

**ROLE OF WATER TEMPERATURE VARIABILITY IN
STRUCTURING AQUATIC MACROINVERTEBRATE
COMMUNITIES – CASE STUDY ON THE KEURBOOMS
AND KOWIE RIVERS, SOUTH AFRICA**

By

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PREFACE

This MSc thesis forms a component of a Water Research Commission (WRC) project, entitled: Water Temperatures and the Ecological Reserve. This component of the research is WRC Project K5/1799, deliverable number 26.



K3 site.

DECLARATION

This study was undertaken for the fulfilment of Masters degree in Geography and Environmental Science, which represents work originally done by the author. Acknowledgments of other authors or organisations have been made within text and in the references chapter.

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ABSTRACT

Water temperature is a critical factor affecting the abundance and richness of freshwater stream aquatic macroinvertebrate communities. Variable seasonal river temperature patterns are a critical factor in maintaining temporal segregation in aquatic invertebrate communities, allowing for resource partitioning and preventing competitive exclusions, while spatial differences in water temperatures permit zonation of species. This research investigated whether the degree of predictability in a stream's water temperature profile may provide some indication of the degree of structure and functional predictability of macroinvertebrate communities. Quarterly aquatic macroinvertebrate sampling over a single year along the longitudinal axes of two river systems, Keurbooms River in the southern Cape, and the Kowie River in the Eastern Cape, were undertaken as the core component of this research. The two river systems shared similar ecoregions and profile zones, however were expected to differ in their thermal variability, based on the hydrological index and flow regimes for their respective quaternary catchments. Hourly water temperature data were collected at each sampling site from data loggers installed at five paired sites on each stream system. The aquatic biotopes sampled were in close proximity to the loggers. Multivariate analysis techniques were performed on the macroinvertebrate and water temperature data. Macroinvertebrate taxon richness was greater on the perennial Keurbooms than the non-perennial Kowie River where, on a seasonal basis, taxon richness increased from winter to autumn on both systems. Macroinvertebrate species turnover throughout the seasons was higher for sites having lower water temperature predictability values than sites with higher predictability values. This trend was more apparent on the Keurbooms with a less variable flow regime. Temporal species turnover differed between sites and streams, where reduced seasonal flows transformed the more dominant aquatic biotopes from stones-in-current into standing pools. Findings included aquatic macroinvertebrates responding typically in a predictable manner to changing conditions in their environment, where water temperature and flow varied. The findings of this research demonstrate that macroinvertebrate taxa do respond in a predictable manner to changes in their environment. This was particularly evident in relation to variability in water temperature and flow.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

South Africa, classified as a semi-arid country, has a mean annual rainfall of 500 mm (Dallas and Rivers-Moore, 2008a), where this low mean belies an uneven rainfall distribution, causing precipitation to be unpredictable and variable (Rivers-Moore *et al.*, 2008a). Rainfall ranges from below 100 mm to greater than 1200 mm per annum (Lynch, 2004, cited in Schulze and Lynch, 2007), where the general trend is high in the south-east and low in the north-west of the country. This high variability results in a diverse range of aquatic ecosystems, where associated species have had to adapt accordingly to either regular or irregular flows on perennial or non-perennial streams respectively. Variability, as a consequence, plays a crucial role in the survival of freshwater ecosystems (Vannote and Sweeney, 1980).

Water is the key to survival, where one of its many roles is to maintain aquatic and terrestrial ecosystems and associated biodiversity (DEAT, 2006). Stream ecosystems are affected and driven by a large number of biotic and abiotic aspects that create biotic patterns through their interactions, resulting in complex systems (Dallas, 2007; Dollar *et al.*, 2007). Unfortunately, many freshwater systems are under threat, predominantly as a result of direct anthropogenic impact (Bates *et al.*, 2008), with South Africa being no exception (DEAT, 2006). As a consequence of these impacts, aquatic invertebrates have become widely recognized as identifiers of water quality, both in South Africa (Dickens and Graham, 2002; Thirion, 2007; Oberholster *et al.*, 2008) and other parts of the world (Buffagni *et al.*, 2001; Bonada *et al.*, 2006; Dinakaran and Anbalagan, 2007; Macedo-Sousa *et al.*, 2008). One of these water quality variables is water temperature.

Temperature affects various factors in water, including water quality (chemical characteristics, dissolved oxygen and sewage fungus) and the aquatic biota (stages in life cycles, physiological effects and effects on the communities as a whole) (Dallas and Day, 1993). Water temperature is a primary abiotic driver affecting the types and quantities of species in streams (Vannote and Sweeney 1980; Quinn and Wright-Stow,

2008), and is a particularly important parameter to monitor within sensitive aquatic environments. Diel temperature ranges impact on the potential diversity of species that can coexist within freshwater ecosystems, due to every individual occurring in the zone of its most optimum temperature during part of the day (Vannote and Sweeney 1980). According to Vannote and Sweeney (1980), the key to sustaining temporal segregation within aquatic invertebrate communities is seasonal stream temperature patterns, enabling resource partitioning to occur, thus preventing the competitive exclusions, while species zonation occurs partly due to water temperature differing spatially.

In streams, it is hypothesised that the biotic diversity role becomes less crucial for sustaining stability of ecosystems within physical systems that are highly stable, for example, headwaters (Rivers-Moore *et al.*, 2008a). On the contrary, as increases in variability with downstream distance occur (for example, water temperature), the biotic diversity role becomes increasingly important for maintaining the stability of the ecosystem (Rivers-Moore *et al.*, 2008a). This paradigm indicates how water temperatures contribute towards system stability (Vannote *et al.*, 1980). Therefore, a correlation between daily temperature variability and biotic diversity becomes evident along a stream's longitudinal axis, peaking in mid-reach regions (Rivers-Moore *et al.*, 2008a). According to Vannote *et al.* (1980), aquatic diversity is lower in the headwaters compared to the remaining stream profile as only macroinvertebrates with narrow temperature tolerances are present.

Predictions such as this have significant consequences in terms of assessing the applicability of the River Continuum Concept to streams in South African (Rivers-Moore *et al.*, 2008a; Rivers-Moore, 2010), and ultimately, developing an ecologically meaningful water temperature classification for the ecological Reserve provided for in the National Water Act 36 of 1998 (Rivers-Moore, 2009).

From a South African perspective, there is still a great deal to be learnt about water temperatures, as quoted by Rivers-Moore *et al.* (2008a, pp. 47): “*What is known about water temperatures in South African rivers is considerably less than what is unknown*”.

This research aims to enhance our understanding of water temperature variability and how it affects macroinvertebrate community structures.

With the above-mentioned in mind, the core component of this research was to perform quarterly surveys of aquatic macroinvertebrates along the longitudinal axes of two stream systems, Keurbooms River in the Western Cape, and the Kowie River in the Eastern Cape. The two stream systems are comparable in their ecoregions, stream orders and profile zones; however they differ in their thermal variability, based on the hydrological index for their respective quaternary catchments (Rivers-Moore, 2009).

1.2 Aim and Objectives

The aim of this research was to determine whether the degree of predictability in a stream's water temperature regime may provide an indication of the degree of structure and functional predictability of macroinvertebrate communities (Vannote and Sweeney, 1980). Objectives were:

1. To establish whether aquatic macroinvertebrates typically respond in a predictable manner to changing environmental conditions, temperatures and flows;
2. To test whether the temporal partitioning of macroinvertebrate species, such as diversity indices and functional feeding groups, are related to water temperature variability.

This thesis includes a literature review in chapter two, summarizing the findings of other authors' work in preparation for the results of this research. The thesis concludes with the outcomes of this research in the conclusions chapter, highlighting the impacts of the findings upon macroinvertebrates in freshwater ecosystems.

CHAPTER 2

LITERATURE REVIEW

2.1 Role of variability in ecosystems

There are three different components that contribute towards stream ecosystems, namely; riparian, surface and subsurface systems (Ward and Tockner, 2001), with variability in each of these components playing a crucial role in changing stream dynamics. Frissel *et al.* (1986) emphasise the importance of understanding the physical patterns influencing biological relationships within stream ecosystems, particularly across space and time, as macroinvertebrate distribution, along with their microhabitat distribution, are controlled by physical attributes. Studies undertaken by Skoulikidis *et al.* (2009) mention several characteristics that determine macroinvertebrate faunal assemblages, including water temperature, altitude, geographical position, current velocity, catchment area, slope and conductivity. At a local geographic context, Dallas (2004) found that macroinvertebrate assemblages were distinctly different between streams in the Western Cape and Mpumalanga with temperate and tropical climates respectively. Dallas (2004) further noted that taxa richness was higher in the tropical region than the temperate region, with exclusive taxa being higher in Mpumalanga than the Western Cape.

Richter *et al.* (1996) emphasise how seasonal hydrologic variation is critical to the survival of species living in different aquatic habitats, where natural disturbances and reproductive cycles are important components of population dynamics. Variability is scale-dependant, where daily, weekly, monthly, seasonal and annual flows are all equally important temporal measurements that contribute towards the function of aquatic ecosystem communities (Jewitt and Görgens, 2000).

Ecosystems on a typical river can be broken into different zones. These zones consist of the headwater zone, the middle zone and the lower zone (Dallas and Day, 1993), where certain characteristics are generally prominent in these different zones. Headwater zones, typically in mountain streams, have clear, swift flowing oxygenated waters, with steep gradients and stream beds consisting of boulders and stones (Gerber and Gabriel, 2002). Particular characteristics define the middle zones, where streams become wider

and more turbid than the headwaters, velocity is reduced due to a more gentle gradient, water flow is less turbulent and water temperatures are higher than mountain streams (Gerber and Gabriel, 2002). Finally, features of the lower zones are that they are wider and velocity is slower than the middle zones, where stream beds consist of sand and silt and waters are rich in nutrients as a result of contributing tributaries (Gerber and Gabriel, 2002). Within each of these zones, particular biotopes are present.

There are several types of aquatic biotopes (or habitats) that have been explained in freshwater streams. A biotope, as defined by Dallas and Day (1993, pp. 214) is “*a homogeneous environment that satisfies the habitat requirements of a biotic community*”. Some of the more common types of biotopes in streams, described by Gerber and Gabriel (2002) include the following: runs (tranquil flow without any broken surface water); riffles (fast-flowing, shallow water, creating turbulent flows resulting in broken surface water); pools (generally deep water that is slow-flowing); aquatic vegetation (fully or partially submerged plants living within the stream channel); marginal vegetation (plants living at the water’s edge, particularly reeds and grasses – can be in or out of current, Dickens and Graham, 2002) and algae (simple plants occurring in either colonial, filamentous or unicellular forms). Other biotopes that occur in freshwater streams include stones-in-current (Palmer, 1997, Dickens and Graham, 2002), stones-out-of-current (Dickens and Graham, 2002), stony backwaters (Palmer *et al.*, 1991) and biotopes on the stream bed, including gravel, sand and mud (Dickens and Graham, 2002).

Certain macroinvertebrate species have adapted to different regions in streams. An example of how certain invertebrates evolve to inhabit specific biotopes is explained in O’Keeffe and de Moor (1988), who deduced that certain beetle families, including Hydrophilidae and Dytiscidae, are frequently associated with pools and marginal vegetation surroundings. Palmer *et al.* (1991) found that several Ephemeroptera, Plecoptera and Trichoptera taxa had over 50 % occurrences in certain biotopes, particularly riffles and stony backwaters.

2.2 Variability in freshwater systems

2.2.1 Variability and the River Continuum Concept

Streams vary significantly as they progress from the headwaters towards the mouth, particularly width, depth, gradient, flow discharge and water temperature. These abiotic features influence aquatic ecosystems differently along the longitudinal gradient. The River Continuum Concept (Vannote *et al.*, 1980) explains this with particular emphasis on aquatic fauna. The concept states that in physically stable stream systems, biotic diversity may appear low, whereas a high biotic diversity may be prevalent in systems with physical variation of higher magnitudes. Physical variability may be stable in certain positions along a stream gradient, particularly headwaters and the lower reaches, where the mid-regions may exhibit higher degrees of physical variation. This is as a consequence of variability, where diel temperatures are greatest in the mid-regions; flow, riparian influence, food and substrate may effect the community structure variations along the course of the stream (Vannote *et al.*, 1980).

Within the diel temperature range, each organism is exposed to its optimum temperature range, where energy processed by organisms oscillates around its optimum mean temperature, where energy processing rates may increase or decrease amongst aquatic populations (Vannote *et al.*, 1980). Therefore, high diel ranges in the mid-regions may promote optimum temperatures to become available to a greater number of macroinvertebrate species, possibly being one of the reasons for yielding a high biodiversity.

2.2.2 Flow variability patterns

No two catchments are alike. There are several driving forces that control how streams navigate their route within catchments, which may significantly control invertebrate grouping. These include: area of upstream catchment, distance from the source, channel slope (gradient), altitude, geology and latitude/longitude (Dallas, 2007; Skoulikidis *et al.*, 2009). On a smaller scale, particularly affecting sampling sites, stream depth, velocity and width, flow pattern and canopy cover may alter invertebrate community structure (Vannote *et al.*, 1980; Dallas, 2007), particularly on a seasonal basis.

Therefore, with different rainfall seasonality, the abovementioned may have a significant impact on water temperatures and thus structuring invertebrate communities.

Stream flow is considered the primary driver of aquatic faunal distribution (Hart and Finelli, 1999), as it affects the biota in a variety of ways (King *et al.*, 2008). With regards to stream velocity, studies undertaken by Chutter (1969) recorded that invertebrates are found in a wide variety of stream velocities, with some species responding positively to fluctuation in velocities, for example, certain species prefer specific stream conditions, such as several Blackfly species preferring running waters (Lautenschläger and Kiel, 2005; Rivers-Moore *et al.*, 2008b). The geology of a catchment influences the chemistry of the stream, particularly pH, cation, anion and total dissolved solids concentrations (Dallas, 2007). In catchments with different geological types, the above-mentioned factors could fluctuate.

2.2.3 Thermal variability

Water temperature is a major species pattern driver in aquatic ecosystems (Rivers-Moore *et al.*, 2008a). Furthermore, water temperature is considered an important seasonal fluctuation that many fauna adapt to (Resh *et al.*, 1988). The geographic spreading of aquatic organisms is determined predominantly by water temperature, considered one of the most important abiotic factors (Bartholow, 1989); thus the effect that temperature has on aquatic invertebrate life is undeniable (Vannote and Sweeney, 1980), particularly affecting metabolism, respiration and reproduction.

There are several factors that influence water temperature regimes in natural streams; including climate (altitude, latitude and continentality), hydrology (source, flow, tributaries and groundwater) and insolation (topography, channel form and riparian vegetation) (Ward, 1985). Controlled by wind speed, cloud cover, precipitation events and vapour pressure, air temperature is regarded as the most significant climatic factor on water temperature, having a direct impact on stream and groundwater temperatures (Ward, 1985). Day-length also contributes to temperature (Palmer *et al.*, 1996). As a result of a plethora of factors controlling macroinvertebrate assemblages, many species have adapted to specific regions along stream profiles. Attributed to water temperatures,

Oliff (1960) discovered that the species structure in the headwaters of the Thukela River in KwaZulu-Natal differed significantly to the downstream reaches, whilst Palmer *et al.* (1991) found that macroinvertebrate assemblages on the Buffalo River in the Eastern Cape differed between upper reaches and middle to lower reaches, and between biotopes.

Stream temperatures progressively increase from the headwaters towards the mouths within stream profiles, usually attributed to altitudinal changes (Ward, 1985; Jacobsen *et al.*, 1997). This is due to temperature having a strong correlation with altitude (Dallas, 2007). Temperature variability occurs at different temporal scales, including daily (diel), monthly, annually and inter-annually (Rivers-Moore, 2009). Jacobsen *et al.* (1998) concluded that the number of invertebrate orders and families had a linear increase with maximum water temperature, thus both temperatures and invertebrate orders decreasing with increasing latitude and altitude. Regarding diel temperature fluctuations, stream depth is considered one of the principal drivers, where greater variability occurs in shallower waters (Ward, 1985).

Secondary drivers of water temperature are mentioned by Brunke *et al.* (2001), who highlight immersed tree roots, woody debris, mussel banks, plants and assorted inorganic sediments as affecting microhabitat thermal heterogeneity by creating slight shading or the protection of invertebrates from direct current.

2.3 Role of macroinvertebrates in ecosystems and response to habitat variability

2.3.1 Effects of temperature on aquatic biota

Water temperature plays a significant role on stream biota, supported by a growing literature (Vannote and Sweeney, 1980; Brittain and Campbell, 1991; Hogue and Hawkins, 1991; Dallas and Day, 1993; Johnson, 2003 Allan *et al.*, 2006; Woods and Bonneau, 2006; Haidekker and Hering, 2008; Webb *et al.*, 2008; Dallas, 2009). Aquatic macroinvertebrates are poikilothermic, meaning their body temperatures are not controllable; as a result, their body is the same temperature as the water in which they

exist (Dallas and Day, 1993). Therefore, water temperature affects biota by several means, including the triggering of migration and spawning, reproduction, growth, general fitness, respiration, metabolic rate (Dallas and Day, 1993) and the development and hatching of eggs (Brittain and Campbell, 1991; Dallas and Day, 1993). Thus, water temperature changes affects riverine biota by several means, where macroinvertebrates may become exposed to conditions that are lethal or sublethal (Dallas and Day, 1993).

2.3.2 Functional feeding groups

The river continuum concept is similar to the equilibrium state reached within the physical system, where faunal producer and consumer functional feeding groups may rapidly adjust to any alterations to their surroundings (Vannote *et al.*, 1980). The location of aquatic macroinvertebrates along stream profiles varies depending on their feeding technique. Vannote *et al.* (1980) and Covich *et al.* (1999) describe this in terms of functional feeding groups: collectors, shredders and scrapers, where some species have feeding accessories or specialized mouthparts for breaking up bigger organic detritus into smaller portions, particularly in headwaters, where an estimated 20-73 % of leaf litter entered into headwater streams from riparian areas is processed by benthic invertebrates. As this breakdown of detritus matter occurs during the feeding process, parts are transported further downstream from shredder species, where specialised filter species exploit this food source (Covich *et al.*, 1999). Suspension feeders, grazers, predators, surface and subsurface deposit feeders are other types of invertebrates that contribute to an aquatic ecosystem's continued existence (Dallas and Day, 1993; Gamito and Furtado, 2009). The location of functional feeding groups along the stream profile is explained further by Vannote *et al.* (1980) in the river continuum concept.

The stream order or relative position along the stream profile determines the relative dominance of functional feeding groups, where riparian vegetation in headwater regions contribute leaf litter (course particulate organic matter – CPOM > 1mm) towards the aquatic ecosystem, fed upon by shredders (Vannote *et al.*, 1980). Collectors rely on gathering from sediments or filtering from suspended fine and ultra-fine particulate organic matter (FPOM 50 µm - 1mm and UPOM 0.5 – 50 µm, respectively), suggested by Vannote *et al.* (1980) to increase in importance and dominance down the stream

profile due to a reduction in size of detrital particles and increasing stream size. Scrapers feed by shearing algae attached to surfaces and predators prey upon other invertebrates (Vannote *et al.*, 1980).

Another aquatic specialist group are the sub-surface invertebrates, residing in sediments in the stream-bed. Covich *et al.* (1999) portrays their functions within ecosystems as that of nutrient cycling, sediment mixing and energy flow via food webs. Pertaining to macroinvertebrates burrowing in the benthos, the nutrient cycling process and microbial growth is accelerated, where sediments are mixed, aerated and macro- and micro-nutrients recycled at increased rates, as a result of digging crayfish, insect larvae, tubificid worms and bivalves (Covich *et al.*, 1999; King *et al.*, 2008).

Not all authors agree with the notion of functional feeding groups (Lake *et al.*, 1985, cited in Palmer *et al.*, 1993; King *et al.*, 1988), stating that aquatic invertebrates are polyphagous, or opportunistic generalists (Cummins, 1973) and different locations and diverse life history stages may alter their diet and feeding habits (Minshall, 1988). Palmer *et al.* (1993) examined the gut content of twelve taxa in the Buffalo River between the middle and lower reaches and recorded that detritus was the dominant diet for all the taxa, where invertebrate remains were found in the guts of *Cheumatopsyche afra* and *Macrostemum capense*. Two broad functional feeding groups were categorised from their results: fine detritus microvores (including the mayfly species in their study) and mixed diet microvores (including the caddisfly species due to invertebrate remains) (Palmer *et al.*, 1993).

A disturbance in a system could impact the biota negatively, for instance suspension feeder food availability reduction if headwater shredder species are reduced in numbers or missing completely (Covich *et al.*, 1999). This is an example of how certain aquatic feeders are reliant on others. Drastic changes to aquatic invertebrate habitats may be detrimental to their, as well as other species, survival. This may occur as a result of sensitive species redistributing themselves or dying off due to their surroundings being altered (for example, anthropogenic impacts); this causes their ecosystem function to no

longer be carried out, thus a disproportional imbalance occurs, where others attempt to compensate for their absence (Covich *et al.*, 1999).

All macroinvertebrates play a specific role within their niche. According to Covich *et al.* (1999), some of these ecosystem services provided by benthic populations include the roles of predators, herbivores, performing as a primary consumers, or detritivores. Gamito and Furtado (2009) explain how other species in aquatic ecosystems are dependant upon larger species' survival, where bacteria and detritus in the benthic layer are nourished by benthic invertebrates, where these may further be preyed upon by larger carnivores, such as fish.

2.4 Indicators of variability

There are two types of indicators for variability for freshwater ecosystems, namely abiotic and biotic. This section briefly discusses these indicators.

2.4.1 Abiotic indicators

Abiotic indicators essentially break down time series (flow and temperature) into metrics to 'measure' variability (Rivers-Moore, 2009). For instance, Colwell (1974) derived indices that are useful for classifying the predictability of rivers. Colwell (1974, pp. 1152) defines predictability as “...a measure of the variation among successive periods in the pattern of a periodic phenomena”. When it comes to predicting the presence or absence of certain invertebrates, the relationship strength between the environmental and biological factors at particular locations plays a significant role (Dallas, 2007). One of the foremost phenomena concerning predictability is that it is high when a system's variation is low (Colwell, 1974).

Richter *et al.* (1996) derived the Indicators of Hydrologic Alteration (IHA) method, consisting of 32 parameters including magnitude, duration, timing and frequency of flow events that are ecologically relevant, where one of the purposes was to provide researchers with biotic responses to certain parameters (Table 2.1). These parameters relate predominantly to surface water flows, but incorporates groundwater, including the following: magnitude (mean for a given month); ranges of daily to seasonal extremes of annual conditions (for duration and magnitude); the Julian-date timing of the extremes;

Table 2.1: A summary of the hydrological parameters applied in the Indicators of Hydrologic Alteration (IHA), with associated characteristics (after Richter *et al.*, 1996).

IHA statistics group	Regime characteristics	Hydrologic parameters
Group 1: Magnitude of monthly water conditions	Magnitude	Mean value for each calendar month
Group 2: Magnitude and duration of annual extreme water conditions	Timing Magnitude Duration	Annual minima 1-day means Annual maxima 1-day means Annual minima 3-day means Annual maxima 3-day means Annual minima 7-day means Annual maxima 7-day means Annual minima 30-day means Annual maxima 30-day means Annual minima 90-day means Annual maxima 90-day means
Group 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1 day maximum Julian date of each annual 1 day minimum
Group 4: Frequency and duration of high and low pulses	Magnitude Frequency Duration	Number of high pulses each year Number of low pulses each year Mean duration of high pulses within each year Mean duration of low pulses within each year
Group 5: Rate and frequency of water condition changes	Frequency Rate of change	Means of all positive differences between consecutive daily means Means of all negative differences between consecutive daily means Number of hydrograph rises Number of hydrograph falls

duration and frequency of low and high pulses; and the frequency and rate of alteration in conditions. This technique is useful when rivers need to be ecologically restored (Richter *et al.*, 1996).

Similarly to flow indices, ecologically relevant water temperature metrics have been suggested. Comparable to the IHA parameters derived by Richter *et al.* (1996), Indicators of Thermal Alteration (ITA) were suggested by Rivers-Moore *et al.* (2010), adapted from Richter *et al.* (1996). These parameters aim to assist with the interpretation of ecological data, where the magnitude, duration, timing and frequency of water temperature events are used.

2.4.2 Biotic indicators

Whittaker (1972) explains how species evolve to occupy diverse positions along a habitat gradient. The initial species richness at a particular site is termed its alpha diversity, occupying a niche hypervolume; alpha diversity relates to the complexity of the community. Niche partitioning over time and space allow different species to coexist within the same ecosystems along the same resource gradient. Where these niches overlap, a continuum is formed. The extent to which other species fit into the existing continuum causes an increase in species along the habitat gradient within the community composition. The degree to which these communities differentiate (turnover) is known as beta diversity (Whittaker, 1972). Thus, Whittaker's alpha and beta (between sites) diversity become a useful technique to detect change in species community composition over time, in other words, their species turnover.

Thus, by sampling aquatic macroinvertebrates along a stream profile, their diversity at different locations along the profile may indicate thermal variability without measuring any abiotic factor, for example, water temperature. De Moor (1999, cited in de Moor, 2002) identified Trichoptera as being adaptable to many ecological conditions, where this order may be used as an early warning indicator for change.

Diptera are considered one of the most prolific orders of aquatic invertebrates, so much so that Hutchinson (1993, cited in Covich *et al.*, 1999, pp. 120) deduced that "...the

Diptera are by far the most diverse order of insects in fresh water; they are in fact the most diversified of any major taxon of freshwater organisms". Thus, a diverse order such as Diptera could have some species more sensitive to ecological changes than others, thus may be an important order for identifying species to indicate change (de Moor, 2002).

2.5 Anthropogenic impacts on variability

Anthropogenic activities have had significant negative impacts on the dynamics of aquatic environments (Dallas and Day, 1993; Azrina *et al.*, 2006; Macedo-Sousa *et al.*, 2008), where destructive adjustments to physical and chemical water characteristics become detrimental to these ecosystems. Jones (2005; cited in Thieme *et al.*, 2005) describes a number of anthropogenic activities that contribute towards the degradation of freshwater habitats, such as interbasin transfers, runoff of several pollutants (pesticides), water abstraction and dams (particularly relating to agriculture) and prolific urban development. Within aquatic systems, certain fauna, particularly sensitive species, are affected by minor temperature modifications, which may or may not result from human practices upstream. Variability in streams is greatly affected by anthropogenic influences, where thermal signatures are altered due to activities that cause changes in flow volumes, shading and groundwater inputs (Ward, 1985; Dallas and Day, 1993).

Human activities can severely influence a stream flow regime, often negatively. According to Ward (1985), some of these alterations include stream regulation (for example, reservoir construction, interbasin transfers (de Moor, 2002; Rivers-Moore *et al.*, 2007)), thermal pollution and alterations to riparian vegetation (including logging and shading) within the catchment. Changes such as these cause interruptions in species' life cycles to which they have adapted (Ward, 1985). DEAT (2006) mention how the human alterations to environments can lead to the increase of invasive alien species and biodiversity loss. Such anthropogenic manipulations to water courses may cause drastic alterations to aquatic faunal community structures (O'Keeffe and de Moor, 1988), particularly sensitive species. It is thus vital that watersheds are managed efficiently, with particular emphasis on riparian zones (Allan *et al.*, 1997), ensuring the vegetation is not interfered with, as it is a vital component of the stream system.

Field work undertaken by O’Keeffe and de Moor (1988) in the Great Fish River (Eastern Cape) revealed that 41 macroinvertebrate taxa were identified before an interbasin transfer was implemented and 47 taxa afterwards, with 22 taxa common to both periods. Rivers-Moore *et al.* (2007) identified 38 taxa on the same river post-interbasin transfer, a decline of nine taxa 19 years later. The significance of this is that flow variability was different before versus after the construction of the interbasin transfer. This is an indication of how interbasin transfers may be detrimental to certain aquatic species ecosystems, linked to anthropogenic alterations as a result of man causing disruptions to natural stream processes.

