RAPID BIOASSESSMENT OF THE ECOLOGICAL INTEGRITY OF THE LOURENS, PALMIET AND HOUT BAY RIVERS (SOUTH WESTERN CAPE, SOUTH AFRICA) USING AQUATIC MACROINVERTEBRATES

Dean Justin Ollis

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science (Ecological Assessment) at the University of Stellenbosch

Supervisor: Dr. C Boucher
Co-supervisor: Dr. KJ Esler

April 2005

DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature: …………………… Date: …………………………

SUMMARY

The primary aim of this study was to assess and compare the ecological integrity of the Lourens, Palmiet and Hout Bay Rivers (South Western Cape, South Africa) by examining the macroinvertebrate community structure at a series of representative sampling sites along the course of each river, using the South African Scoring System - Version 5 (SASS-5) rapid bioassessment method. Secondary aims included an examination of the effects of seasonal variability, biotope availability and site-specific environmental variables on the macroinvertebrate community structure at sampling sites, as well as the preliminary testing of the Integrated Habitat Assessment System (IHAS) for aquatic macroinvertebrates.

According to results obtained, the ecological integrity of sampling sites in the Mountain Stream Zone of the three rivers was consistently good. The Hout Bay River in the upper portions of the Orange Kloof Reserve was particularly near-pristine, with this area having been identified in this study as a potential biodiversity 'hot-spot' for aquatic macroinvertebrates. Downstream of the Mountain Stream Zone, there was a significant deterioration in the ecological integrity of all three rivers due to a number of probable causes. Results based on recorded SASS Scores and Average Score per Taxon (ASPT) values, using 'biological bands' generated from reference sites in the South Western Cape, were generally similar to and supported by the corresponding multivariate analyses undertaken. From the results of the various analyses undertaken in this investigation and some of the problems encountered in interpreting the data, a number of recommendations are made regarding future bioassessment studies based on the SASS within the national River Health Programme (RHP).

To test the IHAS, secondary data were obtained from reference sites in the Mpumalanga and Western Cape Provinces of South Africa. Assuming that SASS Scores at reference sites are the highest scores attainable, one would expect to find a positive relationship between SASS Scores and IHAS scores at reference sites. The assumption in this investigation was that this relationship should be linear. Non-parametric correlation analyses were undertaken between SASS-4/5 Scores and IHAS scores, using Kendall's Rank-correlation Coefficient (τ), with separate analyses undertaken for different geomorphological zones and biotope groups. Correlations between SASS Scores and IHAS scores were generally weak (τ-values mostly < 0.3) and unsatisfactory, with no significant correlations ($p < 0.05$) for two-thirds of the data sets analysed and a wide degree of scatter generally observed amongst data points in respective scatter plots. The performance of the IHAS varied between geomorphological zones and biotope groups, with the Foothill: Gravel-bed Zone in Mpumalanga showing the best results, particularly when the stones-in-current biotope group was analysed separately. Further testing of the IHAS is required to confirm its relative performance in different bioregions/ecoregions, geomorphological zones and biotope groups, which should be undertaken as a priority research area within the RHP. Unsuccessful attempts to test the IHAS by means of multiple regression analyses were undertaken, suggesting that such techniques should be avoided in further testing of the IHAS.

OPSOMMING

Die hoofdoel van hierdie studie was om die ekologiese toestand van die Lourens-, Palmiet- en Houtbaairiviere (Suidwes Kaap, Suid Afrika) te bepaal en te vergelyk deur die bestudering van die makroinvertebraatgemeenskapstruktuur by verteenwoordigende monsterpunte langs die riviere, met gebruik van die "South African Scoring System" – Weergawe 5 (SASS-5) snelle biologiese bepalingsmetode. Sekondêre doelwitte het die bepaling van die gevolge van seisoenele veranderlikheid, biotoop beskikbaarheid en ligging-bepaalde omgewingsveranderlikes op die makroinvertebraatgemeenskapstruktuur by monsterpunte ingesluit, asook die inleidende toetsing van die "Integrated Habitat Assessment System" (IHAS) vir watermakroinvertebrate.

Volgens die resultate verkry, was die ekologiese toestand van monsterpunte in die Bergstroomsone van die drie riviere konsekwent goed. Die Houtbaairivier in die boonste gedeelte van die Oranjekloofreservaat was veral feitlik onversteurd en hierdie streek is in die studie as 'n potensiaal biodiversiteit "hot-spot" vir watermakroinvertebrate geidentifiseer. Stroomafwaarts van die Bergstroomsone was daar 'n beduidende verswakking in die ekologiese toestand van al drie riviere, as gevolg van 'n aantal moontlike oorsake. Resultate gebaseer op bepaalde "SASS Scores" en 'Gemiddelde Waarde per Takson' ("Average Score per Taxon" - ASPT) waardes, met gebruik van 'biologiese bande' wat van verwysingsmonsterpunte in die Suidwes Kaap afgelei is, was oor die algemeen soortgelyk aan en gestaaf deur die ooreenstemmende multiveranderlikke ("multivariate") statistiese analises wat gedoen is. Uit die resultate van die verskeie analises wat in hierdie ondersoek gedoen is en sommige van die probleme wat in die dataverklaring gevind is, is 'n aantal aanbevelings gemaak met betrekking tot toekomende biologiese bepalingstudies vir die nasionale Riviergesondheidsprogram ("River Health Programme" - RHP) wat op die SASS gebaseer is.

Om die IHAS te toets is sekondêre data van verwysingsmonsterpunte in die Mpumalanga en Wes Kaap Provinsies van Suid Afrika verkry. As aangeneem word dat die "SASS Scores" by verwysingsmonsterpunte die hoogste moontlike tellings is wat bereik kan word, sou 'n positiewe verwantskap tussen "SASS Scores" en IHAS tellings by verwysingsmonsterpunte verwag word. Die veronderstelling in hierdie studie was dat dié verwantskap lineêr moet wees. Nie-parametriese korrelasieanalise tussen "SASS-4/5 Scores" en IHAS tellings is gemaak, deur gebruik van Kendall se Rangkorrelasiekoëffisiënt (τ), met afsonderlike analises vir verskillende geomorfologiese sones en biotoopgroepe verrig. Korrelasies tussen "SASS Scores" en IHAS tellings was algemeen swak (τ-waardes < 0.3) en onbevredigend, met geen beduidende korrelasies ("p" < 0.05) vir twee-derdes van die datastelle wat geanaliseer is nie en 'n wye verspreiding tussen datapunte in die onderskeie "scatter plots" wat waargeneem is. Die funksionering van die IHAS was verskillend tussen geomorfologiese sones en biotoopgroepe. Die beste resultate is vir die Voorheuwel: Gruisbeddingsone in Mpumalanga verkry, veral indien die klippe-in-stroom biotoopgroep afsonderlik geanaliseer is. Verdere toetsing van die IHAS is nodig om die relatiewe funksionering in verskillende biostreke/"ecoregions", geomorfologiese sones en biotoopgroepe te bevestig en dit behoort voorangs te geniet binne die RHP. Pogings om die IHAS deur middel van veelvoudige regressie analise te toets het misluk, wat aandui dat sulke tegnieke vermy moet word in verder toetsing van die IHAS.

ACKNOWLEDGEMENTS

Firstly, thanks to my long-suffering fiancé, Jules, for all the support and encouragement, and for bearing with me through the sometimes torturous journey of completing this thesis.

Secondly, thanks to my family (Mom, Dad and Samantha) for all your support and encouragement.

Sincere thanks to both my supervisors, Charlie Boucher and Karen Esler, for all their inspiration, input and assistance and for making this project a possibility.

A special thanks to the "River Health Team" – Melanie Withers, Emily Dawson and Johan Hayes – for assisting with field-work and general discussions regarding "our rivers".

In addition, I would like to thank the following people for their assistance and input:

- Toni Belcher (DWAF), Tovho Ndiitwani (DWAF), Dean Impson (CapeNature) and Candice Haskins (Scientific Services Department, City of Cape Town) for involving the University of Stellenbosch in this project, assisting with summer data collection and providing requested data;
- Dr. Martin Kidd (Statistics Department, University of Stellenbosch) for assistance with statistical analyses, particularly for Chapter 3 of this thesis;
- Helen Dallas (Freshwater Research Unit, University of Cape Town) for advice, input and discussions regarding many sections of this thesis;
- Charlene April (Freshwater Research Unit, University of Cape Town) for providing access to the PRIMER computer programme and users' manual;
- Justine Ewart-Smith (then with Southern Waters Research & Consulting cc) for providing access to the Rivers Database;
- Glenda Swart (SA Weather Service) and Lynn Taute (Lourensford Estate) for providing rainfall data;
- Barry Humby for granting access to the upper reaches of the Lourens River via Lourensford Estate;
- Samantha Wright (Table Mountain National Park) for granting access to the upper reaches of the Hout Bay River;
- Mark Johns for granting access to the Palmiet River within the Kogelberg Nature Reserve;
- Any other officials and landowners who provided permission for and assistance with accessing any of the study sites sampled during this investigation;
- Patrick Beneke (Zoology Department, University of Stellenbosch) for assisting with sampling equipment; and
- The National Research Foundation (NRF) for financial assistance.

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STRUCTURE OF THESIS

This thesis, which has been formatted according to the style of the *African Journal of Aquatic Science*, has been structured as follows:

- A general introduction to the meaning and assessment of ecological integrity and the use of aquatic macroinvertebrates for the rapid bioassessment of river ecosystems is provided in **Chapter 1**, with particular reference to South Africa and the South Western Cape.

- The results of an assessment of the macroinvertebrate communities of the Lourens, Palmiet and Hout Bay Rivers are presented and discussed in **Chapter 2**, including an examination of the effects of seasonal and biotope variability at the sampling sites. The influence of environmental variables (physical parameters and water chemistry) on the macroinvertebrate community structure at sampling sites is also considered in this chapter.

- In **Chapter 3**, a preliminary assessment to test and validate the Integrated Habitat Assessment System (IHAS) for aquatic macroinvertebrates is outlined.

- Finally, a synopsis and general conclusions are presented in **Chapter 4**.

<u>CHAPTER 1</u>:

GENERAL INTRODUCTION

A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.
Aldo Leopold, 1949 (Leopold 1966: 240)

INTRODUCTION

The concepts of ecological health and ecological integrity

The concepts of ecological or ecosystem health and, more specifically, river health have become quite prominent in ecology (Rapport 1989, Costanza *et al*. 1992, Shrader-Frechette 1994, Rapport *et al*. 1998b), especially in the domain of aquatic ecology (Uys 1994, Scrimgeour & Wicklum 1996, Boulton 1999). There is much debate amongst ecologists as to the meaning of 'ecosystem health' (Haskell *et al*. 1992, Karr 1993a, Shrader-Frechette 1994, Rapport *et al*. 1998a) or 'river health' (Boulton 1999, Karr 1999, Norris & Thoms 1999), and even as to whether these concepts are useful for ecosystem management (Suter 1993, Wicklum & Davies 1995). The majority of definitions put forward for ecosystem or river health, however, incorporate a consideration of human or societal values in addition to biophysical factors (Roux & Everett 1994, Meyer 1997, Roux 1997, Rapport 1998, Boulton 1999, Fairweather 1999).

The concept of ecological integrity, which became a major framework for investigation amongst ecologists before the emergence of the concept of ecological health (Karr & Dudley 1981, Woodley *et al.* 1993, Roux & Everett 1994, Cairns 1995), is firmly rooted in the natural sciences (Noss 1995, Bunn & Davies 2000, Moog & Chovanec 2000). Although an assessment of the health and integrity of an ecosystem both provide an indication of its condition, ecological *health* is measured relative to a human value-system, while ecological *integrity* is measured relative to the unimpaired state of the ecosystem.

There are differences of opinion as to the meaning and relevance of the concept of ecological integrity (Shrader-Frechette 1995, Wicklum & Davies 1995), particularly as applied to aquatic ecosystems, as well as disagreement amongst ecologists as to how it should be measured (see, for example, Woodley *et al*. 1993 and Westra & Lemons 1995). While the measurement of ecological integrity can be undertaken within a scientific framework that is largely objective (Steedman & Haider 1993, Moog & Chovanec 2000), the choice of indices and criteria to ultimately judge the integrity of an ecosystem is subjective (Kay 1993), as are decisions relating to management actions (Shrader-Frechette 1995). It is also important to realise that ecological integrity can be considered from an array of different spatial and temporal scales of analysis (Frissell *et al*. 1986, King 1993, Noss 1995, Allan *et al*. 1997).

The focus of this thesis is the ecological integrity (as opposed to ecological health) of river ecosystems, using aquatic macroinvertebrate community structure as an indicator. Ecological integrity can be defined as "the ability of an ecosystem to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components, on a temporal and spatial scale comparable to the natural characteristics of ecosystems within a specific region" (Kleynhans 1996 and Roux 1997, adapted from Karr & Dudley 1981). As such, ecological integrity implies that the structure and functioning of an ecosystem is unimpaired by anthropogenic stresses (Roux & Everett 1994, Roux 1997), and naturally occurring species are able to maintain viable population levels (Moog & Chovanec 2000). Ecological integrity can be conceptualised as an integration of the physical, chemical and biological conditions at a site relative to what would be expected in the absence of human activity (Karr & Dudley 1981, Cairns 1995, Karr & Chu 1995).

Although, on the one hand it is argued that, "Indeed, the whole concept of ecosystem integrity seems to be conceptually opaque and vague" (Shrader-Frechette 1995), on the other hand, "The notion of ecosystem integrity is intuitively appealing and understandable. We wish our ecosystems to be sound, whole, and unimpaired, and we understand, intuitively, what it means for an ecosystem to be in that state" (King 1993). Either way, the conservation of ecological integrity is critically important for aquatic ecosystems, as they are amongst the most threatened yet essential ecosystems on the planet.

The importance of assessing the ecological integrity of rivers

Freshwater ecosystems provide a host of critical life-support services and have an irreplaceable intrinsic value (Karr 1995, Davies & Day 1998, Karr & Chu 2000, Van Nieuwenhuizen 2001). There is widespread evidence that freshwater ecosystems, and rivers in particular, are amongst the most threatened ecosystems on Earth (O'Keeffe *et al*. 1989; Allan & Flecker 1993; Karr 1993a, b, 1995; Allanson 1995; Davies *et al*. 2000; Karr & Chu 2000). This is not surprising, since the ecological integrity of rivers and other freshwater ecosystems is a direct reflection of all the activities in the catchments they drain (Hynes 1975, O'Keeffe *et al*. 1989, Allanson *et al*. 1990, Dallas & Day 1993, Allanson 1995, Davies & Day 1998), and most catchments are subject to an array of ecologically unsustainable land-use and development activities.

Threats to the ecological integrity of river systems are most apparent in arid areas, being particularly severe in developing regions, where exponentially increasing water demands as a result of population growth and development pressure are placing excessive stress on freshwater resources (Davies & Wishart 2000). South Africa falls into this category, with water availability especially critical in the dry western sector of the country (Davies *et al*. 1995, Van Nieuwenhuizen 2001), which encompasses the South Western (SW) Cape Mediterranean-climate Region. River systems in the SW Cape, which falls within the Cape Floral Kingdom, are characterised by aquatic biota with high levels of diversity and endemism (Harrison & Agnew 1962, Van Nieuwenhuizen 2001, Wishart & Day 2002). Like rivers in other Mediterranean-climate regions, these systems (with large degrees of natural variability and low-flows during summer) are particularly susceptible to human impacts (Gasith & Resh 1999, Bonada 2003). The most effective way of protecting vulnerable systems such as these together with their biota, according to Karr (1992) and Angermeier & Karr (1994), would be to focus policy directives and management actions on the maintenance of ecological integrity, instead of on the less comprehensive aspect of conserving biodiversity.

The conservation of the ecological integrity of freshwater ecosystems in the South Western Cape Region is critical because, firstly, species and whole ecosystems are under threat of extinction and, secondly, fresh water as a resource is fast becoming a limiting factor for economic development (Van Nieuwenhuizen 2001). Assessing the ecological state of the rivers and other freshwater ecosystems in the region is a vital starting point for the development of appropriate conservation strategies. Furthermore, the country's National Water Act No. 36 of 1998 (Republic of South Africa 1998b) provides legal impetus for ecological assessments of water resources to be undertaken.

Relevant national legislation in South Africa

The assessment and protection of the ecological integrity of aquatic ecosystems is a central tenet of the South African National Water Act (Republic of South Africa 1998b), which establishes the national Department of Water Affairs and Forestry (DWAF) as the custodian of the country's water resources. According to Section 13(1) of the Act, every significant water resource in the country must be classified and verifiable resource quality objectives must be determined according to the assigned class. The classification system and resource quality objectives must take into account, *inter alia*, the characteristics and quality of the water resource and of the instream and riparian habitat, and the characteristics and distribution of aquatic biota (Section 13(3), Republic of South Africa 1998b). Environmental Impact Assessment (EIA) Regulations (Government Notice R.1182 of 5 September 1997, as amended), promulgated under the Environment Conservation Act No. 73 of 1989 (Republic of South Africa 1989), and the National Environmental Management Act

(Republic of South Africa 1998a) also contain provisions whereby, under certain circumstances, ecological assessments of freshwater ecosystems are required to be undertaken.

