sedimentation processes (Reinecke et al. 2007).

RESEARCH OBJECTIVES

The main objectives of the study are:

- To determine whether the physical influence of flow on the zonal structure of riparian communities is exerted pre- or post -recruitment, and;
- To investigate whether the absence of dry season low flows has an influence on the recruitment success of selected (common) riparian species.

RESEARCH QUESTIONS

The key research questions of the study are:

- Are the physical influences of flow on riparian communities exerted before or after recruitment?
- What are the influences of the lack of dry season low-flows on the lateral distribution of riparian vegetation communities?

LITERATURE REVIEW

HYDROCHORY

River margins are among the most structurally-complex and biologically-diverse terrestrial landscapes on earth (Merritt and Wohl, 2002). Hydrochory, the dispersal and transport of seeds by flowing water, is an effective means of seed dispersal and may be a key factor in controlling the position of species laterally up river banks. Of equal importance however is the scouring effect of floods, which flush seeds and seedlings. Through serving as a vector for long-distance seed dispersal, hydrochory may enable new plant populations to become established at great distances from parent populations and may facilitate genetic continuity between spatially separated populations (Merrit and Wohl, 2002). Rising and falling water levels can erode land surfaces; picking up sediments, vegetation debris and propagules and depositing them at different locations, mainly downstream (Goodson et al. 2001). This process may play an important role in structuring plant communities (Merrit and Wohl, 2002) and maintaining high species richness in riparian ecosystems (Richardson et al. 2007; Chambert, 2006).

RIPARIAN ZONATION

Riparian zones occupy a three-dimensional transitional area between aquatic and terrestrial ecosystems and serve as conduits for the exchange of materials and energy from the one to the other (Reinecke et al. 2007; Richardson et al. 2007). These zones are highly modified in most parts of the world with scarce frameworks for their management (Richardson et al. 2007). There are four common groupings of species making up distinct riparian vegetation communities, or zones, recognized from the water's edge outwards up the banks. Naming conventions differ. This study will use the names used by Reinecke et al. (2007): the wet bank is composed of the Water's Edge (WE) and the Channel Fringe (CF), whilst the dry bank is made of the Tree-Shrub (TS) and the Outer Transitional zones (OT). The latter forms the outer boundary of the riparian zone and remains dry for most of the year. The wet bank is determined by within-year flows, while the location of the dry bank is determined by floods with recurrence intervals of more than one year (Boucher 2002). Riparian vegetation in the Western Cape has been described as hygrophilous mountain fynbos, closed-scrub fynbos or broad sclerophyllous closed scrub (Reinecke et al. 2007).

DETERMINANTS OF RIPARIAN VEGETATION COMPOSITION AND STRUCTURE

Gradients and patterns of zonation in aquatic and riparian biotas result from the spatial and temporal variation in the retention and flow of matter along a river's length, (Lorenz et al. 1997). Constantly changing channel and floodplain features results in riparian species being distributed patchily within the riparian zone. Riparian plants tend to occur in patterned locations reflecting their adaptation to the frequency and duration of flood pulses, the various habitat effects possibly caused by floods (Reinecke et al. 2007), sediment deposition, physical abstraction and stem breakage (Richardson et al. 2007). Naiman et al. 2005 (pg51), also emphasizes that natural riparian systems are often shaped by high-energy which are system-resetting disturbance regimes. Holmes et al. (2005) adds on that riparian vegetation is also shaped by disturbance regimes of the surrounding landscape, such as wind and fire, together with those associated with lotic and lentic systems, such as flooding, debris flows and sedimentation processes. Riparia continuously respond in time and space to a diverse array of landscape, hydrologic and biotic influences producing a broad array of community types (Naiman et al. 2005, P76). Prolonged drought or flow reductions relating to diversions, impoundments, or ground water pumping can lead to a lowering of riparian water tables and ultimately mortality in riparian trees (Richardson et al. 2007).