According to Allan (2004) and Allan *et al.* (1997), landuse practices within a catchment influence several characteristics of a river system, both directly and indirectly; these include biotic integrity, water quality and habitats. A particular conclusion of these authors was that an increase in sediment was positively correlated to the area of land under agricultural use up-river. Landuse change to agriculture or urban use often results in loss of biodiversity due to aquatic ecosystems becoming degraded (Utz *et al.*, 2009). Different landuse types contribute greatly towards changes in flow variability. This is caused by surface runoff, where more impermeable surfaces, such as tar or cement under urban landuse initiate more surface runoff than a pristine grassland or forest landuse.

Reservoir discharge may affect biota depending on the method of release: bottom (or hypolimnetic) discharges are often cool, oxygen deficient and nutrient rich, whereas top (epilimnetic) discharges are warmer (Hart and Allanson, 1984; Malan and Day, 2002). The presence of dams along a stream have shown to cause adverse conditions on water quality and quantity in streams (Mantel *et al.*, 2010a), also negatively effecting macroinvertebrate distribution, particularly opportunistic and sensitive taxa quantities (Mantel *et al.*, 2010b).

Other factors that may result in biodiversity loss in the systems include growing human populations and alien species introductions, placing negative impacts upon water quantity

and quality and future concerns such as rising sea levels relating to climate change in coastal regions (Jones, 2005; cited in Thieme *et al.*, 2005).

Although temperature is regarded as one of the more comprehensible factors effecting community structure changes, flow, substrate, food and riparian influence are equally important (Vannote *et al.*, 1980). McKee and Atkinson (2000) simulated climate change scenarios on *Cloeon dipterum* by heating water to 3 °C for different trials over a period of time. Their results demonstrated adult emergences starting earlier in the year from ponds that had been heated, particularly ponds with added nutrients. Studies undertaken by Allan *et al.* (2006) demonstrate how water temperature influences the respiration rate of the *Palaemon peringueyi* shrimp, where respiration rates increased with increasing temperature. These are two examples of how water temperature changes effect taxa in different ways, where anthropogenic actions impacting upon climate change and global warming may affect many other aquatic macroinvertebrates by various means.

2.6 Conclusions

A plethora of factors, both biotic and abiotic, have been mentioned in this literature review that affect macroinvertebrate community structures. From this review, it is evident from the authors' findings that macroinvertebrate community structures and distribution varies depending on the type of stream and its location, particularly climate, which is the driver for seasonal variability of flows, scale-dependant temperature variation and different types of aquatic biotopes present in streams. Of the abiotic factors influencing the macroinvertebrates community structures, water temperature and its associated variability will be the core focus for this research.

CHAPTER 3 METHODS

3.1 Study sites

Five paired sites were sampled along two rivers (Keurbooms and Kowie/Bloukrans Rivers) on a seasonal basis between June 2009 and April 2010 (Figure 3.1). To synchronize sites on each river system, several conditions had to be met for site selection, the installation of water temperature loggers and macroinvertebrate sampling.

3.1.1 Keurbooms River

The source of the Keurbooms River is situated close to the town of Uniondale, flowing through the Prince Alfred pass and entering the sea at Plettenberg Bay, over 70 km downstream from the K1 site at the headwaters (Figure 3.1). The ecoregions are classified by Kleynhans *et al.* (2005) as south eastern coastal belt for most of the study area, and southern folded mountains with the underlying geology classified as Table Mountain. The Acocks' veld type groups along this system include False Sclerophyllous Bush Types (for a small segment of the uppermost part of the river), where Coastal Tropical Forest Types is present for the remaining parts of the river (ARC-ISCW, 2004). More detailed vegetation types along this stream system include North Outeniqua Sandstone Fynbos, Tsitsikamma Sandstone Fynbos, Langkloof Shale Renosterveld, South Outeniqua Sandstone Fynbos and Southern Afrotropical Forest (Mucina and Rutherford, 2006).

The top two sites are both of first river order, site 3 is second order and sites 4 and 5 are both third order (1:500 000 river coverage, DWAF, 2009). This river is classified by DWAF (2009) as being perennial. The longitudinal profile for sites, altitude plotted against downstream distance, is presented (Figure 3.2), where the uppermost site was at 583 m.a.s.l (meters above sea level) and the lowest site 1 m.a.s.l. A gauging weir, K6H019, is present along this stream, located approximately one kilometre downstream of the K4 site.

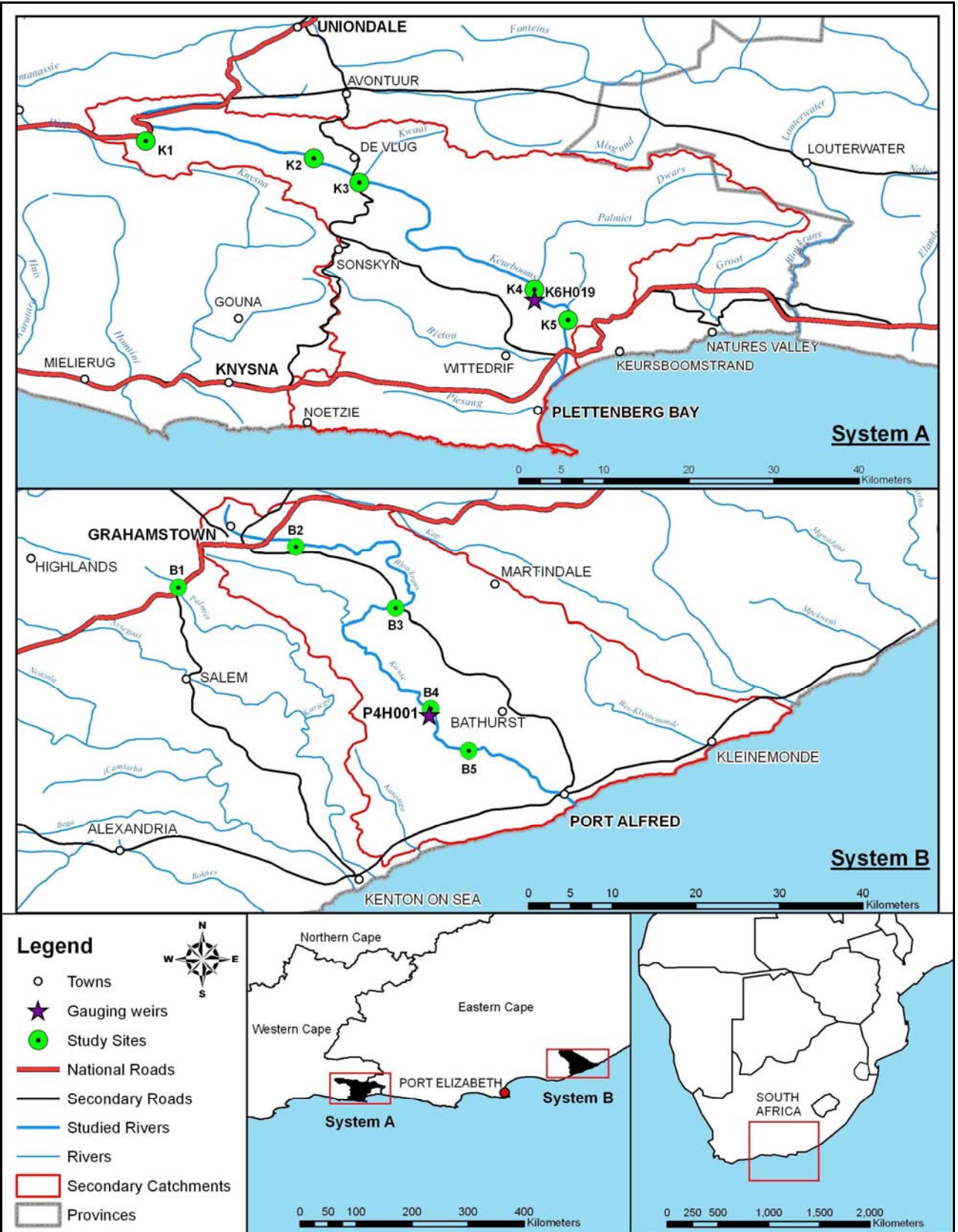


Figure 3.1: Study area, showing the paired sample sites from each river system.

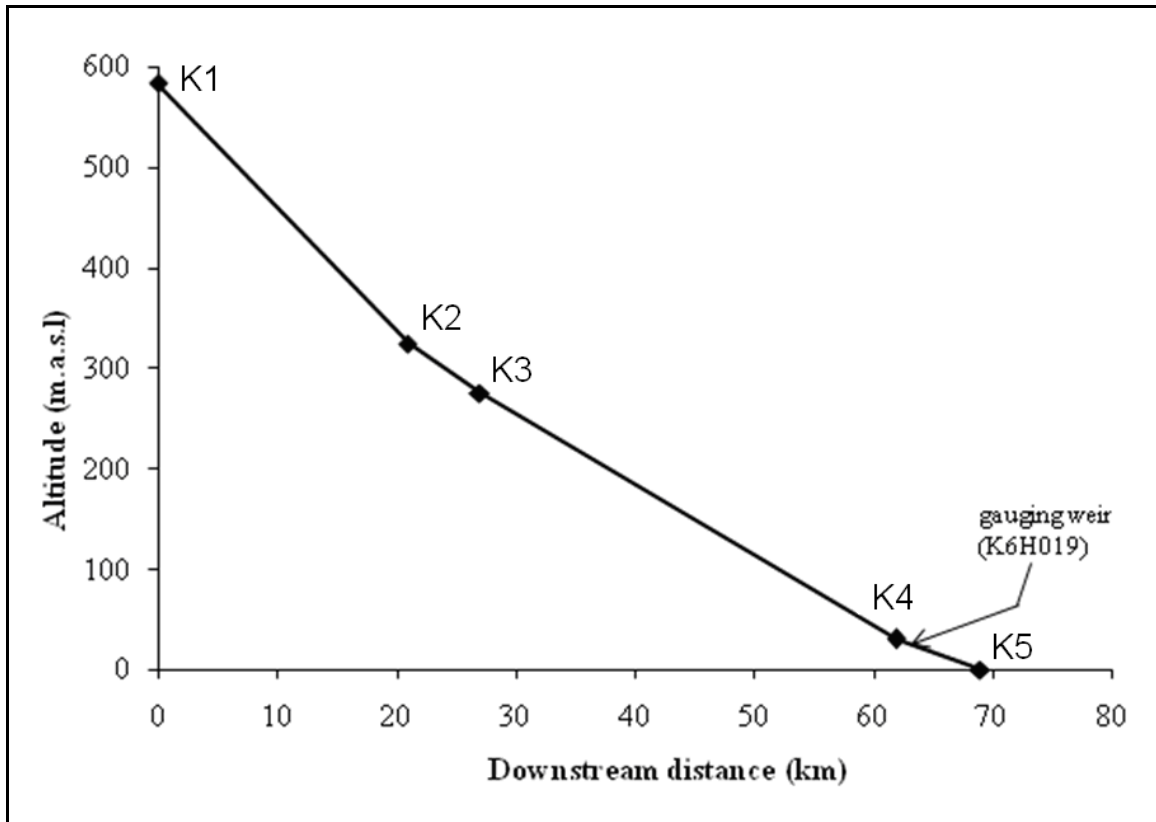


Figure 3.2: Longitudinal profile of the study sites along the Keurbooms River.

3.1.2 Kowie/Bloukrans River

Since the source of the Kowie River is situated in the middle of the town of Grahamstown (Figure 3.1), the upper-most site on this system was ‘offset’ to B1, an equivalent headwater site that was not affected by urban pollution, runoff or other anthropogenic activity that may hinder aquatic macroinvertebrate communities. This is the reason why the upper-most site is situated outside the secondary catchment (Figure 3.1). This river flows through agricultural land in the middle reaches, where water is abstracted for irrigation. Along with drought, this practice attributed to the no flows experienced at some sites in summer and autumn downstream of these irrigated lands.

The mouth of this system enters the sea at Port Alfred, situated 100 km downstream of B1. The ecoregions here are classified by Kleynhans *et al.*, (2005) as southern folded mountains for the top three sites and south eastern coastal belt for the bottom two. The underlying geology is classified as Witteberg for all sites, except the B2 site, being

Dwyka. According to ARC-ISCW (2004), the Acocks' veld types present along this river include the following: Coastal Tropical Forest Types, False Sclerophyllous Bush Types and Karoo and Karroid Types, similar vegetation types to those on the Keurbooms River. More detailed vegetation types along this stream system include Suurberg Quartzite Fynbos, Suurberg Shale Fynbos and Kowie Thicket (Mucina and Rutherford, 2006).

The top three sites are all of first river order, where this segment of river is classified by DWAF (2009) as being non-perennial. Sites 4 and 5 are second and third order respectively and are on a perennial river segment (DWAF, 2009). However, due to a drought in this region, these segments were not flowing during summer and autumn.

The longitudinal profile for sites, altitude plotted against downstream distance, is presented (Figure 3.3), where the upper-most site was at 400 m.a.s.l and the lowest site 5 m.a.s.l. A gauging weir, P4H001, is present along this stream, located approximately 800 meters downstream of the B4 site.

3.1.3 Site selection criteria

The initial method used to assess the appropriate location for the temperature data loggers and corresponding sample sites was by using a number of criteria using GIS layers. Paired sites in two river systems were chosen based on their ecoregions (Kleynhans *et al.*, 2005) and geomorphological zones, with their primary differences being differences in flow variability (which were assumed to translate into thermal variability). The headwater, mid-reaches and bottom sites on the Kowie River were selected to be similar to the corresponding sites on the Keurbooms River (Table 3.1).

The two quaternary catchments were similar in their stream orders, profile zones and ecoregions. Jones (2005; cited in Thieme *et al.*, 2005) names the ecoregion for these two river systems as Cape Fold, with the major habitat type being defined as Mediterranean Systems. This ecoregion classification was too coarse, thus the Level I ecoregions of Kleynhans *et al.* (2005) were used.

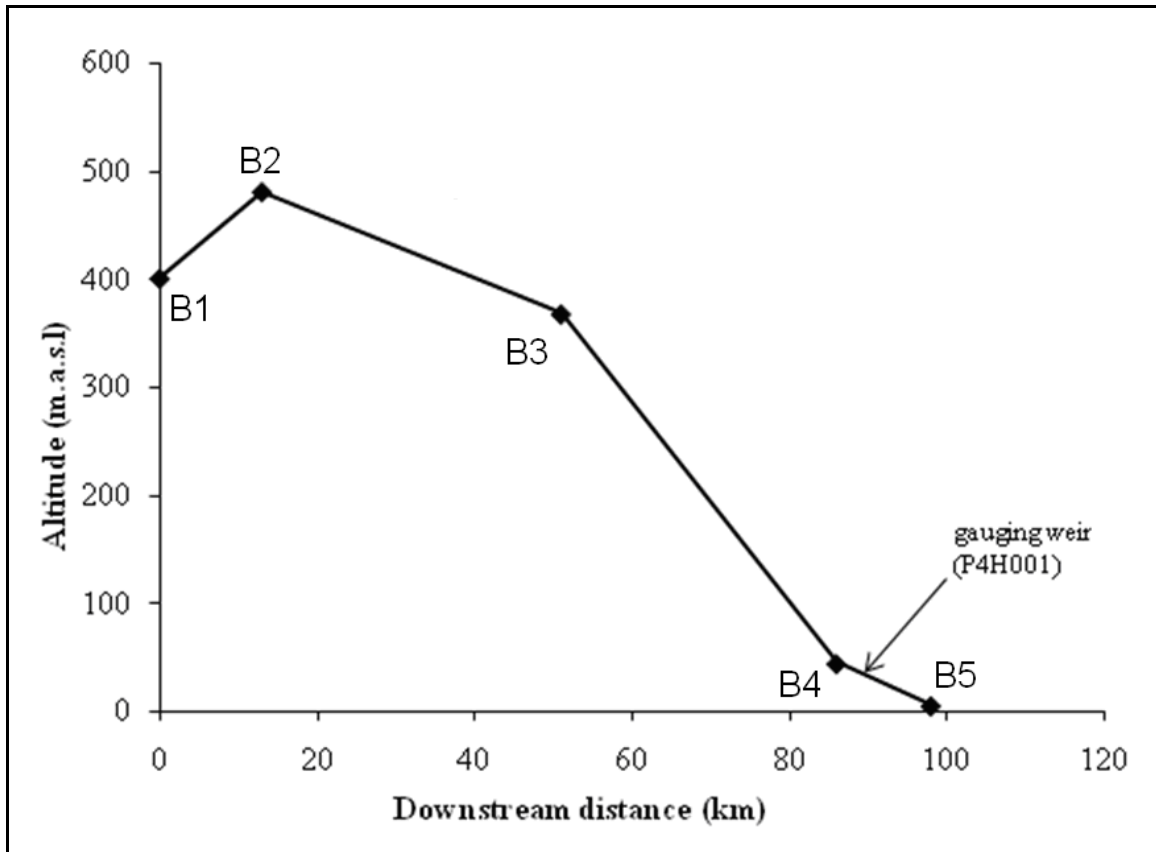


Figure 3.3: Longitudinal profile of the study sites along the Kowie/Bloukrans River (the upper-most site on this system was ‘offset’ to B1, an equivalent headwater site that was not affected by anthropogenic activity).

3.2 Data collection

This section provides a detailed account on how the data were collected.

3.2.1 Aquatic macroinvertebrate sampling

Macroinvertebrate sampling was undertaken in close proximity to where the water temperature loggers were positioned, to relate water temperature data to aquatic macroinvertebrate data. Only hydraulic biotopes close to the temperature logger were sampled. The depth at which macroinvertebrate sampling occurred varied, depending on the stream discharge.

Table 3.1: Summary of site criteria characteristics taken into consideration for the Kowie/Bloukrans and Keurbooms river systems (the Hydrological Index Class is a measure of variability in the river systems – Hughes and Hannart, 2003).

River Name	Site Name	Mean annual Rainfall (mm)	Mean annual Temp (°C)	Geology	Ecoregion Level 1	Stream Order	Longitudinal Zone	Hydrological Index Class	Altitude (m.a.s.l)
PALMIET	B1	587	17.6	Witteberg	Southern Folded Mountains	1	Transitional	4	363
BLOUKRANS	B2	560	16.7	Dwyka	Southern Folded Mountains	1	Upper foothill	4	480
BLOUKRANS	B3	541	18.1	Witteberg	Southern Folded Mountains	1	Lower foothill	4	367
KOWIE	B4	589	18.6	Witteberg	South Eastern Coastal Belt	2	Rejuvenated foothill	5	44
KOWIE	B5	622	18.3	Witteberg	South Eastern Coastal Belt	3	Lowland	5	2
KEURBOOMS	K1	787	14.4	Table Mountain	South Eastern Coastal Belt	1	Transitional	2	583
KEURBOOMS	K2	730	15.0	Table Mountain	Southern Folded Mountains	1	Upper foothill	2	324
KEURBOOMS	K3	732	15.6	Table Mountain	South Eastern Coastal Belt	2	Upper foothill	2	275
KEURBOOMS	K4	699	16.8	Table Mountain	South Eastern Coastal Belt	3	Lower foothill	1	30
KEURBOOMS	K5	767	16.6	Table Mountain	South Eastern Coastal Belt	3	Lower foothill	1	0
Reference:		Schulze (2007)	Schulze (2007)	ARC-ISCW, (2004)	Kleynhans <i>et al.</i> (2005)	DWAF (2009)	Dallas and Rivers-Moore (2008b)	Hughes and Hannart (2003); Dallas and Rivers-Moore (2008b)	

Hydrological Index Class: 1 = very low variability; 2 = moderately low variability; 4 = moderate variability; 5 = moderately high variability

Precautions were taken to ensure the selected macroinvertebrate sample sites had minimal anthropogenic disturbance. Several biotopes were sampled separately (Table 3.2), which were likely to exhibit macroinvertebrate presence. The biotopes that were sampled were as follows:

- for fast flowing water, the only biotope sampled was stones-in-current;

- for standing waters, macroinvertebrate sampling was performed in muddy, sandy and at times, pools and stony bottoms, particularly for sites at low altitudes with meandering river channels; where stones-out-of-current and marginal vegetation were included if present.

Table 3.2: Summary of the biotopes sampled per site. Biotopes sampled at the sites varied throughout the seasons, depending on water availability.

	Stones-in-current	Stones-out-of-current	Pools	Marginal vegetation	Gravel, sand, mud
K1	*	*	*		
K2	*	*	*		*
K3	*		*	*	*
K4	*	*	*		
K5		*		*	*
B1	*	*	*		
B2	*		*		
B3	*				
B4	*	*	*		
B5		*		*	*

For the headwater sites, a common feature on both streams was fast-flowing water and shade provided by riparian vegetation. The common macroinvertebrate biotope sampled was stones-in-current (where some sites turned into stones-out-of-current due to insufficient water flow). Although samples were dominantly in-current, stones from pools, glides and runs, and marginal vegetation in current were sampled, with the intention of obtaining taxa from as many different habitats as possible.

For the sites second from the top, stones-in-current remained the dominant biotope, where samples were again taken from pools, glides and runs, together with riffles. These biotopes were sampled, as different macroinvertebrates adapt to various extents of features including current, depth, and temperature, which may alter depending on their biotope habitat.

The middle sites were dominated by stones-in-current. This was the only biotope sampled on the Kowie/Bloukrans until the site dried up in the summer and autumn seasons. Marginal vegetation and stony bottom habitats were sampled in and around pools at the K3 site.

K4 and B4 were sampled in stones-in-current. B4 was no longer flowing in summer and autumn, but water was present in a big pool, where stones-out-of-current were sampled.

The manner in which river profiles form is by more sediment accumulating towards the mouth of the river than the headwaters or mid-reaches, where stones are more dominant. This was observed on the Kowie/Bloukrans and Keurbooms rivers for the lowest sites. For this reason, gravel, sand and mud habitats were included in sampling at the lowest sites for sub-surface macroinvertebrates, including any other predominant biotope present. For example, the stones-out-of-current biotope was present on flood-plains bordering the water's edge at lowest sites on both rivers, and reed and sedge marginal vegetation out of current¹.

Aquatic macroinvertebrates were sampled from the stones-in-current and stones-out-of-current biotopes as follows (Rivers-Moore, 2009):

- For each repetition, five to seven stones were identified for sampling.
- A stone fitting into one hand was identified (between 10 and 20 cm diameter). Before removing it from the stream, a net of 250 µm mesh size was positioned downstream of the stone to capture macroinvertebrates either attempting to escape or becoming dislodged from the stone in the removal process.
- The stone was placed in a bucket of water along with the net contents. The surface of the stone was carefully scraped to dislodge the contents on the stone. When

¹After the first survey trip at the B5 site, it was confirmed that the logger was positioned in estuarine conditions. On the second trip, the water temperature logger was repositioned further upstream in more freshwater conditions. For consistency, the estuarine site was surveyed for macroinvertebrates for the remainder of the study, however the more freshwater site was also surveyed, but only for spring, summer and autumn.

necessary, substances not becoming dislodged with fingers were displaced using a scrubbing brush.

- The contents in the bucket and the water were then poured through the 250 μm net to separate the macroinvertebrates from the water.
- The contents in the net were emptied into a plastic jar containing 80 % alcohol for preservation.

The method used for obtaining macroinvertebrates from the marginal vegetation biotope was as follows (Rivers-Moore, 2009):

- A net with 1 000 μm mesh size and a frame with dimensions of 30 x 30 cm was used to disturb the vegetation, enabling disrupted and dislodged invertebrates to become captured in the net. This procedure was carried out for approximately five minutes.
- The contents in the 1 000 μm net were emptied into a bucket of water, which was then transferred into the 250 μm mesh size net for making the transfer of the invertebrates into the jar containing 80 % alcohol easier.

The method used to sample macroinvertebrates from soft sediments was performed using a surber sampler in the same way as Cucherousset *et al.* (2008):

- Pointing the container downstream, sediment is disturbed within the rectangular base, where the benthos flows into the netting. The container at the end of the net (mesh size of 250 μm) has the lid covered with mesh (1000 μm) on the outside, allowing the sediment to flow out, where the invertebrates remain captured in the jar. Thereafter, the contents are emptied into a jar with 80 % alcohol for preservation.

Macroinvertebrates were identified to finest taxonomic resolution possible using the Guides to the Freshwater Invertebrates of Southern Africa (Day *et al.*, 2001; Day *et al.*, 2002; Day and de Moor, 2002a; Day and de Moor, 2002b; de Moor *et al.*, 2003a; de Moor *et al.*, 2003b; Stals and de Moor, 2007). Where identification was uncertain, expert

assistance was sought. The procedure carried out for macroinvertebrate identification and counting is explained in detail in Appendix A.

Macroinvertebrates were assigned functional feeding groups categories. The references to the macroinvertebrate FFG categories were obtained from the following sources, unless stated otherwise: Day *et al.*, 2001; Day *et al.*, 2002; Day and de Moor, 2002a; Day and de Moor, 2002b; de Moor *et al.*, 2003a; de Moor *et al.*, 2003b; Stals and de Moor, 2007.

3.2.2 Environmental data

Water temperature, flow and certain water quality data were collected to correspond with the macroinvertebrate data.

3.2.2.1 Flow

A single flow gauging weir was present on each river system containing reliable data, namely K6H019 (Keurbooms River @ Newlands) and P4H001 (Kowie River @ Bathurst) stations (DWA, 2010). The period of data common to both sites was 12 years, enabling comparison of sites.

Due to insufficient gauging weirs or gauging weir data in both of the secondary river catchments, simulated flow data for each of the quinary catchments along the rivers was used. In this way, there was consistent flow data for each site (based upon the quinary catchment) for corresponding periods. These data were obtained from the School of Bioresources, Engineering and Environmental Hydrology at the University of KwaZulu-Natal, Pietermaritzburg (BEEH, 2010) from 1950 – 1999. These flow data were simulated under a baseline climate, based upon Acocks natural vegetation (BEEH, 2010).

3.2.2.2 Water Temperature

Water temperature was recorded using Hobo UTB1-001 TidBit V2 data loggers (Onset, 2008). These data loggers were programmed to record hourly water temperatures, which were downloaded using a mobile shuttle device on seasonal macroinvertebrate sampling

trips. If on seasonal trips the loggers were close to the surface of the water, they were repositioned if possible to be further submerged in the water to avoid the loggers recording air temperature rather than water temperature.

The following criteria were met for water temperature site selection:

- Representativeness of the entire longitudinal profile was required, thus distribution of the loggers was to be as evenly-spread as possible, but at the same time striving to achieve the research aim and objectives.
- As a result of high and low seasonal flows, loggers were positioned such that they remained submerged as often as possible, but ultimately striving for them to be submerged for the entire duration of the study. This was achieved by securing the loggers to boulders in or to the side of the stream where possible, otherwise large tree roots were used.
- The positioning of the loggers was carried out such that they were out of sight of passers-by, thus reducing the possibility of vandalism or theft.

The hourly water temperature data were converted into daily temperature values (mean, minimum and maximum). This was achieved by running the hourly data through macros calculations in Microsoft excel (created by Rivers-Moore, 2009).

The K4 and K5 water temperature loggers did not record data for a complete years' cycle. To patch these time series, a scatter graph was plotted using the temperature data common to K4 and the next closest site, namely K3. The trend line and equation for the scatter plot were included in the graph. The unknown mean, minimum and maximum water temperatures were calculated using this equation from the known values at the K3 site. The equations used for the mean, minimum and maximum temperatures at K4 (Equation 1, Equation 2 and Equation 3 respectively) are as follows:

$$y = 1.005x + 0.978 (R^2 = 0.991) \quad [1]$$

$$y = 0.913x + 3.554 (R^2 = 0.989) \quad [2]$$

$$y = 0.931x + 1.728 (R^2 = 0.952) \quad [3]$$

The equations used for the mean, minimum and maximum temperatures at K5 (Equation 4, Equation 5 and Equation 6 respectively) are as follows:

$$y = 0.992x - 1.959 \quad (R^2 = 0.982) \quad [4]$$

$$y = 0.858x + 1.284 \quad (R^2 = 0.948) \quad [5]$$

$$y = 0.961x - 3.074 \quad (R^2 = 0.976) \quad [6]$$

3.2.2.3 Water quality data

Conductivity, pH and total dissolved solids were measured using a hand-held meter (Cyberscan 200, with ± 0.05 % accuracy), along with a reference temperature using a probe attached to the meter. The depths of the rivers/pools were measured with a depth stick and wetted width measured with a measuring tape. Turbidity was determined using a Secchi disc. All these criteria were measured seasonally at every site, except for the B3 site (site 3), which dried up completely for the summer and autumn seasons due to drought conditions in the region. The freshwater site at B5 was not measured for spring, as the batteries in the hand-held meter became depleted and spare batteries were not taken into the field.