According to Section 137 of the National Water Act (Republic of South Africa 1998b), a national monitoring system must be established to collect information and data on, *inter alia*, the quality of water resources, compliance with resource quality objectives, and the health of aquatic ecosystems. The national River Health Programme (RHP) plays a direct role in this regard for river ecosystems, and in the determination of the classes and resource quality objectives for rivers (Mangold 2001).

The South African River Health Programme (RHP)

The RHP was initiated by the DWAF in 1994, with the main purpose of providing information regarding the overall ecological status of river ecosystems in South Africa (Roux *et al*. 1999b). The objectives of the RHP, which grew out of the National Aquatic Ecosystem Biomonitoring Programme (NAEBP), are to (Roux 1997):

- measure, assess and report on the ecological state of river ecosystems;
- detect and report on spatial and temporal trends in the ecological state of river ecosystems; and
- identify and report on emerging problems regarding the ecological state of river ecosystems in South Africa.

The approach of the RHP is to characterise the effect of multiple disturbances on the aquatic environment by monitoring the response of the biota, with the assumption that the integrity of the biota provide a measure of the ecological integrity of the river as a whole (Roux *et al*. 1999b). Consequently, the RHP rests on the foundations of rapid biomonitoring and the use of standardised indicators (Mangold 2001).

Communities of fish, aquatic invertebrates and riparian vegetation are the primary indicators of ecological integrity used in the RHP, with a number of abiotic indicators (including geomorphology and habitat integrity) used to characterise a site (Dallas 2000a) and aid interpretation of the biological results (Roux *et al*. 1999b, Mangold 2001). One of the main outputs of the RHP is the production of “State-of-Rivers (SoR) Reports” (e.g. River Health Programme 2001a, b, 2002, 2003a, b).

BIOTIC INDICES IN AQUATIC ECOSYSTEM ASSESSMENT

The use of biota

A multitude of inter-related physical, chemical and biological factors affect the ecological integrity of river ecosystems (Hawkes 1979, Dallas & Day 1993, Metcalfe-Smith 1994, Friedrich *et al*. 1996). These factors can be grouped into classes such as water quality, flow regime, habitat structure, biotic interactions and energy sources (Karr 1993a, b, 1995; Roux 1997; Karr & Chu 2000), as presented in Figure 1.1. It is impractical and probably impossible to measure and monitor all the factors contributing to the ecological integrity of a river system. Therefore, as in the South African RHP, a limited number of indicators are generally used to determine the ecological status of a river.

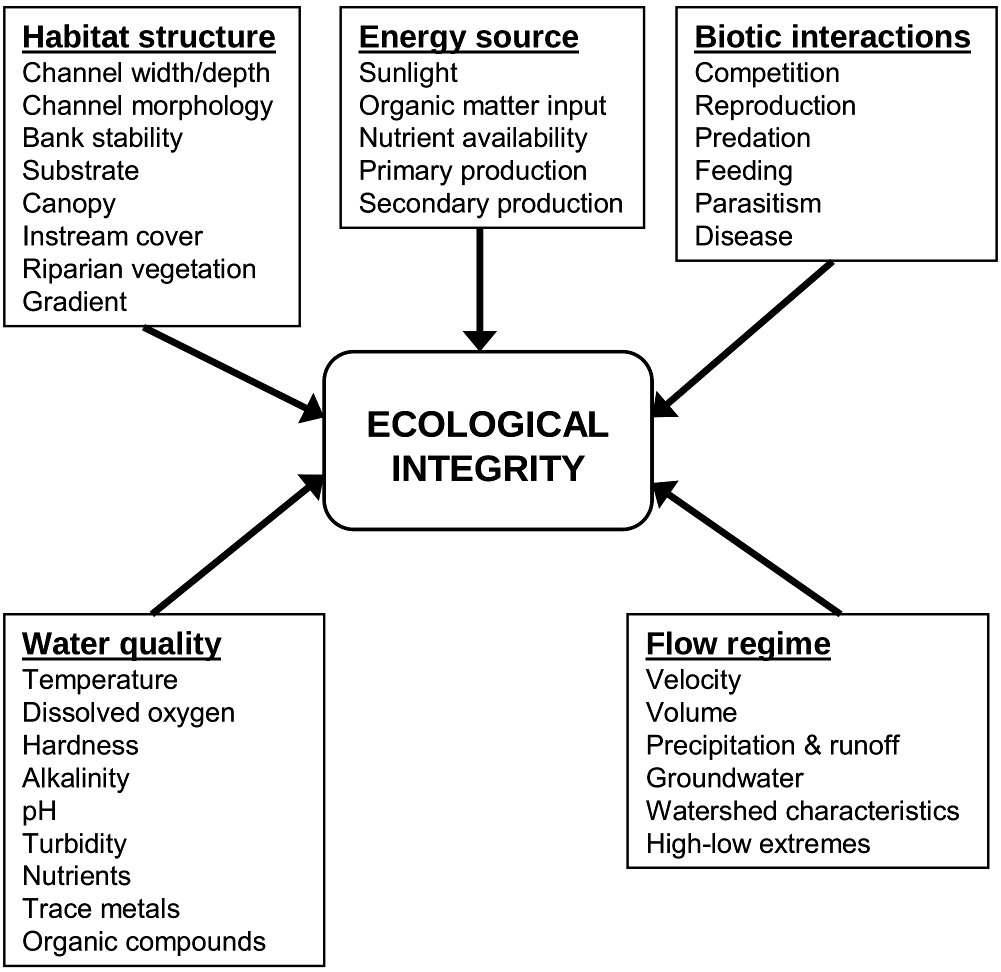

Figure 1.1: Factors affecting the ecological integrity of river ecosystems (modified from Dallas & Day 1993 and Roux 1997, originally from Karr *et al*. 1986)

Elements of the biota are considered to be particularly good indicators of ecological integrity, or of the degree of water quality impairment in an aquatic system (Hynes 1960; Chandler 1970; Hawkes 1979, 1982; Hellawell 1986; Wright 1995; Friedrich *et al*. 1996, Norris *et al*. 2001), because they integrate and reflect the cumulative effects of the factors impacting on an ecosystem over time (Balloch *et al*. 1976, Cullen 1990, Dallas & Day 1993, Roux *et al*. 1993, Metcalfe-Smith 1994, Roux & Everett 1994, Chutter 1995, Dallas 1995, Resh *et al*. 1996, Barbour *et al*. 1999, Karr & Chu 2000). It has been recognised that the limited application of bioassessment in the past has been a major factor responsible for the deterioration of the ecological integrity of river ecosystems (Cairns 1990; Roux & Everett 1994; Karr 1993a, b, 1995; Karr & Chu 1995, 2000; Roux *et al*. 1999a; Dallas 2002). Consequently, biological indicators (or bio-indicators) are now a key element of environmental and water resource management policies in many countries (Chessman 1995, Norris & Norris 1995, Noss 1995, Moog & Chovanec 2000).

Biomonitoring and bioassessment are based on the assumption that measurements of the responses, condition and/or community integrity of biota can be used to assess the ecological integrity of an ecosystem (Hawkes 1979, 1982; Herricks & Cairns 1982; Hellawell 1986; Cullen 1990; Spellerberg 1991; Cairns & Pratt 1993; Karr 1993a; Roux *et al*. 1993; Roux & Everett 1994; Dallas 1995, 2002; Karr & Chu 2000). The ecological integrity of an ecosystem can be determined by using numerous attributes of individual species (e.g. growth rate), biotic communities (e.g. species composition) or natural processes (e.g. rate of nutrient cycling) as biological indicators (Dallas & Day 1993, Johnson *et al*. 1993, Dallas 1995, Friedrich *et al*. 1996). In the aquatic sciences, the use of biotic communities in bioassessments is relatively well established (Dallas 1995, Uys *et al*. 1996) and this thesis is concerned with the ecological assessment of river ecosystems at the community level.

Biotic indices and rapid bioassessment

Biological community data can be summarised and presented as simple, numeric or categorised indices. These indices allow the results of ecological assessments to be communicated in a way that is understandable to natural resource managers, decision-makers, politicians and the general public (Beck 1955, Hawkes 1979, Spellerberg 1991, Resh & Jackson 1993, Davis 1995, Resh *et al*. 1995, Uys *et al*. 1996, Stark 1998). Three basic types of indices can be generated (Johnson *et al*. 1993): diversity indices, comparison (similarity or dissimilarity) indices and biotic indices. The differences between these index types are discussed in detail by Hawkes (1982), Washington (1984), Resh & Jackson (1993), Metcalfe-Smith (1994) and Dallas (1995). Of these, biotic indices are the most widely used.

With biotic indices, each taxon from a particular group of organisms is assigned a sensitivity weighting or 'score' based on the tolerance or sensitivity to particular pollutants. The scores of all the individual taxa sampled at a site are summed and/or averaged to provide a value by which the integrity of the biotic community at the site can be gauged. Some biotic indices include abundance estimates in the scoring system.

The Saprobien or Saprobic System, which stems from the research work of Kolkwitz and Marsson in German rivers in the early 1900's, is generally considered to be the first biological scoring system for the assessment of water quality in river ecosystems (Washington 1984, Rico *et al*. 1992, Knoben *et al*. 1995, Friedrich *et al*. 1996, Verdonschot 2000, Sandin *et al*. 2001). Indices based on the Saprobien System are determined by the presence and absence of specific indicator species from a number of different groups and trophic levels (mainly bacteria, algae, protozoans and rotifers, but including some benthic invertebrates and fish) for which the tolerances to organic pollution have been established (Herricks & Cairns 1982, Metcalfe 1989, Reynoldson & Mecalfe-Smith 1992, Metcalfe-Smith 1994). Selected components of the total aquatic community are thus used as an indicator for the degree of organic pollution (Tolkamp 1984, Guhl 1987, Spellerberg 1991, Friedrich *et al*. 1996). Most modern biotic indices, on the other hand, are based on the presence and pollution-tolerances of the community of organisms sampled from a particular group (such as the benthic macroinvertebrates).

Saprobien-based systems still in use in Western Europe include the German Standard Method and the Biologically Effective Organic Loading (BEOL) Method in Germany (Metcalfe-Smith 1994, Friedrich *et al*. 1996), the Quality-index or K-index in the Netherlands (Metcalfe-Smith 1994), and saprobic systems for ecological river surveys in Belgium (Moog & Chovanec 2000) and Austria (Chovanec *et al*. 2000, Iverson *et al*. 2000) that are also used in Sweden (Johnson & Goedkoop 2000). Generally, the Saprobien System has been used more commonly in Central and Eastern Europe (Ghetti & Bonazzi 1977, Hawkes 1982, Rico *et al*. 1992, Davis 1995, Knoben *et al*. 1995, Friedrich *et al*. 1996) than in other parts of the world. The saprobic approach has never found widespread acceptance in North America (Cairns & Pratt 1993, Davis 1995) nor, it seems, in other parts of the world outside of Europe (Herricks & Cairns 1982).

In recent years, with limited time and resources available for ecological impact assessments, there has been a great emphasis on community-level rapid bioassessment techniques and the use of biotic indices (Spellerberg 1991), particularly in the field of aquatic ecosystem assessment (Cairns & Pratt 1993, Norris & Georges 1993, Resh & Jackson 1993, Norris 1994, Norris & Norris 1995, Resh *et al*. 1995, Chessman & McEvoy 1998, Barbour *et al*. 1999, Norris & Thoms 1999, Brown 2001, Dallas 2002, Metzeling *et al*. 2003). Rapid bioassessment techniques, which usually involve qualitative (or semi-quantitative) sampling with few or no replicates and limited taxonomic resolution, have been developed to cost-effectively highlight problem areas where follow-on and more intensive, quantitative ecological and chemical studies need to be undertaken (Chessman 1995, Chutter 1995, Resh *et al*. 1995). Rapid assessment techniques are therefore not seen as a replacement for more traditional quantitative studies, but rather as a precursor to these.

A variety of organisms have been used in the bioassessment of the water quality and ecological integrity of freshwater ecosystems, including bacteria, protozoans, diatoms, algae, macrophytes, macroinvertebrates and fish (Dallas & Day 1993, Roux *et al*. 1993, Dallas 1995, Barbour *et al*. 1999, Brown 2001). Of these, benthic macroinvertebrates are the most widely used group (Cairns & Dickson 1971, Hellawell 1986, Norris 1994, Resh *et al*. 1995, Dallas 2002), especially for lotic systems (Chandler 1970; Hawkes 1979, 1982; Metcalfe 1989; Dallas & Day 1993, 2004; Metcalfe-Smith 1994; Chutter 1995; Knoben *et al*. 1995; Resh *et al*. 1996; Norris & Thoms 1999; Milner & Oswood 2000; Moog & Chovanec 2000; Sandin *et al*. 2001). Consequently, a number of biotic indices based on aquatic macroinvertebrates have been developed for the assessment of river ecosystems.

Biotic indices based on aquatic macroinvertebrates

There are a number of advantages to using benthic aquatic macroinvertebrates in the bioassessment of river ecosystems, including the following (summarised from Hellawell 1986, Metcalfe 1989, Reynoldson & Metcalfe-Smith 1992, Rosenberg & Resh 1993, Metcalfe-Smith 1994, Dallas 1995):

- They are ubiquitous and relatively abundant inhabitants of rivers, occupying most habitats;
- There are large numbers of species within aquatic macroinvertebrate communities with varying sensitivities to a wide variety of stresses and relatively quick reaction times, resulting in a spectrum of graded, recognisable responses to environmental perturbation;
- The responses to different types of pollution have been established for many common species;
- They are largely non-mobile and thus representative of the location being sampled, which enables effective spatial analyses of pollutant or disturbance effects to be undertaken;
- They have life cycles that are long enough for temporal changes caused by perturbations to be detected, but their life spans are also short enough to enable the observation of recolonisation patterns following perturbation;
- They are relatively easy and inexpensive to collect, particularly if qualitative sampling is undertaken;
- Their taxonomy is well established, at least to the family level for most groups, with identification keys available;

- Macroinvertebrate communities are very heterogeneous, with numerous phyla and trophic levels represented, so there is a high probability that at least some of these organisms will react to a particular change in environmental conditions;
- They are particularly well-suited to experimental approaches to biomonitoring; and
- Many methods of data analysis have been developed and are widely used for community-level assessments, including biotic indices.

Indeed, "benthic macroinvertebrates act as continuous monitors of the water they inhabit, enabling long-term analysis of both regular and intermittent discharges, variable concentrations of pollutants, single or multiple pollutants, and even synergistic or antagonistic effects" (Rosenberg & Resh 1993). As such, they are particularly useful for the bioassessment of aquatic ecosystems.

Numerous biotic indices and scoring systems, which are widely used for community-level assessments, have been developed. A number of these have been described by Washington (1984), Metcalfe (1989), Metcalfe-Smith (1994), Resh & Jackson (1993) and Dallas (1995). A comprehensive, updated comparative description of the more important or widely used indices and bioassessment methods, listed in chronological order, is provided below. A comparative summary of the biotic indices discussed is provided in Table 1.1, listed in alphabetical order. For each biotic index, a description is given of the habitats or biotopes sampled, the sampling equipment used, the sampling protocol followed, the level of taxonomic identification, whether identifications are laboratory- or field-based, the range of the final index value, and its current usage.

Beck's Biotic Index (Beck's BI) – 1954

Beck's BI (Beck 1954, cited by Beck 1955), developed for streams in Florida (USA), is considered to be the first true biotic index, with Beck credited for coining the term 'biotic index' (Washington 1984) or at least popularising it (Davis 1995). This index is based on the relative tolerances of macroinvertebrates to organic pollution, with field-sorting undertaken and identification to species level. Species known to be intolerant to slight organic pollution ("Class I organisms") and those known to be tolerant of moderate organic pollution ("Class II organisms") are distinguished from the rest of a sample. The final index value for a site is calculated by summing the number of species of Class I organisms, multiplied by two, and the number of species of Class II organisms. A single value ranging between 0 and approximately 40 is generated, with values greater than 10 indicating unpolluted sites and values between 1 and 6 indicating moderately polluted sites.

A modified version of Beck's Biotic Index, known as the *Florida Index (FI)* (Beck 1965, cited by Barbour *et al*. 1996, 1999; Ross & Jones 1979, cited by Resh & Jackson 1993 and Barbour *et al*. 1999), has been developed further. The sampling protocol for the FI involves the successive collection and field-sorting of specimens from all available biotopes by means of a hand-net for

10 minutes or until no new taxa are found (Resh & Jackson 1993). Laboratory-based identification is undertaken to genus and species levels (Barbour *et al*. 1999). The FI is currently used, where applicable, as a metric in the multimetric Rapid Bioassessment Protocols (RBPs) of the USEPA (Resh & Jackson 1993, Resh 1995, Barbour *et al*. 1995, 1999) or in regional adaptations thereof such as the Stream Condition Index for Florida streams (Barbour *et al*. 1996).