SEEDLING RECRUITMENT

Recruitment, the addition of new individuals into a community, is an important factor that can substantially affect community composition and dynamics (Ribbens et al. 1994). Establishment includes germination, seedling establishment, and growth to maturity (Richardson et al. 2007). A seedling recruit is a propagule that has germinated and is able to survive without maternal resources (Ribbens et al. 1994). To successfully recruit from seed in the post-flood environment the reproductive phenology must correspond to the flooding season, so that seeds are dispersed into a favourable germination environment, or else the species requires a propagule bank, such as a persistent soil-stored seed bank that may be triggered to germinate following the flood (or rain) event (Richardson et al. 2007). Many species produce their seeds during a specific season which should synchronize with the timing of hydrological events in order to be dispersed successfully (Chambert, 2006).

METHODOLOGY

The methodology design has two distinct parts, each addressing one of the study objectives respectively. Thus below each section explains how data for each objective will be collected.

Objective 1: are the physical influences of flow on the zonal structure of riparian communities exerted pre- or post recruitment.

The population structure of undisturbed riparian zones at three rivers will be assessed over a period of 9 years. Attention will be paid to the distribution of saplings and seedlings in order to determine preferred recruitment location and survival post recruitment. A long term data set will be constructed using data collected at permanently marked plots on the Elands and Molenaars rivers during 2004 and 2011. Data collection will be centred on sample grids adopted from Reinecke et al. (2007), which are a modified version of the Whittaker nested vegetation sampling method as according to Stohlgren et al. (1995, cited by Reinecke et al. 2007). Sample grids will be established on one side of the bank for each site. Each sample grid will be 20 m long, along the wetted edge of the river, and several metres wide as dictated by the width of the zone of riparian vegetation. The entire grid will be divided into a series of 1 x 5 m sample plots. Sample plot labelling will be done by number (1 to 'n') to indicate distance from the water in metres, and by letter A to D to indicate location along the 20 m length of the grid. The number, height, and contribution to canopy cover of each species shall be recorded for every species in every 5 m^2 plot. A cross-section survey will be conducted across the full width of the macro-channel, from bank top to bank top. Channel surveying will be done through each of the lines B and C of sample plots. Surveying cross-sections will be laid out at points 5m and on 15m on the plots; this will enable the comparison of the channel shape to the distribution riparian vegetation across the banks.

Two sites will be sampled for each river; the naming of the sites shall be the same as those used in Reinecke et al. (2007). The first three letters of the river name will be used to name sites, Ela_3, Ela_4 at the Elands and Mol_2, Mol_5 at the Molenaars. All four sites have been established by Reinecke et al. (2007) and were permanently marked and sampled in 2007 and again in 2011. Thus two sets of historic data exist, a whole community sampling was done for all the four sites.

To address the second objective (whether the lack of dry season low-flows has an influence on the zonal structure of riparian vegetation communities), an assessment of recruitment over one hydrological year will be done up- and downstream of an abstraction point that removes all summer flow.

The occurrence and lateral distribution of seedlings, saplings and adults of six common species will be compared at each upstream/downstream combination during the late winter and late summer. Six indicator species will be used, thus: *Salix mucronata* (Cape willow), *Metrosideros angustifolia* (smalblad), *Brabejum stellatifolium* (wild almond), *Morella serrata* (lance-leaved wax-berry), *Freylinia lanceolata* (honeybell bush) and the *Braclylaena neriifolia* (water white alder). At least five are present at each river, with *Salix* absent from the Jonkershoek.

The aim is to test the ability of each species to establish and survive in the riparian area (zone) and within the active channel under two different flow regimes, i.e., one where the flow regime is near natural, and the second one where dry season low-flows are absent. Three rivers are used for this purpose; the Sanddrifskloof, Keurhoek and Moraineskloof Rivers. Each has a low flow weir from which summer base flows are abstracted leaving the downstream surface flows absent for most of the summer months. Two sites will be established on each river; one upstream of the weir and one downstream.

The whole community will be assessed at these sites. This will allow a comparison of the entire species complement as well as adaptations and survival of the six common plants in relation to the absence and presence of the surface flows. The working hypothesis of Part 2 of the study is that: most seedlings in the downstream sites will establish in the active channel, but will then be washed away in the winter during the high flows.