3.3 Statistical analyses

3.3.1 Species diversity indices

Sørensen's similarity index was used (Sørensen, 1948; cited in Stratton *et al.*, 1978) to quantify how different macroinvertebrate communities differed seasonally (Equation 7). This was calculated to compare the two streams with sites situated along a similar position on each stream, i.e., top site on the Keurbooms compared to top site on the Kowie/Bloukrans, and so on.

$$QS = 2C / (A + B) \quad [7]$$

where C is the number of species common to both sites and A and B are the number of species at sites A and B respectively.

3.3.2 Determination of generalist and specialist taxa

Generalist and specialist macroinvertebrate taxa were determined by the number of times taxa were present at sites over seasons, i.e. spatial and temporal presence (Rivers-Moore, 2009). If present over many seasons at the same site or many sites on the same stream, taxa were categorized as generalist, whereas if taxa were present for few or one season at few or one site on the same stream, taxa were categorized as specialist. Thus, generalist (common) and specialist (rare) species were identified using the following method:

- A presence value of one was assigned to a macroinvertebrate taxon if present at a site for a season. If this taxon were present at the same site for all four seasons, it was assigned a value of four (being a common taxon at that specific site), for three seasons, a value of three, and so on.
- Thereafter, if this taxon were present at one site on the stream system (for however many seasons), it was assigned a value of one. If it were present at five sites for however many seasons, it was assigned a value of five.
- Thus, two values were needed to assign a taxon to a certain group. The first value being number of seasons and the second value being number of sites. Thus, a matrix was formed where number of sites was represented in columns and number of seasons represented in rows. Once all the taxa from each category in the matrix were summed, the taxa in the matrix were expressed as percentages, where number of taxa in a category (for example, six taxa in the three sites-four seasons category) were divided by the total taxa present on that stream throughout all seasons (for example, six taxa divided by sixty-one taxa, multiplied by one hundred percent).

The method used to determine the macroinvertebrate turnover throughout the seasons was by determining the coefficient of variability in seasonal macroinvertebrate diversity. This was achieved by calculating the mean taxon richness values and standard deviation (SD, number of variables = 4 and degrees of freedom = 3) from all seasons and for each site. The coefficient of variation was determined by equation below (Equation 8),

$$CV = (100 \times SD) / \bar{X} \quad [8]$$

where SD is standard deviation and \bar{X} is the mean.

This procedure was carried out for all sites on both streams. These CV values were used to gain an understanding of the relationship between macroinvertebrate turnover and water temperature predictability.

3.3.3 Flow and temperature metrics – IHA and ITA

The quinarys chosen for the simulated flow were selected based on having a site situated in that quinary or by being the closest quinary to a site. The date format was altered to the correct format for the IHA software to read, where the flow data was left as cubic meters per second. The flow data was then run through the IHA software (Table 2.1 - Richter *et al.*, 1996). Analysis was performed for each quinary and the output data saved in a spreadsheet. Once all the quinarys had been run through the software, the data was collated into a single spreadsheet to enable easier visual data comparisons.

Daily mean, minimum and maximum water temperature values were used to calculate Indicators of Thermal Alteration (or ITA – adapted from the IHA by Richter *et al.*, 1996), obtained from Rivers-Moore *et al.* (2010) (Table 3.3). These calculations were created in Microsoft Excel spreadsheets using Microsoft Visual Basic Editor, creating macros. Similar to the parameters in Table 2.1, the macros were used to calculate values for parameter groups 1, 2 and 4, where group 3 was determined by visual means of the data, ascertaining what the Julian date was for the minimum and maximum daily temperatures for each site. The values in parameter group four were calculated by determining how many times the minimum or maximum temperature exceeded a temperature threshold. For example, minimum temperature count is the sum of how many days the minimum temperature was less than 12 °C, where the maximum temperature threshold value used was 18 °C (Rivers-Moore, 2009). The minimum temperature duration was calculated by the amount of consecutive days where the values were either above or below the set minimum or maximum temperature threshold. Further descriptive statistics that were calculated either manually or by using macros in Microsoft Excel are equally important to the groups mentioned above, which included: mean annual temperature, annual coefficient of variation and standard deviation, temperature predictability, annual range,

range coefficient of variation and standard deviation, summer and winter range and degree days (Table 3.3).

Before the flow and temperature data was run through a Principal Component Analysis (PCA), a correlation analysis was performed in Microsoft Excel to remove the redundant variables, resulting in a more meaningful PCA.

The ITA data for temperature was calculated using macro calculations in Microsoft Excel (Rivers-Moore, 2009) and was not run through the same software used for the flow data. The IHA software was not used as it was specifically created for flow data over a number of years, whereas the water temperature recorded is for a year's cycle only.

3.3.4 Multivariate Analyses

Multivariate analysis allows comparison of more than one set of statistical variables with one another, particularly in this research where sites were characterised by numbers of species and their abundances, where these were affected by environmental factors, enabling multivariate analyses to be performed (Gauch, 1982). Multivariate statistics were performed using species and water quality data, including temperature and flow parameters, in order to identify which environmental variables affect certain macroinvertebrate groups.

Table 3.3: Indicators of Thermal Alteration parameters used for water temperature analyses (adapted from Rivers-Moore *et al.*, 2010).

Annual descriptive statistics	Mean annual temperature SD of mean annual temperature Annual coefficient of variability Predictability (Colwell 1974) Annual range (mean) SD of annual range Annual coefficient of variability of range Summer range Winter range
Group 1 Monthly magnitudes (measure of central tendency)	Oct – Sept mean temperatures
Group 2 Magnitude and Duration of annual extreme water temperature conditions (Based on moving averages of different durations)	1, 3, 7, 30 & 90-day minima 1, 3, 7, 30 & 90-day maxima Degree days (annual/ monthly/ seasonal) Mean daily minimum Maximum diel range
Group 3 Timing - Julian date of maximum and minimum metrics (thermal triggers)	Date of minimum Date of maximum
Group 4 Frequency and duration (successive days of event above or below a threshold)	Min. temp threshold count & duration Max. temp threshold count & duration Duration between two temperatures (an upper and lower as determined either the temp data or biological cues)

3.3.4.1 Principal Component Analysis

Principal Component Analyses (PCA) are one of the more common (Jackson, 1993; Fore and Karr, 1996) and simple (Jackson, 1993) multivariate methods. PCAs were undertaken for temperature and flow data per site to obtain an understanding of how sites compare with each other. The software used to perform PCAs for the flow and temperature data was PC-ORD 4 (McCune and Mefford, 1999).

3.3.4.2 Canonical Correspondence Analysis

Canonical Correspondence Analysis (CCA – ter Braak, 1986) was used to relate the temporal species data per site to certain flow and temperature parameters. This analysis was performed using PC-ORD 4 (McCune and Mefford, 1999). This technique assisted in the recognition of how different metrics impact on macroinvertebrate communities. In this way, an indication of which environmental variables driving the various sites could be obtained.

3.3.4.3 Bray-Curtis

Bray-Curtis (1957) is an ordination technique to assess how dissimilar diversity is between sites or regions, where environmental data is used to ascertain how species distribution differs (Gauch, 1982). The Bray-Curtis statistic was used as the distance measure in the PC-ORD 4 software as a basis for performing the non-metric multidimensional scaling (NMS) ordination. Similarly, the Bray-Curtis dissimilarity index was used in the multivariate analyses performed using CANOCO software (ter Braak and Šmilauer, 1998), for example, a NMS was performed for sites using species data and the type of distance between the sites that was used was Bray-Curtis.

3.3.4.4 CANOCO software

CANOCO (ter Braak and Šmilauer, 1998) software was used for presenting the species data statistically and graphically, where NMS were performed using this software. The purpose of performing NMS was to identify dissimilarities between sites,

macroinvertebrate taxa and environmental data by the arrangement of points in a two-dimensional space (Cox and Cox, 2008).

3.4 Research Limitations

The scope of this research limited the timeframe for recording water temperature at the sites to one year. If the water temperature could have been recorded for a five year cycle (along with continuous water presence at all the sites), the data may reveal different results in the sense that one year may be an outlier year (for instance, in this study, where the study areas were under drought conditions especially for the later part of the sampling period). However, this would be particularly difficult to achieve, especially on a variable, non-perennial stream such as the Kowie/Bloukrans River.

The collection of macroinvertebrate data at the same sites on both rivers over a greater time span (two – three years) without any dry sites and fairly consistent flow may well have yielded different results. This may have yielded a more true reflection of how water temperature impacts upon macroinvertebrates, particularly due to the biotopes remaining constant throughout the research period. Biotope differences at the same position on both streams made the comparison of macroinvertebrate taxa difficult. This, however, would have been particularly difficult to achieve, especially on a non-perennial system like the Kowie/Bloukrans River. Drier conditions experienced along the streams resulted in reduced flows, resulting in changes to the macroinvertebrate biodiversity and biotopes. The waste water treatment works on the Kowie/Bloukrans was unfortunate, as tolerant taxa may have been the only macroinvertebrates present at this site (B3) due to poor water quality. Unfortunately the paired sites were not perfect, as site access was difficult due to insufficient roads, harsh vegetation and sheer slopes.

3.5 Conclusions

This research involved the collection of large amounts of data. Data had to be collated and statistically analysed to interpret into more meaningful values. This data is presented in the succeeding chapter.

CHAPTER 4 RESULTS

4.1 Flow analyses

4.1.1 IHA data analysis for observed flow

From the observed twelve years of raw flow data, low flow periods regularly occurred at both weirs, particularly on the Kowie/Bloukrans. Flow levels over the macroinvertebrate sampling period (June 2009 – April 2010, Figure 4.1) were significantly lower in comparison to the flow data for previous years. The abundance of the Keurbooms River peaks (perennial) was more prevalent compared to the Kowie/Bloukrans River peaks (non-perennial), experiencing no flow between January and April 2010 (Figure 4.1).

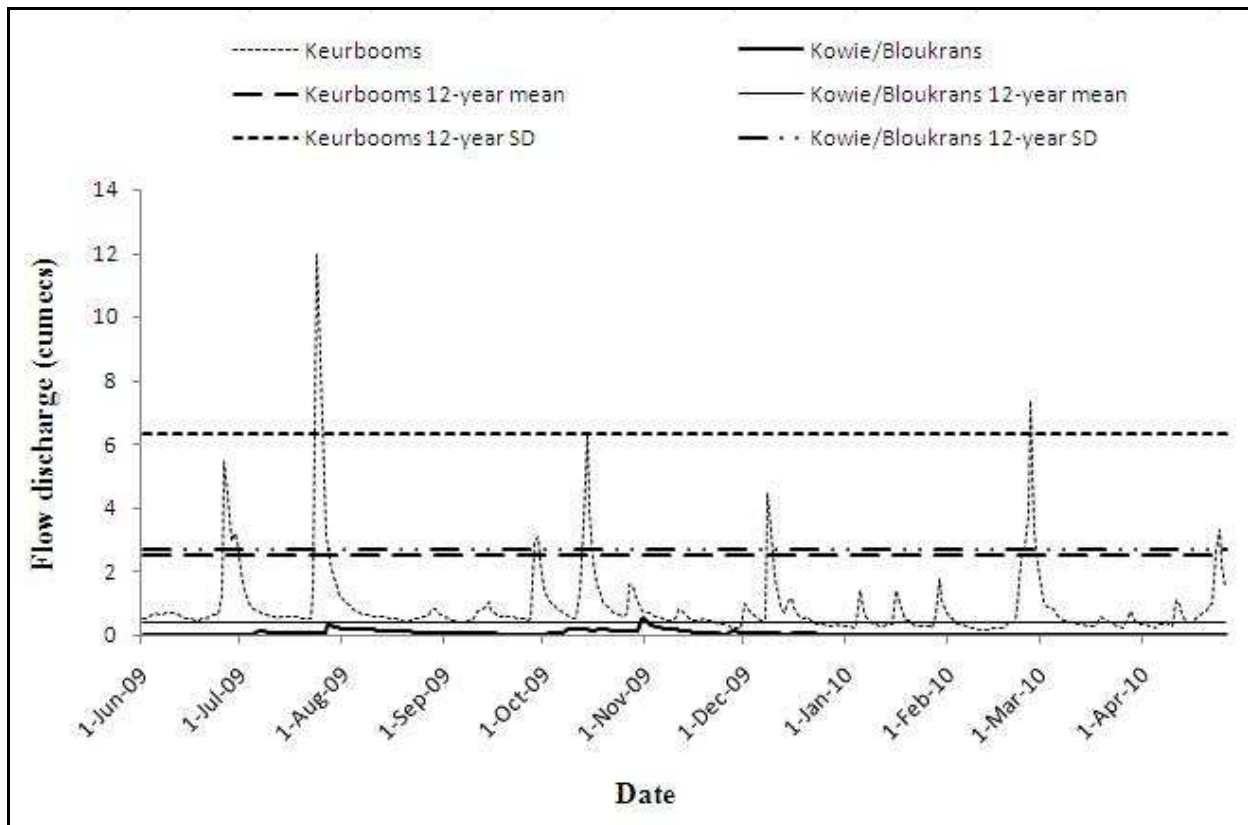


Figure 4.1: Gauging weir flow data for both rivers from the beginning of the sampling period (June 2009) to the end (April 2010). The mean and standard deviation (SD) lines are for the 12 year timeframe common to both streams.

The IHA analyses were performed for the same 12 years of data for both weirs to avoid bias. The Keurbooms River had more predictable (0.43) flows than the Kowie/Bloukrans River (0.33) (Table 4.1). A predictability value of 1 interprets the streamflow to be totally predictable, whereas a value of 0 indicates a totally unpredictable system. These results are interpreted by the categories in Table 2.1. Variables that indicate variability are shaded in grey; annual coefficient of variation (CV) is almost three times greater on the Kowie/Bloukrans than the Keurbooms, indicating a more variable system. Streams with a high base flow index are less variable than streams with a low base flow index (Hughes and Hannart, 2003), suggesting that the Kowie/Bloukrans is more variable than the Keurbooms.

Table 4.1: IHA results for the Keurbooms and Kowie/Bloukrans Rivers for observed flow data between 1998 and 2009² (shaded cells highlight the parameters which particularly demonstrate flow variability).

	Keurbooms River		Kowie/Bloukrans River	
Mean annual flow	2.53		0.40	
Annual CV	2.52		6.96	
Flow predictability	0.43		0.33	
Constancy/predictability	0.68		0.47	
Percentage of floods in 60 day period	0.29		0.33	
Flood-free season	37		82	
	Mean	CV	Mean	CV
Parameter Group number 1				
January	3.07	0.84	0.13	0.94
February	1.78	0.69	0.10	1.33
March	3.65	0.85	0.18	1.50
April	2.11	0.62	0.37	1.56
May	2.15	1.11	0.25	1.68
June	1.26	0.83	0.09	1.10
July	1.38	0.64	0.10	1.03
August	3.42	1.90	1.05	2.26

² 2009 was the latest year used for this analysis rather than 2010, as there was not a full years' flow data available at the time when this analysis was run (January to April 2010). The output values of the IHA software become skewed if a full year is not used, hence 2009 was used instead of 2010.

September	2.78	1.30	1.20	2.80
October	2.74	0.64	0.47	2.39
November	2.52	0.71	0.55	1.54
December	3.31	1.24	0.26	1.26
Parameter Group number 2				
1-day minimum	0.21	0.88	0.01	2.44
3-day minimum	0.23	0.84	0.01	2.22
7-day minimum	0.28	0.65	0.01	1.64
30-day minimum	0.46	0.47	0.01	1.35
90-day minimum	0.81	0.49	0.03	0.90
1-day maximum	58.34	0.66	16.75	1.88
3-day maximum	42.29	0.79	11.32	1.97
7-day maximum	24.64	0.80	6.37	1.80
30-day maximum	9.75	0.63	2.70	1.80
90-day maximum	5.24	0.49	1.24	1.60
Number of zero days	6.25	2.72	43.17	1.60
Base flow index	0.10	0.56	0.01	1.98
Parameter Group number 3				
Date of minimum	310.8	0.28	12.75	0.16
Date of maximum	295.0	0.26	88.25	0.31
Parameter Group number 4				
Low pulse count	9.08	0.37	3.58	0.44
Low pulse duration	9.55	0.43	19.76	0.96
High pulse count	6.50	0.36	1.25	1.19
High pulse duration	2.50	0.48	4.34	0.95
Low Pulse Threshold	0.63		0.01	
High Pulse Threshold	8.90		3.17	
Parameter Group number 5				
Rise rate	1.88	0.53	0.38	1.56
Fall rate	-0.73	-0.46	-0.12	-1.57
Number of reversals	89.58	0.14	63.92	0.25

4.1.2 IHA data analysis for simulated flow

The common timeframe overlap for both the observed and simulated flow was two years (1998 – 1999). Graphs were plotted for observed versus simulated streamflow for both streams (Figure 4.2 and Figure 4.3). The R^2 values were low for both systems, where a longer common timeframe or a calibration of the model used to simulate the flow data may have resulted in a higher R^2 value. The observed values were higher than the simulated values on the Keurbooms, and vice versa for the Kowie/Bloukrans. The main reason why simulated streamflow data was used rather than only observed is that each quinary catchment had simulated flow data, enabling the comparison of sites with stream systems to occur. Observed streamflow had one gauging weir on each stream, therefore, observed flow enabled easier stream comparisons, whereas simulated flow enabled easier site comparisons.

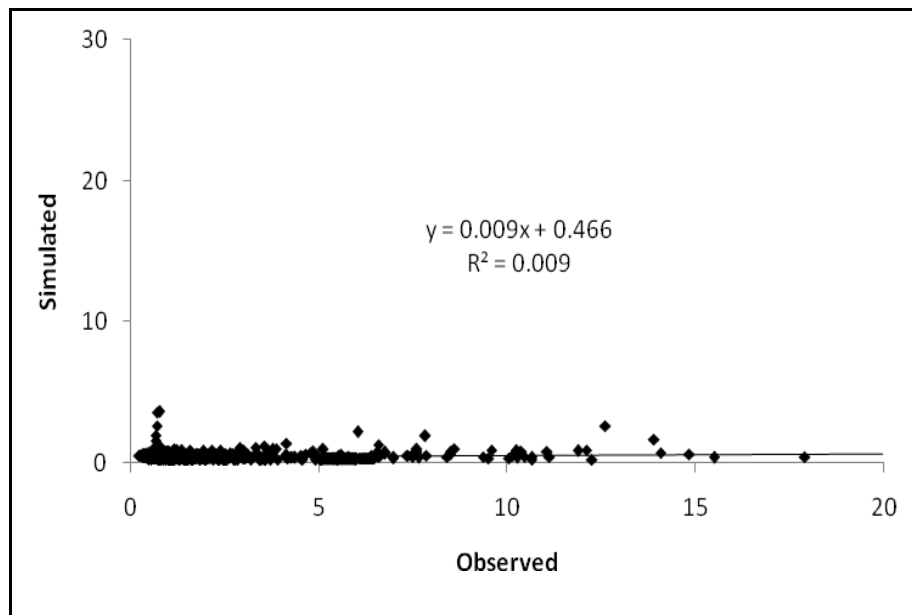


Figure 4.2: Simulated versus observed streamflow for the Keurbooms River (the simulated streamflow data was used from the quinary catchment in which the gauging weir was situated).

Simulated flow data for each quinary was run through the IHA software (Table 4.2). Results indicate similar trends for simulated flow data to the observed flow data, such

that the predictability values were higher for all the Keurbooms River quinaryes than the Kowie/Bloukrans Rivers quinaryes, albeit the differences were small (Table 4.2).

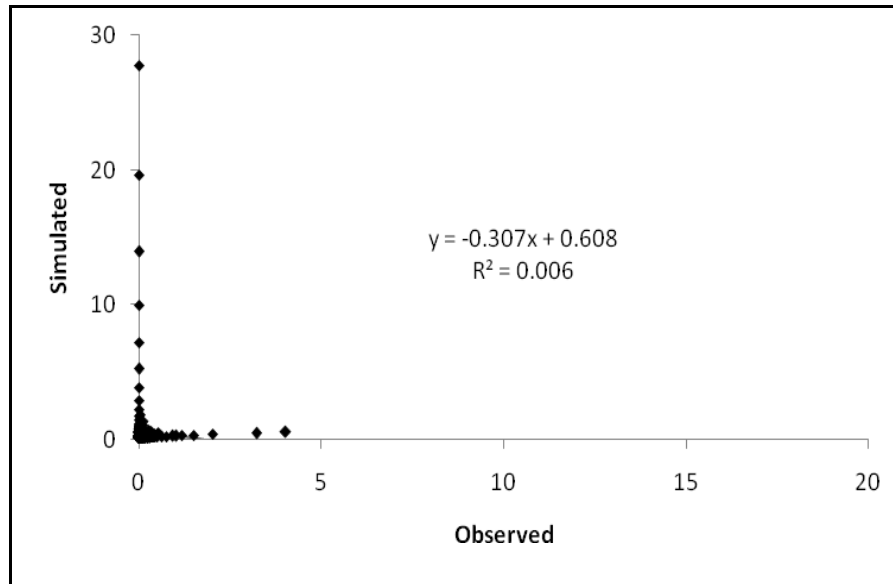


Figure 4.3: Simulated versus observed streamflow for the Kowie/Bloukrans River (the simulated streamflow data was used from the quinary catchment in which the gauging weir was situated).

4.1.3 Flow statistical data analysis

Not all the variables (first column in Table 4.2) were used in the statistical analysis, as several were repetitive, exhibiting high correlations with each other, for example, most of the monthly flow conditions yielded similar values (Parameter group number 1) and particular magnitude and duration of annual extreme water conditions parameters (Parameter group number 2). Only variables that were correlated ($> 80\%$) were used, which contribute towards the points in the PCA (Figure 4.4), where the corresponding eigenvectors are represented (Table 4.3). Variation on axis one was largely explained by mean annual flow, 30 day minimum and low threshold, clearly separating the two river systems from each other, primarily due to the Keurbooms being perennial and the Kowie/Bloukrans non-perennial. Variation on axis two was driven by flow predictability, low duration and high duration, indicating the Keurbooms is more predictable, where values increase progressively down the longitudinal profile, similarly for the Kowie/Bloukrans (indicated by arrows).

Table 4.2: IHA results for the Keurbooms and Kowie/Bloukrans River sites for simulated flow data between 1950 and 1999 (50 years). The values given for groups 1 – 5 are all means.

	K1	K2	K3	K4	K5	B1	B2	B3	B4	B5
Mean annual flow	0.39	0.62	1.09	1.69	3.39	0.32	0.60	0.94	1.58	2.70
Annual CV.	3.77	3.79	2.92	2.60	2.57	3.12	3.27	3.44	3.26	3.25
Flow predictability	0.31	0.31	0.35	0.36	0.37	0.28	0.29	0.29	0.29	0.30
Constancy/ predictability	0.86	0.86	0.87	0.86	0.84	0.90	0.90	0.90	0.87	0.86
Percentage of floods in 60 day period	0.29	0.29	0.29	0.31	0.3	0.28	0.29	0.29	0.27	0.25
Flood-free season	28	28	14	12	13	36	37	33	21	14
Parameter Group number 1										
January	0.26	0.41	0.69	1.10	2.01	0.32	0.59	0.88	1.31	2.10
February	0.19	0.30	0.56	0.94	1.91	0.21	0.38	0.57	0.97	1.57
March	0.20	0.32	0.63	1.03	1.93	0.33	0.66	1.03	2.03	3.21
April	0.26	0.41	0.78	1.23	2.41	0.31	0.59	0.87	1.46	2.34
May	0.37	0.59	1.06	1.62	3.01	0.32	0.63	0.98	1.73	2.99
June	0.69	1.10	1.58	2.14	3.55	0.23	0.42	0.66	1.17	2.21
July	0.41	0.65	1.11	1.62	3.56	0.34	0.67	1.11	1.64	2.81
August	0.57	0.90	1.47	2.13	4.57	0.31	0.57	0.94	1.39	2.47
September	0.53	0.84	1.66	2.70	6.13	0.29	0.53	0.86	1.73	3.38
October	0.44	0.71	1.35	2.21	4.80	0.33	0.59	0.95	1.66	2.95
November	0.48	0.76	1.31	2.06	4.03	0.36	0.65	1.01	1.69	2.94
December	0.30	0.48	0.88	1.45	2.72	0.49	0.91	1.37	2.08	3.40
Parameter Group number 2										
1-day minimum	0.08	0.13	0.25	0.39	0.75	0.06	0.12	0.19	0.32	0.53
3-day minimum	0.08	0.13	0.25	0.40	0.75	0.06	0.12	0.19	0.32	0.54

7-day minimum	0.08	0.13	0.25	0.40	0.76	0.06	0.12	0.19	0.32	0.54
30-day minimum	0.09	0.14	0.27	0.44	0.83	0.07	0.13	0.21	0.36	0.60
90-day minimum	0.12	0.19	0.36	0.58	1.12	0.09	0.18	0.28	0.49	0.83
1-day maximum	7.86	12.74	19.81	28.63	60.51	7.13	14.23	23.60	41.37	70.83
3-day maximum	6.21	10.06	15.62	22.60	48.04	5.47	10.88	18.00	31.73	54.30
7-day maximum	4.29	6.91	10.82	15.80	33.24	3.68	7.27	11.91	20.72	35.09
30-day maximum	1.78	2.84	4.65	7.04	14.20	1.47	2.82	4.44	7.45	12.49
90-day maximum	0.92	1.46	2.49	3.81	7.74	0.81	1.54	2.40	3.97	6.67
Number of zero days	0	0	0	0	0	0	0	0	0	0
Base flow index	0.32	0.32	0.33	0.33	0.31	0.29	0.31	0.31	0.31	0.30
Parameter Group number 3										
Date of minimum	269.1	269.1	268.4	278.4	208.2	311.4	306.5	310.2	300.4	299.1
Date of maximum	199.8	199.7	198.7	274.2	198	61.88	61.74	62.24	64.36	80.08
Parameter Group number 4										
Low pulse count	1.00	0.98	1.30	1.38	1.72	0.70	0.82	0.86	1.04	1.08
Low pulse duration	95.65	100.50	85.48	76.11	51.04	144.00	117.10	118.20	100.20	96.43
High pulse count	1.36	1.36	1.68	1.76	1.92	1.34	1.30	1.38	1.72	1.78
High pulse duration	5.34	5.22	6.06	7.51	6.79	9.40	9.25	8.01	6.85	6.67
Low Pulse Threshold	0.09	0.14	0.29	0.44	0.91	0.06	0.11	0.17	0.29	0.48
High Pulse Threshold	1.88	2.99	4.27	6.08	12.08	1.32	2.58	4.17	6.72	11.50
Parameter Group number 5										
Rise rate	1.03	1.73	2.35	3.34	6.48	1.31	2.79	4.09	5.96	9.68
Fall rate	-0.04	-0.06	-0.09	-0.14	-0.29	-0.03	-0.06	-0.10	-0.18	-0.30
Number of reversals	12.32	12.04	14.98	15.78	17.68	9.46	9.10	10.00	12.88	13.52

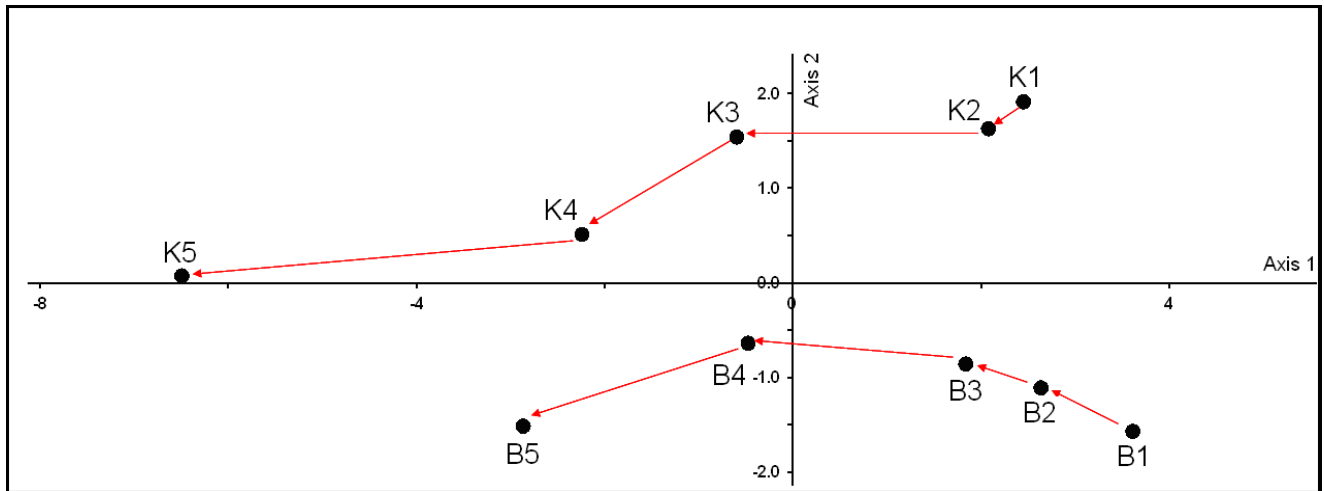


Figure 4.4: PCA of simulated flow data with sites. Axis one accounts for 74.9 % of the data, whereas axis two accounts for 13.5 %. Associated dendrogram in Appendix B. Arrows connect the sites as one progresses from highest to lowest.