Trent Biotic Index (TBI) – 1964

The TBI (Woodiwiss 1964), to which the origin of most modern biotic indices is often traced (e.g. Metcalfe 1989, Reynoldson & Metcalfe-Smith 1992, Friedrich *et al*. 1996), was developed by the Trent River Authority in England. Qualitative, combined sampling of all available habitats is undertaken for 10 minutes by means of a hand-net. A single value is generated by this index, ranging from 0 (grossly polluted) to 10 (unpolluted). The value at a site is determined by the presence or absence of six key types of invertebrates with varying degrees of tolerance to organic pollution, together with the number of specific "groups" identified to family, genus or species levels.

In its application, the TBI was found to show a lack of sensitivity to water quality changes (e.g. Balloch *et al*. 1976, Hellawell 1977, Murphy 1978, Tolkamp 1984, Pinder *et al*. 1987, Friedrich *et al*. 1996). Consequently, an updated version of the index known as the *Expanded TBI* or *Extended Biotic Index (EBI)* (Woodiwiss 1978, cited by De Pauw & Vanhooren 1983 and Rico *et al*. 1992), with the maximum attainable value extended to 15, was produced (Hawkes 1982, Washington 1984, Metcalfe 1989, Spellerberg 1991). The EBI, modified to account for differences in the invertebrate taxa encountered, is widely used in Italy (Solimini *et al*. 2000), as is a further adaptation of the EBI based on family-level taxonomy and known as the *Indice Biotico Esteso (IBE)* (Ghetti 1997, cited by Solimini *et al*. 2000).

Indice Biotique (IB) – 1968

The IB (Tuffery & Verneaux 1968, cited by Metcalfe 1989) was derived from the TBI, for use in France. Lotic and lentic habitats are sampled separately using Surber and grab samplers, respectively, and two indices are calculated: a lotic sub-index and a lentic sub-index. Index values for the IB are determined by the presence of key groups and the number of pre-defined taxa (or 'systematic units', identified to family, genus or species level) in each sample, with laboratory-based identification. The IB was modified into the *Indice Biologique de Qualité Générale (IBQG)* (Verneaux *et al*. 1982, cited by Metcalfe 1989), which introduced a greater number of indicator groups and the sampling of eight different habitats at a site, defined on the basis of substrate and velocity conditions. The *Indice Biologique Global (IBG)* (AFNOR 1985, cited by Metcalfe 1989), which is based on the IBQG, was adopted as the standard bioassessment method throughout France (Metcalfe-Smith 1994). The IBG was superseded by an updated version known as the *Indice Biologique Global Normalisé (IBGN)* (AFNOR 1992, cited by Waterview Database n. d.).

With the IBGN, lotic habitats are sampled with a Surber sampler and lentic habitats with a hand-net (both 500 μm mesh). All these later modifications differ from the original IB in that faunal groups are mostly identified to family level.

Chandler's Biotic Score (CBS) – 1970

The CBS (Chandler 1970), originally developed for upland rivers in the Lothians Region of Scotland, is based on the TBI. However, unlike the TBI, it includes an abundance factor in the final calculation of the index score and only riffle (stones-in-current) areas are sampled with a hand-net (1 000 μm mesh size) for a total of 5 minutes. The total score is determined by summing the pollution tolerance scores for each defined "group" of invertebrate sampled (identified to genus or species), with a sliding scale for individual scores based on the estimated level of abundance. There is no upper limit for the final CBS value, but unpolluted sites generally have scores greater than 3 000 (Johnson *et al*. 1993).

The *Average Chandler Biotic Score (Avg. CBS)* (Jones 1973, cited by Hawkes 1979; Balloch *et al*. 1976), a modification of the CBS system with the final score for the number of groups present in a sample normalised, was developed because the original system generated low scores for unpolluted, headwater sites (Murphy 1978, Johnson *et al*. 1993). This normalised scoring system, which generates values ranging from 0 (severely polluted) to 100 (unpolluted), is more reliable than the original CBS system at discriminating between polluted and unpolluted sites (Washington 1984) and has been found to be a relatively robust indicator of water quality (e.g. Balloch *et al*. 1976, Cook 1976, Murphy 1978, Tolkamp 1984). However, the Avg. CBS has also been shown to be unreliable in certain situations, for example, the assessment of water quality in a chalk stream in England (Pinder & Farr 1987, Pinder *et al*. 1987). The CBS is currently used in some States of the USA as a metric in the multimetric RBPs of the USEPA (Resh & Jackson 1993, Resh 1995, Barbour *et al*. 1995, 1999).

Chutter's Biotic Index (CBI) – 1972

The CBI (Chutter 1972) for South African streams and rivers was developed to provide a measure of the degree of organic pollution. This system, which is loosely based on the TBI (Metcalfe-Smith 1994), involves sampling the stones-in-current biotope with a hand-net or Surber sampler (mesh size 290 μm). A spectrum of 'Quality Values' has been determined for an extensive list of pre-defined taxa (identified to various taxonomic levels), based on the known occurrence of the defined groups in polluted waters. A sliding scale, taking into account abundance and diversity, is used to assign Quality Values, which range from 0 (extremely sensitive taxa) to 10 (extremely tolerant taxa). Individual scores for each taxon are derived by multiplying the Quality Value by the number of individuals sampled. The final CBI value, which ranges from 0 (unpolluted) to 10 (severely polluted) and represents the average Quality Value for the organisms sampled, is calculated by dividing the sum of the individual scores for all the taxa sampled by the total number of individuals in the sample. The CBI was never widely used because it is based only on the stones-in-current biotope, it requires advanced taxonomic skills and the analysis of samples is slow, resulting in the method being too expensive for rapid bioassessments (Chutter 1994, 1995, 1998).

Hilsenhoff's Biotic Index (HBI) – 1977, 1982, 1987

The HBI (Hilsenhoff 1977, 1982, cited by Davis 1995; Hilsenhoff 1987), an adaptation of the CBI, was developed for evaluating organic and nutrient pollution in streams in the Wisconsin Region of North America. To determine the index value for a site, a sample of 100 or more arthropods is collected from riffle areas using a hand-net, which is taken back to the laboratory where at least 100 arthropods greater than 3 mm in length are picked out for identification to genus or species level. Each defined taxon was originally assigned a tolerance value between 0 (extremely pollution-sensitive) and 5 (extremely pollution-tolerant), based on information from streams in the Wisconsin area but, to provide greater precision, the scale for tolerance values was later extended to range from 0 to 10. As per the CBI, the final index value for a site is the average of the tolerance values for all individuals sampled. The original HBI has been refined in recent years by limiting the number of individuals scored in each taxon to ten, which remedies some problems commonly encountered with the system and reduces seasonal variability in the index value (Hilsenhoff 1998).

Hilsenhoff adapted his original index system for rapid, field-based bioassessment by providing mean tolerance values for common invertebrate families and limiting the sample size to 100 organisms (Hilsenhoff 1988). This modified, rapid assessment system generates a *Family-level Biotic Index (FBI)*. The final index-value for both HBI and FBI ranges from 0 (excellent water quality) to 10 (very poor water quality). The HBI, with tolerance values modified for specific geographic regions, is regularly used for water quality assessments in many States across the USA (Reynoldson & Metcalfe-Smith 1992). It also constitutes one of the metrics in many of the multimetric indices used in the USA (Davis 1995, Resh *et al*. 1995), including the RBPs of the USEPA (Fore *et al*. 1996; Barbour *et al*. 1992, 1995, 1999) or regional modifications thereof such as the Coastal Plain Macroinvertebrate Index (Maxted *et al*. 2000). In recent years, the FBI has been used successfully for the assessment of the water quality of rivers in southern Chile (Figuero *et al*. 2003).

Biological Monitoring Working Party (BMWP) Score System – 1978/79, 1980, 1983

The BMWP Score System (ISO-BMWP 1980, cited by Tolkamp 1984, 1985; Armitage *et al*. 1983) for the running waters in the United Kingdom, originally formulated in 1978 and modified in 1979 (Hawkes 1997), is loosely based on the CBS system. Scores are assigned to commonly-occurring invertebrate families, based on tolerances to organic pollution determined by the known distribution and abundances of the various family groups. Individual scores range from 1 (extremely pollution-tolerant) to 10 (extremely pollution-sensitive). All major aquatic habitat types are sampled with a pond-net of 900 μm mesh-size for a total of 3 minutes and taxa are identified in the field. The score values for all the pre-defined invertebrate families present in the sample for a site are summed to give the Total BMWP Score, which is divided by the number of taxa sampled to determine the Average Score Per Taxon (ASPT) for the site. The BMWP-ASPT index is a relatively robust measure of water quality for rivers in the United Kingdom (Armitage *et al*. 1983, Pinder & Farr 1987, Pinder *et al*. 1987, Metcalfe-Smith 1994).

The BMWP Score System is applied mainly in the UK, although it is also used in Finland (Iverson *et al*. 2000, Johnson *et al*. 2001) and Sweden (Johnson & Goedkoop 2000, Sandin *et al*. 2001). A version with tolerance scores adapted for tropical regions has been applied in an assessment of the water quality of streams in Chiang Mai, Thailand (Nuntakwang *et al*. 2002). Modified versions of the Score System, as used in Spain (IBMWP), South Africa (SASS), Australia (SIGNAL) and New Zealand (MCI), are described below.

Belgian Biotic Index (BBI) – 1983

The BBI (De Pauw & Vanhooren 1983) combines the sampling procedure of the TBI and the scoring system of the IB, but with lotic and lentic habitats scored together. All available habitats are sampled with a 300–500 μm hand-net for a total of 3 minutes (for rivers less than 2 m wide) or 5 minutes (for larger rivers). Collected macroinvertebrates are preserved *in situ* and taken back to the laboratory for identification, mainly to family or genus levels. The final index value ranges from 0 (very heavily polluted) to 10 (unpolluted), with values less than 5 indicating that the situation is critical. The BBI has been successfully applied throughout Belgium and in other countries, including Spain, Algeria, Luxemburg, Portugal and Canada (Metcalfe 1989). It is currently used in Belgium and some surrounding countries (Metcalfe-Smith 1994, Iverson *et al*. 2000).

Macroinvertebrate Community Index (MCI) – 1985

The MCI (Stark 1985, cited by Stark 1993), developed for assessing water quality in New Zealand streams, is based on the BMWP method and is similar to the CBI and HBI. Riffle areas are sampled with a hand-net or Surber sampler. Collected macroinvertebrates are preserved in the field and taken back to the laboratory for identification, mainly to genus level. Scores are allocated to a list of pre-defined taxa based on their pollution tolerances, with values from 1 (extremely pollution-tolerant) to 10 (extremely pollution-sensitive). The final index value for a site is calculated by summing the tolerance values for each taxon present in a sample, dividing by the number of taxa sampled and multiplying by a scaling factor of 20. Although the MCI can theoretically range between 0 and 200, in practice it rarely exceeds 150, with scores greater than 120 indicating pristine conditions and scores less than 50 indicating extreme pollution (Stark 1993).

A quantitative version of the MCI known as the Quantitative Macroinvertebrate Community Index (QMCI), which requires macroinvertebrate densities and multiple-replicate sampling has also been developed (Stark 1985, cited by Stark 1993). More recently, a Semi-Quantitative MCI (SQMCI) based on hand-net sampling that uses coded abundance estimates and requires fewer replicate samples has been derived from the QMCI (Stark 1998). The MCI has been used widely in New Zealand (Stark 1998), where it has been found to be effective in detecting water quality impacts in stony streams (Quinn & Hickey 1990, Stark 1993), and in lowland streams with both diverse substrates (Collier 1995) and predominantly fine bed-substrates (Collier *et al*. 1998). The QMCI has also been widely applied in New Zealand (Quinn & Hickey 1990, Stark 1993, Quinn *et al*. 1997, Stark 1998), while the SQMCI has been shown to be capable of providing similar assessments to the QMCI with less than 40% of the effort (Stark 1998).

Iberian BMWP (IBMWP/BMWP') – 1988

The IBMWP (Alba-Tercedor & Sánchez-Ortega 1988, cited by Bonada 2003), previously known as the BMWP' index (Rico *et al*. 1992, Zamora-Muñoz *et al*. 1995, Zamora-Muñoz & Alba-Tercedor 1996) and initially developed for rivers of the Iberian Peninsula (southern Spain), is an adaptation of the BMWP System. It is a qualitative or semi-quantitative method that uses a kick-net with 250 μm mesh size and field-based macroinvertebrate identification to family level. All available habitats are successively sampled over a 100 m stretch of river until no new taxa are recorded. Although all habitats should be sampled together, traditionally, lotic (mainly riffles) and lentic habitat groups have been sampled and analysed separately (Bonada 2003), and this procedure has been adopted for the recently-developed GUADALMED sampling methodology for river bioassessment in the Mediterranean Basin (Jáimez-Cuéllar *et al*. 2002, cited by Bonada 2003). Organisms not collected but observed in the field are included in the calculation of the final index.

The final IBMWP Score, Number of Taxa and IASPT (IBMWP Score divided by Number of Taxa) are calculated for a site based on all the taxa collected and observed. Separate indices can also be calculated for lotic and lentic habitat groups, if they have been collected and analysed separately. Abundances are estimated according to the following ranks: 1 = 1-3, 2 = 4-10; 3 = 11-100; 4 = >100 (Bonada 2003). Although these abundance estimates are not used to calculate the final indices, they aid the interpretation of IBMWP results. The IBMWP has been shown to be effective for the bioassessment of Iberian rivers and, in 1991, it was adopted by the Spanish Society of Limnology for use throughout the Iberian Peninsula (Zamora-Muñoz *et al*. 1995, Zamora-Muñoz & Alba-Tercedor 1996). This biotic index is the basis of the GUADALMED sampling methodology for river bioassessment in the Mediterranean Basin (Jáimez-Cuéllar *et al*. 2002, cited by Bonada 2003) and it is used in the ECOSTRIMED (ECOlogical STatus RIvers MEDiterranean) integrated river assessment index (Prat *et al*. 2000). It has also shown great potential for the assessment of rivers in the Basque Region of northern Spain (Rico *et al*. 1992). Furthermore, the IBMWP is used in Italy, where it has been shown to perform well and is predicted to perform even better with minor adaptations for that country (Solimini *et al*. 2000). Recently, the IBMWP has been successfully applied to the rapid assessment of river water quality in south-eastern Brazil (Cota *et al*. 2002).

South African Scoring System (SASS) – 1994/95, 1998, 2002

The SASS (Chutter 1994, 1995, 1998) was developed over several years as a macroinvertebrate-based biotic index for river assessments in South Africa by modifying and adapting the BMWP System. It is intended to be a rapid and inexpensive technique for the detection of water quality degradation or for revealing trends in water quality change over time (Chutter 1998) although, more broadly, it is also suitable for the assessment of the ecological integrity of river ecosystems (Dallas 1995, 1997, 2002; Uys *et al*. 1996; Dickens & Graham 2002). The SASS method has been developed for perennial, lotic systems with low to moderate flow hydrology, so it is not applicable in lentic systems or estuaries and should be used with caution in ephemeral systems (Dallas 2000b, Dickens & Graham 2002).

For the SASS, a list of pre-defined taxa (mostly identified to family level, but with a few groups such as the Oligochaeta identified to higher levels) have been allocated sensitivity weightings or "scores" based on their sensitivity to pollution and disturbance. Taxon scores range from 1 (extremely pollution-tolerant) to 15 (extremely pollution-sensitive). Macroinvertebrates are collected by qualitative "kick and sweep sampling", using a standardised collection net with 1 000 μm mesh size. Initially, up until Version 4 of the system (SASS4; Thirion *et al*. 1995), all biotopes at a site were sampled together. However, with the recent Version 5 (SASS5; Dickens & Graham 2002), macroinvertebrate samples are collected separately from three pre-defined biotope groups (stones in and out of current; marginal and aquatic vegetation; and gravel, sand and mud) according to a specified protocol (see Dickens & Graham 2002 and Chapter 2 of this thesis). Macroinvertebrates collected from each biotope group are identified in the field, and abundances are estimated using a coded log-scale to aid the interpretation of results. Two species-rich taxa, the Baetidae (Ephemeroptera) and Hydropsychidae (Trichoptera) are scored according to the number of different types/species present because both these groups include mostly pollution-sensitive species except for one (in the case of the Baetidae) or two (in the case of the Hydropsychidae) tolerant species (Chutter 1998, Dallas 2002).

Three principal indices are generated by SASS assessments, which are calculated for each biotope group and for the site as a whole: SASS5 Score, Number of Taxa and Average Score Per Taxon (ASPT). The SASS5 Score is the sum of the sensitivity scores for all SASS taxa present, while ASPT is calculated by dividing the SASS5 Score by the Number of Taxa. The SASS5 Score and ASPT are generally used together for the analysis and interpretation of SASS data (Chutter 1994, 1998; Dallas 1995, 1997, 2000b, 2002). However, the ASPT value has been shown to be a more robust and reliable measure of water quality impairment than the SASS Score, except at polluted sites where the SASS Score provides more meaningful results (Chutter 1994, 1998; Dallas 2000b; Dickens & Graham 2002).