PLOT DESIGN

Sample grids will be established on each side of the bank for each site. Each sample grid will be 10 m long, along the wetted edge of the river, and several metres wide as dictated by the width of the zone of riparian vegetation. The entire grid will be divided into two of 1 x 5 m sample plots. Sample plot labelling will be done by number (1 to ‘n’) to indicate distance from the water in metres, and by letter A and B to indicate location along the 10 m length of the grid.

The following will be recorded in each sample plot: the relative position of the indicator species in each plot, the height of each species as an indication of its size, the substrate composition and percentage in each subplot and the percentage of water in each subplot. Replicate samples will be collected on opposing banks during late winter (September 2012), and late summer (February 2013). This will allow sampling to be done at time of high flows and that of reasonably constant low or no surface flows.

DATA ANALYSIS

A single species list will be compiled for each study site based on the presence/absence of species in each sample grid in each assemblage type. The lists for all sites will be compared using CLUSTER analysis and non-metric Multi-dimensional scaling (MDS) ordination; which is an application that measures the similarities in species between sites. According to Clarke and Warrick (2001, cited by Reinecke et al. 2007), CLUSTER analysis (or classification) aims to find 'natural' groupings of samples such that samples within a group are more similar to one another generally, than to samples in different groups. Multidimensional scaling has become known as a technique for both multivariate and exploratory data analysis. The primary outcome of an MDS analysis is a spatial configuration, in which the objects are represented as points; the points are arranged in such a way that their distances correspond to the similarities of the objects: similar objects are represented by points that are close to each other, dissimilar objects by points that are far apart (Wickelmier, 2003).

Reference List

Boucher, C. (2002). Flows as determinants of riparian vegetation zonation patterns in selected southern African rivers. Riparian vegetation zonation patterns. Environmental flows 2002 4th Ecohydraulics, University of Stellenbosch.

Chambert, S. (2006). Sorting of seeds by hydrochory. Master's thesis, Department of civil and environmental engineering division of water environment technology. Chalmers University of Technology Göteborg, Sweden.

Goodson, J.M., Gurnell, A.M., Angold, P.G., and Morrissey, I.P. (2001). Riparian seed banks: structure, process and implications for riparian management. Progress in Physical Geography 25, 3 pp. 301-325

Holmes, P.M., Richardson, D.M., Esler, K.J., Witkowski, E.T.F. and Fourie, S. 2005. A decision making framework for restoring riparian zones degraded by invasive alien plants in South Africa. South African Journal of Science 101: 553-564.

Lorenz. C.M., V. Dijk. G.M., van Hattum, A.G.M. and Cofina, W.P. 1997. Concepts in River Ecology: Implications for indicator Development. Regulated Rivers: Research and Management 13: 501-516.

Merritt, D.M. and Wohl, E.E. (2002). Processes Governing hydrochory along Rivers: Hydraulics, hydrology, and dispersal phenology: Ecological applications, Vol. 12, No. 4 (Aug., 2002), pp. 1071-1087. Ecological society of America.

Naiman, R.J., Decamps, H. and McClain, M.E. (2005). Riparia. Ecology, conservation and management of streamside communities. Elsevier Academic Press, MA, USA.

Reinecke, M. K. and King, J. M. (2007). The nature and invasion of riparian vegetation zones in the South Western Cape. Water Research Commission report project K5/1407 "The nature and rehabilitation of alien-invaded riparian zones".

Ribbens, E., Silander, J.A., and Pacala, S. W. (1994).Seedling Recruitment in Forests: Calibrating models to predict patterns of tree seedling dispersion. Ecological Society of America Vol. 75, No. 6 (Sep., 1994), pp. 1794-1806.

Richardson, D.M., Holmes, P.M., Esler, K.J., Galatowitsch, S.M., Stromberg, J.C., Kirkman, P.S., Pysek, P. and Hobbs, R.J. (2007). Riparian vegetation: degradation, alien plant invasions, and restoration prospects. Diversity and Distributions, 13, 126-139.

Wickelmaier, F. (2003). An introduction to MDS. Sound quality research unit, Aalborg University, Denmark.