Table 4.3: Eigenvectors of the flow parameters from axes one and two that contributed towards the PCA. Shaded cells contributed to the distribution of points in Figure 4.4 the most.

	Axis one	Axis two
Cum. Variance	74.9	88.4
Mean Flow	-0.3225	-0.1590
Annual CV	0.2348	0.1549
Flow Pred	-0.2456	0.4114
January	-0.2953	-0.2927
30 day Min	-0.3280	-0.1204
30 day Max	-0.3158	-0.1917
Low Count	-0.3026	0.2855
Low Durat	0.2872	-0.3728
High Count	-0.3173	-0.0118
High Durat	0.0855	-0.6218
Low Thresh	-0.3278	-0.0324
High Thresh	-0.3108	-0.1905

4.2 Temperature analyses

The cumulative mean temperature for each site over a single year yielded expected results, such that the sites at higher altitude have lower degree day values (K1 and B1), whereas sites at lower altitudes had greater values (K5 and B5; Figure 4.5). All sites corresponding to each other on both rivers had similar total cumulative degree day values, except the highest sites on both rivers. This may be attributed to the differences in altitude (Table 3.1) and the reason why B1 was selected as an equivalent headwater site at a lower altitude than what would have been the headwater site in the town of Grahamstown.

4.2.1 ITA data-related criteria regarding predictability values

The predictability results infer that both river systems are predictable, where all ten sites fell between 0.6 and 0.7 (Table 4.4). The duration of the recorded data and the amount of classes that temperatures are partitioned into may have affected the calculated values (Gordon *et al.*, 2004). In this case, the duration was a single year owing to the scope of this research, resulting in the high values; it has been suggested that 10 – 20 years is a sufficient duration for measures to be stable (Esterby 1996), whereas other authors suggest 40 years (Gan *et al.*, 1991; cited in Gordon *et al.*, 2004).

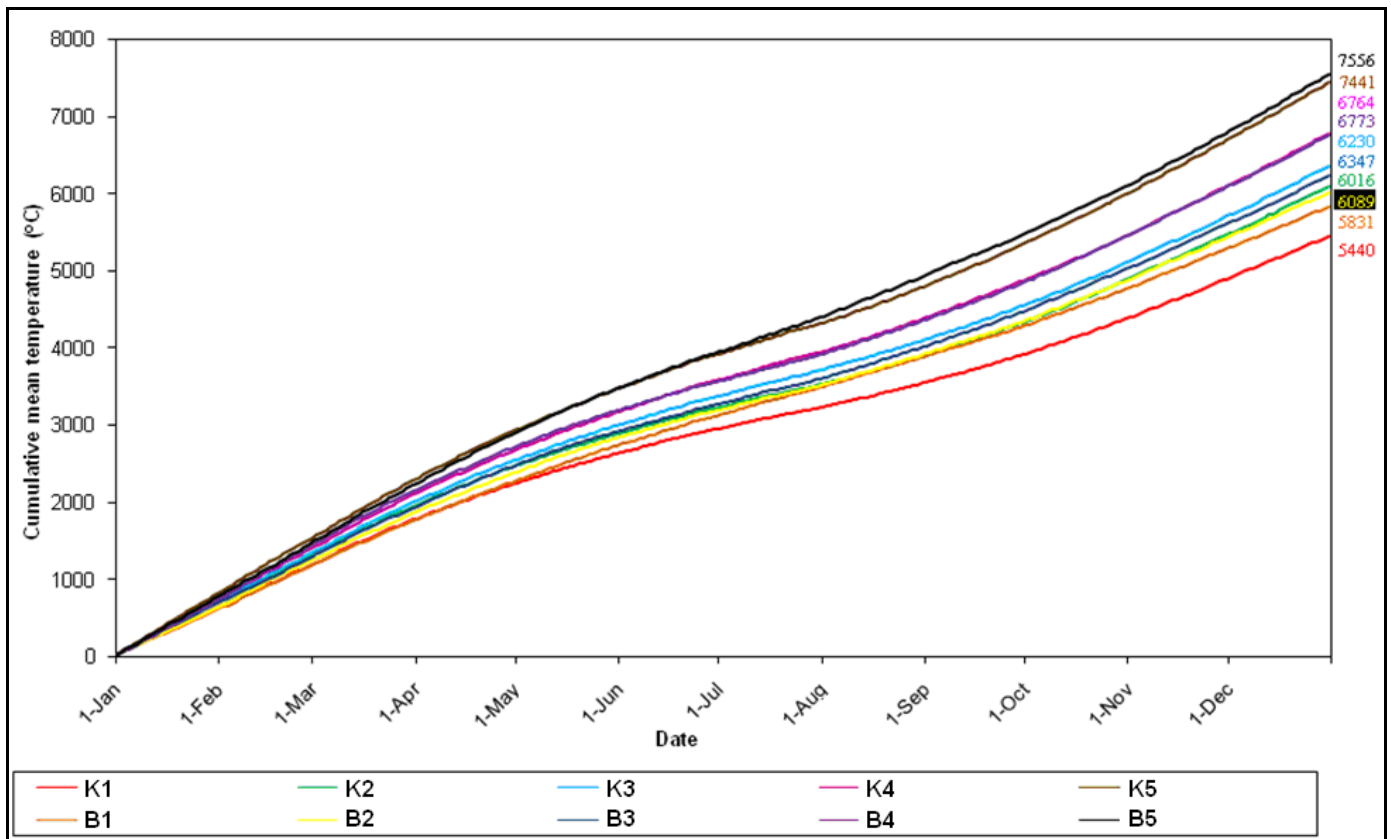


Figure 4.5: Cumulative mean temperature degree days for the duration of a year (2009-2010) for each site. Site names in the legend are arranged to correspond to each site on each river, i.e. K1 and B1 are the uppermost sites on the Keurbooms and Kowie/Bloukrans Rivers respectively. These corresponding sites have similar degree day values for a yearly period. Degree day values are displayed to the right of the graph, colour-coded according to the site.

Table 4.4: ITA results for the Keurbooms and Kowie/Bloukrans River sites for temperature for one years' cycle. The values given for Groups 1 are all means.

	K1	K2	K3	K4	K5	B1	B2	B3	B4	B5
Mean annual temp.	14.91	16.68	17.37	18.53	20.35	15.95	16.46	17.05	18.51	20.65
Annual SD	4.02	4.47	4.23	4.21	4.56	2.98	3.65	4.00	4.60	3.89
Annual CV	26.99	26.81	24.34	22.72	22.39	18.67	22.18	23.45	24.83	18.85
Predictability	0.63	0.60	0.63	0.65	0.64	0.68	0.69	0.66	0.64	0.63
Annual range	22.52	24.69	22.56	19.07	19.9	15.15	17.34	19.80	23.64	23.89
Range SD	3.95	4.41	4.17	4.15	4.5	2.91	3.59	3.94	4.55	3.80
Range CV	17.55	17.88	18.51	21.78	22.6	19.19	20.71	19.91	19.23	15.93
Range summer	6.65	6.55	6.3	5.94	6.57	7.26	6.65	7.13	9.37	5.49
Range winter	5.06	6.43	5.76	7.16	7.66	5.03	5.85	5.91	6.80	6.41
Degree days	5440.1	6089.3	6347.2	6773.7	7441.4	5831.2	6016.3	6230.1	6763.9	7555.7
Parameter Group number 1										
January	19.92	22.11	22.72	23.67	26.13	19.24	20.40	21.99	23.36	24.82
February	19.88	21.83	22.20	23.38	25.41	20.32	21.51	21.22	25.17	24.75
March	19.04	20.73	21.43	22.71	24.62	19.03	20.08	20.89	23.19	24.56
April	15.61	17.41	18.11	19.12	21.21	16.96	17.30	18.05	18.82	22.24
May	12.55	13.42	14.64	15.93	17.46	14.96	14.70	14.30	15.31	18.82
June	10.68	11.26	12.41	13.83	14.99	12.92	11.82	11.77	12.47	15.61
July	9.04	9.91	11.15	11.69	12.81	11.86	10.49	10.65	11.30	14.64
August	10.13	11.73	12.40	14.07	15.47	12.76	12.94	13.33	14.23	17.15
September	12.25	14.63	15.01	16.44	18.51	13.18	14.31	15.36	16.31	18.18
October	14.97	17.70	17.87	18.68	20.74	15.69	17.05	17.71	19.57	20.44
November	17.23	19.47	20.02	21.54	23.35	17.42	18.83	19.50	21.34	22.99
December	17.93	20.38	21.05	22.01	24.32	17.69	18.73	20.33	21.78	24.47

Mean spring	14.81	17.27	17.64	18.88	20.86	15.43	16.74	17.53	19.08	20.54
Mean summer	19.22	21.43	21.98	23.01	25.28	19.04	20.17	21.18	23.38	24.68
Mean autumn	15.73	17.18	18.06	19.25	21.1	16.98	17.36	17.75	19.11	21.87
Mean winter	9.94	10.96	11.98	13.19	14.42	12.51	11.75	11.92	12.67	15.80
Parameter Group number 2										
1-day minimum	5.92	5.18	6.56	8.93	8.99	9.21	7.14	8.37	8.69	7.32
3-day minimum	6.26	5.73	6.70	9.00	9.23	9.76	7.98	8.70	8.74	8.73
7-day minimum	6.69	6.14	7.97	9.58	9.80	10.16	8.59	9.06	9.72	9.95
30-day minimum	7.64	7.95	9.21	11.33	11.49	11.14	9.56	9.95	10.44	11.18
90-day minimum	8.58	9.45	10.34	12.76	11.49	11.80	11.05	11.04	11.89	12.98
1-day maximum	28.44	29.87	29.12	28.00	28.89	24.36	24.48	28.17	32.33	31.20
3-day maximum	20.48	23.02	23.26	25.02	26.49	21.45	22.75	22.47	26.10	24.40
7-day maximum	19.69	22.25	22.67	24.39	25.94	20.83	22.21	22.23	25.31	23.34
30-day maximum	18.05	20.54	21.02	22.82	25.11	19.51	20.88	21.38	23.30	22.28
90-day maximum	17.52	19.83	20.57	22.43	24.34	18.78	19.96	20.37	22.28	22.25
Parameter Group number 3										
Date of minimum	199	199	208	207	208	180	204	199	182	181
Date of maximum	40	58	13	13	13	40	40	26	40	26
Parameter Group number 4										
Minimum Temp count	146	120	85	27	21	51	69	74	42	27
Maximum Temp count	164	213	220	229	263	142	167	198	219	320
Minimum Temp duration	101	55	19	11	11	17	38	38	18	5
Maximum Temp duration	82	175	186	192	241	89	125	121	193	194

There is a trend for parameter group number 4 (Table 4.4), where maximum counts and durations increase from high to low altitudes for both rivers, whereas minimum counts and durations decrease in value from higher to lower altitudes for the Keurbooms, but not Kowie/Bloukrans, which is highest at the middle site and lower at the upper and lower sites.

4.2.2 Temperature statistical data analysis

Similarly to flow, not all the temperature variables (first column in Table 4.4) were used in the statistical analysis. The PCA (Figure 4.6) illustrates how the sites vary from one another across the two river systems and in between sites, where Table 4.5 represents the eigenvectors for the various parameters. The trends for temperature were not as clear as the trends for flow, where a clear division was delineated by the first axis. From the eigenvectors (Table 4.5), deductions can be made that the major drivers of variability on axis one are annual temperature (mean), degree days, and mean spring and summer temperatures. Within the PCA (Figure 4.6), the temperatures increase as one moves from right to left, increasing with decreasing altitude along the longitudinal gradient (depicted by the arrows). Variability on axis two was explained by annual standard deviation, coefficient of variation, predictability, annual range and the standard deviation of the range. Two of the major drivers are annual range and the related range coefficient of variation, where range increases from top (B1 having the least range of 15.15 – Table 4.4) to bottom (K2 having the greatest range of 24.69 – Table 4.4).

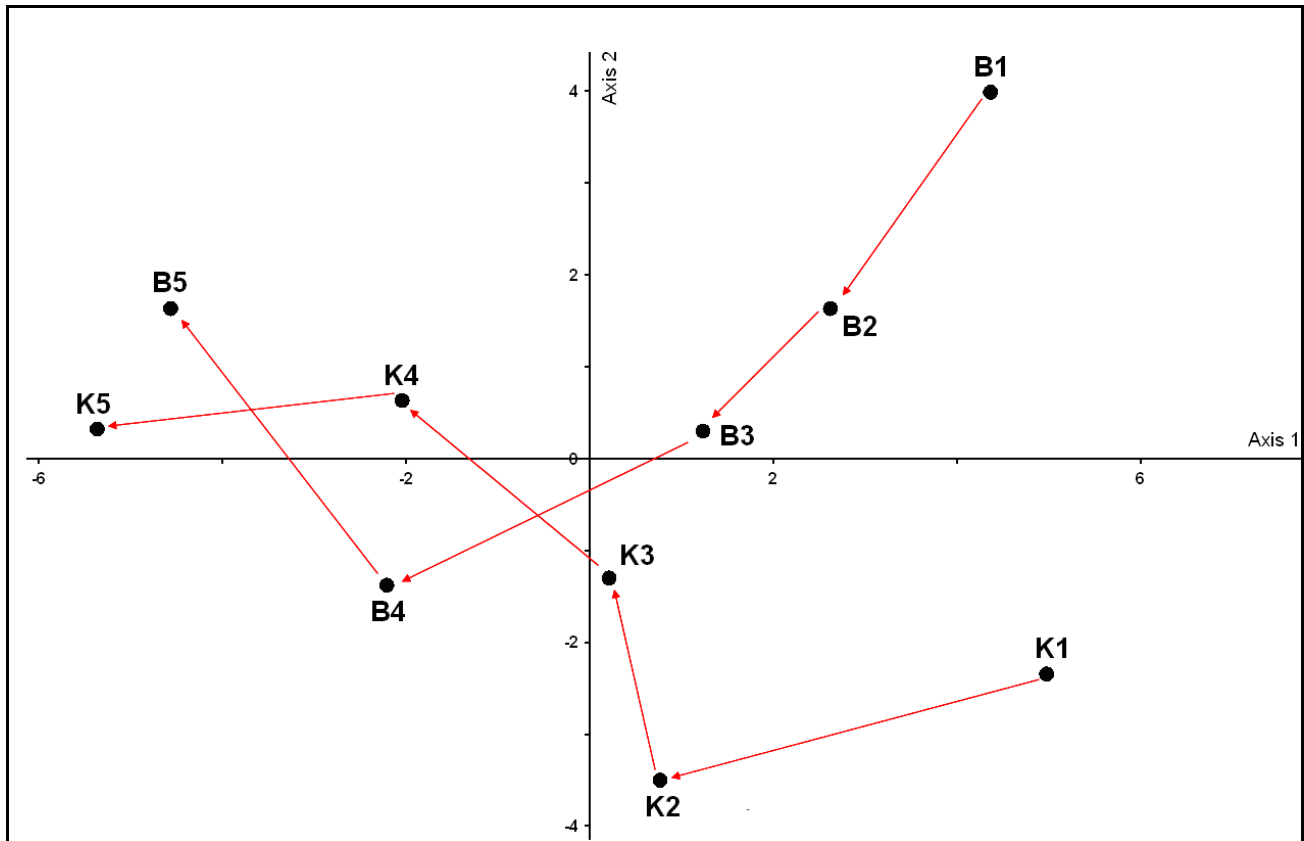


Figure 4.6: PCA of temperature data with sites. Axis one accounts for 65.7 % of the data, whereas axis two accounts for 25.4 %. Associated dendrogram in Appendix B. Arrows connect the sites as one progresses from highest to lowest altitude.

4.3 Water Quality data

The main trends from the water quality data revealed that for all the variables measured, there was a general increase from the headwater sites to the lower-most sites for both streams (Appendix C). Water quality variables did not differ greatly between seasons.

4.3.1 Water quality statistical data

To enable certain water quality variables to contribute towards the PCA, avoiding skewness or bias, values were log-transformed to reduce the range of the values. For example, the maximum and minimum conductivity values across all seasons were 44 700 and 37.4 $\mu\text{S}/\text{cm}$ respectively. When log-transformed, these values are calculated to be

Table 4.5: Eigenvectors of the temperature parameters from axis one and two that contributed towards the PCA (Figure 4.6). Shaded cells contributed to the distribution of points in Figure 4.6 the most.

	Axis one	Axis two
Cum. Variance	65.70	91.10
Annual Temp	-0.2931	0.0845
Annual SD	-0.1771	-0.3675
Annual CV	0.0708	-0.4516
Predictability	0.0978	0.3834
Annual Range	-0.1062	-0.3813
Range SD	-0.1748	-0.3677
Range Winter	-0.2657	-0.0653
Degree days	-0.2928	0.0866
November	-0.2985	0.0123
Mean Spring	-0.2976	0.0269
Mean Summer	-0.2983	-0.0264
Mean Autumn	-0.2852	0.1217
Mean Winter	-0.2474	0.2470
30 Day Min	-0.1817	0.3540
30 Day Max	-0.2741	0.0475
Max Count	-0.2728	-0.0304
Max Duration	-0.2798	-0.0929

4.65 and 1.57, reducing the range between maximum and minimum significantly. The variables that were log-transformed included depth, width, total dissolved solids and conductivity. The trend in the PCA (Figure 4.7) is for the logDEPTH, logWIDTH, logTDS and logCOND³ water quality variables to increase in value progressively downstream for both rivers (differs in a spatial context), whereas TEMP (reference temperature for pH, conductivity and total dissolved solids) differs seasonally (temporal context). Distribution of the points is supported by the eigenvectors (Table 4.6). Within the same sample site, the further the points are from one another (creating larger polygons), the greater the seasonal variation (for example, K2), whereas the closer the points are together, less variance occurred (K3). The way in which these polygons are distributed vertically and horizontally are explained by the variables (arrows in Figure 4.7).

³ The B5 conductivity values used in this PCA were from the estuary site to ensure consistency, as measurements were not taken at the freshwater site for winter (Appendix C).

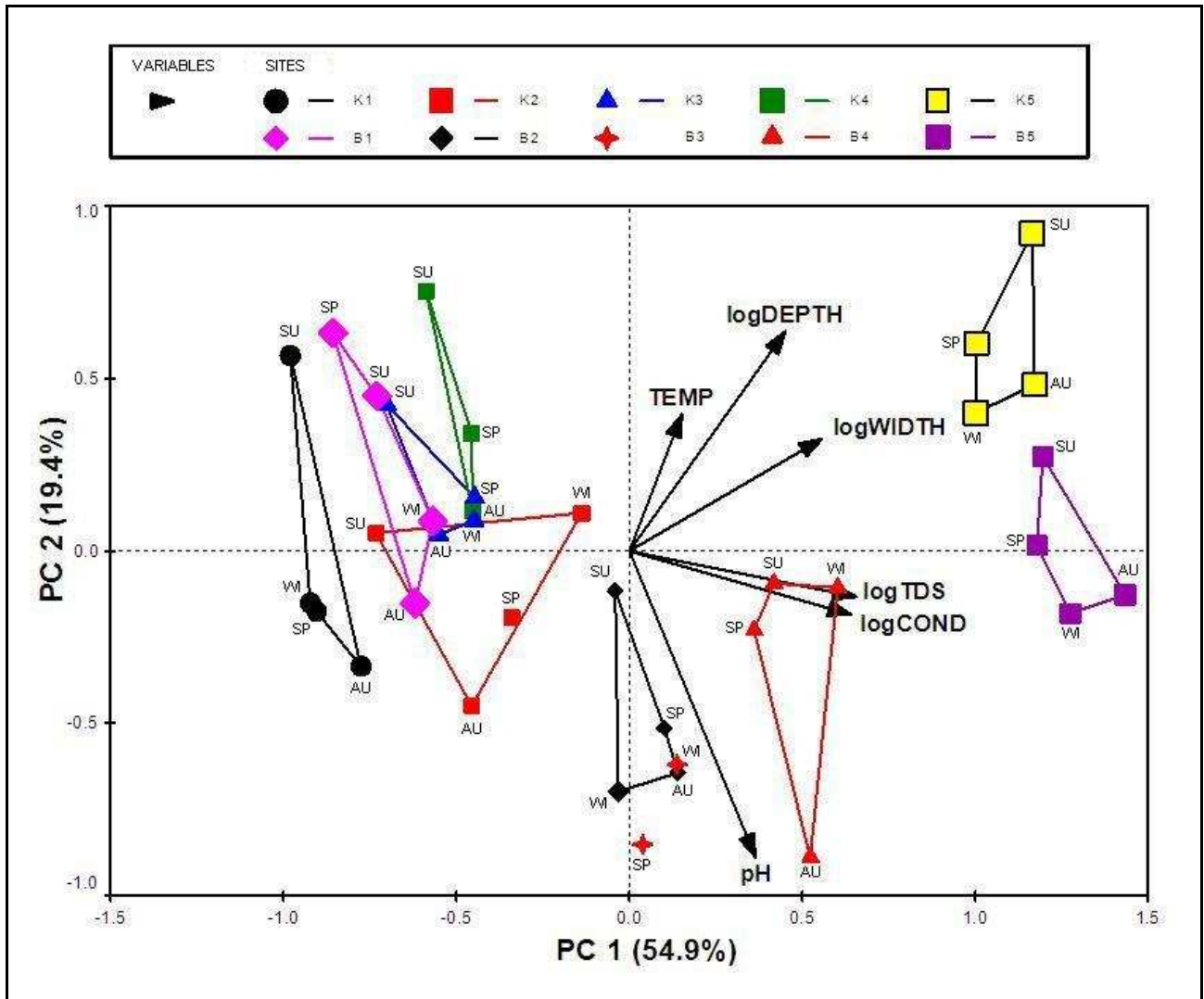


Figure 4.7: PCA of all the water quality parameters for all seasons for each site, where certain parameters were log-transformed to reduce amount of outliers. This PCA was produced using CANOCO software (ter Braak and Šmilauer, 1998). Axis one accounts for 54.9 % of the data, whereas axis two accounts for 19.4 %. Season abbreviations are as follows: SU = summer; AU = autumn, WI = winter; SP = spring.

Table 4.6: Eigenvectors of the water quality variables from axis one and two that contributed towards the PCA (Figure 4.7).

	Axis one	Axis two
Cum. Variance	54.89	74.26
pH	0.2961	-0.7227
logTDS	0.5332	-0.1080
logCond	0.5214	-0.1502
logDepth	0.3676	0.5160
logWidth	0.4535	0.2636
RefTemp	0.1240	0.3282

4.4 Macroinvertebrate data

A total of 32 394 specimens from 67 different families were identified and counted (Table 4.7). The Keurbooms River had more macroinvertebrate taxa than the Kowie/Bloukrans, primarily as a result of better flows for the duration of this research. A total of 73 and 61 taxa (ranging between family and species level of identification) were recorded on the Keurbooms and Kowie/Bloukrans rivers respectively. Sites with a higher number of biotopes generally yielded more taxa compared to sites with a single biotope. Seasonal taxa for sites are represented in Appendix D⁴.

4.4.1 Seasonal pattern of taxa

The taxon richness (total macroinvertebrate taxa at a site) per season with downstream distance for the Keurbooms River provides a clear trend for each season and the totals per site, where there is an increase towards the middle reaches, thereafter a tapering off of species towards the lower reaches of the river (Figure 4.8). This is a similar trend to what Vannote *et al.* (1980) describes. Interestingly, an inverse trend was found for the Kowie/Bloukrans River, where there was greater taxon richness at the upper and lower sites and a lower diversity at the middle sites (Figure 4.9). The middle site (B3) was dry for the summer and autumn seasons, thus no macroinvertebrates were present. The site higher up from this one (B2) is situated approximately six kilometres downstream of a sewerage works, thus only taxa resilient to the moderately polluted water were found.

⁴ The K4 site was not sampled in winter due to adverse weather conditions.

Table 4.7: Pooled macroinvertebrate data from all seasons for all sites. Detailed seasonal macroinvertebrate data available in Appendix D.

GROUP/ORDER	FAMILY	GENUS/SPECIES	K1	K2	K3	K4	K5	B1	B2	B3	B4	B5	TOTAL
Amphipoda	Paramelitidae sp.1						88					116	204
	Paramelitidae sp.2						1158					390	1548
	Sternophysingidae											22	22
Mollusca (Basommatophora)	Lymnaeidae			4	1								5
Mollusca (Caenogastropoda)	Littorinidae											9	9
Coleoptera	Dytiscidae			4	1			13				1	19
	Elmidae		186	4	6	18		4		4		1	223
	Gyrinidae		15	28	7	1		16					67
	Hydraenidae		4	12							1		17
	Hydrophilinae							1			5	71	77
	Ptilodactylidae					1							1
	Scirtidae		1					4					5
Decapoda	Atyidae											19	19
	Palaemonidae					1	2					1	4
	Potamonautidae						8	4	5		3	14	34
Diptera	Ceratopogonidae		3	8	7	4	1	1			15	34	73
	Chironomidae		203	339	575	258	34	299	1924	80	686	116	4514
	Culicidae			32	5			7			27	38	109
	Dixidae							1					1
	Forcipomyiinae							1					1
	Muscidae				1								1
	Simuliidae	<i>S (Meilloniellum)</i>		5									5

		<i>S (M) hargreavesi</i>	23	5	5457	880							6365
		<i>S (P) alcocki</i>				5							5
		<i>S (P) bequaerti</i>	388		200	985							1573
		<i>S (P) harrisoni</i>	270										270
		<i>S (P) merops</i>				30							30
		<i>S. (Nevermania) sp.</i>				170		32					202
		<i>Simulium nigrিতarse</i>	36	44	965				1830	1475	23		4373
	Stratiomyidae											2	2
	Tabanidae				2								2
	Tipulidae				279			1					280
Ephemeroptera	Baetidae	<i>Afroptilum sudafricanum</i>	38		97			59	639	1020	155		2008
		<i>Baetis harrisoni</i>	147	9	651	37			204				1048
		<i>Centroptiloides bifasciata</i>			6	1							7
		<i>Cloeon sp.</i>	39	25	2			2			760	292	1120
		<i>Demoreptus rapensis</i>	109	86									195
		<i>Demoulinia crassi</i>	2	14	6			1			12		35
		<i>Pseudocloen vinosum</i>	139	34	383	152		12	6				726
		<i>Pseudopannota sp.</i>			197	35							232
	Caenidae	<i>Caenis sp.</i>	18	11	14			19	10		448		520
	Heptageniidae	<i>Afronurus sp.</i>	31					103		58	1		193
	Leptophlebiidae	<i>Adenophlebia sp.</i>			89	15							104
		<i>Choroiterpes nigrescens</i>									22		22
		<i>Euthraulius elegans</i>		8	40	26							74
		<i>Lestagella penicillata</i>	5										5
	Teloganodidae	<i>Nadinetella sp.</i> (unidentifiable species)	4										4
Hemiptera	Belostomatidae				1	1						2	4

	Corixidae		8					6			3	17	
	Gerridae		1	9	2			8	4		28	52	
	Mesoveliidae							1			2	3	
	Naucoridae			3	6			7				16	
	Notonectidae			32	6			8			5	51	
	Pleidae									52		52	
	Veliidae			5	34		1			6	19	65	
Isopoda	Anthuridae										6	6	
	Sphaeromatidae						76				249	325	
Lepidoptera	Nymphulinae			1	1							2	
Megaloptera	Corydalidae		9	5	12	2						28	
Mollusca (Mytiloidea)	Mytilidae						2724				16	2740	
Odonata (Anisoptera)	Aeshnidae			3	5	1		7			15	31	
	Corduliidae			3	4	1						8	
	Gomphidae			26	90							116	
	Libellulidae		4	13	23	1		3		2	37	83	
Odonata (Zygoptera)	Chlorocyphidae					1						1	
	Coenagrionidae			3	22			11		1	66	103	
	Lestidae			2				9	2			13	
	Platycnemididae							1	1			2	
	Protoneuridae							3				3	
Oligocheata							157				101	258	
Plecoptera	Notonemouridae	<i>Aphanicercella sp 1</i>	23					3				26	
		<i>Aphanicercella sp 2</i>			1							1	
		<i>Desmonemoura sp.</i>	6									6	
	Perlidae	<i>Neoperla sp.</i>				1						1	
Mollusca (Pulmonata)	Ancylidae								57	10	316	8	391

	Physidae										1	26	27
	Planorbidae											7	7
Trichoptera	Ecnomidae	<i>Ecnomus thomasseti</i>						1			13		14
	Glossosomatidae	<i>Agapetus agilis</i>	4										4
	Hydropsychidae	<i>Cheumatopsyche afra</i>			688	3		2	116	68			877
		<i>Cheumatopsyche type 2</i>			31	66							97
		<i>Cheumatopsyche type 7</i>	66	2	7			1					76
		<i>Hydropsyche longifura</i>			72	49							121
		<i>Macrostemum capense</i>			1								1
	Hydroptilidae	<i>Hydroptila cruciata</i>				22							22
	Leptoceridae	<i>Athripsodes sp.</i>			10								10
		<i>Athripsodes bagensis</i>	21			14							35
		<i>Leptocerus sp.</i>										78	78
		<i>Oecetis sp.</i>	4			30		4					38
	Philopotamidae	<i>Chimarra sp.</i>	6		4	60							70
	Pisuliidae	<i>Pisulia sp.</i>						6					6
	Sericostomatidae	<i>Cheimacheramus caudalis</i>						5					5
Turbellaria	Rhabdozoa				5				125	13	3		146
Mollusca (Veneroida:Sphaeriacea)	Sphaeriidae											3	3
TOTAL TAXA			31	31	44	31	10	37	13	8	21	33	94

A further reason for low taxon richness at the B2 site was that there was only one biotope present (stones-in-current), where it was assumed that if another biotope were present, the diversity may have been higher.