The SASS method has been applied and extensively tested in different regions of South Africa, in rivers with varying degrees of impact (e.g. Chutter 1994, 1995, 1998; Dallas *et al*. 1994, 1998; Dallas 1995, 1997, 2000b, 2002; Dickens & Graham 2002). Provided data are analysed and interpreted appropriately, it has been shown to be a relatively robust and reliable indicator system, with the three indices (SASS Score, Number of Taxa and ASPT) reflecting changes in macroinvertebrate community structure (Vos *et al*. 2002). Revisions have been made where problems with the SASS have been identified, as evidenced by the fact that the system is in its fifth version. In recent years the SASS method has become the standard for the rapid bioassessment of rivers in South Africa and southern Africa (Dickens & Graham 2002), and it forms an integral component of the RHP (Uys *et al*. 1996, Dallas 2002, Vos *et al*. 2002). More recently the SASS is being used in other regions of southern Africa, including Zimbabwe (Phiri 2000), Swaziland and Zambia (pers. comm., Dr H. Dallas, Freshwater Research Unit, University of Cape Town).

Stream Invertebrate Grade Number – Average Level (SIGNAL) Biotic Index – 1995, 2003

The SIGNAL Biotic Index was initially developed for the assessment of water quality in the Hawkesbury-Nepean River system of New South Wales, eastern Australia (Chessman 1995) and later modified to broaden its applicability to the whole of Australia (Chessman 2003). Macroinvertebrates are collected from six pre-defined habitats present at a site. Riffles, pool edges and aquatic macrophytes are sampled with a hand-net (250 μm mesh), pool rocks and submerged wood are removed from the stream by hand, and soft sediment samples in deep lowland rivers are obtained with a grab sampler and then sieved through 250 μm mesh. For each habitat type, 100 invertebrates in total are collected with no more than 10 specimens per taxon. Specimens are preserved and taken back to the laboratory for identification to family level.

Sensitivity grades ("SIGNAL 1 grades") ranging from 1 (pollution-tolerant) to 10 (pollution-sensitive) were initially assigned to widespread families of macroinvertebrates in river systems of south-eastern Australia (Chessman 1995). Modified "SIGNAL 2 grades" were subsequently derived for macroinvertebrate families occurring across Australia (Chessman 2003). The SIGNAL biotic index, which is based on the ASPT component of the BMWP System and is calculated for each habitat type, is derived by summing the sensitivity grades of all families in a sample and dividing by the number of families present. A weighted index (SIGNAL-W), which takes abundance estimates into account, can also be calculated (Chessman 1994, 1995).

If a site has a SIGNAL 1 value greater than 6, water quality is considered to be good, while a

SIGNAL 1 value less than 4 indicates that severe pollution is probable (Chessman 1995). The original version of the SIGNAL Biotic Index is effective for the rapid bioassessment of water quality in rivers of south-eastern Australia (Chessman 1994, Growns *et al*. 1995, Metzeling *et al*. 2003), and the modified version is sensitive to a broad range of water quality variables in rivers across Australia (Chessman 2003). The SIGNAL Biotic Index constitutes the 'Aquatic Life' Sub-index of the Index of Stream Condition (ISC), which is a multiple index system developed for reporting on the ecological integrity of streams in the state of Victoria, eastern Australia (CEAH and ID&A 1997, Ladson *et al*. 1999, Ladson & White 2000).

Danish Stream Fauna Index (DSFI) – 1998

The DSFI (Skriver *et al*. 2000) was developed between 1996 and 1998 as a modification of earlier macroinvertebrate-based biotic indices used for the biological assessment of running waters in Denmark, *viz*. what became known as the Viborg Index (Andersen *et al*. 1984) and a subsequent adaptation known as the Danish Fauna Index (DFI). The DSFI is based on the TBI, but both positively and negatively scoring diversity groups are used. Also, sampling involves kick-sampling of all available habitats along each of three transects, at four equidistant points across the width of the stream, with transects approximately 10 m apart (placed diagonally across the stream if stream width is less than 1 m). The 12 kick samples, which are obtained using a hand-net with 500 μm mesh size, are combined for further analysis, and 5 minutes of hand-picking from submerged stones and large wooden debris is carried out. The pooled kick sample and the hand-picked sample are preserved separately in the field, with identification (to genus and family level) undertaken in the laboratory, keeping the two groups of samples separate.

The final index value for the DSFI varies from 1 (severely impaired) to 7 (best ecological quality). It is calculated by taking into account the number of diversity groups (i.e. the number of positive groups of taxa minus the number of negative groups of taxa, based on a list of positive and negative taxon groups) and the presence of particular indicator groups of taxa in the total fauna sample (i.e. kick samples plus hand-picked sample from each site). The final DSFI index value is obtained from a matrix table that has four categories for the number of diversity groups as columns and six indicator groups (with corresponding lists of indicator taxa) as rows. In 1998, the DSFI was adopted as the official method for the bioassessment of running waters in Denmark (Skriver *et al*. 2000), and it is currently used in Denmark and Sweden (Johnson *et al*. 2001, Sandin *et al*. 2001).

BalkaN Biotic Index (BNBI) – 1999

The BNBI (Simić & Simić 1999) was developed on tributaries of the Danube River in Serbia, for river water quality assessment in the Balkan Peninsula. Loosely based on the CBS, the BNBI requires an estimation of the abundance of sampled macroinvertebrates. It incorporates measures of the dominance and constancy of the taxa sampled, together with a measure of the diversity of the macroinvertebrate community at a sampling site. Quantitative sampling is undertaken with a benthos net and laboratory identification of preserved samples (invertebrates >0.5 mm) is undertaken to the level of genera, families, subfamilies and/or pre-defined groups (generally at the level of class or order). The final BNBI value for a sampling site is calculated from a matrix table, which includes groups of commonly occurring taxa together with categorised values for the dominance of specific taxa according to the Tischler Scale (Tischler 1949, cited by Simić & Simić 1999), and the diversity of various genera and groups according to the Shannon-Weaver Index (Shannon & Weaver 1963, cited by Simić & Simić 1999). The BNBI ranges from 0 (for heavily polluted waters) to 5 (for very clean waters). Before it can be widely applied in the Balkan Region of South East Europe, the BNBI requires testing and refinement through further studies in countries neighbouring Serbia (Simić & Simić 1999).

Table 1.1: Comparison of biotic indices based on aquatic macroinvertebrates

Biotic Index	Abbreviation	Biotopes sampled[1]	Sampling equipment[2]	Sampling protocol[3]	Taxonomic level[4]	Identification protocol[5]	Final index range	Current usage
Average Chandler Biotic Score	Avg. CBS	SIC	Hand-net (1000 μm)	SQ, 5 min	S+G	NS	0–100	USA
BalkaN Biotic Index	BNBI	All, combined	Benthos net	Q	G+sF+F	Lab-based	0–5	Serbia
Beck's Biotic Index	Beck's BI	All, combined	NS	NQ	S	Lab-based	0–*c.*40	None
Belgian Biotic Index	BBI	All, combined	Hand-net (300–500 μm)	NQ, 3/5 min	G+F	Lab-based	0–10	Belgium and surrounding countries
Biological Monitoring Working Party Score System	BMWP	All, combined	Hand-net (900 μm)	NQ/SQ, 3 min	F	Field-based	0–*c.*200 (Score) 0–10 (ASPT)	UK, Finland, Sweden
Chandler's Biotic Score	CBS	SIC	Hand-net (1000 μm)	SQ, 5 min	S+G	NS	0–∞	USA
Chutter's Biotic Index	CBI	SIC	Hand-net / Surber (290 μm)	Q	S+G+F	NS	0–10	None
Danish Stream Fauna Index	DSFI	All, combined	Hand-net (500 μm)	SQ, 12 samples	G+F	Lab-based	0–7	Denmark, Sweden
Extended Biotic Index / Expanded TBI	EBI	All, combined	Hand-net	NQ, 10 min	S+G+F	Lab-based	0–15	Italy (modified)
Family-level Biotic Index	FBI	SIC	Hand-net	Q, 100 organisms	F	Field-based	0–10	USA, Chile
Florida Index	FI	All, combined	Hand-net	NQ, 10 min	S+G	Lab-based	0–40	Florida (USA)
Hilsenhoff's Biotic Index	HBI	SIC	Hand-net	Q, >100 organisms	S+G	Lab-based	0–10	USA
Iberian BMWP	IBMWP / BMWP'	Lotic + Lentic, combined/ separate	Hand-net	NQ	F	Field-based	0–*c.*200 (Score) 0–10 (ASPT)	Spain, Italy

Biotic Index	Abbreviation	Biotopes sampled[1]	Sampling equipment[2]	Sampling protocol[3]	Taxonomic level[4]	Identification protocol[5]	Final index range	Current usage
Indice Biologique Global Normalisé	IBGN	8 pre-defined habitats, separate	Surber + Hand-net (500 μm)	NQ/SQ	F	Lab-based	0–20	France
Indice Biotico Esteso	IBE	All, combined	Hand-net	NQ, 10 min	F	Lab-based	0–15	Italy
Indice Biotique	IB	Lotic + Lentic, separate	Surber + Grab	SQ	S+G+F	Lab-based	0–10	None
Macroinvertebrate Community Index	MCI	SIC	Hand-net / Surber	NQ	G	Lab-based	0–200	New Zealand
Quantitative MCI	QMCI	SIC	Surber	Q	G	Lab-based	0–10	New Zealand
Semi-Quantitative MCI	SQMCI	SIC	Hand-net	SQ	G	Lab-based	0–10	New Zealand
South African Scoring System, Version 4	SASS4	S+V+GSM, combined	Hand-net (1000 μm)	NQ/SQ	F	Field-based	0–*c*.250 (Score) 0–15 (ASPT)	None
South African Scoring System, Version 5	SASS5	S+V+GSM, separate	Hand-net (1000 μm)	NQ/SQ	F	Field-based	0–*c*.250 (Score) 0–15 (ASPT)	Southern Africa
Stream Invertebrate Grade Number – Average Level Weighted Biotic Index	SIGNAL-W	6 pre-defined habitats, separate	Hand-net (250 μm) + Grab	SQ, 100 orgs.	F	Lab-based	0–10	Australia
Trent Biotic Index	TBI	All, combined	Hand-net	NQ, 10 min	S+G+F	Lab-based	0–10	None

[1] SIC = stones-in-current (riffles); S = stones (in- & out-of-current); V = vegetation; GSM = gravel, sand and mud
[2] Mesh size in brackets, where known; hand-net also known as a kick-net, sweep-net, dip-net or pond-net; NS = not stipulated
[3] Q = quantitative; SQ = semi-quantitative; NQ = non-quantitative (qualitative)
[4] S = species; G = genus; F = family; sF = sub-family
[5] NS = not stipulated

Limitations of biotic indices and alternative approaches

It is clear that a number of biotic indices based on aquatic macroinvertebrates have been developed and are successfully being used for the bioassessment of rivers in many parts of the world. However, biotic indices have not to date been developed or used to any significant extent in Latin America (Pringle *et al*. 2000), Central and Eastern Asia (Li *et al*. 2000), or South-east Asia (Dudgeon *et al*. 2000). On the Indian sub-continent, no biotic indices are used for assessing the water quality of rivers because none of the currently available biotic indices from other countries have been found to be entirely suitable (Gopal *et al*. 2000).

Despite their proven utility in rapid bioassessments, biotic indices must be carefully interpreted using supplementary data and will always have significant limitations (Hellawell 1977, Herricks & Cairns 1982, Washington 1984, Guhl 1987, Spellerberg 1991, Reynoldson & Metcalfe-Smith 1992, Cairns & Pratt 1993, Norris & Georges 1993, Metcalfe-Smith 1994, Knoben *et al*. 1995, Norris 1995, Resh *et al*. 1995, Friedrich *et al*. 1996, Verdonschot 2000). Some limitations include the restricted applicability to a particular geographic area and/or type of stressor (Washington 1984, Johnson *et al*. 1993, Norris & Georges 1993, Metcalfe-Smith 1994, Friedrich *et al*. 1996), usually organic pollution, and the inability to detect moderate degradation.

As a result of the limitations of biotic indices, a number of alternative approaches to the rapid bioassessment of river ecosystems from a community perspective have been pursued. These include the use of community comparison indices, functional feeding groups and reduced assemblages (see Metcalfe-Smith 1994 and Dallas 1995 for descriptions of these alternative approaches), or simplified diversity indices such as the Sequential Comparison Index (SCI; Cairns *et al*. 1968, Cairns & Dickson 1971). The use of family-level meta-analysis and abundance/biomass curves, which require quantitative sampling and have been more widely applied in marine pollution studies, have also been explored (Brown 2001). The development of diagnostic biotic indices, which have a suite of sensitivity scores for different types of impact (to address the problem of invertebrate taxa having varied responses to different impacts), has also been pursued using the SIGNAL biotic index system (Chessman & McEvoy 1998). Few of these approaches to rapid bioassessment have, however, found widespread application.

USING BIOTIC INDICES AND INTERPRETING BIOASSESSMENT DATA

Multimetric versus multivariate approaches to interpretation

The most significant advances in the bioassessment of aquatic ecosystems using macroinvertebrates have, arguably, been the development of the multimetric and multivariate approaches to the interpretation of bioassessment data, including biotic indices. There are differences in opinion and conflicting evidence as to which of these divergent approaches to interpretation is the most reliable (Milner & Oswood 2000, Sandin *et al*. 2001), with most countries/regions following or moving towards one of the two approaches.

Multimetric approach

The multimetric approach involves the integration of a number of structural and functional attributes of macroinvertebrate communities, known as metrics, into a composite index. Most multimetric indices are based on the Index of Biotic Integrity (IBI) (Karr 1981; Karr *et al*. 1986, cited by Barbour *et al*. 1995), initially developed for riverine fish communities. Multimetric indices are constructed and interpreted in an ecoregional or bioregional context (see discussion on reference conditions below). Comprehensive descriptions of the multimetric approach to bioassessment are given by Barbour *et al*. (1995) and Barbour & Yoder (2000). The multimetric approach was developed and is followed mainly in the USA, where it is used by most state water resource management agencies (Southerland & Stribling 1995, Barbour & Yoder 2000, Milner & Oswood 2000, Sandin *et al*. 2001). This approach has more recently been applied in other regions, for example, for river biomonitoring in west-central Mexico (Weigel *et al*. 2002) and within a regional, macroinvertebrate-based comparative assessment of the ecological integrity of streams and rivers in eight European countries (Sandin *et al*. 2001).

The macroinvertebrate Rapid Bioassessment Protocols (RBPs) for streams and rivers (Plafkin *et al*. 1989, Barbour *et al*. 1999), developed by the US Environmental Protection Agency (EPA) and used widely throughout the USA, are based on the multimetric approach to bioassessment. Other good examples of multimetric indices for macroinvertebrates are the Invertebrate Community Index (ICI) (Ohio EPA 1987, cited by DeShon 1995) and the Benthic IBI (B-IBI) (Kerans & Karr 1994). The ICI is frequently used for bioassessment, where applicable, in the USA (Reynoldson & Metcalfe-Smith 1992), while the B-IBI, appropriately modified for the region of application, has been shown to have great potential in the assessment of the ecological integrity of aquatic systems (Kerans & Karr 1994, Fore *et al*. 1996, Karr & Chu 2000).

Multivariate approach

The predictive multivariate approach to bioassessment is, in contrast to the multimetric approach, based on the association between macroinvertebrate communities and the environmental attributes of sampling sites (Reynoldson & Metcalfe-Smith 1992, Metcalfe-Smith 1994). The basis for the multivariate approach is the similarity index, with classification, ordination and discriminant analysis being the most common multivariate techniques used (Sandin *et al*. 2001). This approach is exemplified by the River InVertebrate Prediction And Classification System (RIVPACS) developed for lotic systems in the UK (Wright *et al*. 1984, 1989; Furse *et al*. 1984; Moss *et al*. 1987), where it has since 1990 been used in five-yearly nation-wide bioassessments of river water quality (Wright 1995, Wright *et al*. 1998a, Hemsley-Flint 2000). A thorough account of the development and use of RIVPACS is provided by Wright (1995, 2000), while recent modifications to the system and some of its potential applications are discussed by Wright *et al*. (1998a) and in Wright *et al*. (2000).

Briefly, RIVPACS (a computer software package) uses a small number of site-specific environmental features to predict the macroinvertebrate fauna to be expected in the absence of major environmental stress. Predictions of the expected taxa can be undertaken at a species or family level, or at the level of BMWP groups of taxa, and the expected BMWP indices (BMWP Score, Number of Taxa, ASPT) can also be predicted. Macroinvertebrate taxa collected at a site (or the biotic indices calculated), following the BMWP sampling protocol, are compared with those expected to determine the degree of impairment. RIVPACS also includes a site classification based on the macroinvertebrate fauna of the component reference sites.

In Australia, the development and use of a RIVPACS-type approach for the biomonitoring of river ecosystems has been advocated within their National River Health Programme, as part of the component based on aquatic macroinvertebrates known as the AUStralian RIVer Assessment Scheme (AusRivAS) (Uys *et al*. 1996, Smith *et al*. 1999). Fundamental to AusRivAS are predictive models, based on the British RIVPACS models (Wright 1995). In each state or territory, lead agencies have been given responsibility for developing models relevant to their region, which are used to predict the potential number of taxa and SIGNAL value at a site. A standardised sampling protocol is followed throughout the country. The use of habitat-specific sampling, whereby the major macroinvertebrate habitats present at a site are sampled and analysed separately, has been stipulated (Parsons & Norris 1996). Taxonomic identification is generally taken to family level (Eekhout *et al*. 1996, Smith *et al*. 1999), but can be to genus/species level if expertise is available (Marchant *et al*. 1997). Comprehensive reviews on the development and use of AusRivAS models are given by Davies (2000) and Simpson & Norris (2000), while recent advances are provided on the AusRivAS website (http://ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates). Data from AusRivAS models were recently used in a nation-wide assessment of the ecological condition of Australian rivers (Norris *et al*. 2001).

Predictive multivariate models, based on and similar to RIVPACS, are under development in Sweden (SWEDEPACS), the Czech Republic (PERLA) and for the Nordic region (NORDPACS) (Johnson *et al*. 2001, Sandin *et al*. 2001), and have been successfully used for the bioassessment of montane streams in California, USA (Hawkins *et al*. 2000). Promising attempts have also been made to develop a RIVPACS-type system for certain regions of Spain (Alba-Tercedor & Pujante 2000). The potential value of implementing a predictive multivariate system similar to RIVPACS or AusRivAS for the management of aquatic ecosystems in South Africa, with SASS as a possible tool to be used in the development of such a system, has been emphasised by Dallas (1995, 2002).

An integrated approach

In Europe, an assessment framework has been developed to enable comparisons to be made between the results from macroinvertebrate-based bioassessments undertaken in different countries using different methods (Sandin *et al*. 2001). This assessment framework, known as AQEM (Integrated Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates), involves the classification of the results from multimetric or multivariate assessments, with directly comparable ecological integrity classes generated on the basis of reference conditions.

Regional reference conditions as a tool for data interpretation

Whichever approach to bioassessment of river ecosystems using macroinvertebrate communities is adopted, one of the most critical issues is the identification of reference sites and reference conditions (De Pauw & Vanhooren 1983; Tolkamp 1984, 1985; Wright *et al*. 1984; Reynoldson & Metcalfe-Smith 1992; Metcalfe-Smith 1994; Davis & Simon 1995; Knoben *et al*. 1995; Norris 1995; Resh *et al*. 1995; Norris & Thoms 1999; Sandin *et al*. 2001; Skriver 2001; Dallas 2000b, 2002). Management action depends on the knowledge that a certain impact causes an aquatic assemblage or ecosystem to respond in some way that is outside the natural range of variation (Roux *et al.* 1999a) and the ultimate objective of any bioassessment programme is to facilitate the detection of disturbance at a site, as reflected by one or more components of the biota. Reference conditions facilitate this by defining what is expected at a site and provide a means of comparing observed conditions with expected conditions so that the degree of impairment or deviation from natural conditions can be determined.

The need for ecological reference conditions, based on biological community data from non-impacted sites, has been recognised for quite some time in the field of aquatic bioassessment. Indeed, more generally, the importance of having a representative portion of 'healthy' or 'wild' land in each region as a starting point for ecological assessment was already highlighted by Aldo Leopold in his infamous "land ethic" of the 1940's (Leopold 1966, originally 1949; also see Hellawell 1977), with the definition of 'land' incorporating the biota and energy flows in an area (Leopold 1939). Unfortunately, an historical lack of attention to Leopold's and others' calls for the conservation of pristine areas has left us with a dearth of non-impacted sites in most regions today, especially in lowland areas. Therefore, it is usually not possible to obtain baseline data from a river system before impairment occurs. Consequently, minimally-disturbed or least-impacted sites are generally used to determine the *best attainable* reference condition for a region (Roux & Everett 1994, Hughes 1995, Omernik 1995, Reynoldson *et al*. 1997, Norris & Thoms 1999, Verdonschot 2000).

A reference condition, then, is the condition that is representative of a group of minimally-disturbed or least-impacted sites organised by selected physical, chemical and biological characteristics (Reynoldson *et al*. 1997). It is usually derived from a suite of similar reference sites and is termed a regional reference condition (Dallas 2002). Once the best attainable reference conditions have been established for the aquatic ecosystems of a region, these can be used as benchmarks to classify the degree of impairment at monitoring sites (Hughes *et al*. 1986, Norris 1994, Hughes 1995, Resh *et al*. 1995, Gerritsen *et al*. 2000, Dallas 2002) and can form a scientific basis for setting ecological resource quality objectives (Roux & Everett 1994, Roux *et al*. 1999a). However, before the reference conditions for a region can be defined, a classification system is required to group similar reference sites and to provide a framework for data analysis.

Essentially, one of two approaches can be used to classify reference sites: a regional *a priori* (deductive) approach or a multivariate *a posteriori* (inductive) approach (Conquest *et al*. 1994, Norris 1994, Resh *et al*. 1995, Reynoldson *et al*. 1997, Gerritsen *et al*. 2000, Dallas 2002), although a hybrid approach using elements of both is also possible (Gerritsen *et al*. 2000). The regional approach involves the initial classification of sites on the basis of geographic and physical attributes, while the multivariate approach involves the classification of sites by means of multivariate statistical analysis using site-specific biological data and supplementary environmental data as the starting point.

Using the regional approach, geographic regions known as "ecoregions" are predefined (largely on the basis of mapped landscape characteristics such as climate, physiography, geology, soils, potential natural vegetation, etc.) before collecting biological data from reference sites (Hughes *et al*. 1986, Hughes & Larsen 1988, Hughes *et al*. 1994, Omernik 1995). This approach has been shown to be unreliable in certain areas or situations, for example in classifying reference sites for lotic macroinvertebrate assemblages in New Zealand (Quinn & Hickey 1990), Sweden (Skriver 2001), the state of Victoria in Australia (Marchant *et al*. 2000) and for the Fraser River in British Columbia, Canada (Reynoldson *et al*. 1997). Indeed, more generally, the existence of regional uniformity amongst biological communities is questionable (Corkum 1990, 1991; Norris 1995) and very much dependent on the scale of spatial resolution considered (Skriver 2001). For example, although relatively good correspondence has been shown between ecoregions and observed patterns of fish, macroinvertebrates and periphyton in the North American state of Oregon (Whittier *et al*. 1988), very little congruence was found between the patterns of existing vegetation types and ecoregions in the states of Idaho, Oregon and Washington (Wright *et al*. 1998b). Despite potential shortcomings, the regional approach to the derivation of reference conditions, with the delineation and use of ecoregions, has been successfully used in the USA (generally with multimetric indices), Canada (Omernik 1995) and New Zealand (Biggs *et al*. 1990).

With the multivariate approach to the derivation of reference conditions, biological and supplementary environmental data from minimally-disturbed sites are used directly to generate reference conditions on the basis of observed biotic assemblages (e.g. Wright *et al*. 1984, 1989; Norris 1994; Marchant *et al*. 1997; Bailey *et al*. 1998; Smith *et al*. 1999). The multivariate approach forms the backbone of predictive models such as RIVPACS and AusRivAS (Reynoldson & Metcalfe-Smith 1992, Norris 1994, Resh *et al*. 1995, Dallas 2002). The robustness of predictive models can be improved by applying the multivariate approach within a regionally stratified spatial framework, as is done with NORDPACS (Skriver 2001).

If a regional (or hybrid) approach to river classification and bioassessment is followed, a hierarchical spatial framework with several levels of resolution is generally used to partition the spatial heterogeneity of lotic ecosystems that occurs at a variety of different scales (after Frissel *et al*. 1986). The appropriateness of a hierarchically nested model of river classification is reinforced by findings that macroinvertebrate assemblages along the length of rivers are influenced by biogeographical variables at a landscape level (Corkum 1989, 1991) and, at a smaller scale, by the adjacent land-use and associated vegetation type (Corkum 1990, Quinn & Hickey 1990, Allan *et al*. 1997, Quinn *et al*. 1997). At the regional catchment scale, ecoregions or bioregions can be delineated. Then, at a sub-regional scale of individual river systems, longitudinal zones can be distinguished while, at the site scale, the biotopes or habitats available for biotic communities can be characterised.

The South African spatial framework

In South Africa, where a regional approach to the derivation of reference conditions has been adopted within the RHP (Brown *et al*. 1996; Eekhout *et al*. 1996; Roux 1997; Dallas 2000b, 2002), three levels of classification have been prescribed as the spatial framework for bioassessment: a biogeographic or physiographic regional classification (Level I: bioregions or ecoregions), a sub-regional classification (Level II: geomorphological zones) and river types (Level III).

Level I: Bioregions or ecoregions

In terms of Level I, regions have been delineated both into bioregions on the basis of biogeographic (i.e. biotic) patterns, and into ecoregions on the basis of physiographic (abiotic) patterns as followed, for example, by the US Environmental Protection Agency (EPA). A consensus has not yet been reached as to whether the use of bioregions or ecoregions is preferable for the bioassessment of river ecosystems in the country (Dallas 2000b, 2002), although King & Schael (2001) strongly advocate the use of a biologically-based classification scheme. Longitudinal changes in macroinvertebrate communities have been shown to be important, and their effects on SASS Scores and ASPT values need to be taken into consideration (Dallas 1997). Bioassessments based on SASS should, therefore, be undertaken within a spatial framework that incorporates both a regional and a longitudinal component. Level II sub-regions reflect longitudinal river zones, as discussed below.

Level II: Sub-regions

The recognition of changes in the geomorphic and ecological characteristics of streams and rivers along their length, due largely to changes in altitude and gradient, is one of the cornerstones of lotic ecosystem theory (Vannote *et al*. 1980, Statzner & Higler 1986, Dallas & Day 1993, Cummins *et al*. 1995, Davies & Day 1998, Ward *et al*. 2002). Consequently, longitudinal river zonation has, for a number of years, been regarded as an important factor to take into consideration for the bioassessment of river ecosystems (e.g. Balloch *et al*. 1976; Hawkes 1979, 1982). Hawkes (1975) provides a comprehensive review of both the concept of river zonation, which can be defined as "the longitudinal variation of physical characteristics and associated biological distributions down the length of a river" (Rowntree *et al*. 2000), and of major attempts to universally classify rivers according to zonal characteristics. Naiman *et al*. (1992), Rowntree & Wadeson (1999) and Rowntree *et al*. (2000) provide good synopses of recent developments in the classification of rivers according to their zonal characteristics.

Early work on the application of the concept of longitudinal zonation to South African rivers was undertaken by Harrison & Elsworth (1958) and Harrison (1965), while Noble & Hemens (1978) provided a generic, descriptive classification scheme for the zonation observed in most South

African rivers. More recently, a geomorphological classification system for the longitudinal zonation of South African rivers, based loosely the classification of Noble & Hemens (1978), has been developed (Rowntree *et al*. 1996, Rowntree & Wadeson 1999, Rowntree & Ziervogel 1999, Rowntree *et al*. 2000). This zonation scheme (Table 1.2) has been widely accepted throughout South Africa for the geomorphological classification of rivers when conducting bioassessments and Environmental Flow Assessments. However, considering species-level invertebrate data, it has been shown that 'catchment signatures' or even 'river signatures' can override the influence of longitudinal geomorphological zonation, with the catchment and riverbed substratum influencing the similarity between upland sites more than geomorphological zonation (King & Schael 2001). In the light of these findings, it has been suggested that it may be more appropriate to develop and use biologically relevant zones, as opposed to geomorphologically derived ones, for ecological assessments of river ecosystems.

Despite its potential shortcomings, the geomorphological sub-regional classification system (Table 1.2) has been successfully used for bioassessment studies in South Africa, particularly within the RHP. It was therefore used in this thesis to classify the rivers investigated at a sub-regional level.

Level III: River types

Level III of the hierarchical spatial framework aims to account for variation among rivers within a sub-region or geomorphological zone. Factors such as river size, hydrological type (ephemeral, seasonal or perennial), geomorphological characteristics (channel type, substratum composition), and other chemical and biological factors are considered.

Bioassessment 'tools' developed to date

Within the regional spatial framework for the RHP, protocols have been established for the selection of reference sites and monitoring sites (Eekhout *et al*. 1996) and for the derivation of ecological reference conditions for riverine macroinvertebrates (Dallas 2000b). In addition, reference conditions for aquatic macroinvertebrates, with 'biological bands' based on SASS indices (*viz*. SASS4 Score and ASPT), have been developed for rivers in the province of Mpumalanga (Dallas 2000b) and for upland rivers in the Fynbos Bioregion of the Western Cape (Dallas 2002). A comprehensive field manual for the characterisation of sampling sites has also been produced (Dallas 2000a).

Table 1.2: Classification system for the geomorphological zonation of river channels (from Rowntree & Ziervogel 1999, after Rowntree & Wadeson 1999)

Geomorphological Zone	Characteristic gradient	Channel characteristics
Source Zone	Not specified	Low gradient, upland plateau or upland basin able to store water. Spongy/peaty hydromorphic soils.
Mountain Headwater Stream	0.1 – 0.7	Very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools.
Mountain Stream	0.01 – 0.1	Steep gradient stream dominated by bedrock and boulders, with cobble or course gravels in pools. Approximately equal distribution of vertical and horizontal flow components.
Foothills: Cobble-bed	0.005 – 0.001	Moderately steep, cobble-bed or mixed bedrock–cobble-bed channel. Length of pools and riffles/rapids similar. Narrow floodplain of sand, gravel or cobble often present.
Foothills: Gravel-bed	0.001 – 0.005	Lower gradient, mixed-bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock-controlled. Pools of significantly greater extent than rapids/riffles. Floodplain often present.
Lowland Sand-bed or Lowland Floodplain	0.0001 – 0.001	Low gradient, alluvial sand-bed channel. Often confined, but fully developed meandering pattern within a distinct floodplain develops in unconfined reaches where there is an increased silt content in bed/banks.
Rejuvenated Bedrock-fall/ Cascades*	0.01 – 0.5	Moderate to steep gradient, often confined channel (gorge) resulting from uplift in middle to lower reaches of the long profile. Limited lateral development of alluvial features.
Rejuvenated Foothills*	0.001 – 0.01	Steepened section within middle reaches of river caused by uplift, often within or downstream of gorge. Characteristics similar to foothill rivers but of a higher order. Compound channel often present, possibly with floodplain between active and macro channels.
Upland Floodplain*	0.0001 – 0.001	Upland, low-gradient channel, often associated with uplifted plateau areas.

* Zones associated with a rejuvenated river profile

Site-scale habitat assessment

Physical habitat structure has been identified as one of the major factors affecting the ecological integrity of an aquatic ecosystem (Figure 1.1) and all bioassessment studies should include some form of habitat assessment to enable the accurate interpretation of results (Chutter 1994, 1995, 1998; Rankin 1995; Thirion *et al*. 1995; Uys *et al*. 1996; Dallas 1997, 2000b; McMillan 1998; Barbour *et al*. 1999; Dickens & Graham 2002; Vos *et al*. 2002). Multimetric indices based on macroinvertebrates such as the ICI and B-IBI used in the USA do not include any form of habitat assessment (Maddock 1999), but the RBPs for fish, macroinvertebrates and periphyton developed by the USEPA (Plafkin *et al*. 1989, Barbour *et al*. 1999) include a habitat assessment that must be completed with all biological sampling that is undertaken. With the multivariate approach to bioassessment (e.g. RIVPACS and AusRivAS), habitat assessment is implicit in that a number of physical habitat measurements are taken when macroinvertebrates are collected at sampling sites so that sites with similar characteristics can be grouped together for comparison.

In South Africa, currently, the most widely used method of invertebrate habitat assessment is the Integrated Habitat Assessment System (IHAS, Version 2), developed by McMillan (1998). The IHAS has not, to date, been tested and validated scientifically (Dallas 2000b, Dickens & Graham 2002).

AIMS OF STUDY

The primary aim of the current study was to assess and compare the ecological integrity of the Lourens, Palmiet and Hout Bay Rivers (SW Cape) by examining the macroinvertebrate community structure at a series of representative sampling sites along the course of each river, using the SASS rapid bioassessment method. This would highlight potential problem areas where further, more detailed investigations are required.

The secondary aims were as follows:

- To examine the effect of seasonal variability on the macroinvertebrate community structure at sampling sites;
- To examine the effect of biotope variability on the macroinvertebrate community structure at sampling sites;
- To examine the influence of site-specific environmental variables on the macroinvertebrate community structure at sampling sites; and
- To apply the IHAS and to undertake preliminary testing of this habitat scoring system.