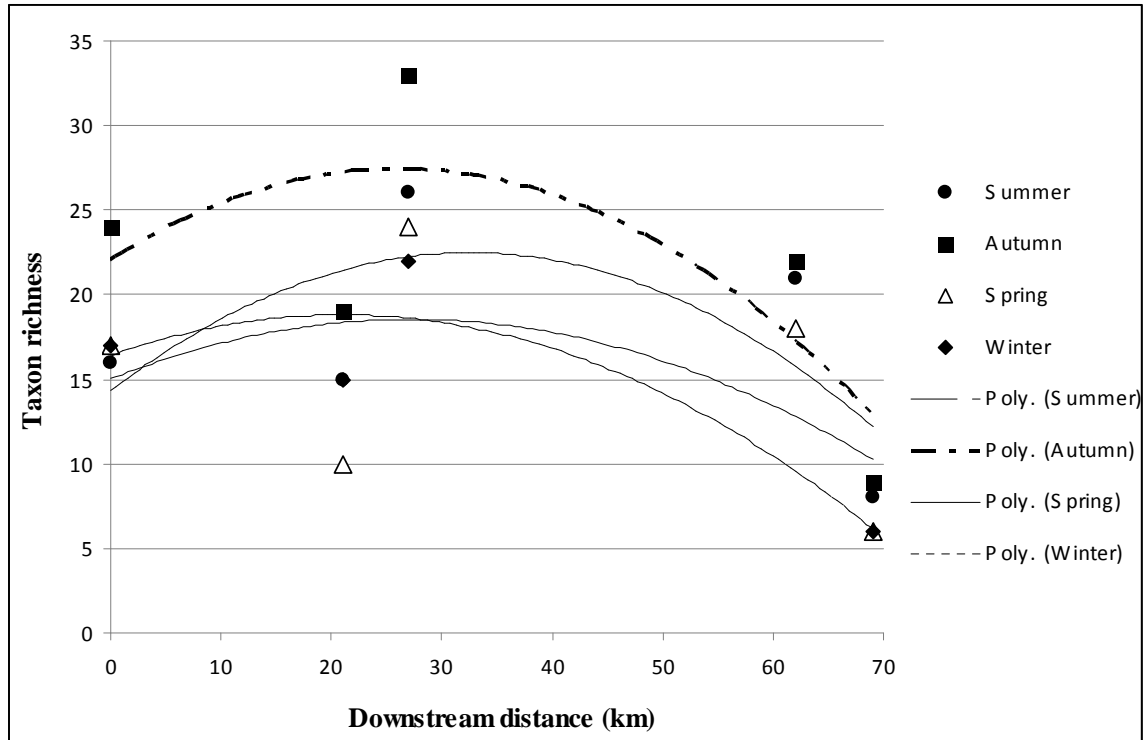


Figure 4.8: Taxon richness with downstream distance for the Keurbooms River per season (Polynomial trendlines are of the 2nd order).

The total macroinvertebrate richness from all seasons and each stream system is represented (Figure 4.10), obtained from the total taxa in the last row of the pooled macroinvertebrate data (Table 4.7). This exhibits similar trends to the graphs for each stream per season (Figure 4.8 and 4.9).

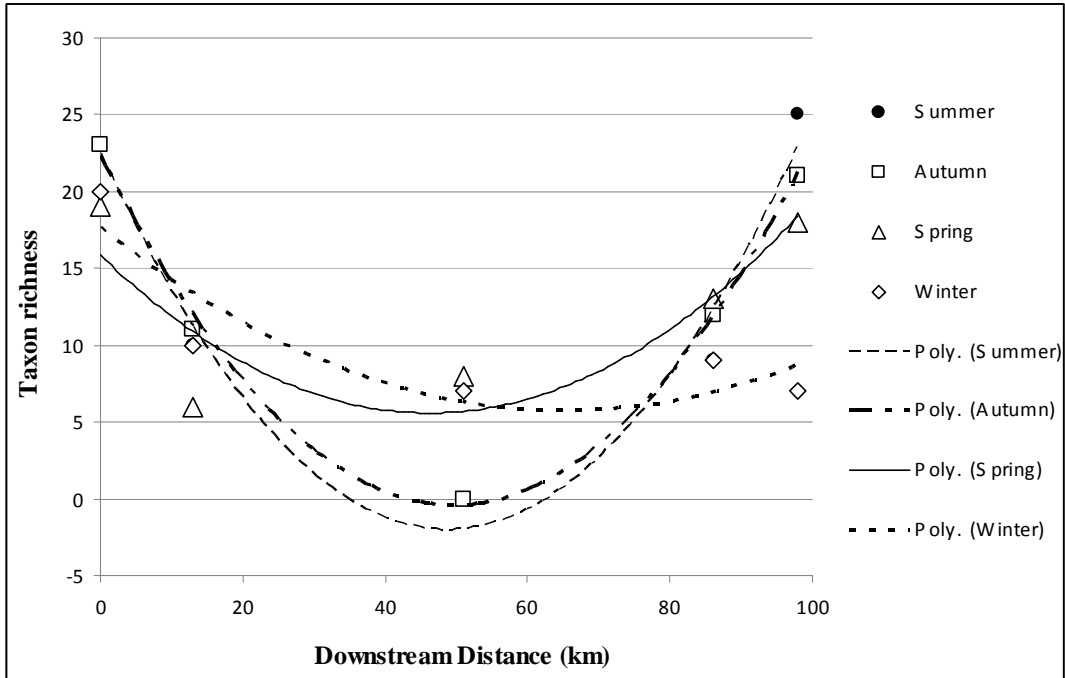


Figure 4.9: Taxon richness with downstream distance for the Bloukrans/Kowie River per season (Polynomial trendlines are of the 2nd order).

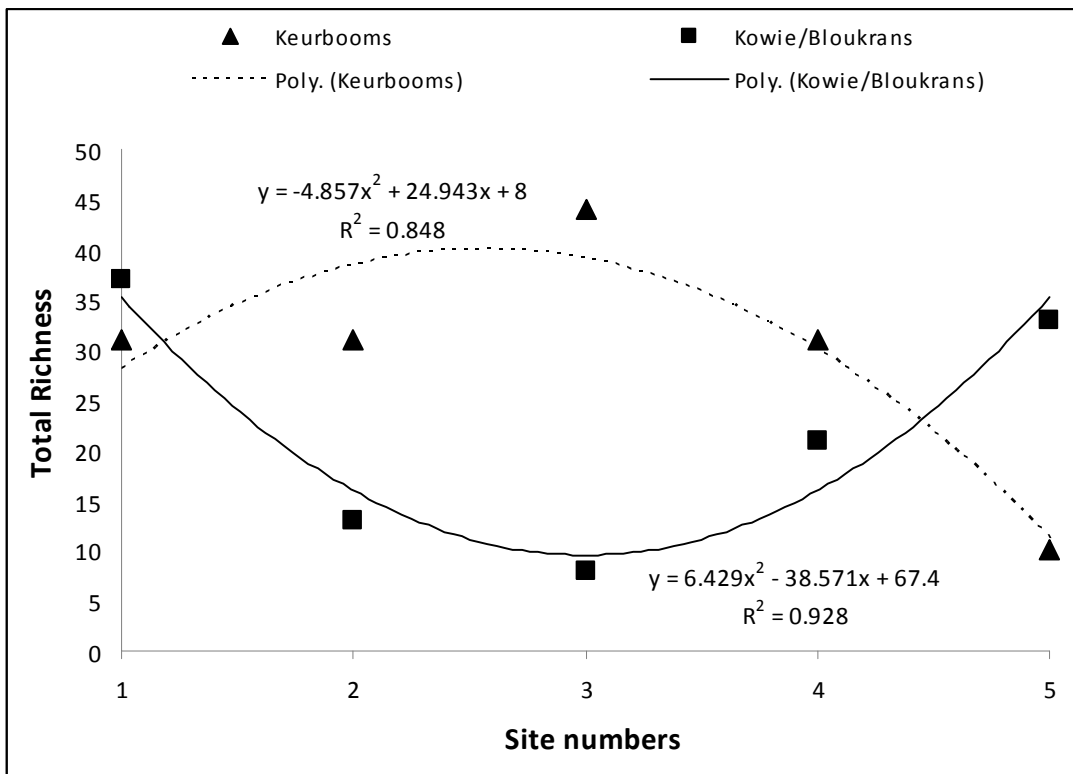


Figure 4.10: Total macroinvertebrate richness for all seasons for both rivers (Polynomial trendlines are of the 2nd order).

Sørensen's similarity indices between site pairs did not yield clear trends (Table 4.8). For the upper-most sites, the macroinvertebrate taxa progressively increased in similarity from winter to autumn. This trend was not evident for any of the other paired sites. The sites sharing the highest similarity were the lowest paired sites, with an average of 55.9 % over all four seasons. The three middle sites exhibited lower average similarity values than the upper- and lower- most sites.

Table 4.8: Sørensen's similarity indices, comparing sites situated at similar positions along both stream longitudinal gradients. N/A means that the similarity value was not available.

	K1 and B1	K2 and B2	K3 and B3	K4 and B4	K5 and B5
winter	21.6%	24.0%	27.6%	N/A	76.9%
spring	22.2%	25.0%	31.3%	6.5%	41.7%
summer	35.9%	24.0%	N/A	19.4%	47.1%
autumn	46.8%	20.0%	N/A	11.8%	58.1%
AVERAGE	31.6%	23.3%	29.4%	12.5%	55.9%

In a similar way that Vannote *et al.* (1980) describe their trends comparable to the trend in Figure 4.8, a related trend was found for stream order for both streams (Figure 4.11). Taxon richness values showed distinct seasonal trends, where for both of the streams, lowest taxon richness was recorded for winter (where daily water temperature range was lowest) and thereafter increasing towards autumn, where the highest taxon richness was recorded (Table 4.9), except on the Kowie/Bloukrans River from summer to autumn, decreasing by one taxon. These values were calculated by summing all the individual taxon richness values for sites in a season (Total taxa at the bottom of each seasonal table in Appendix D).

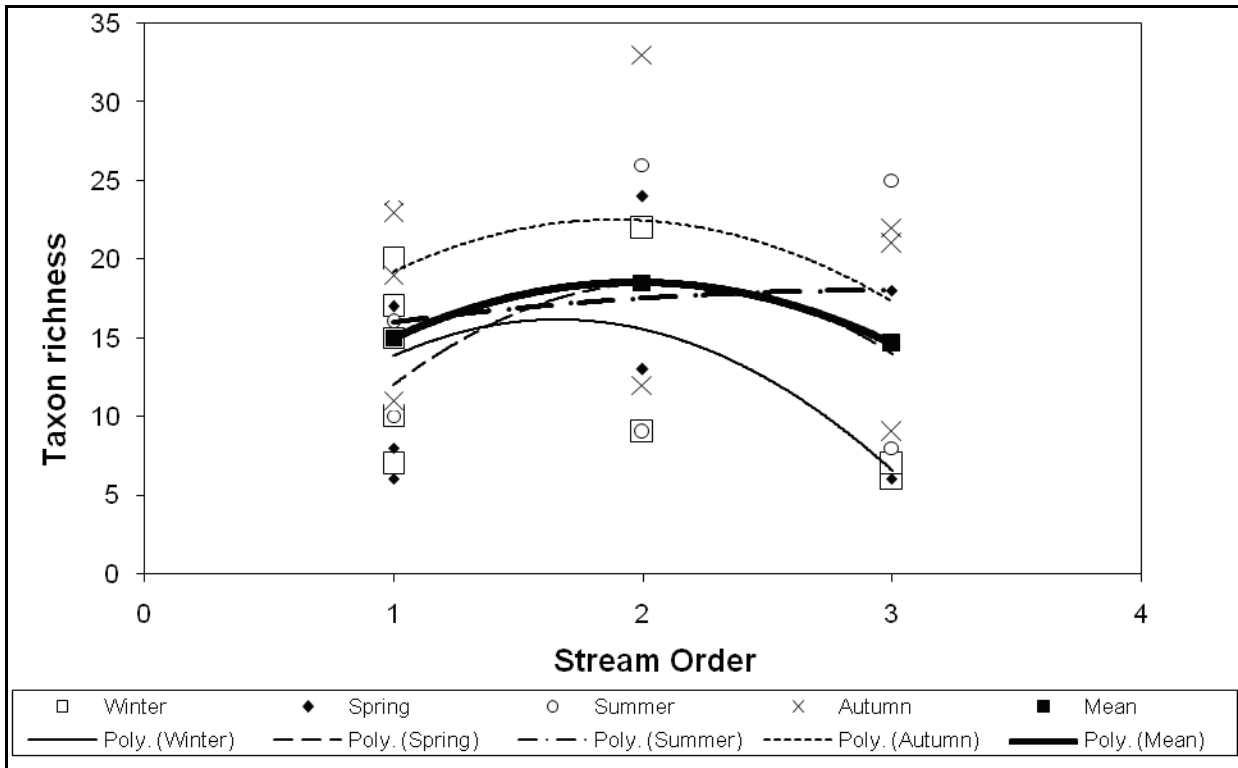


Figure 4.11: Taxon richness per stream order per season for both the Keurbooms and Kowie/Bloukrans Rivers. The mean was calculated by summing all the taxon richness values for each stream order, then dividing that value by the number of individual stream orders. Polynomial trendlines are of the 2nd order.

Table 4.9: Total taxon richness for all sites per season for the Keurbooms and Kowie/Bloukrans Rivers.

Season	Winter	Spring	Summer	Autumn
Keurbooms Taxon Richness	60	75	86	107
Kowie/Bloukrans Taxon Richness	53	64	69	68

4.4.2 Functional feeding groups in relation to the River Continuum Concept

Certain functional feeding group (FFGs) similarities were evident, both on a temporal and spatial basis, on both streams. A full list of the FFG's assigned to most of the macroinvertebrates in this study are at the end of this thesis (Appendix E).

A temporal and spatial shift in FFGs was evident at several sites over the duration of this research, particularly spatially (Appendix D). Similar to the River Continuum Concept (Vannote *et al.*, 1980), macroinvertebrate community structure varied spatially along the longitudinal profile. Where riparian vegetation was abundant in the upper reaches, Notonemouridae shredders were present for all seasons at the highest site (K1) on the Keurbooms River, and only one season (autumn) at the highest site (B1) on the Kowie/Bloukrans (Appendix D). Pisuliidae shredders were found at B1 for all seasons except winter (Appendix D). Other shredders that were at the upper-most sites were Elmidae (especially at K1) and Leptoceridae (Appendix D).

Similar results to the River Continuum Concept were those of collector-gatherers, where many different Ephemeropteran species were found in the headwaters of both streams for all seasons. In terms of taxa abundance, the lowest FFG contribution at headwater sites were predators and grazers, particularly Odonata (opportunistic predators), Hemiptera (predators), Gyridae (Predators), Leptoceridae and Notonemouridae (with certain genera belonging to the grazer FFG).

The middle sites of both streams were dominated by the collector and grazer FFGs, particularly in the form of Simuliidae (collector-filterers), Chironomidae (collector-gatherers and scrapers; although Chironomidae were present throughout both stream profiles, highest numbers were recorded at the three middle sites), several Ephemeropterans, mostly Baetidae genera (most Ephemeropterans are described as collector-gatherers or grazers, where others are collector-filterers and few are predatory) and Trichoptera, primarily Hydropsychidae (both collectors and predators). These high abundances of collector and grazer FFGs are similar to the River Continuum Concept,

where the predator minority occurred mostly as Odonata and Hemiptera taxa. This trend was more apparent on the Keurbooms River, attributed to the continuous water supply.

Lower-most sites on both streams, analogous to the River Continuum Concept, largely comprised collectors. This included families from the orders Amphipoda and Isopoda, where most species are described as detritus feeders (detritivores) or scavengers. Mytilidae (Mollusca) were also present in high abundances, categorized as collector-filterers, along with Oligochaeta making up collector-gatherer numbers. Few Odonata and Hemiptera predators were present, particularly in still waters on the Kowie/Bloukrans River. The collector FFG abundances were high for these lower-most sites due to the amount of sediment on the river-bed due to reduced flow velocity.

The FFG taxa on both streams were similar to one another, including the River Continuum Concept.

4.4.3 Generalist versus specialist taxa

The Keurbooms and Kowie/Bloukrans generalist and specialist macroinvertebrate taxa were assigned values based on their spatial and temporal distribution (Table 4.10 and Table 4.11). The information from these tables was used to generate graphs (Figure 4.12 and 4.13).

From the percentage presence at one site for one season, i.e. specialists (Figure 4.12 and Figure 4.13), it is evident that the Keurbooms River yielded more taxa than the Kowie/Bloukrans River, with values of 23.3 % and 19.7 % respectively. Similarly, 27.4 % of the taxa on the Keurbooms River were present for one season compared to 23 % on the Kowie/Bloukrans. Conversely, the total presence values over all four seasons from all five sites were greater on the Kowie/Bloukrans than the Keurbooms, with values of 34.4 % and 32.9 % respectively.

Table 4. 10: Keurbooms River assigned values of generalist and specialist taxa, determined by spatial and temporal distribution.

	1 Site	2 Sites	3 Sites	4 Sites	5 Sites
1 Season	23.3%	4.1%			
2 Seasons	1.4%	9.6%	6.8%	1.4%	
3 Seasons	6.8%	6.8%	5.5%		1.4%
4 Seasons	11.0%	8.2%	4.1%	8.2%	1.4%

Table 4.11: Kowie/Bloukrans River assigned values of generalist and specialist taxa, determined by spatial and temporal distribution.

	1 Site	2 Sites	3 Sites	4 Sites	5 Sites
1 Season	19.7%	3.3%			
2 Seasons	11.5%	4.9%	8.2%		
3 Seasons	11.5%	3.3%	3.3%		
4 Seasons	9.8%	8.2%	9.8%	4.9%	1.6%

For the streams, sites and seasons, certain taxa were more abundant than others, where a single taxon may have been present at one site for only one season (for example, *Macrostemum capense*) and others were found at all sites on both rivers for all seasons (Chironomidae). A summary of this data was compressed into a single graph for each stream system. In this way, one obtains an idea of the specialists, with a single occurrence, and the generalists, which had several occurrences across seasons (Figure 4.12 contains this data for the Keurbooms River and Figure 4.13 for the Kowie/Bloukrans River). Two seasons were not sampled at the B3 site on the Kowie/Bloukrans River due to the absence of water. This missing data may affect the graph, as seven out of eight of the taxa were present for both seasons sampled. Thus, these two seasons contribute largely to the two seasons category in the graph (Figure 4.13), where it may have been possible for these taxa to spread over three or four seasons across more sites, classifying them further into the generalists category.

The Keurbooms (Figure 4.12) had more specialist taxa (present for one season) and the Kowie/Bloukrans (Figure 4.13) had more generalist taxa (present for four seasons). The trend evident for both streams is that taxa numbers decrease from the one site category to-

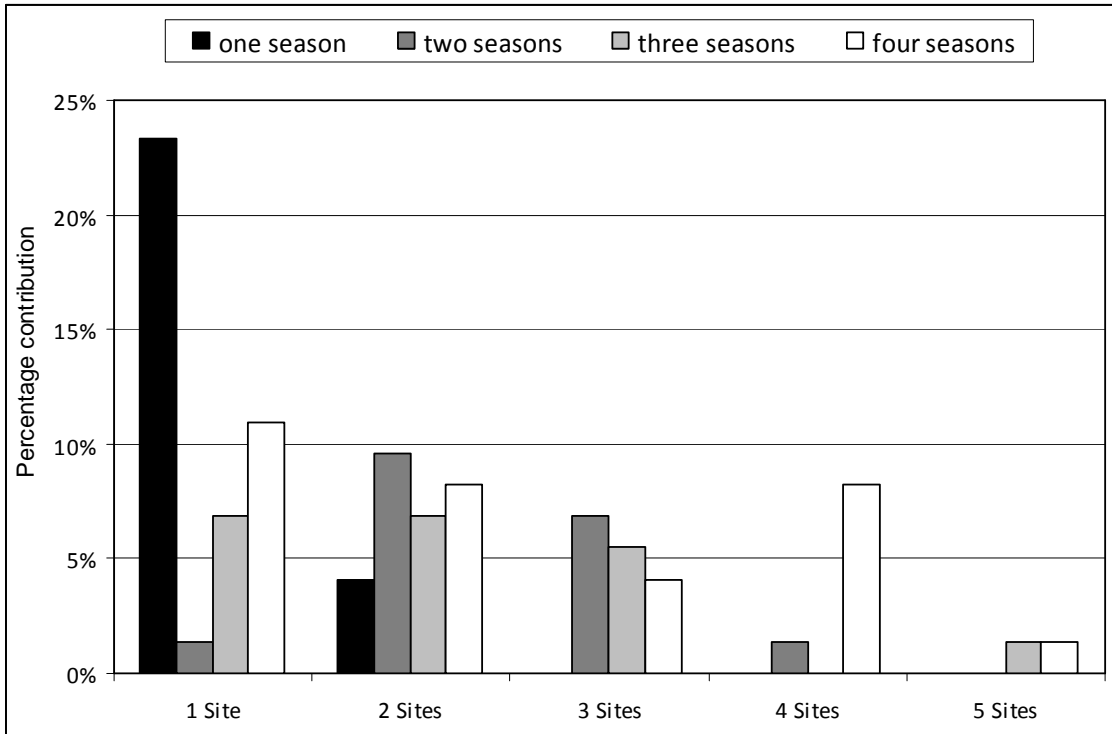


Figure 4.12: Percentage of taxa present on the Keurbooms River across number of seasons and sites.

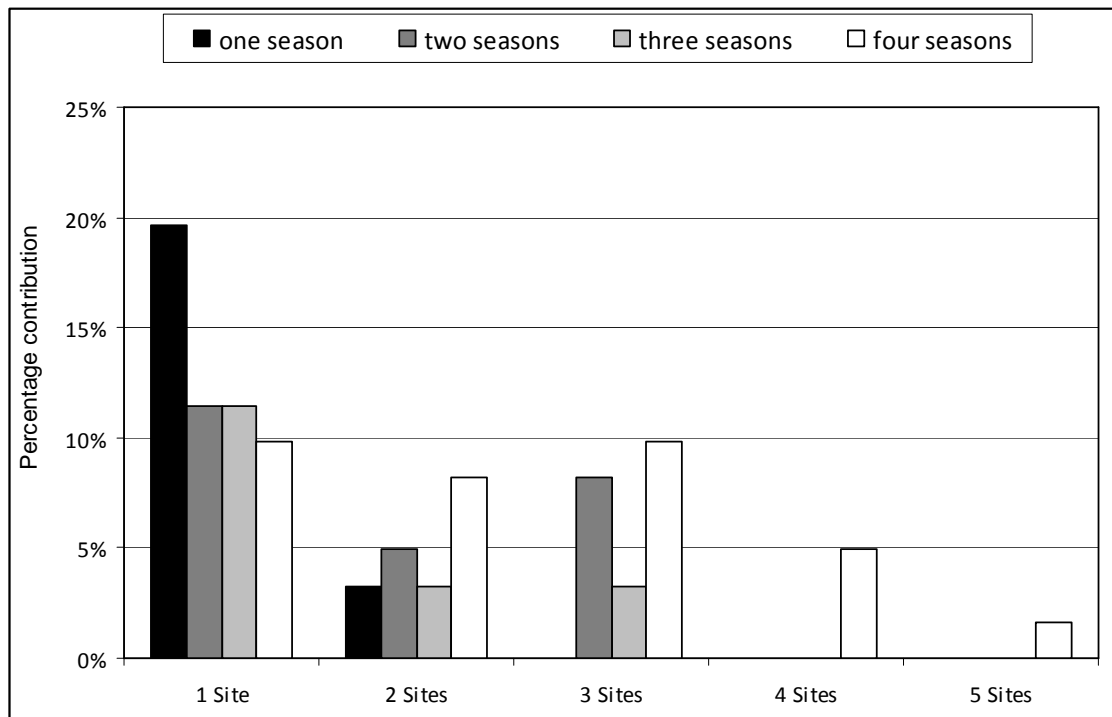


Figure 4.13: Percentage of taxa present on the Kowie/Bloukrans River across number of seasons and sites.

wards the five sites category. Furthermore, for both the four and five sites categories on both streams, taxa were present primarily for all four seasons. The reduced flow over the duration of this research on the Kowie/Bloukrans (and to a lesser extent, the Keurbooms) altered certain biotopes, especially from stones-in-current to stones-out-of-current. This may have masked certain taxa and introduced others.

4.4.4 Macroinvertebrate association with predictability values

The water temperature predictability values were plotted against macroinvertebrate coefficient of variation (CV) values (Figure 4.14), calculated using Equation 8. A trend for CV to decrease with increasing predictability values was evident for both streams, more so for the Keurbooms ($R^2 = 0.698$) than the Kowie/Bloukrans ($R^2 = 0.296$).

Water temperature predictability was plotted against stream order to determine how predictability changed with longitudinal stream gradient (Figure 4.15). The two streams were opposite, such that temperature predictability increased with increasing stream order for the Keurbooms ($R^2 = 0.642$) but decreased for the Kowie/Bloukrans ($R^2 = 0.769$), similar to the findings of Rivers-Moore *et al.* (2008c). Their findings were decreasing water temperature predictability values with increasing stream order on the Sabie River.