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CHAPTER 2:

BIOASSESSMENT OF THE ECOLOGICAL INTEGRITY OF THE LOURENS, PALMIET AND HOUT BAY RIVERS (SOUTH WESTERN CAPE, SOUTH AFRICA)

This study presents results from an investigation of the ecological integrity of the Lourens, Palmiet and Hout Bay Rivers (South Western Cape, South Africa) using the SASS-5 (South African Scoring System, Version 5) rapid bioassessment method. Macroinvertebrate samples were collected from the Stones, Vegetation and Gravel-Sand-Mud (GSM) biotope groups during autumn, spring and summer 2002/2003. The ecological integrity along the three rivers was categorised relative to regional reference conditions, according to the SASS-5 Score and Average Score per Taxon (ASPT) recorded at each sampling site, with biotope groups treated in combination and separately. Sampling sites in the Mountain Stream Zone had consistently good ecological integrity, particularly along the Hout Bay River where it flows through the upper portions of the Orange Kloof Reserve. Downstream of the Mountain Stream Zone, a significant deterioration in the ecological integrity of all three rivers was observed, resulting from a number of probable causes. Multivariate analyses of the macroinvertebrate data, using classification and ordination techniques, generally confirmed and supported SASS-5 results. From the results of the various analyses and some of the data interpretation problems encountered, a number of recommendations are made regarding future bioassessment studies, and a number of areas for potential research and development are identified.

Keywords: river health, biological assessment, macroinvertebrates, South African Scoring System, SASS-5, Western Cape, South Africa

INTRODUCTION

The main aim of this study was to assess and compare the ecological integrity of the Lourens, Palmiet and Hout Bay Rivers in the South Western Cape (SW Cape) Region of South Africa by examining the macroinvertebrate community structure at a series of representative sampling sites along the course of each river, using a rapid bioassessment method. Secondary aims included an examination of the effects of seasonal and biotope variability on the macroinvertebrate community structure at sampling sites, and the influence of site-specific environmental variables.

The Lourens, Palmiet and Hout Bay Rivers (Figure 2.1) were selected as part of a broader project, initiated by the the River Health Programme (RHP) in the Western Cape, to produce a 'State of Rivers (SoR) Report' for these three rivers as well as for the Diep River[2] (RHP 2003). Reasons for choosing the Lourens, Palmiet, Hout Bay and Diep Rivers as 'focus catchments' for the production

[2] Due to time constraints and coursework commitments, the Diep River was not included in the current research project. Furthermore, as a result of water abstraction this river is no longer perennial, evidenced by no flow observed in the upper reaches during a reconnaissance survey in autumn 2002.

of a SoR Report included the following:

- The four systems are all very different and thus represent a range of river types occurring in the region;
- A broad range of impacts and states of river health are represented by the four rivers;
- A relatively wide range of habitats/biotopes are represented along the rivers;
- Accessible sampling sites are available along the four rivers, which are suitable for the application of the South African Scoring System (SASS) for aquatic macroinvertebrates, the Fish Assemblage Integrity Index (FAII), the Riparian Vegetation Index (RVI) and the Index of Habitat Integrity (IHI); and
- Data from previous studies and/or long-term monitoring records are available for the four river systems.

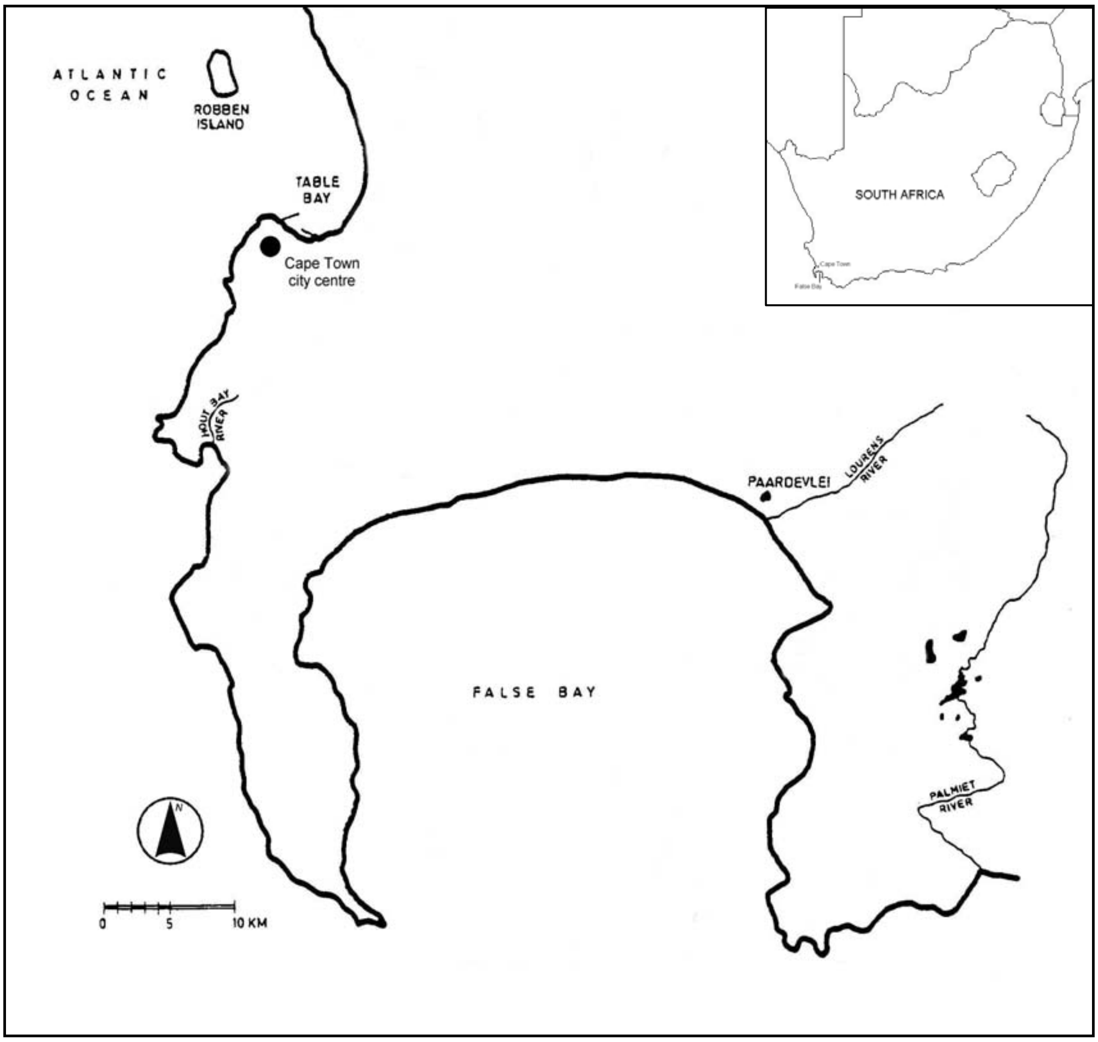

Figure 2.1: Map showing locations of Lourens, Palmiet and Hout Bay Rivers (adapted from Cape Town City Council 1994). INSET: Regional locality map

Each of the rivers selected for the current study was divided longitudinally into geomorphological zones by Dawson (2003), following the classification system of Rowntree *et al*. (2000) (see Table 1.2, **Chapter 1**). For each river, sampling sites were then chosen to represent the geomorphological zones identified. Additional site selection criteria included:

- Suitability for the application of the SASS, FAII, RVI and IHI in autumn, spring and summer;
- Accessibility; and
- Representivity of the major impacts on the ecological integrity of each river.

REGIONAL DESCRIPTION OF SELECTED RIVERS

The Lourens, Palmiet and Hout Bay Rivers are located in the Fynbos Biome of the SW Cape Region of South Africa, which is characterised by a Mediterranean Climate with hot, dry summers and cool, rainy winters (Preston-Whyte & Tyson 1988). According to the classification system of the national Department of Water Affairs and Forestry (DWAF), these rivers fall into ‘Drainage Region G’, which forms part of the proposed ‘Southern and Western Coast Water Quality Management Region’ (Day *et al*. 1998). This drainage region is characterised by rainfall-dominated waters, with sodium (Na^+) and chloride (Cl^-) generally being the dominant ions (Day & King 1995), and conductivity values and nutrient concentrations generally being very low (Davies & Day 1998, Dallas & Day 2004).

The selected river systems all fall within Harrison’s ‘Hydrobiological Region A’ – the Cape System Region (Harrison 1959, cited by Allanson *et al.* 1990). This hydrobiological region corresponds largely with Noble & Hemens’ (1978) Cape clear acid river type of the SW Cape, and with Allanson *et al*.’s (1990) ‘Limnological Region 4’ for the temperate, generally acid waters of the Cape Fold Montane Region. The upper catchments of rivers in these hydrobiological or limnological regions are typically characterised by acid waters that are dark brown in colour, as a result of the leaching of humic substances from the dominant fynbos vegetation (Raubenheimer & Day 1991, Dallas & Day 1993).

According to the preliminary classification scheme of the RHP (Brown *et al.* 1996), the Lourens, Palmiet and Hout Bay Rivers all fall within the ‘Fynbos Bioregion’ and the ‘Southern and Western Cape Biogeographic Region’. At a finer resolution, according to this classification scheme, the upper reaches of the Lourens River and most of the Palmiet River flow through the ‘Cape Fold Belt Topographic Zone’, while the Hout Bay River and the middle to lower reaches of the Lourens River flow through the ‘Coastal Belt Topographic Zone’.

The preliminary division of South African rivers into bioregions (or biogeographic regions) is based largely on the broad-scale distribution of selected groups of biota. However, a division into 'ecoregions' (*sensu* Omernik 1987, cited by Omernik 1995) on the basis of landscape features (such as physiography, climate, geology and soils) and potential natural vegetation can also be made. In terms of 'Level 1 Ecoregions' for the Western Cape, as used by the DWAF (Kleynhans & Hill 1999, Moolman n. d.), the upper reaches of the Lourens River flow through the 'Cape Folded Mountain Ecoregion', with the middle and lower reaches of the river flowing through the 'Southern Coastal Belt Ecoregion'. The Palmiet and Hout Bay Rivers both flow exclusively through the 'Cape Folded Mountain Ecoregion' according to this classification scheme (RHP 2003)[3].

A detailed description of each of the selected rivers follows.

DESCRIPTION OF LOURENS RIVER

General description

The Lourens River rises at an altitude of 1 080 m above Mean Sea Level (AMSL) in the Hottentots Holland Mountain Range (Tharme *et al*. 1997), within the Hottentots Holland and Helderberg Nature Reserves (RHP 2003). It flows in a south-westerly direction through the town of Somerset West, discharging into False Bay to the west of the seaside town of Strand (Figure 2.2). The river is approximately 20 km in length and has a total catchment area of 92 km^2 (Cliff & Grindley 1982) to 128 km^2 (RHP 2003).

Although the Lourens River has no major tributaries, it was significantly supplemented in its upper reaches by minor tributaries arising in gorges in the surrounding Cape Fold Mountains (Cliff & Grindley 1982) prior to the damming of a number of these side-streams (pers. comm., Mr D. Impson, CapeNature: Jonkershoek). Furthermore, there are a number of minor tributaries that flow through agricultural areas adjacent to the Lourens River, which contribute significantly to the runoff-related pollution loading of the main stem of the river (Schultz 2001, Dabrowski *et al*. 2002). The mean annual runoff (MAR) of the river is roughly calculated at 59×10^6 m^3, with a mean annual precipitation (MAP) of 1 410 mm (WRC 1994, RHP 2003).

[3] Both the bioregional and ecoregional classifications have been described for the selected rivers because widespread consensus has not yet been reached on which is preferable for the first-level classification of South African rivers in bioassessments (Dallas 2002).

In April 1997, largely through the efforts of the Lourens River Conservation Society, the Lourens River was declared a Protected Natural Environment (PNE) from its source to the sea (Tharme *et al*. 1997). It is the only river in South Africa to have been declared a PNE along its entire course (RHP 2003), which provides the river with a great deal of legal protection (see Hanks & Glavovic 1994 for a description of the legislative implications of a PNE) and elevates the importance of the river in terms of conservation. With the PNE status of the Lourens River, regular assessments of the ecological integrity of the river become particularly critical.

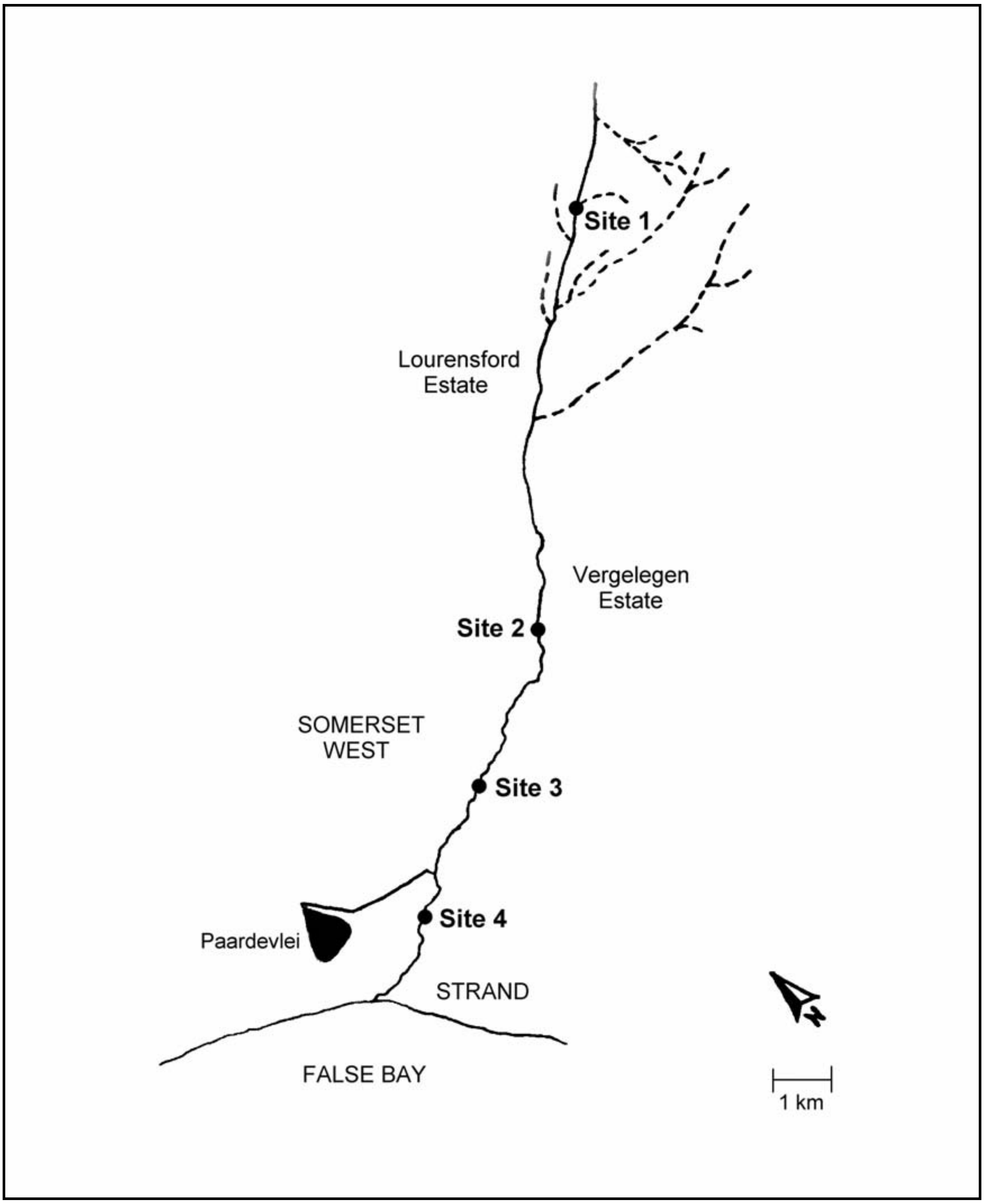

Figure 2.2: Map of Lourens River, indicating Sampling Sites 1 to 4 (adapted from Dawson 2003)

Catchment geology

Three major geological zones can be distinguished along the Lourens River. The headwaters flow primarily through sandstones of the Table Mountain Group (TMG), although shallow soils overlying TMG shale also occur in this zone. Lower down, in the Mountain Stream Zone, the river flows through an area comprising shallow soils overlying Pre-Cape Granites, and over shales and greywackes of the Malmesbury Group. In its foothill zones, the Lourens River passes through a shallow valley predominantly overlain with alluvium and wind-blown sediments (Cliff & Grindley 1982, Tharme *et al*. 1997).

Catchment vegetation

The natural vegetation along the Lourens River consists of Mountain Fynbos in the upper reaches, grading into Coastal Renosterveld in the foothill and lowland zones, with Dune Thicket occurring near the coast (Low & Rebelo 1996a, b). Very small patches of Afromontane Forest occur in ravines and scree areas alongside the upper reaches of the river.