The first graph (Figure 4.14) indicated how macroinvertebrate turnover varies with water temperature predictability, where the second graph (Figure 4.15) indicated how water temperature predictability varies with stream order. These graphs were created in order to get an indication of the whereabouts on the stream where the water temperature predictability was highest and lowest and to see how seasonal macroinvertebrate turnover was linked to predictability values. For example, in Figure 4.15, a site on the Keurbooms had a water temperature predictability value of 0.6 on a first order stream; in Figure 4.14, this site has the highest seasonal turnover, with a macroinvertebrate CV value of 0.25. This indicates that seasonal macroinvertebrate turnover on this stream was greatest on a first order stream with a low water temperature predictability.

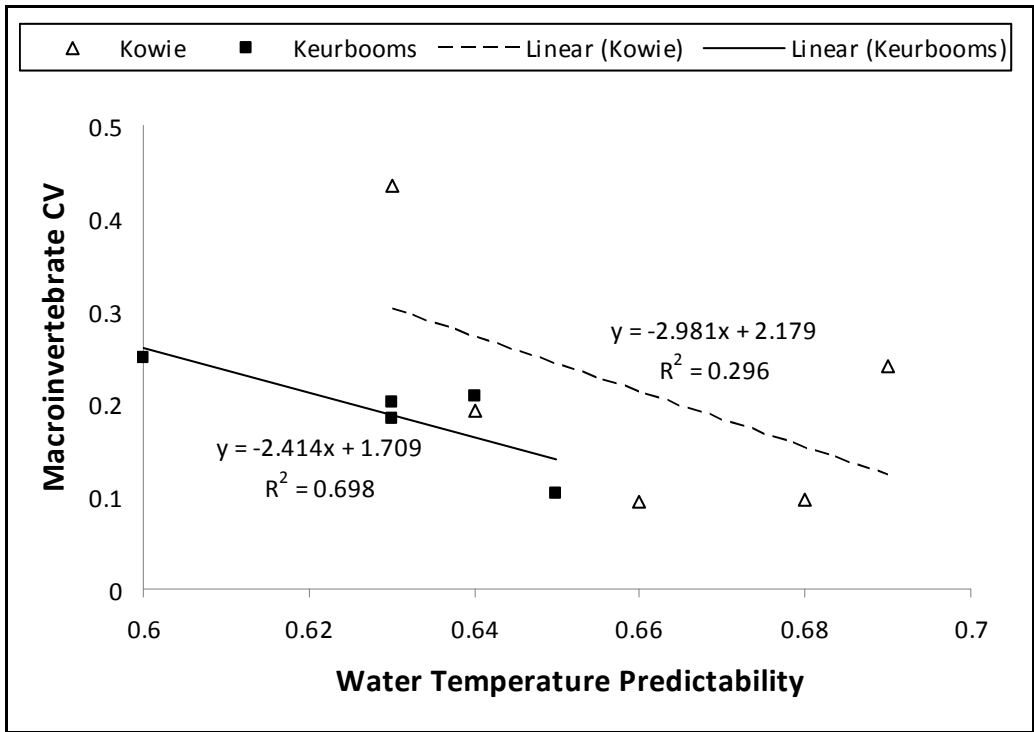


Figure 4.14: Water temperature predictability values plotted against macroinvertebrate coefficient of variation (CV) for each stream system

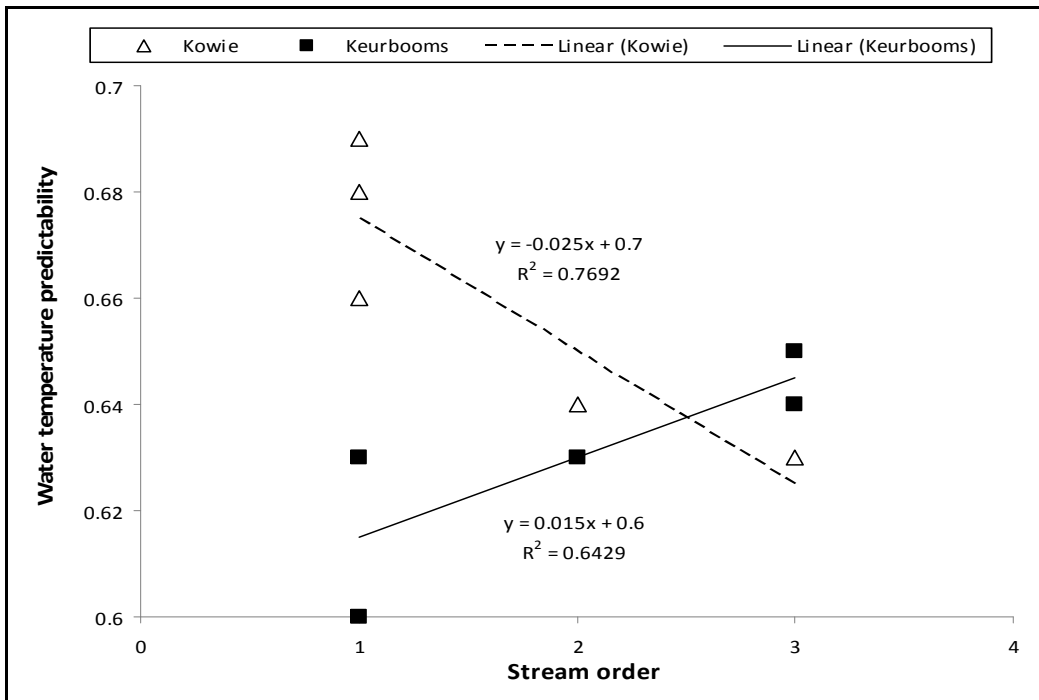


Figure 4.15: Water temperature predictability plotted against stream order, with corresponding trendline for each stream.

4.4.5 Macroinvertebrate distribution

One of the main issues that were to be addressed with regards to water temperature influencing the taxa was to identify which temperature variables (range, CV, and others) were the main drivers at the various sites. Non-metric multidimensional scaling (NMS) was used to determine how species abundance data varied across sites and between the two streams. This NMS ordination was performed to identify which taxa were dominant at which sites, using only those taxa that had a correlation of 0.7 or more (Figure 4.16 and Appendix F). This NMS (Figure 4.16) indicates similarity amongst the top four sites on the Keurbooms, as all these sites are grouped close to each other. However, the lower-most site was different to the other four sites. On the Kowie/Keurbooms, sites differ more, as the sites are distributed further apart from one another. B2 and B3 have the most similar macroinvertebrate taxa, with six out of fifteen taxa common to both sites.

Certain taxa had a higher presence at particular sites, especially the lower-most sites on both rivers, where only certain taxa were found at the lowest sites on both streams. These included: Mytilidae, Oligochaeta, Paramelitidae sp.1 and Paramelitidae sp. 2. This could be predominantly due to higher salinity levels, motionless waters and the gravel/sand/mud biotope at the lower-most sites, suiting these taxa only. The low correlations in Appendix F are indicated by the short arrows, compared to the long arrows for correlations of 0.7 and above.

Several environmental variables appeared to be driving the highly corresponding taxa, particularly at the lower-most sites (Figure 4.17). The environmental parameters driving the downstream sites at B5 and K5 are partially due to these sites having the warmest temperatures (DegreDay, AnnuTemp), highest flows (MeanFlow), deepest (LogDepth) and widest (LogWidth) streams and the highest conductivity readings (LogCond). Temperature variability (AnnTemCV and AnualRng) was the main driver for the K1, K2 and K3 sites, whereas temperature predictability (TempPred) drives B1, B2 and B3. The associated axis one and two values for this NMS are situated below Figure 4.17 (Table 4.12).

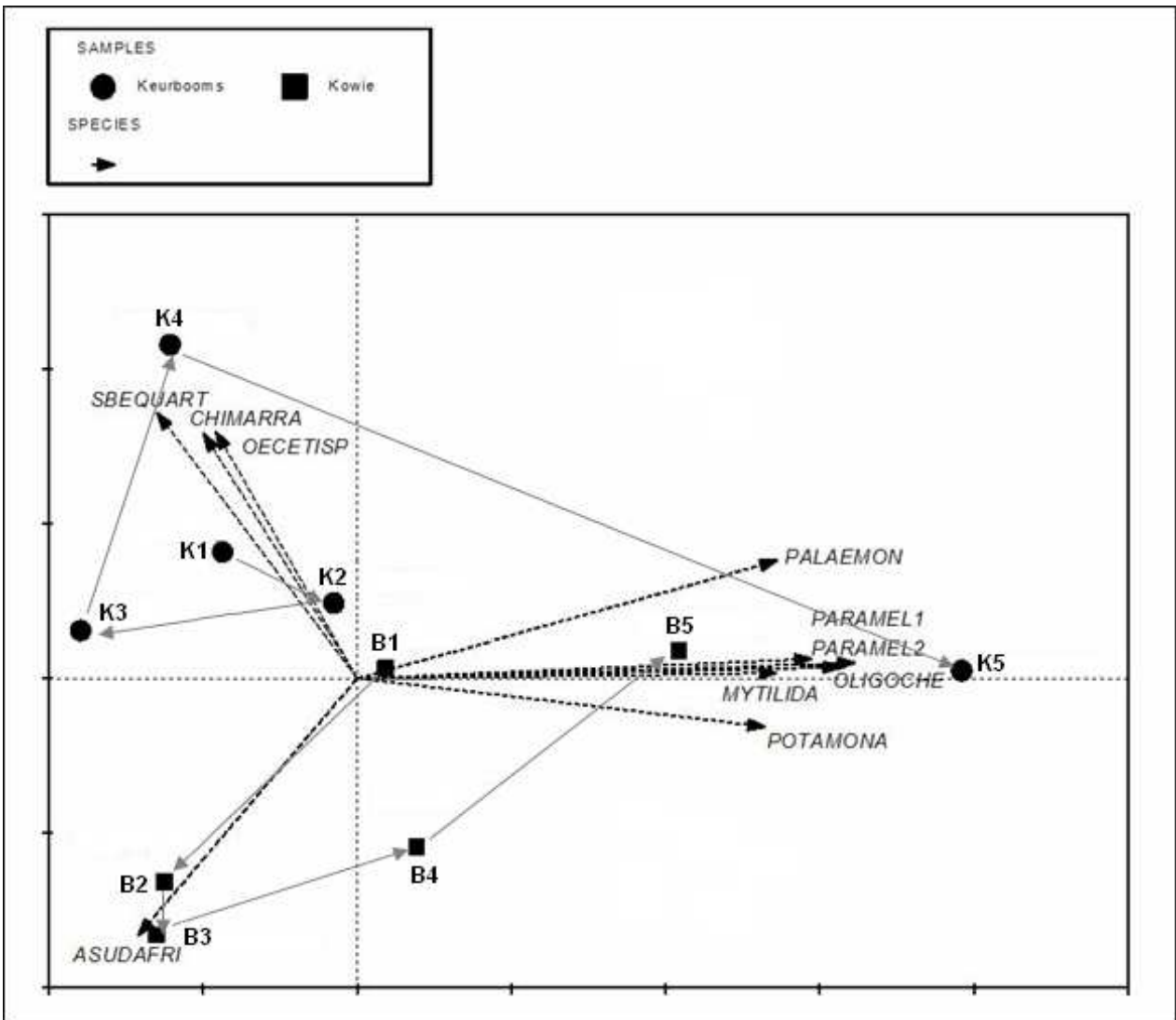


Figure 4.16: Non-metric multidimensional scaling (NMS) ordination (based on Bray-Curtis distance), rotated by principal component analysis (PCA), of species (italics) abundance data (square-root transformed) from Keurbooms and Kowie/Bloukrans River sites. Stress = 0.06. Species with a single occurrence were excluded from the analysis. Only species with a correlation of ≥ 0.7 (absolute value) are displayed.

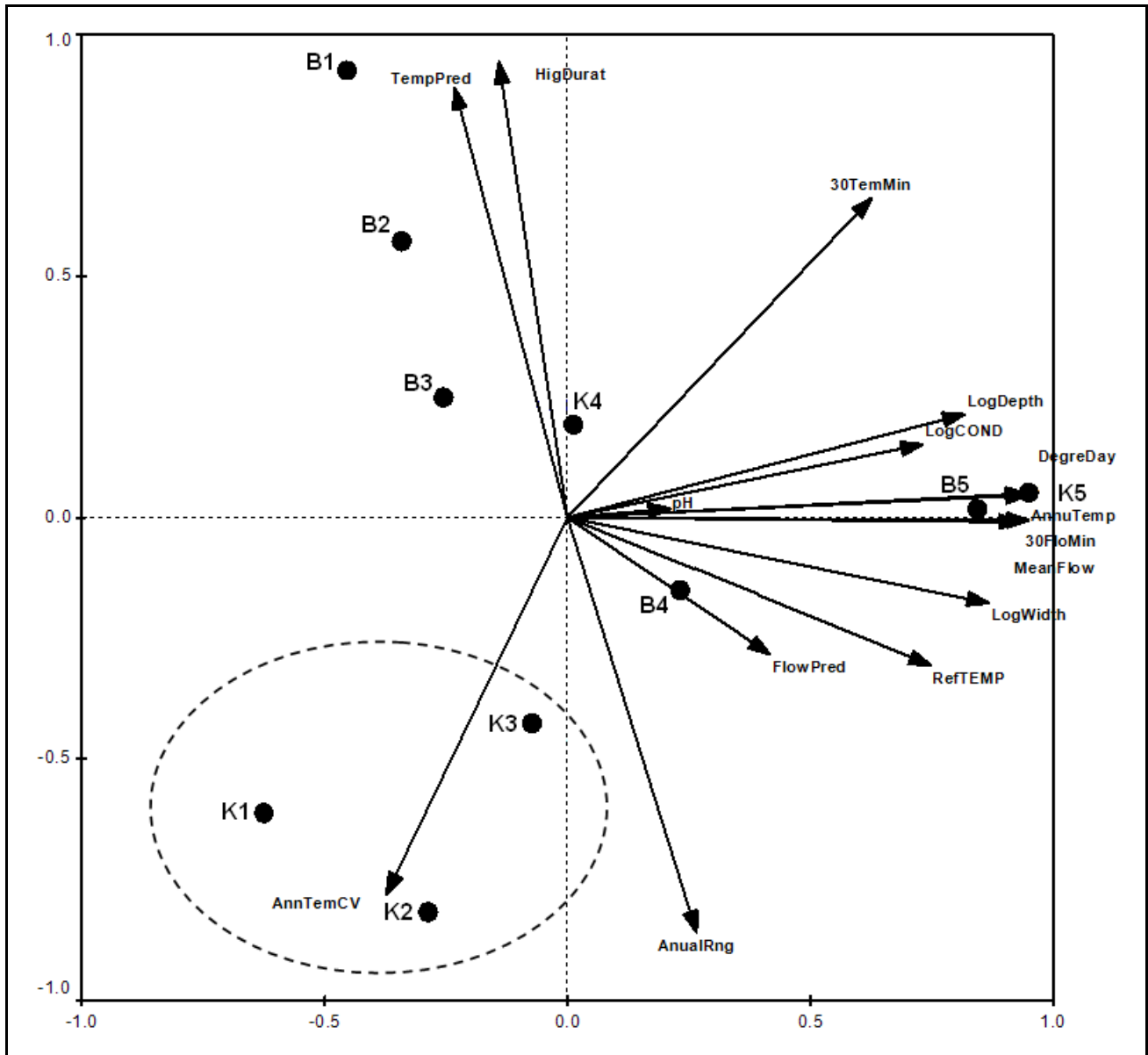


Figure 4. 17: NMS of the environmental parameters with the highest correlations, indicating which sites were driven by them. Axis one accounts for 49.3 % of the data, whereas axis two accounts for 26.6 %. Sites are represented by the points and the environmental parameters are represented by the arrows. Dashed oval indicates the three sites most affected by annual temperature coefficient of variation.

Table 4.12: Eigenvectors for axes one and two that contributed towards the NMS. Shaded cells indicate the environmental parameters that mostly effected the distribution of the arrows in Figure 4.17.

NAME	Axis 1	Axis 2
Cum. Variance	49.3	75.9
pH	0.2171	0.0188
LogCOND	0.7528	0.1559
RefTEMP	0.7701	-0.3161
LogDepth	0.8418	0.2203
LogWidth	0.8936	-0.1824
MeanFlow	0.9783	-0.0062
FlowPred	0.4292	-0.2923
HigDurat	-0.1459	0.9717
30FloMin	0.9611	-0.01
DegreDay	0.9756	0.051
AnnuTemp	0.9758	0.0469
AnnTemCV	-0.3843	-0.805
TempPred	-0.2399	0.9173
AnualRng	0.2735	-0.8864
30TemMin	0.6456	0.6818

One of the objectives for this research was to gain a better understanding of macroinvertebrate taxa turnover variation with seasons at the sites (temporal changes). A CCA was performed for all the sites from all seasons, with the species data and particular environmental variables (Figure 4.18). The environmental variables used included the following: temperature and flow coefficient of variation, temperature range, mean flow, pH, conductivity (log-transformed), temperature CV / flow CV and temperature CV x flow CV. The ratios between temperature and flow CV (Tcv/Fcv) for all seasons and sites were greater than 1, indicating temperature variability was a greater contributor than flow variability. In the CCA output, the environmental variables having correlations above 0.7 are present. This analysis indicated the dominant environmental variables driving the macroinvertebrate distribution at the different sites: conductivity (LogCond) driving B5,

mean flow (FlowMean) driving K5, pH driving B3, B4 and B2, and the ratio between temperature and flow CV (Tcv/Fcv) driving the remainder of the sites (Figure 4.18).

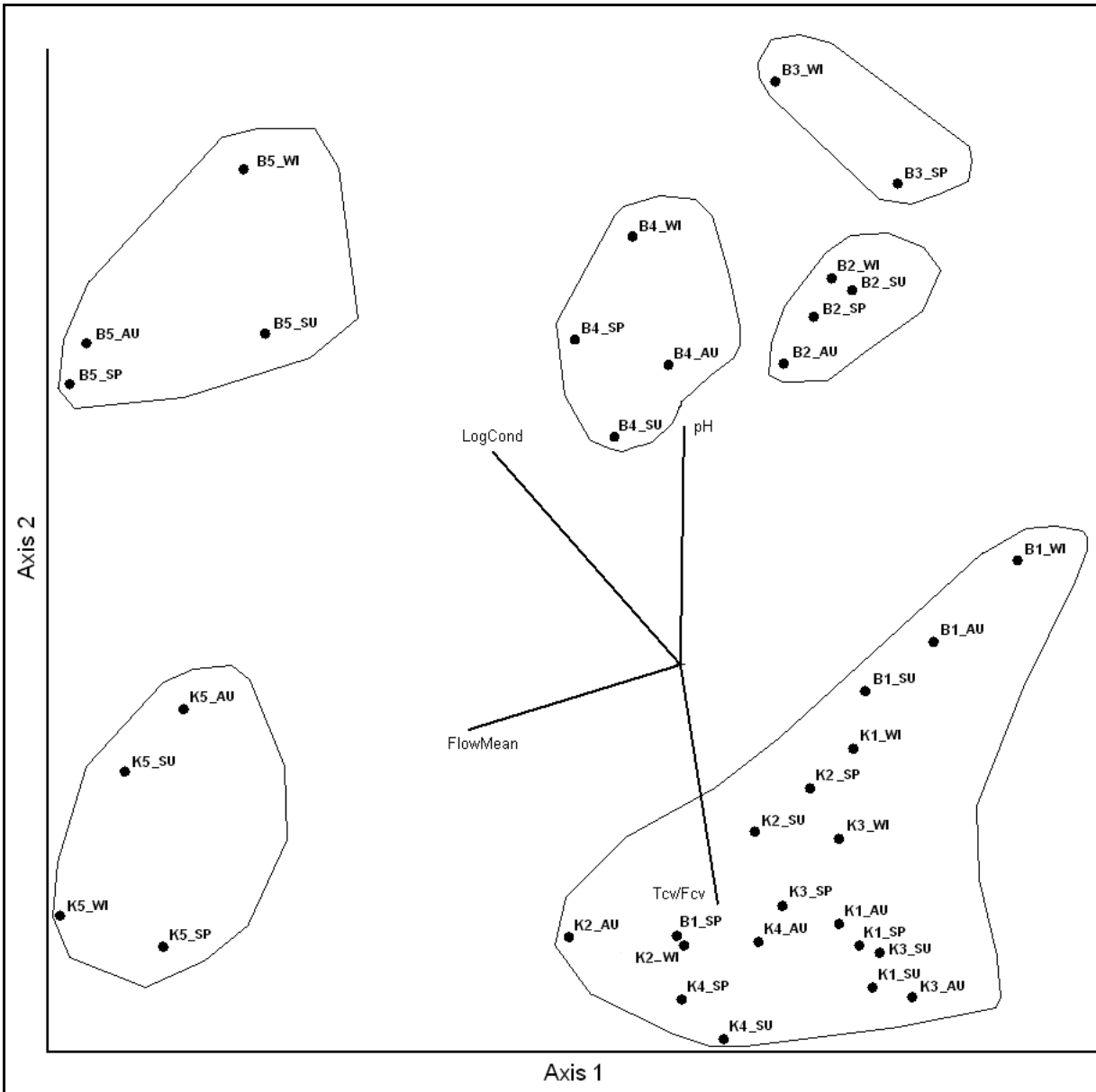


Figure 4.18: CCA of temporal macroinvertebrate taxa distribution with sites. Taxa with single occurrences were not included. Polygons enclose sites that yielded similar taxa over the seasons. Season abbreviations are as follows: SU = summer; AU = autumn, WI = winter; SP = spring. Environmental variable abbreviations are as follows: pH = pH; LogCond = log-transformed conductivity; FlowMean = mean annual flow; Tcv/Fcv = temperature coefficient of variation / flow coefficient of variation.

4.5 Conclusions

From these results, it is apparent that the streams in this research are different from one another. This could largely be a result of the different flow regimes, namely perennial versus non-perennial, affecting the macroinvertebrate community structures and distributions. The next chapter discusses these findings, with particular emphasis on how different water temperature metrics affect macroinvertebrate communities.

CHAPTER 5 DISCUSSION

This chapter will discuss the findings outlined in the results section and whether the aim and objectives of the research were achieved, i.e., whether macroinvertebrate communities respond in a predictable manner depending on the water temperature predictability, whether macroinvertebrates respond in a predictable way to changes in their environment and test whether the temporal partitioning of macroinvertebrate taxa are related to water temperature variability.

5.1 Relationship between water temperature predictability values and macroinvertebrate data

There was a tendency for macroinvertebrate assemblages to differ on a temporal basis as temperature predictability values decreased (higher macroinvertebrate CV, indicating seasonal turnover). This trend was more evident on the Keurbooms River ($R^2 = 0.698$ – Figure 4.14) than the Kowie/Bloukrans River ($R^2 = 0.296$). This may be attributed to the more frequent supply of water on the perennial Keurbooms than on the non-perennial Kowie/Bloukrans.

Water temperature predictability values calculated from the year cycle did not provide a direct relationship with macroinvertebrate communities. The range of predictability values for all ten sites was between 0.60 and 0.69, which indicated that there were no sites that stood out having either highly or poorly predictable thermal regimes. The site having the highest predictability value was B2 (0.69, Table 4.4), which, over the seasons, yielded 13 different taxa under flowing conditions. Of these taxa, six (46 %) were present for every season, leading to the assumption that these taxa are not greatly influenced by temperature. One of the reasons for the high temperature predictability at this site was attributed to riparian vegetation, where constant shading over the stream was provided throughout the research period. Shading reduces direct solar radiation, thus reducing temperature fluctuations and ranges (Dallas and Day, 1993). These six taxa are:

Chironomidae, *Simulium nigrিতarse*, *Afroptilum sudafricanum*, *Baetis harrisoni*, Ancyliidae (Mollusca) and Rhabdocoela (Platyhelminthes) (Appendix D).

The lowest water temperature predictability value calculated was for K2 (0.6), where thirty-one different taxa were collected over the seasons. Of these taxa, three (10 %) were present for all the seasons, namely Gyrinidae, Chironomidae and Gomphidae. It must be noted that there was flowing water at this site for the first two sampling seasons (winter and spring), and only pools for the remaining seasons, due to a drought in the region. This shift from flowing waters to pools may be the reason for the low predictability value at this site, as temperatures differ between flowing and non-flowing systems (Dallas and Day, 1993), which furthermore, may have hindered the findings of taxa preferring flowing water (*Simulium nigrিতarse*, *Cheumatopsyche type 7*) in the drier seasons. Therefore, an inference is made that the more temperature predictable sites have less macroinvertebrate taxa turnover across seasons (Figure 4.14), making it easier to predict what macroinvertebrate taxa may be present for a particular season due to more stable communities, depending on the flow regime (flowing versus non-flowing). This trend was more conclusive for the Keurbooms than the Kowie/Bloukrans (R^2 values in Figure 4.14).

Throughout the seasons, total taxon richness increased from winter to autumn for all sites on both stream systems, except for the Kowie/Bloukrans system, which increased from winter through to summer, then decreased by one taxon between summer and autumn (Table 4.9). This may be attributed to the middle site (B3) not being sampled due to the absence of water. This increase in richness from winter to autumn is similar to the findings across seasons for Closs and Lake, (1994) and Minshall *et al.* (1985), where several sites experienced greater species diversity in autumn. This could illustrate how taxon richness tended to increase temporally due to increasing water temperature over the seasons. Similar results were obtained by Palmer (1997), who found that total number of taxa was highest at temperatures above 25 °C. This trend is similar to the results obtained by Dallas (2004) for taxa richness varying spatially (or geographically) due to

temperature differences associated with latitude and climate (temperate in Western Cape and sub-tropical in the Mpumalanga Province, South Africa).

The results from this research are similar to those of Minshall *et al.* (1985), who sampled invertebrates in spring, summer and autumn, where autumn yielded the greatest richness for several of the sites. These authors found similar trends to those found on the Keurbooms River (Figure 4.8), such that species richness is low in the headwaters, peaks in the mid-reaches, then decreases in the lower reaches as the stream becomes progressively larger (Minshall *et al.*, 1985). These trends were found to be similar to both Minshall *et al.* (1985) and Vannote *et al.* (1980) for both streams in this research, where along the longitudinal gradient, taxon richness increases from 1st to 2nd stream order, then further decreases from 2nd to 3rd stream order (Figure 4.11). This is attributed to variability being the greatest in the mid-regions of the stream (Vannote *et al.*, 1980).

The major environmental drivers at the K1, K2 and K3 sites are annual temperature coefficients of variation and annual temperature range (Figure 4.17). Thus, these sites have high temperature variability over the years' cycle, encouraging a range of thermal niches for macroinvertebrate communities to establish. Out of these sites, the greatest macroinvertebrate diversity is present, being K3 with 44 different taxa, where K2 had 31 taxa and K1 31 taxa (Table 4.7). This could indicate that the high annual temperature fluctuations and persistent flowing conditions (K3) may well be the driver for a high temporal macroinvertebrate turnover. Although altitude is a primary driver of temperature, more site specific conditions may alter temperature trends (range, standard deviation, coefficient of variation); where riparian vegetation contributing towards shading (Dallas and Day, 1993), flowing versus non-flowing systems and depth of the logger (Dallas and Day, 1993; DWAF, 1996) may alter the site temperatures.

A plausible reason for higher numbers of taxa being present in warmer seasons may be linked to planktonic algae. Palmer (1997) sampled for planktonic algae over a five year period on the Orange River, finding concentrations were lowest in winter and highest in autumn. Several taxa had a positive correlation with this increase in algae concentration

in Palmer's research. Similarly in this research, even though planktonic algae was not measured, several taxa yielded positive correlations with taxa abundance generally increasing between winter and autumn, across all sites and both river systems. These taxa included Hydrophilinae (Coleoptera), Chironomidae, Culicidae (Diptera), *Caenis sp.* (Ephemeroptera), Veliidae (Hemiptera), Libellulidae (Anisoptera), Oligocheata, *Cheumatopsyche afra*, *Cheumatopsyche type 2*, *Hydropsyche longifura*, *Oecetis sp.*, *Chimarra sp.* and *Pisulia sp.* (Trichoptera). Similarly, certain taxa yielded clear negative correlations, where abundances decreased between winter and autumn, across all sites and both river systems. These taxa included Elmidae (Coleoptera), *Afroptilum sudafricanum* (Ephemeroptera) and *Cheumatopsyche type 7* (Trichoptera). Taxa were more sensitive to variation over seasons and within the same biotope than others. For example, particular Simuliidae species were abundant in the cooler seasons and scarce in the warmer seasons (*Simulium (Pomeroyellum) bequaerti* and *Simulium (Pomeroyellum) harrisoni*), whereas other species were relatively abundant over all seasons (*Simulium (Metomphalus) hargreavesi* and *Simulium nigritarse*).