Except for the Mountain Fynbos that has been conserved within the Hottentots Holland and Helderberg Nature Reserves, most of the natural vegetation along the Lourens River has been replaced, by forestry and agriculture/viticulture higher up, and by urban/residential development lower down. Furthermore, outside the Nature Reserve area, the invasion of alien plants into the riparian vegetation zone is a major problem along the entire river (Tharme *et al*. 1997, Withers 2003).

Water abstraction

There are no dams on the Lourens River itself. However, there are a number of small to medium-sized farm dams on tributaries of the river, with an estimated total storage capacity of 9×10^6 m^3 or 17% of the natural MAR (RHP 2003), and an extensive network of irrigation furrows that draw water from off-stream storage dams or the river itself (Cliff & Grindley 1982). In addition, there are a number of in-stream diversion weirs and off-takes for municipal water supply to Somerset West and Strand (Tharme *et al*. 1997), as well as a canal linking the river to Paardevlei (Figure 2.2).

Land-use in the catchment

Conservation and recreation are the dominant land-uses in the upper reaches of the Lourens River where it flows through the Hottentots Holland and Helderberg Nature Reserves. In the upper to middle reaches of the river, forestry and agriculture (predominantly orchards) or viticulture are the main land-uses, while in the middle to lower reaches, peri-urban, urban and industrial land-uses associated with the towns of Somerset West and Strand dominate. For the catchment area as a whole, the proportional land-uses are as follows (RHP 2003):

- Forestry – 33%;
- Natural areas – 28%;
- Vineyards and orchards – 20%;
- Urban areas – 18%; and
- Other – 1%.

At present there are no wastewater treatment works along the Lourens River, as wastewater from the catchment area is exported to the Macassar Wastewater Treatment Works located near the mouth of the Eerste River (RHP 2003). Adjacent to the estuary of the Lourens River at the town of Strand, however, the settling ponds of an old sewage treatment works have been converted into a bird sanctuary.

Geomorphological zonation and sampling sites

The longitudinal profile for the Lourens River (from Dawson 2003) is presented in Figure 2.3, with the geomorphological zones and sampling sites indicated. The river has been divided into three geomorphological zones on the basis of the classification system of Rowntree *et al.* (2000): a Mountain Stream Zone, a Foothill: Cobble-bed (or Upper Foothill) Zone and a Lowland Floodplain Zone.

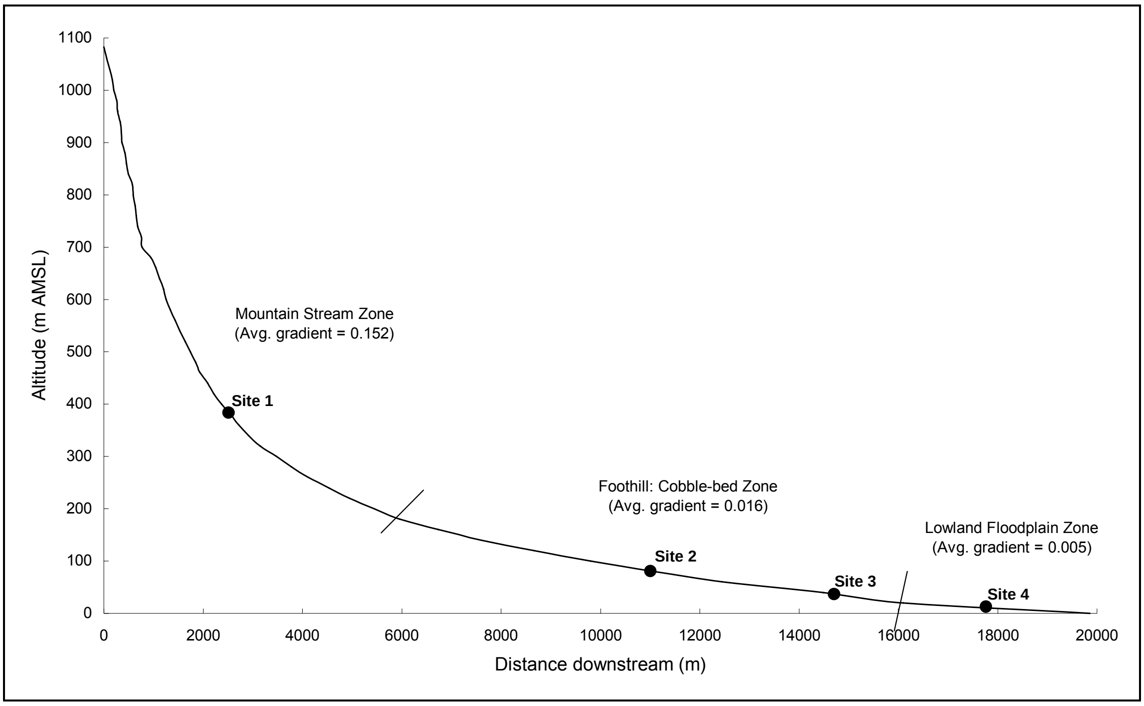

Figure 2.3: Longitudinal profile of the Lourens River (from Dawson 2003)

The geographical characteristics of the sampling sites selected for the ecological assessment of the Lourens River are presented in Table 2.1.

Table 2.1: Geographical characteristics of sampling sites along the Lourens River

Site #	Description	Geomorphological zone	Latitude (°S)	Longitude (°E)	Alt. (m AMSL)	Dist. from source (km)
1	Picnic Bush	Mountain Stream	34° 01.7’	18° 57.4’	380	2.5
2	Vergelegen	Foothill: Cobble-bed	34° 04.5’	18° 53.3’	90	11.0
3	Stormhaven Park	Foothill: Cobble-bed	34° 05.2’	18° 51.5’	45	14.3
4	Victoria Road	Lowland Floodplain	34° 05.8’	18° 49.8’	12	17.8

DESCRIPTION OF PALMIET RIVER

General description

The Palmiet River rises at an altitude of 1 133 m AMSL near Landdroskop in the Hottentots Holland Mountain Range (Clarke 1989), within the Hottentots Holland and Nuweberg Nature Reserves. It flows generally southward, through the Kogelberg Nature Reserve (the core area of the internationally significant Kogelberg Biosphere Reserve) in its rejuvenated lower reaches, before discharging into the Atlantic Ocean to the west of the seaside town of Kleinmond (Figure 2.4). The river is approximately 70 km in length and has a total catchment area of approximately 500 km^2 (Brown & Day 1998).

The Palmiet River has eleven perennial tributaries with catchments greater than 4.5 km^2 (Clarke 1989), and there are numerous smaller and seasonal streams feeding into the river (Brown & Day 1998). The MAR of the river is estimated to be approximately 253 x 10^6 m^3, with a MAP of 1 176 mm (WRC 1994, RHP 2003). Rainfall in the larger catchment varies from approximately 700 mm per annum in the low-lying areas to approximately 1 500 mm per annum in the high-lying inland areas (Gale 1992).

Catchment geology

The geology of the upper and lower areas of the Palmiet River catchment is dominated by weathered TMG sandstones, quartzites and shales, while the geology of the middle part of the catchment is dominated by fertile shales and sandstones of the Bokkeveld Group (Clarke 1989).

Catchment vegetation

The natural vegetation along the Palmiet River consists of Mountain Fynbos in the TMG soils of the upper and lower reaches, with ‘South and South-West Coast Renosterveld’ in the Bokkeveld Group soils of the middle reaches (Low & Rebelo 1996a, b). With the exception of pine plantations along the upper to middle reaches of the river, the natural Mountain Fynbos vegetation of the upper and lower catchment areas remains relatively undisturbed, covering approximately 45% of the entire catchment (Gale 1992, Withers 2003). The natural Renosterveld vegetation along the middle section of the Palmiet River has, on the other hand, been almost entirely replaced by plantations and, to a greater extent, by orchards (mainly apples) (Withers 2003).

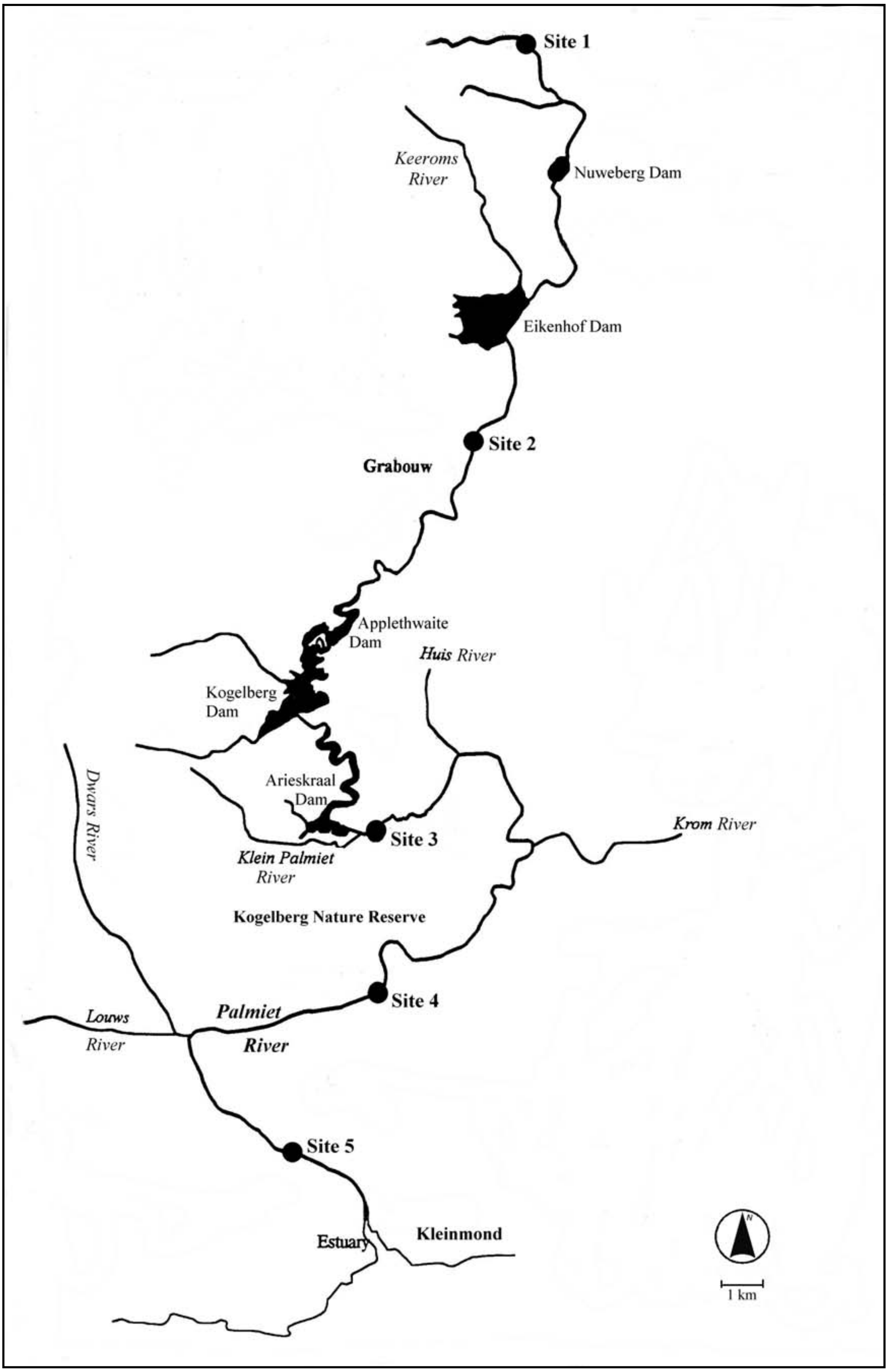

Figure 2.4: Map of Palmiet River, indicating Sampling Sites 1 to 5 (adapted from Brown & Day 1998)

Water abstraction

The Palmiet River is impounded by five major in-stream dams (Clarke 1989): Nuweberg Dam (capacity 3.9 x 10^6 m^3), Eikenhof Dam (capacity 22.7 x 10^6 m^3), Applethwaite Dam (capacity 3.3 x 10^6 m^3), Kogelberg Dam (capacity 19.0 x 10^6 m^3) and Arieskraal Dam (capacity 5.9 x 10^6 m^3). All these dams are located in the upper and middle reaches of the river, within 35 – 40 km from the source. The Nuweberg Dam is used for domestic supply, while the Eikenhof, Applethwaite and Arieskraal Dams are used for irrigation supply (Gale 1992). The Kogelberg Dam and the off-stream Rockview Dam together comprise the Palmiet Pumped Storage Scheme, which is used to generate electricity. Flow releases from the five major in-stream dams vary from no release except when overtopping (Applethwaite Dam), to controlled release (Nuweberg, Eikenhof and Kogelberg Dams), to constant bottom-release (Arieskraal Dam).

In addition to the main in-stream dams on the Palmiet River, there are a large number of smaller in-stream and off-stream farm dams throughout the upper reaches of the catchment (Brown & Day 1998). The Huis and Kromme River tributaries, which enter the Palmiet River between the Nuweberg Forest Station (within the Hottentots Holland Nature Reserve) and the Kogelberg Nature Reserve, are subject to particularly extensive impoundment, mainly for irrigation supply (Gale 1992). The total storage capacity of dams impounding the Palmiet River has been estimated to be 101 x 10^6 m^3 or 40% of the natural MAR (RHP 2003).

Direct abstraction of water from the river also takes place in certain parts of the Palmiet River catchment, while sub-surface water is abstracted by means of numerous boreholes that operate within the catchment area of the river (Brown & Day 1998). Although not used for abstraction purposes, there are three DWAF gauging weirs that impound water along the course of the river (Clarke 1989).

Land-use in the catchment

Along the upper reaches of the Palmiet River, within the Hottentots Holland and Nuweberg Nature Reserves, conservation and recreation are the dominant land-uses, while pine plantations occur in the vicinity of the Nuweberg Forest Station. Below the forest station, along the middle reaches of the river, agriculture (particularly apple farming) is the major land-use, except for peri-urban/urban land-use and light industry associated with fruit farming in the vicinity of the town of Grabouw. In the lower, rejuvenated reaches, where the river flows through the Kogelberg Nature Reserve, conservation and recreation are again the dominant land-uses. Extensive agriculture (mainly deciduous fruit farming) occurs along the Huis and Kromme River tributaries.

The proportional land-uses in the Palmiet catchment as a whole are as follows (RHP 2003):

- Natural areas – 56%;
- Orchards and vineyards – 29%;
- Forestry – 12%;
- Urban areas – 1%; and
- Other – 2%.

Treated sewage is discharged into the Palmiet River from wastewater treatment works near the town of Grabouw (RHP 2003).

Geomorphological zonation and sampling sites

The longitudinal profile of the Palmiet River, with sampling sites and geomorphological zones (Figure 2.5), shows that the river can be divided into three zones according to the classification system of Rowntree *et al*. (2000): a Mountain Stream Zone, a Foothill: Cobble-bed Zone and a Rejuvenated Foothill Zone.

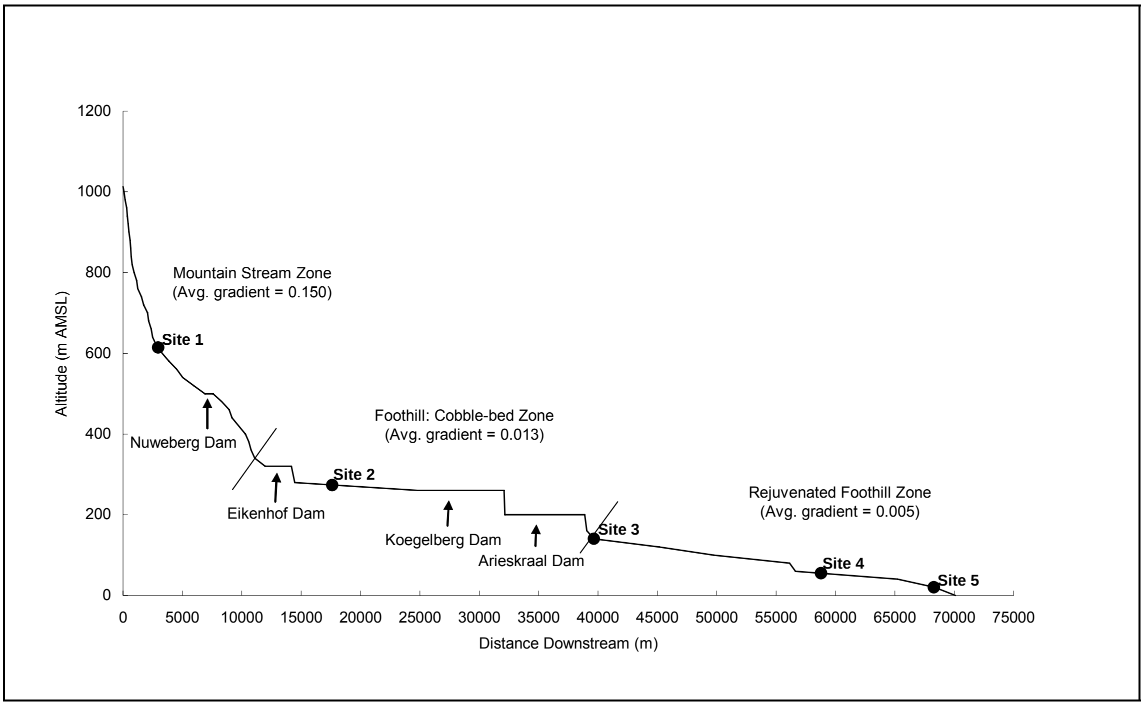

Figure 2.5: Longitudinal profile of the Palmiet River (from Dawson 2003)

The geographical characteristics of the sampling sites selected for the ecological assessment of the Palmiet River are summarised in Table 2.2.