Palmer *et al.* (1991) identified *Baetis harrisoni* and *Cheumatopsyche afra* to be prolific in the riffle biotope on a 4th order stream on the Buffalo River, Eastern Cape. These findings are very similar to those in this research, where *Baetis harrisoni* and *Cheumatopsyche afra* abundances were greatest in the stones-in-current biotope (riffle) in the mid-reaches of both rivers, particularly the Keurbooms. From the research in this thesis, these two taxa specialise in their habitat (fast flowing waters) but not in their surroundings (differences in water temperature, pH and conductivity over seasons). This was demonstrated in this research, where *Baetis harrisoni* and *Cheumatopsyche afra* were found throughout all seasons on both streams, suggesting that water temperature does not effect their distribution, classifying these taxa as generalists. This is further supported by these findings, where these taxa were most abundant at the K3 site (Table 4.7 and the relationship between Figure 4.16 and Appendix F in the K3 site direction) which had the greatest water temperature and flow variability across the seasons (Figure 4.18). This, however, did not seem to correlate with water temperature predictability values.

Water quality data from this research exhibit a similar trend to those found by Palmer and O' Keeffe (1991), where water temperature, pH and conductivity increase from upper to lower reaches. Combined with the physical parameters in upper reaches (turbulent flow, velocity high, dissolved oxygen high, discharge and water temperatures low) compared to lower reaches (flow laminar, velocity low, dissolved oxygen low due to light absence, discharge and water temperatures high – Harrison, 1965) and the chemical parameters mentioned above, specific taxa were only found in particular biotopes along the longitudinal profile, namely stones-in-current. Similarly to the fauna described by Harrison (1965) found in the cool, upper reaches of a river, Elmidae (Coleoptera), Corydalidae (Megaloptera) and Notonemouridae (Plecoptera) thrived in cool, upper regions on both systems, particularly the Keurbooms. Interestingly, the abovementioned taxa abundances were greater in the cool seasons than the warm seasons (Appendix D), suggesting these taxa prefer cool water temperatures.

Buschke *et al.* (2010) identified several taxa that did not exhibit distinct habitat specialization patterns; all these taxa are common to the results in this research (identified to genus level for most taxa by Buschke *et al.* (2010), but some families in this research were considered the equivalent taxa). These include: Ceratopogonidae, Chironomidae, Simuliidae, *Cloeon sp.*, *Caenis sp.*, Corixidae, Notonectidae, Coenagrionidae and *Cheumatopsyche afra*. These taxa were found on both rivers at some time during the year's sampling, ranging in presence and abundance. For example, Chironomidae were present at all sites on both rivers for all seasons. Thus, with regards to water temperature, Chironomidae are considered generalists in this research due to their presence not being affected by water temperature. However, certain species of the Chironomidae family may well be affected by water temperatures.

Although the difference in results between specialist and generalist was slight (Table 4.10 and Table 4.11), these trends indicate that there is greater taxa resilience to change on the Kowie/Bloukrans than the Keurbooms. This is possibly as a result of the flow variability of the two systems, where taxa on the Kowie/Bloukrans River system may be termed opportunistic, as when water is present (either flowing or pools), taxa seize the

opportunity to inhabit the water. Compared to the taxa on the Keurbooms River where taxa may be termed specialists, as being a perennial system, this stream is predominantly in the flowing form.

With regards to historical data, there are several similarities in taxa found on the Keurbooms River (unfortunately no records were found for the Kowie/Bloukrans). Out of nine taxa found on the Keurbooms in 1962 by Harrison and Agnew (1962; cited in Duvenage and Morant, 1984), eight taxa were common to the findings in this study. These taxa are *Baetis harrisoni*, *Pseudocloeon sp.*, *Adenophlebia sp.*, *Cheumatopsyche afra*, *Hydroptila sp.*, *Simulium* larvae, Chironomidae and Elmidae. Of these taxa common to both years, *Hydroptila sp.* is considered the only specialist as this taxon was only found at the K4 site (3 seasons, 1 site category in Table 4.10), the remaining taxa categorised as generalists. This may suggest that in a 48 year period, the conditions of this river have not been significantly altered.

A particular macroinvertebrate taxon exhibited typical temperature specialist behaviour in this research, as it was only present in the warm seasons. The ephemeropteran (family: Baetidae) *Centroptiloides bifasciata* was present in summer and autumn at the K3 site and at the K4 site only in summer (Appendix D). *C. bifasciata* nymphs are not found at high altitudes or cold streams, and is sensitive to silt and mild pollutants in water and upstream agricultural activity (Agnew, 1962), suggesting this species prefers clear, warm waters. This temperature and habitat specialist (stones-in-current) is particularly different to the generalist *Baetis harrisoni* (Baetidae: Ephemeroptera) found at many sites on both streams, predominantly stones-in-current biotopes, throughout all seasons. *C. bifasciata* was only present on the flow and temperature predictable Keurbooms for warm seasons, further suggesting its specialist status, whereas *B. harrisoni* was present on both streams with predictable and unpredictable flows and predictable temperatures, further suggesting its generalist status. Therefore, this species could provide a good indicator for increasing water temperatures associated with climate change by monitoring its range expansion, assuming the Keurbooms River remains predictable and the water quality remains good.

Agnew (1962) reported that the South African southern-most limit of *C. bifasciata* was the Krom River at Assegaaibosch (Eastern Cape) at an altitude of 300 m.a.s.l. No mention was made of the presence of this species on the Keurbooms River in 1962, as “*the species is probably also limited by the low pH of the acid streams in the Southern and Western Cape*” (Agnew, 1962, pp. 369). Observations during recent decades have shown increasing water temperatures in rivers, resulting in transformations of species composition, phenological shifts, organism productivity and abundance (Bates *et al.*, 2008). Therefore, seeing as *C. bifasciata* was only found in summer and autumn, suggesting that this species prefers warmer water temperatures, particularly as this species is found in many rivers north of the Keurbooms in the KwaZulu-Natal, Free State and Mpumalanga provinces (Agnew, 1962), Limpopo and Mpumalanga provinces (Roux *et al.*, 2008) and the Northern Cape (Palmer 1997). One specimen was found at the K4 site in summer (altitude 30 m.a.s.l) and three specimens at the K3 site in both summer and autumn (altitude 275 m.a.s.l), compared to a cooler 300 m.a.s.l on the Krom River at Assegaaibosch in 1962 (Agnew, 1962). Therefore, within 48 years, this species may be migrating towards the Western Cape province. Although these two sites share the same line of latitude, movements in a westerly direction towards a mediterranean, temperate climate may suggest increasing temperatures over this 48 year period. Recent research by Dallas (2010) indicates this species is not present in summer in the Western Cape, where ten sites were sampled at the beginning and end of summer. No specimen of *C. bifasciata* has yet been recorded in the Western Cape prior to this research (an enquiry was made via email in the database at the department of Freshwater Invertebrates at the Albany Museum). Thus, this further suggests that *C. bifasciata* may be a good indicator species for climate change.

5.2 Relationship between observed and simulated streamflow predictability values and macroinvertebrate data

The flow predictability values increased with downstream distance for both rivers (Table 4.2). This is unlike the results of Rivers-Moore and Jewitt (2006, unpublished data), who found that predictability values decreased with downstream distance for the Sabie River. It was interesting to note that although the flow predictability values were greater on the

Keurbooms River versus the Kowie/Bloukrans River for all quinarys, this was not the case for the temperature predictability values. The three high altitude sites on the Kowie/Bloukrans system had greater temperature predictability values than the two low altitude sites, whereas the two lowest sites on the Keurbooms system had greater values than the three high altitude sites (Table 4.4). This is evident in the PCA (Figure 4.6), where ITA predictability has separated four of the five paired sites on axis two (Table 4.5).

From the taxa collected across all seasons for both rivers, several taxa were only found on one stream system; 33 and 21 unique taxa on the Keurbooms and Kowie/Bloukrans systems respectively. An interesting trend is that the majority of the unique taxa on the Keurbooms (mostly Simuliidae, Ephemeroptera and Trichoptera) were found in the stones-in-current biotope, suggesting they have adapted to conditions of constant flow. King *et al.* (2008) mention that certain Trichoptera, Simuliidae and Odonata (damselflies) taxa are not capable of surviving current speeds of zero, even if oxygen levels are very high. Similarly, the taxa unique to the Kowie/Bloukrans (Mollusca, Diptera, and some Trichoptera) were predominantly found in biotopes with calm or stagnant waters, further suggesting that these taxa have adapted to conditions consisting of pools and sluggish waters due to inconsistent flow. These two trends distinguish the types of river systems from one another, i.e. perennial versus non-perennial.

The flow pattern on the Kowie/Bloukrans is typical of a non-perennial river, flowing as a result of rainfall only, causing this stream to be erratic and event driven. One of the reasons why the Keurbooms River is perennial is that the middle site (K3) lies several hundred meters downstream of the Kwaai River confluence, a perennial tributary fed by a spring at its source.

A reason for the diversity being low on the Kowie/Bloukrans River at the middle B3 site has to do with flow. It has already been stated that only winter and spring sampling was carried out at this site due to the complete absence of water for the summer and autumn seasons. However, the most plausible reason why this site had a low biodiversity in

comparison to the middle site on the Keurbooms River is due to the flow history. The water temperature logger was secured at this site in a run biotope when water was flowing (14th October 2008). There was constant flow up to the 10th January 2009, and then from this date until the 23 February 2009 there was a period of very low or no flow (DWA, 2010), thus no stones-in-current biotope existed. In-between this date and the first sampling season (winter), the river began flowing again, offering the stones-in-current biotope four months to recover until sampling took place in June 2009. This short period for the biodiversity to recover by the first macroinvertebrate sampling may be the reason for such a low taxon richness being present at this site (Figure 4.9) compared to the middle site on the Keurbooms (Figure 4.8). Therefore, on this non-perennial stream yielding unpredictable flows, both observed and simulated (Table 4.1 and Table 4.2), it becomes a difficult task for macroinvertebrate communities to prosper due to the variation between the presence and absence of water. Thus, macroinvertebrate response to changing environmental conditions becomes predictable, where reduced or no flows causes sensitive taxa to perish and the resumption of flows after drought results in macroinvertebrate communities to slowly re-establish in the various aquatic biotopes.

5.3 Temporal and spatial partitioning of diversity indices and functional feeding groups

Temporal macroinvertebrate turnover was more prominent at some sites than others. B2 yielded the lowest temporal turnover (Figure 4.18), indicated by the least distance between points. This was due to riparian shading promoting less diel temperature range and the taxa present being more tolerant of polluted waters. Sites exhibiting greatest temporal turnover were B1, K1, K2, K3 and K4 (Figure 4.18), where high variation in temperature and flow (Tcv/Fcv) contributed to seasonal changes. This allows different macroinvertebrate taxa to become better suited to a range of ecological niches. These sites had some of the highest taxa richness of all sites, with values of 31, 31, 44, 31 and 37 at K1, K2, K3, K4 and B1 respectively, over the research period. Therefore, where seasonal variation in temperature and flow are more prominent, higher macroinvertebrate turnover is likely to occur.

A clear distinction in species distribution between the two streams is apparent (Figure 4.16). This could indicate the preference of river system, such that taxa found in the Keurbooms River prefer constant, perennial and predictable flow, whereas those in the Kowie/Bloukrans prefer erratic, non-perennial and unpredictable flow. However, certain taxa were common to both rivers, indicated by Sørensen's similarity index (Table 4.8). Sørensen's similarity index reveal that the lower-most sites from both streams had the most similar taxa, with an average of 56 % over all seasons. This may be as a consequence of high conductivity levels, still, deep waters, high water temperatures and high flows (Figure 4.17). The sites having the least similarity were K4 and B4 (an average of 12.5 %), largely owing to different flow regimes, with K4 flowing throughout the research duration and B4 consisting of the stones-out-of-current biotope for most of the seasons. The reason why B1 and K2 sites are situated close together in Figure 4.16 is that over the duration of this study, 18 taxa were common to these sites. This is attributed to these sites containing biotopes in both flowing waters and pools in winter and spring, but only pools in summer and autumn due to reduced flows.

FFGs variations were not as temporally pronounced as spatially. The temporal partitioning of macroinvertebrates was seen to be primarily driven by alterations in flow and water temperatures. Perhaps Lake *et al.*, (1985; cited in Palmer *et al.*, 1993) and King *et al.* (1988) were correct in stating that aquatic invertebrates are polyphagous, or opportunistic generalists, where the only limitation would depend on the speciality of their mouthparts.

5.4 External factors influencing trends

During this research, certain sites were transformed from flowing streams into pools. This transformation exhibited changes in the dominant taxa present at the sites, where taxa preferring stones-in-current disappeared and where pools developed, taxa preferring still waters dominated. It appeared the period 2009/2010 was a dry cycle as a result of low flows at some sites and completely dry at others, which may have masked some species. Palmer (1997) found that species abundance and composition differed between long-term dry and wet cycles, where some species are better adapted to high flows and others to low

flows. Wood *et al.* (2000) discovered distinct differences in macroinvertebrate composition between drought and non-drought periods. As a result, from sampling at a site only once in one season, approximately 60 % of possible present taxa may not be sampled as a result of flow variations, where some taxa are better adapted to certain flow conditions than others (Palmer, 1997). For example, *Afronurus sp.* (Heptageniidae, Ephemeroptera) requires strong flows to survive (King *et al.*, 2008). Therefore, within this research, high flow tolerant species may have been masked due to the dry cycles experienced on both rivers. This is a demonstration of how macroinvertebrate taxa may react in a predictable manner to variation in their surroundings due to taxa preferring specific flow conditions.

Over the duration of this research, drought conditions (as difficult as it is to detect when droughts actually begin, Lake, 2000) were experienced on both rivers, affecting certain sites on each river, particularly for summer and autumn. This lack of water reduces the movement of biomass within the stream (similarly to the study undertaken by Clarke *et al.*, 2010 due to drought), as droughts have a negative effect on stream biomass. Reduced habitat space transpires, creating pools, further increasing competition amongst the biota; water temperature increases, water quality deteriorates and oxygen deficiency (hypoxia) occurs, ultimately resulting in a loss of species diversity (Lake, 2000). Due to certain sites having transformed from flowing streams to pools over the duration of this study, taxa tolerant to the abovementioned effects associated with droughts may have been present. Nonetheless, these taxa may be indicative of higher water temperatures than others, since the pools were only present for the warm seasons of summer and autumn. However, certain taxa are adapted to flowing conditions, such as Simuliidae and Corydalidae, which were only found during winter and spring at K2 when the stream was flowing, and not found in summer and autumn when pools were present.

The flow conditions at the B2 site did not alter significantly between seasons (personal observation), such that the stones-in-current biotope remained the only habitat that was sampled across seasons. It must be noted that this site lies approximately six kilometres downstream of the sewerage works for the town of Grahamstown, from where effluent is

discharged into the stream. Although nutrient analysis was not carried out, an assumption was made (based upon observations - foam and algal growths, and smell at this site over seasons) that the macroinvertebrate assemblages at this site have a high tolerance for polluted waters. According to Dickens and Graham (2002), the sensitivity scale for the six taxa present at this site for all seasons (Chironomidae, *Simulium nigritarse*, *Afroptilum sudafricanum*, *Baetis harrisoni*, Ancyliidae (Mollusca) and Rhabdocoela (Platyhelminthes)) range between two and six, describing these taxa to be highly tolerant to pollution. All of these taxa are considered generalists on this stream, found at several sites and over many seasons (Figure 4.13). The greatest richness of Chironomidae and Rhabdocoela over all sites and seasons was found here, indicating that the water quality is poor. Therefore, this would reduce the likelihood of more sensitive species, i.e. specialists, to be found at this site, being the primary reason for the low macroinvertebrate biodiversity.

One of the macroinvertebrate taxa present for every season at B2 was *B. harrisoni*. Williams *et al.* (2003) found that *Baetis harrisoni* is capable of building up resistance to polluted waters, which could well be the case here having a presence in these sewage waters. Certain Chironomidae genera (*Chironomus sp.*) have adapted to endure conditions with low dissolved oxygen, typically found in sewage waters where organic load is high and organic matter is decomposed rapidly by fungi, bacteria, protozoans and algae, leading to oxygen depletion (Palmer and Williams, 2000). Decomposition of organic matter is exacerbated by higher water temperatures (Bates *et al.*, 2008).

There was an increasing trend in the different taxon richness amounts from winter to autumn (Table 4.9). This correlates to a trend in moving from colder temperatures in winter to warmer in summer and autumn, suggesting that more taxa in these rivers prefer warm waters rather than cool waters. However, in stating this, the hydrological conditions of both rivers did alter over the duration of the study, more so the Kowie/Bloukrans than the Keurbooms, suggesting that certain taxa at some sites prefer pools, rather than flowing conditions.

5.5 Conclusions

Variability in water temperatures and flow were the driving environmental variables that resulted in the dissimilarity of macroinvertebrate community structures across sites and seasons. This relationship was, however, more pronounced at some sites than others as discussed above, with variation occurring spatially and temporally. This was evident on both the perennial and non-perennial streams. Final conclusions to this research follow in the succeeding chapter.

CHAPTER 6 CONCLUSIONS

The aim of this research was to determine whether water temperature predictability could provide an indication of structure and functional predictability in macroinvertebrate communities. This hypothesis proved to hold true, where macroinvertebrate species turnover through the seasons was greater for sites having lower water temperature predictability values (i.e. more variable) than sites with high predictability values.

Aquatic macroinvertebrates do respond in a predictable manner to modifications in their environment. This was particularly evident in relation to variability in flow and water temperature, depending on the sensitivity of the taxa to changes in their habitat, although this was more evident amongst certain taxa than others. More taxa were only present when water temperatures were warm rather than cool, with overall taxon richness being higher in warmer water temperatures. Reduced flows resulted in the loss of flow-dependant taxa, primarily functional feeding groups relying on flowing streams for their food supply.

Temporal partitioning was greater at more variable sites (lower temperature predictability values and high temperature range and coefficient of variation), whereas temporal macroinvertebrate turnover was less obvious at sites with high temperature predictability values. Functional feeding groups did not vary temporally, however did appear to differ spatially, similar to the River Continuum Concept (Vannote *et al.*, 1980).

Studies of the life history of the macroinvertebrate taxa may explain why some species occurred at sites in different seasons, as certain species are triggered to emerge when the water temperatures reach a certain threshold. The scope of this research did not cover life history patterns of species, however further studies on this may reveal explanations for some of the results obtained in this study.

Meteorological events control aquatic ecosystems significantly, with climate change predicted to amplify variability in ecosystems (Dallas and Rivers-Moore, 2009). Freshwater reserves are becoming increasingly vulnerable, where impacts due to climate change are likely and could have considerable impacts upon ecosystems and human societies, where climate change is proposed to threaten freshwater aquatic ecosystems the most, as a high proportion of taxa are threatened by extinction (Bates *et al.*, 2008).

Changing precipitation patterns and increased air temperature are the primary climatic variations that are predicted to occur in South Africa with climate change (Dallas and Rivers-Moore, 2009). In Africa, climate change threatens freshwater systems due to alterations in temperature and precipitation, which would have unfavourable impacts on water quantity, water quality and water temperature (Lehner, 2005). It becomes an important task to discover to what extent climate change may have on amplifying existing variability in aquatic ecosystems and how this may affect the predictability of these ecosystems.

In a semi-arid country such as South Africa, macroinvertebrates are at a risk, particularly in non-perennial rivers where flow predictability is low. Anthropogenic impacts could threaten macroinvertebrate communities on perennial rivers, where the construction of dams and water abstractions for irrigation may alter the usually predictable flow regime. The results from this research could aid decision makers in making correct choices in the future, especially on streams with unpredictable flows, for example, the management of water releases from dams to uphold the ecological reserve. With these findings, we are potentially able to predict what the aquatic macroinvertebrate communities may consist of at various stages on streams, depending on the degree of water temperature and flow predictability.

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APPENDIX A: Detailed overview of macroinvertebrate identification and counting procedure.

- The sequence that was used for identification was to start with the samples from the first field trip, sorting out all of the biotopes separately per site (starting at the upper-most site on the river system, progressing downstream), thereafter moving onto the next site.
- The bottle containing the raw sample from the river was emptied into a white tray, where the white background enabled the specimens to stand out clearly. All the major debris (including leaves, sticks, stones and pebbles) was removed from the tray to enable easier finding of specimens.
- Using forceps, macroinvertebrate specimens were removed from the tray and placed into labelled glass vials containing 80 % alcohol for preservation. A single vial was used for a particular class/order of macroinvertebrate, for example, all the Ephemeroptera were stored in one vial, all the Trichoptera in another, and so on. In this way, detailed identification at a later stage would become easier and quicker, where a particular guide would be used focussing on a specific order and subtle differences in specimens would be easier to recognise (for example, the mouthparts of the Baetidae family, order Ephemeroptera).
- Once all the specimens were removed, the remaining debris was discarded and the next bottle was emptied into the tray. This procedure was carried out until all the samples from a single seasonal trip had been sorted.
- The next step once macroinvertebrates had been sorted to class/order level from a seasonal field trip was to go back and identify to a further level and count the specimens per species. Magnification was performed using a 20x and 40x dissecting microscope. Only certain orders were identified to genus and species levels, including Ephemeroptera, Trichoptera, Plecoptera, and the Simuliidae family of the Diptera order, as several environmental conditions are indicated by species from these orders (de Moor, 2002). For species identification of the abovementioned orders and Simuliidae, assistance from persons at the Albany Museum was required.

APPENDIX B: Dendrograms

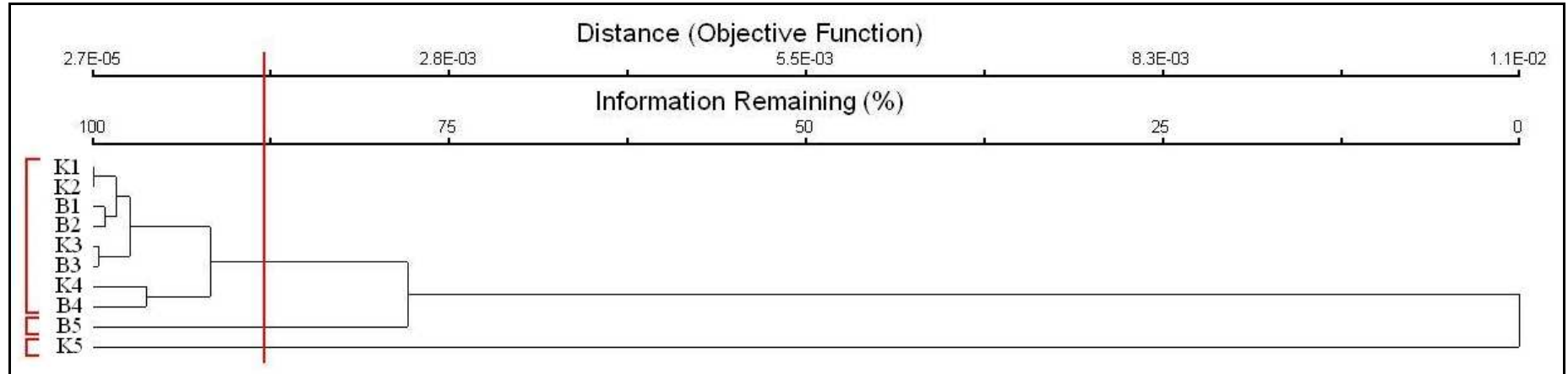


Figure B.1: Dendrogram for cluster analysis of 12 IHA flow parameters (same parameters as the eigenvectors in Table 4.3)

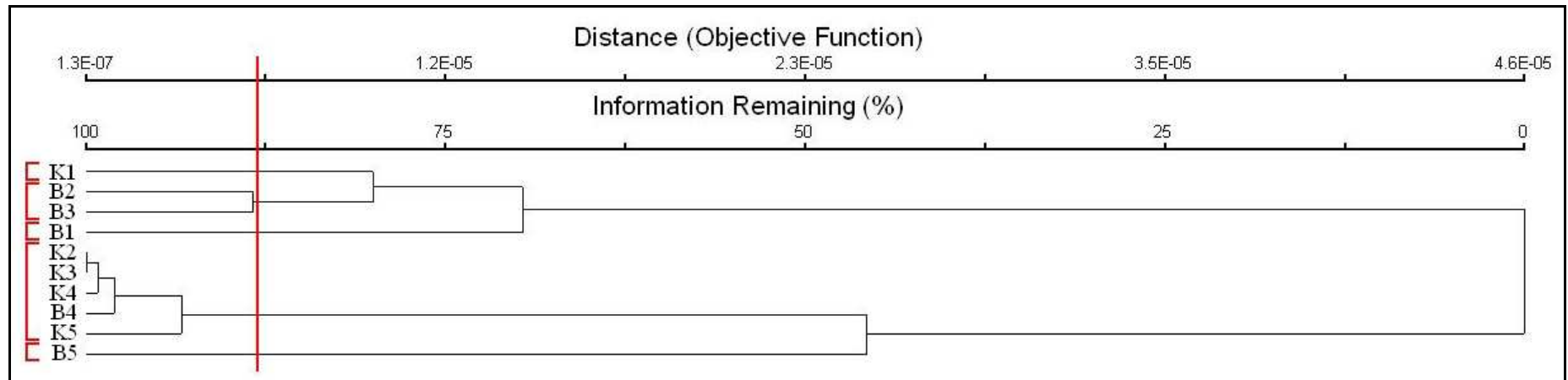


Figure B.2: Dendrogram for cluster analysis of 17 ITA temperature parameters (same parameters as the eigenvectors in Table 4.5).

APPENDIX C: Water quality variables for each site per season

(no data exists for K4 in winter and B3 for summer and autumn)⁵.

	pH	Conductivity (μ S/cm)	TDS (ppm)	ref temp ($^{\circ}$ C)	Depth (m)	Secchi depth (m)	Width (m)
Summer							
K1	4.3	64.5	32.6	26.1	0.19	>0.19	2.3
K2	4.91	275	135	19.5	0.13	>0.13	3.0
K3	5.2	56.4	27.9	21.6	0.24	>0.24	6.5
K4	4.63	74.1	37	24	0.37	>0.37	6.0
K5	5.57	8950	4460	25	>2.1	2.1	35.0
B1	4.75	131.9	67	18.9	0.45	>0.45	1.5
B2	6.7	814	408	20.2	0.25	>0.25	5.5
B4	7.53	2400	1180	24	0.4	1.0	5.5
B5 (estuary)	6.67	28300	14146	24.1	0.64	1.1	16.5
B5 (fresh)	7.87	2390	N/A	24.3	> 1.0	1.1	14.5
Autumn							
K1	6.69	101.7	50.6	16	0.19	>0.19	2.3
K2	6.82	440	222	18.7	0.13	>0.13	3.0
K3	6.45	37.4	73.4	19.2	0.24	>0.24	6.5
K4	6.41	97.1	47.1	18.6	0.33	>0.33	6.0
K5	6.89	6400	3320	20.4	>2.0	2.0	35.0
B1	6.33	185	87.9	14.3	0.37	>0.37	1.5
B2	8.04	1607	811	15.8	0.23	>0.23	5.0
B4	9.97	2600	1270	22.5	0.25	0.7	5.0
B5 (estuary)	8.19	44700	22800	23.5	0.64	1.0	16.5
B5 (fresh)	7.1	3380	1720	19.4	> 1.0	1.0	14.0
Winter							
K1	5.59	93.5	47.6	12.9	0.2	>0.20	2.3
K2	6.1	247	124	10.5	0.5	>0.5	12.0
K3	5.79	146.9	74	12.5	0.35	>0.35	7.0
K5	5.92	8140	4170	11.7	>1.1	1.1	35.0
B1	5.99	158.9	78.3	14.1	0.59	>0.59	2.0
B2	7.41	1470	735	13.3	0.14	>0.14	6.5
B3	7.65	2120	1060	12.8	0.27	>0.27	4.5
B4	7.42	3560	1790	13	1.04	0.85	6.0
B5 (estuary)	7.54	42200	21000	16.7	> 1.0	1.1	16.5
Spring							
K1	5.74	85.1	42.5	10.7	0.25	>0.25	2.3
K2	6.53	234	114	16.7	0.16	>0.16	10.0
K3	6.11	111	56.3	18.6	0.29	>0.29	7.0
K4	5.59	100.4	50.7	16.6	0.42	>0.42	7.0
K5	6.19	1467	7230	18	>2.7	2.7	35.0

⁵ The B5 conductivity values used in the PCA (Figure 4.7) were from the estuary site to ensure consistency, as measurements were not taken at the freshwater site for winter.

B1	3.45	152	75.8	13.6	0.52	>0.52	1.75
B2	7.52	1332	668	13.8	0.25	>0.25	6.5
B3	8.42	1378	687	16	0.16	>0.16	4.0
B4	7.16	2810	1400	15.5	0.45	>0.45	6.0
B5 (estuary)	6.93	33000	16200	18	0.64	>0.64	16.5
B5 (fresh)	N/A	N/A	N/A	N/A	> 1.0	1.1	15.0

APPENDIX D: Total macroinvertebrate taxa per season

Table D.1: June 2009 winter data

GROUP/ORDER	FAMILY	TAXON	K1	K2	K3	K5	B1	B2	B3	B4	B5
Amphipoda	Paramelitidae	sp.1				6					54
	Paramelitidae	sp.2				92					141
	Sternophysingidae										20
Mollusca (Basommatophora)	Lymnaeidae										
Mollusca (Caenogastropoda)	Littorinidae										
Coleoptera	Dytiscidae			2			6				
	Elmidae		97				1		3		
	Gyrinidae			5			4				
	Hydraenidae		3	4							
	Hydrophilinae										
	Ptilodactylidae										
	Scirtidae						1				
Decapoda	Atyidae										12
	Palaemonidae										
	Potamonautidae					3	2	2			3
Diptera	Ceratopogonidae			3	2						
	Chironomidae		46	154	84		17	750	12	7	
	Culicidae						2			15	
	Dixidae										
	Forcipomyiinae										
	Muscidae										
	Simuliidae	<i>S (Meilloniellum) sp.</i>		5							
		<i>S (M) hargreavesi</i>		5	1970						
		<i>S (P) alcocki</i>									
		<i>S (P) bequaerti</i>	60		150						

		<i>S (P) harrisoni</i>	90								
		<i>S (P) merops</i>									
		<i>S. (Nevermania) sp.</i>									
		<i>Simulium nigrirtarse</i>		30	635			350	175		
	Stratiomyidae										
	Tabanidae										
	Tipulidae				4						
Ephemeroptera	Beatidae	<i>Afroptilum sudafricanum</i>			64		9	280	600		
		<i>Baetis harrisoni</i>	37	9	92			20			
		<i>Centroptiloides bifasciata</i>									
		<i>Cloeon sp.</i>	31							340	
		<i>Demoreptus rapensis</i>	23	24							
		<i>Demoulinia crassi</i>		7	2					2	
		<i>Pseudocloen vinosum</i>	15	17	68						
		<i>Pseudopannota sp.</i>			5						
	Caenidae	<i>Caenis sp.</i>	9		4		8	5		39	
	Heptageniidae	<i>Afronurus sp.</i>			26						
	Leptophlebiidae	<i>Adenophlebia sp.</i>	8				18		28		
		<i>Choroterpes nigrescens</i>								12	
		<i>Euthraulius elegans</i>			27						
	Teloganodidae	<i>Lestagella penicillata</i>	1								
		<i>Nadinetella sp. (unidentifiable species)</i>									
Hemiptera	Belostomatidae										
	Corixidae						6				
	Gerridae						1				
	Mesoveliidae										
	Naucoridae						2				

	Notonectidae						1			
	Pleidae								50	
	Veliidae									
Isopoda	Anthuridae									
	Sphaeromatidae					21				79
Lepidoptera	Nymphulinae									
Megaloptera	Corydalidae		3	5						
Mollusca (Mytiloida)	Mytilidae					204				
Odonata (Anisoptera)	Aeshnidae				1		3			
	Corduliidae				1					
	Gomphidae			7	22					
	Libellulidae			1						
Odonata (Zygoptera)	Chlorosyphidae									
	Coenagrionidae									
	Lestidae						5	2		
	Platycnemididae							1		
	Protoneuridae									
Oligochaeta						12				47
Plecoptera	Notonemouridae	<i>Aphanicercella sp 1</i>	10							
		<i>Aphanicercella sp 2</i>			1					
		<i>Desmonemoura sp.</i>								
	Perlidae	<i>Neoperla sp.</i>								
Mollusca (Pulmonata)	Ancylidae							28	2	270
	Physidae									
	Planorbidae									
Trichoptera	Ecnomidae	<i>Ecnomus thomasseti</i>					1			2
	Glossosomatidae	<i>Agapetus agilis</i>								
	Hydropsychidae	<i>Cheumatopsyche afra</i>			104		1		51	
		<i>Cheumatopsyche type 2</i>			15					
		<i>Cheumatopsyche type 7</i>	31		7					

		<i>Hydropsyche longifura</i>										
		<i>Macrostemum capense</i>			1							
	Hydroptilidae	<i>Hydroptila cruciata</i>										
	Leptoceridae	<i>Athripsodes sp.</i>										
		<i>Athripsodes bagensis</i>	8									
		<i>Leptocerus sp.</i>										
		<i>Oecetis sp.</i>						1				
	Philopotamidae	<i>Chimarra sp.</i>	4									
	Pisuliidae	<i>Pisulia sp.</i>										
	Sericostomatidae	<i>Cheimacheramus caudalis</i>						3				
Turbellaria	Rhabdocoela								7			
Mollusca (Veneroida:Sphaeriacea)	Sphaeriidae											
TOTAL TAXA			17	15	22	6	20	10	7	9	7	

Table D.2: September 2009 spring data

GROUP/ORDER	FAMILY	TAXON	K1	K2	K3	K4	K5	B1	B2	B3	B4	B5
Amphipoda	Paramelitidae sp.1						16					17
	Paramelitidae sp.2						490					19
	Sternophysingidae											2
Mollusca (Basommatophora)	Lymnaiedae											
Mollusca (Caenogastropoda)	Littorinidae											9
Coleoptera	Dytiscidae							3				
	Elmidae		49	4	5	2		2		1		1
	Gyrinidae			16				7				
	Hydraenidae		1	8							1	
	Hydrophilinae										3	

	Ptilodactylidae											
	Scirtidae		1									
Decapoda	Atyidae											
	Palaemonidae											
	Potamonautidae											8
Diptera	Ceratopogonidae		3		1							
	Chironomidae		82	22	340	73	6	79	550	68	48	
	Culicidae							5				
	Dixidae											
	Forcipomyiinae											
	Muscidae				1							
	Simuliidae	<i>S (Meilloniellum)</i>										
		<i>S (M) hargreavesi</i>			2000	400						
		<i>S (P) alcocki</i>										
		<i>S (P) bequaerti</i>	300		50	800						
		<i>S (P) harrisoni</i>	170									
		<i>S (P) merops</i>				30						
		<i>S. (Nevermania) sp.</i>				170						
		<i>Simulium nigrিতarse</i>		14	330				330	1300	23	
	Stratiomyidae											
	Tabanidae											
	Tipulidae				148							
Ephemeroptera	Baetidae	<i>Afroptilum sudafricanum</i>			21			4	144	420	155	
		<i>Baetis harrisoni</i>	45		313	11			16			
		<i>Centroptiloides bifasciata</i>										
		<i>Cloeon sp.</i>									150	17
		<i>Demoreptus rapensis</i>	81	62								
		<i>Demoulinia crassi</i>									2	
		<i>Pseudocloen vinosum</i>	44	6	213	48						

		<i>Pseudopannota sp.</i>			99	2						
	Caenidae	<i>Caenis sp.</i>	3		4			1				38
	Heptageniidae	<i>Afronurus sp.</i>			8	1						
	Leptophlebiidae	<i>Adenophlebia sp.</i>	1					31			30	1
		<i>Choroterpes nigrescens</i>										10
		<i>Euthraulius elegans</i>		1	2	5						
	Teloganodidae	<i>Lestagella penicillata</i>	2									
		<i>Nadinetella sp. (unidentifiable species)</i>										
Hemiptera	Belostomatidae				1	1						
	Corixidae											
	Gerridae							2				26
	Mesoveliidae							1				
	Naucoridae							4				
	Notonectidae							1				4
	Pleidae										1	
	Veliidae											8
Isopoda	Anthuridae											
	Sphaeromatidae							2				130
Lepidoptera	Nymphulinae											
Megaloptera	Corydalidae		3		7							
Mollusca (Mytiloidea)	Mytilidae							718				2
Odonata (Anisoptera)	Aeshnidae							1				7
	Corduliidae							1				
	Gomphidae			12	15							
	Libellulidae				1							
Odonata (Zygoptera)	Chlorosyphidae											
	Coenagrionidae							7				17
	Lestidae							2				

	Platycnemididae								1			
	Protoneuridae											
Oligochaeta								53				7
Plecoptera	Notonemouridae	<i>Aphanicercella sp 1</i>	1									
		<i>Aphanicercella sp 2</i>										
		<i>Desmonemoura sp.</i>										
	Perlidae	<i>Neoperla sp.</i>										
Mollusca (Pulmonata)	Ancylidae								22	8		
	Physidae											
	Planorbidae											7
Trichoptera	Ecnomidae	<i>Ecnomus thomasseti</i>									8	
	Glossosomatidae	<i>Agapetus agilis</i>										
	Hydropsychidae	<i>Cheumatopsyche afra</i>			181					17		
		<i>Cheumatopsyche type 2</i>			1							
		<i>Cheumatopsyche type 7</i>	26	2								
		<i>Hydropsyche longifura</i>			16	2						
		<i>Macrostemum capense</i>										
	Hydroptilidae	<i>Hydroptila cruciata</i>				2						
	Leptoceridae	<i>Athripsodes sp.</i>			5							
		<i>Athripsodes bagensis</i>				4						
		<i>Leptocerus sp.</i>										6
		<i>Oecetis sp.</i>				3		2				
	Philopotamidae	<i>Chimarra sp.</i>	2		1	11						
	Pisuliidae	<i>Pisulia sp.</i>						1				
		<i>Cheimacheramus caudalis</i>						2				
Turbellaria	Rhabdocoela								60	13	3	
Mollusca (Veneroidea:Sphaeriacea)	Sphaeriidae											3
TOTAL TAXA			17	10	24	18	6	19	6	8	13	18

Table D.3: January 2010 summer data.

GROUP/ORDER	FAMILY	TAXON	K1	K2	K3	K4	K5	B1	B2	B4	B5
Amphipoda	Paramelitidae	sp.1					51				15
	Paramelitidae	sp.2					310				108
	Sternophysingidae										
Mollusca (Basommatophora)	Lymnaeidae			1							
Mollusca (Caenogastropoda)	Littorinidae										
Coleoptera	Dytiscidae			1				4			1
	Elmidae		23		1	9		1			
	Gyrinidae		11	4	4			2			
	Hydraenidae										
	Hydrophilinae										25
	Ptilodactylidae					1					
	Scirtidae							2			
Decapoda	Atyidae										
	Palaemonidae										
	Potamonautidae						1	1	1		2
Diptera	Ceratopogonidae				4	1	1	1		14	32
	Chironomidae		22	16	82	82	27	102	274	131	67
	Culicidae			3							10
	Dixidae										
	Forcipomyiinae										
	Muscidae										
	Simuliidae	<i>S (Meilloniellum)</i>									
		<i>S (M) hargreavesi</i>			287	115					
		<i>S (P) alcocki</i>				5					

		<i>S (P) bequaerti</i>									
		<i>S (P) harrisoni</i>	28								
		<i>S (P) merops</i>									
		<i>S. (Nevermania) sp.</i>					32				
		<i>Simulium nigrirtarse</i>	8					400			
	Stratiomyidae										2
	Tabanidae										
	Tipulidae				126			1			
Ephemeroptera	Baetidae	<i>Afroptilum sudafricanum</i>	15		10			42	164		
		<i>Baetis harrisoni</i>	25		102	10			11		
		<i>Centroptiloides bifasciata</i>			3	1					
		<i>Cloeon sp.</i>		17				2		30	215
		<i>Demoreptus rapensis</i>									
		<i>Demoulinia crassi</i>		5						7	
		<i>Pseudocloen vinosum</i>	24	11	48	11		11	4		
		<i>Pseudopannota sp.</i>			31	21					
	Caenidae	<i>Caenis sp.</i>		9	3			4	1	61	
	Heptageniidae	<i>Afronurus sp.</i>			28	12					
	Leptophlebiidae	<i>Adenophlebia sp.</i>	13					17			
		<i>Choroiterpes nigrescens</i>									
		<i>Euthraulius elegans</i>		7	9	5					
	Teloganodidae	<i>Lestagella penicillata</i>									
		<i>Nadinetella sp. (unidentifiable species)</i>	1								
Hemiptera	Belostomatidae										1
	Corixidae										2
	Gerridae			3				4			2

	Mesoveliidae									2
	Naucoridae		2	3			1			
	Notonectidae		20	4			5			1
	Pleidae									
	Veliidae			12						7
Isopoda	Anthuridae									2
	Sphaeromatidae					11				27
Lepidoptera	Nymphulinae			1						
Megaloptera	Corydalidae		2		1					
Mollusca (Mytiloidea)	Mytilidae					802				12
Odonata (Anisoptera)	Aeshnidae			1			2			8
	Corduliidae		3	3						
	Gomphidae		1	46						
	Libellulidae				1		1		2	19
Odonata (Zygoptera)	Chlorosyphidae									
	Coenagrionidae			4					1	38
	Lestidae						1			
	Platycnemididae									
	Protoneuridae						1			
Oligochaeta						50				18
Plecoptera	Notonemouridae	<i>Aphanicercella sp 1</i>	1							
		<i>Aphanicercella sp 2</i>								
		<i>Desmonemoura sp.</i>								
	Perlidae	<i>Neoperla sp.</i>				1				
Mollusca (Pulmonata)	Ancylidae							4	12	7
	Physidae								1	24
	Planorbidae									
Trichoptera	Ecnomidae	<i>Ecnomus thomasseti</i>								1
	Glossosomatidae	<i>Agapetus agilis</i>	4							
	Hydropsychidae	<i>Cheumatopsyche afra</i>			175			14		

		<i>Cheumatopsyche type 2</i>			13	16					
		<i>Cheumatopsyche type 7</i>	6								
		<i>Hydropsyche longifura</i>			5	32					
		<i>Macrostemum capense</i>									
	Hydroptilidae	<i>Hydroptila cruciata</i>				14					
	Leptoceridae	<i>Athripsodes sp.</i>			2						
		<i>Athripsodes bagensis</i>	11			2					
		<i>Leptocerus sp.</i>									61
		<i>Oecetis sp.</i>	4			8		1			
	Philopotamidae	<i>Chimarra sp.</i>				22					
	Pisuliidae	<i>Pisulia sp.</i>						2			
	Sericostomatidae	<i>Cheimacheramus caudalis</i>									
Turbellaria	Rhabdocoela									51	
Mollusca (Veneroida:Sphaeriacea)	Sphaeriidae										
TOTAL TAXA			16	15	26	21	8	23	10	10	26

Table D.4: April 2010 autumn data

GROUP/ORDER	FAMILY	TAXON	K1	K2	K3	K4	K5	B1	B2	B4	B5
Amphipoda	Paramelitidae sp.1						15				30
	Paramelitidae sp.2						266				122
	Sternophysingidae										
Mollusca (Basommatophora)	Lymnaeidae			3	1						
	Littorinidae										
Coleoptera	Dytiscidae			1	1						
	Elmidae		17			7					
	Gyrinidae		4	3	3	1		3			
	Hydraenidae										
	Hydrophilinae							1		2	46
	Ptilodactylidae										
	Scirtidae							1			
Decapoda	Atyidae										7
	Palaemonidae					1	2				1
	Potamonautidae						4	1	2	3	1
Diptera	Ceratopogonidae			5		3				1	2
	Chironomidae		53	147	69	103	1	101	350	500	49
	Culicidae			29	5					12	28
	Dixidae							1			
	Forcipomyiinae							1			
	Muscidae										
	Simullidae	<i>S (Meilloniellum)</i>									
		<i>S (M) hargreavesi</i>	23		1200	365					
		<i>S (P) alcocki</i>									
		<i>S (P) bequaerti</i>				185					
		<i>S (P) harrisoni</i>	10								
		<i>S (P) merops</i>									

		<i>S. (Nevermania) sp.</i>									
		<i>Simulium nigrirtarse</i>	28						750		
	Stratiomyidae										
	Tabanidae				2						
	Tipulidae				1						
Ephemeroptera	Baetidae	<i>Afroptilum sudafricanum</i>	23		2			4	51		
		<i>Baetis harrisoni</i>	40		144	16			157		
		<i>Centroptiloides bifasciata</i>			3						
		<i>Cloeon sp.</i>	8	8	2					240	60
		<i>Demoreptus rapensis</i>	5								
		<i>Demoulinia crassi</i>	2	2	4			1		1	
		<i>Pseudocloen vinosum</i>	56		54	93		1	2		
		<i>Pseudopannota sp.</i>			62	12					
	Caenidae	<i>Caenis sp.</i>	6	2	3			6	4	310	
	Heptageniidae	<i>Afronurus sp.</i>			27	2					
	Leptophlebiidae	<i>Adenophlebia sp.</i>	9					37			
		<i>Choroaterpes nigrescens</i>									
		<i>Euthraulius elegans</i>			2	16					
	Teloganodidae	<i>Lestagella penicillata</i>	2								
		<i>Nadinetella sp. (unidentifiable species)</i>	3								
Hemiptera	Belostomatidae										1
	Corixidae		8								1
	Gerridae		1	6	2			1	4		
	Mesoveliidae										
	Naucoridae			1	3						
	Notonectidae			12	2			1			

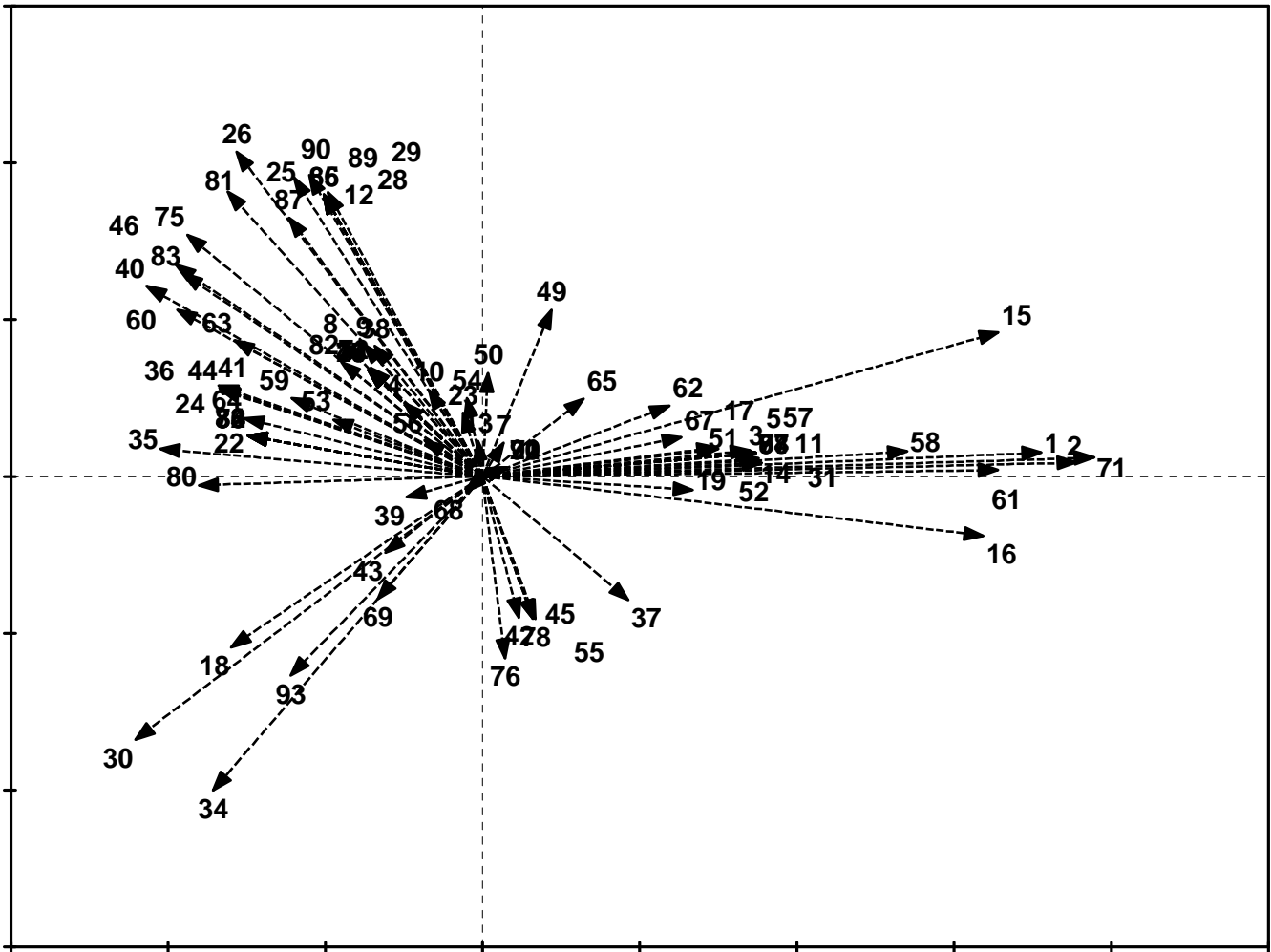
	Pleidae								1	
	Veliidae			5	22		1		6	4
Isopoda	Anthuridae									4
	Sphaeromatidae						42			13
Lepidoptera	Nymphulinae			1						
Megaloptera	Corydalidae		1		5	1				
Mollusca (Mytiloidea)	Mytilidae						1000			2
Odonata (Anisoptera)	Aeshnidae			3	3	1		1		
	Corduliidae									
	Gomphidae			6	7					
	Libellulidae		4	12	22			2		18
Odonata (Zygoptera)	Chlorosyphidae					1				
	Coenagrionidae			3	18			4		11
	Lestidae			2				1		
	Platycnemididae									
	Protoneuridae							2		
Oligochaeta							42			29
Plecoptera	Notonemouridae	<i>Aphanicercella sp 1</i>	11					3		
		<i>Aphanicercella sp 2</i>								
		<i>Desmonemoura sp.</i>	6							
	Perlidae	<i>Neoperla sp.</i>								
Mollusca (Pulmonata)	Ancylidae							3	34	1
	Physidae									2
	Planorbidae									
Trichoptera	Ecnomidae	<i>Ecnomus thomasseti</i>								2
	Glossosomatidae	<i>Agapetus agilis</i>								
	Hydropsychidae	<i>Cheumatopsyche afra</i>			228	3		1	102	
		<i>Cheumatopsyche type 2</i>			2	50				
		<i>Cheumatopsyche type 7</i>	3					1		
		<i>Hydropsyche longifura</i>			51	15				

		<i>Macrostemum capense</i>									
	Hydroptilidae	<i>Hydroptila cruciata</i>				6					
	Leptoceridae	<i>Athripsodes sp.</i>			3						
		<i>Athripsodes bagensis</i>	2			8					
		<i>Leptocerus sp.</i>									11
		<i>Oecetis sp.</i>				19					
	Philopotamidae	<i>Chimarra sp.</i>			3	27					
	Pisuliidae	<i>Pisulia sp.</i>						3			
	Sericostomatidae	<i>Cheimacheramus caudalis</i>									
Turbellaria	Rhabdozoa				5				7		
Mollusca (Veneroida:Sphaeriacea)	Sphaeriidae										
TOTAL TAXA			24	19	33	22	9	23	11	12	22

APPENDIX E: Functional feeding groups for most of the sampled macroinvertebrate taxa.

CLASS/ORDER	FAMILY/GENUS/SPECIES	FUNCTIONAL FEEDING GROUP
Ephemeroptera	Mostly	Collectors-gatherers(scrapers)
	Some	Filter feeders
	Few	Predatory
Diptera	Simuliidae	Collectors-filterers
	Chironomidae (most)	Scrapers (algae and detritus)/ collector-gatherers
	Culicidae	Filter feeders
Trichoptera	Hydropsychidae	Predators/Collector
	Ecnomidae	Predators/Collector
	Pisulidae	Shredders/Collector
	Leptoceridae	Shredder/Collector/Grazer/Predator
Megaloptera	Corydalidae	Predators
Hemiptera	Gerridae	Predators
	Notonectidae	Predators
	Naucoridae	Predators
	Belostomatidae	Predators
Plecoptera	Perlidae	Predators
	Notonemouridae	Shredders/Scrapers/grazers
Odonata	Mostly	Opportunistic predators (generalists)
Coleoptera	Elmidae	Shredders (organic matter)
	Gyrinidae	Predators
Mollusca	Snails	Scrapers/grazers (generalists)
	Bivalves	Collectors-filterers

APPENDIX F: Trend of species abundance across the NMS



All species present across all sites and seasons, where site positions are the same as those in Figure 4.16. The numbers are keyed to the following taxa: 1=Paramelitidae sp.1; 2=Paramelitidae sp.2; 3=Sternophysingidae; 4=Lymnaeidae; 5=Physidae; 6=Littorinidae; 7=Dytiscidae ; 8=Elmidae; 9=Gyrinidae; 10=Hydraenidae; 11=Hydrophilinae; 12=Ptilodactylidae; 13=Scirtidae; 14=Atyidae; 15=Palaemonidae ; 16=Potamonautidae; 17=Ceratopogonidae; 18=Chironomidae; 19=Culicidae; 20=Dixidae; 21=Forcipomyiinae; 22=Muscidae ; 23=*S (Meillonium) sp.*; 24=*S (M) hargreavesi*; 25=*S (P) alcocki*; 26=*S (P) bequaerti*; 27=*S (P) harrisoni*; 28=*S (P) merops*; 29=*S. (Nevermania) sp.*; 30=*Simulium nigritarse*; 31=Stratiomyidae; 32=Tabanidae; 33=Tipulidae; 34=*Afroptilum sudafricanum*; 35=*Baetis harrisoni*; 36=*Centroptiloides bifasciata*; 37=*Cloeon sp.*; 38=*Demoreptus rapensis*; 39=*Demoulinia crassi*; 40=*Pseudocloen vinosum*; 41=*Pseudopannota sp.*;

42=*Caenis* sp.; 43=*Adenophlebia* sp.; 44=*Afronurus* sp.; 45=*Choroterpes nigrescens*;
46=*Euthraulius elegans*; 47=*Lestagella penicillata*; 48=*Nadinetella* sp.(unidentifiable
species); 49=Belostomatidae; 50=Corixidae; 51=Gerridae; 52=Mesoveliidae;
53=Naucoridae; 54=Notonectidae; 55=Pleidae; 56=Veliidae; 57=Anthuridae;
58=Sphaeromatidae; 59=Nymphulinae; 60=Corydalidae; 61=Mytilidae; 62=Aeshnidae;
63=Corduliidae; 64=Gomphidae; 65=Libellulidae; 66=Chlorosyphidae;
67=Coenagrionidae; 68=Lestidae; 69=Platycnemididae; 70=Protoneuridae;
71=Oligocheata; 72=*Aphanicercella* sp 1; 73=*Aphanicercella* sp 2; 74=*Desmonemoura* sp.;
75=*Neoperla* sp.; 76=Ancylidae; 77=Planorbidae; 78=*Ecnomus thomasseti*; 79=*Agapetus*
agilis; 80=*Cheumatopsyche afra*; 81=*Cheumatopsyche* type 2; 82=*Cheumatopsyche* type 7;
83=*Hydropsyche longifura*; 84=*Macrostemum capense*; 85=*Hydroptila cruciata*;
86=*Athripsodes* sp.; 87=*Athripsodes bagensis*; 88=*Leptocerus* sp.; 89=*Oecetis* sp.;
90=*Chimarra* sp.; 91=*Pisulia* sp.; 92=*Cheimacheramus caudalis*; 93=Rhabdoceala;
94=Sphaeriidae.