Table 2.2: Geographical characteristics of sampling sites along the Palmiet River

Site #	Description	Geomorphological zone	Latitude (°S)	Longitude (°E)	Alt. (m AMSL)	Dist. from source (km)
1	Nuweberg	Mountain Stream	34° 03.4'	19° 02.5'	620	3.2
2	Grabouw	Foothill: Cobble-bed	34° 09.1'	19° 01.5'	275	17.6
3	d/s Aries-kraal Dam	Foothill: Cobble-bed / Rejuvenated Foothill	34° 14.6'	18° 59.7'	145	39.6
4	Kogelberg Reserve	Rejuvenated Foothill	34° 17.2'	18° 58.7'	55	59.0
5	Post Office Rock	Rejuvenated Foothill	34° 19.2'	18° 58.2'	20	68.5

d/s = downstream

DESCRIPTION OF HOUT BAY RIVER

General description

The Hout Bay River, which is often erroneously called the Disa River, rises on Table Mountain near Maclear's Beacon (altitude 1 086 m AMSL), within the Table Mountain National Park. It drains the Back Table in a south-westerly direction, flowing through the Orange Kloof Reserve and the outskirts of the town of Hout Bay before discharging into the sea at Hout Bay Beach (Figure 2.6). The river is approximately 12 km in length and has a total catchment area of approximately 34 km^2 (Grindley 1988).

The main tributaries of the Hout Bay River in its upper reaches are the Disa Stream and the Original Disa Stream, while a number of small, mostly intermittent streams join the river along its course (Grindley 1988). The MAR of the river is estimated to be approximately 10.4×10^6 m^3, with a MAP of 923 mm (WRC 1994, RHP 2003). Rainfall in the catchment varies from an annual average of 882 mm (10-year mean) in the low-lying areas to 1 983 mm (53-year mean) at Maclear's Beacon on top of Table Mountain (Grindley 1988).

Catchment geology

The geology of the Hout Bay River catchment is primarily TMG sandstones overlying a base of Cape Granite, with a narrow band of shale at approximately 200 m (Grindley 1988). Outcrops of the underlying Cape Granite rock are very sparse throughout the catchment area.

Catchment vegetation

The natural vegetation along the upper reaches of the Hout Bay River is primarily Mountain Fynbos (in the Table Mountain National Park) and Afromontane Forest (in Orange Kloof Reserve), with Sand Plain Fynbos grading into Dune Thicket in the middle to lower reaches (Low & Rebelo 1996a, b). Very little natural vegetation remains outside the Table Mountain National Park and Orange Kloof Reserve, as a result of agricultural and urban/peri-urban development in the Hout Bay Valley (Withers 2003). The extensive *Prionium serratum* (palmiet) reed beds and *Phragmites australis* reed swamps that occurred naturally along the middle to lower reaches of the river have been virtually totally eliminated through modification of the river channel and development on the river banks (Grindley 1988).

Water abstraction

Five in-stream dams, which supply potable water to the City of Cape Town, impound the headwaters of the Hout Bay River (Grindley 1988): Hely-Hutchinson Dam (capacity 0.9 x 10^6 m^3) and Woodhead Dam (capacity 1.0 x 10^6 m^3) on the Disa Stream; Victoria Dam (capacity 0.1 x 10^6 m^3), Alexandra Dam (capacity 0.1 x 10^6 m^3) and De Villiers Dam (0.2 x 10^6 m^3) on the Original Disa Stream. The total storage capacity of these dams is approximately 2.5 x 10^6 m^3 or 24% of the natural MAR of the river (RHP 2003). Water from the Woodhead Dam (fed by the Hely-Hutchinson Dam) is piped via the Woodhead Tunnel to a water treatment plant above Camps Bay, while water from the De Villiers Dam (fed by the Victoria and Alexandra Dams) is diverted to a water treatment plant in the Orange Kloof Reserve (Grindley 1988).

The Longkloof Weir/Spillway was constructed in the middle reaches of the Hout Bay River in 1961 (and reconstructed in 1983 after flood damage) to stop the upstream erosion of the river (Grindley 1988). Although this in-stream structure is not used for water abstraction, it does alter the flow regime of the river and acts as a barrier to upstream fish migration (pers. comm., Mr D. Impson, CapeNature: Jonkershoek).

Riparian owners in the middle to lower reaches of the Hout Bay River abstract water for livestock watering and irrigation by means of small off-stream dams and direct abstraction from the river. This abstraction significantly reduces the summer flow in these reaches of the river.

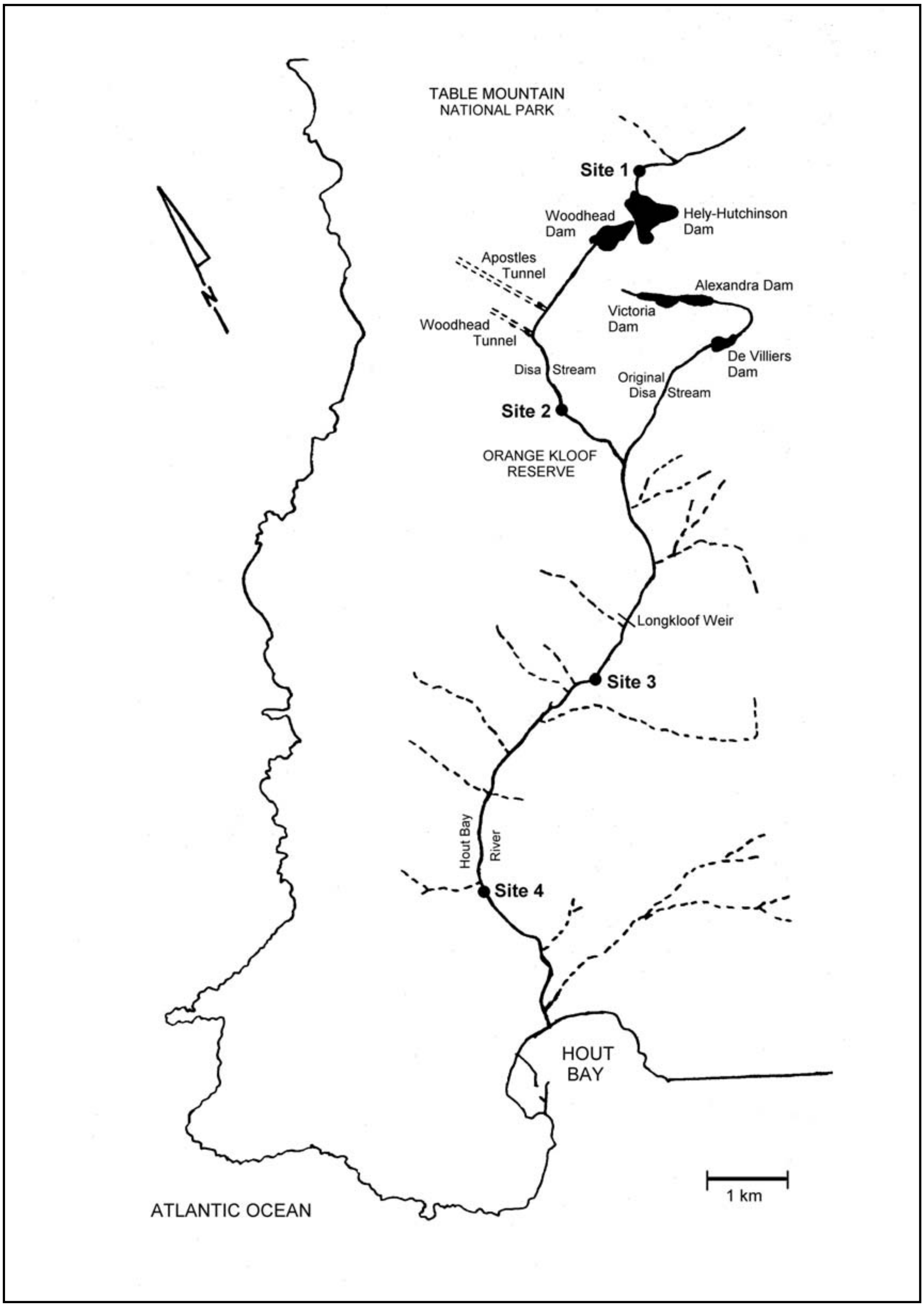

Figure 2.6: Map of Hout Bay River, indicating Sampling Sites 1 to 4 (adapted from Grindley 1988)

Land-use in the catchment

Along the upper reaches of the Hout Bay River where it flows through the Table Mountain National Park, the land-uses are primarily conservation, recreation and water storage, with some forestry (in the process of being removed) in the lower sections of the Park. Land-uses in the Orange Kloof Reserve are conservation, limited recreation (permit-controlled), water treatment and forestry (being phased out). Along the middle and lower reaches of the river, the main land-uses are agriculture and urban/peri-urban activities. Proportional land-uses for the catchment are as follows (RHP 2003):

- Natural areas – 64%;
- Urban areas – 19%;
- Forestry – 15%; and
- Other – 2%.

There are no wastewater treatment plants in the Hout Bay area, as sewage is released into Hout Bay itself via a deep-sea outfall. Prior to the installation of the deep-sea outfall in 1994, sewage disposal in the Hout Bay Valley was primarily by means of septic tanks. Seepage from these systems, where they are still in use, is still a source of surface and groundwater pollution (Catchment Management Department 2000).

Geomorphological zonation and sampling sites

The longitudinal profile for the Hout Bay River is presented in Figure 2.7, showing the sampling sites and the same three geomorphological zones as the Lourens River (according to the classification scheme of Rowntree *et al*. 2000).

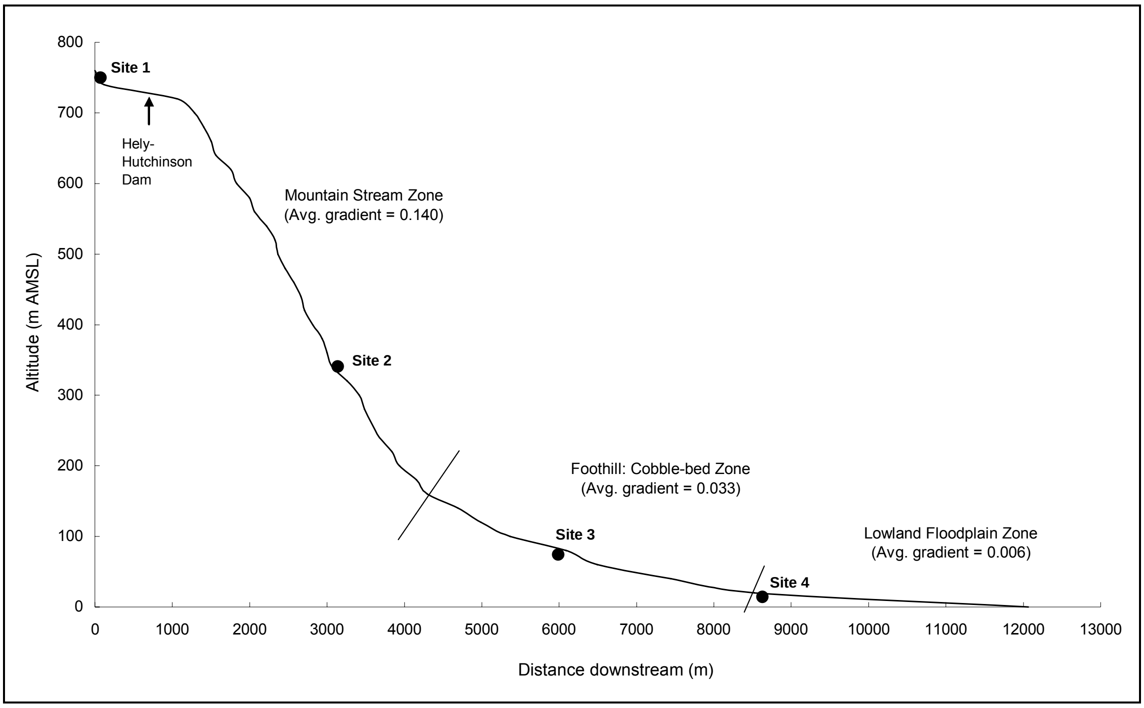

Figure 2.7: Longitudinal profile of the Hout Bay River (from Dawson 2003)

The geographical characteristics of the sampling sites selected for the ecological assessment of the Hout Bay River are summarised in Table 2.3.

Table 2.3: Geographical characteristics of sampling sites along the Hout Bay River

Site #	Description	Geomorphological zone	Latitude (°S)	Longitude (°E)	Alt. (m AMSL)	Dist. from source (km)
1	u/s Hely-Hutch. Dam	Mountain Stream	33° 58.4’	18° 24.6’	740	0.1
2	Orange Kloof	Mountain Stream	33° 59.3’	18° 23.4’	330	3.1
3	u/s Disa River Road bridge	Foothill: Cobble-bed	34° 00.9’	18° 22.9’	75	6.0
4	u/s Victoria Road bridge	Lowland Floodplain	34° 01.8’	18° 21.2’	12	8.7

u/s = upstream

METHODS

Aquatic macroinvertebrate sampling

At each sampling site along the selected rivers, aquatic macroinvertebrates were collected according to the SASS-5 (South African Scoring System, Version 5) sampling protocol (Dickens & Graham 2002). Approximately 20 m to 25 m of river length were sampled at each site.

Qualitative kick and sweep sampling was undertaken, using standardised SASS collection nets (1 000 μm mesh size; 30 cm by 30 cm frame). Samples were collected and analysed separately from the three pre-defined SASS-5 biotope groups (i.e. stones in and out of current; marginal and aquatic vegetation; and gravel, sand and mud), where present. As per the protocol, stones-in-current (SIC) were sampled for two minutes, stones-out-of-current (SOOC) for one minute, and gravel, sand and mud (GSM) for a total of one minute, while 2 m of marginal vegetation and 1 m^2 of aquatic vegetation were sampled. Sampling of each biotope was conducted over the whole sampling area available, as far as possible. Hand-picking and visual observation of aquatic macroinvertebrates was undertaken for one to two minutes, to capture specimens that may have been missed by the sampling procedure. An estimate of the actual sampling effort for each biotope, in terms of time or amount sampled relative to the SASS protocol, was recorded.

At each sampling site, macroinvertebrate samples collected from each of the biotope groups were placed in separate sampling trays (or separately, one after the other, in the same sampling tray) for sorting and identification. Plastic, white-coloured trays, approximately 30 cm by 45 cm in size with a depth of 10 cm, were used. After adding river water from the site to each tray, and carefully removing debris, the macroinvertebrates collected from each biotope group were identified in the field. Identifications were undertaken to the pre-defined taxonomic levels of the SASS (family level for most taxa), using a photographically illustrated identification guide (Gerber & Gabriel n. d.) and a field guide (Gerber & Gabriel 2002) for aquatic invertebrates of South African rivers.

Species-level taxonomic identification, which is time-consuming and costly, is necessary for biodiversity or biogeographic studies (Furse *et al*. 1984, King & Schael 2001), and for detailed assessments of the ecological integrity of aquatic systems or to determine the environmental requirements of particular groups of aquatic invertebrates (Resh & Unzicker 1975, Chessman 1995, Moog & Chovanec 2000, Lenat & Resh 2001, de Moor 2002). Species-level data are also essential in developing a deep understanding of lotic ecosystem functioning (King & Schael 2001, de Moor 2002), and are probably necessary for the predictive approach to bioassessment in environmentally heterogeneous regions where macroinvertebrate families are characterised by high numbers of species (Hawkins & Norris 2000, Hawkins *et al*. 2000). However, there is considerable evidence that, when considering the macroinvertebrate community as a whole, identification to family level is often adequate for discriminating relatively accurately between sampling sites, at least at a coarse level (Furse *et al*. 1984, Hilsenhoff 1988, Corkum 1989, Chessman 1995, Marchant *et al*. 1995, Wright *et al*. 1995, Bournaud *et al*. 1996, Hewlett 2000, Brown 2001, Lenat & Resh 2001, de Moor 2002). Furthermore, it has been shown that there is a very high degree of correlation between the number of species and both the number of families and the number of BMWP (British Monitoring Working Party) taxa (equivalent to SASS taxa) in aquatic macroinvertebrate data from rivers in the United Kingdom (Wright *et al*. 1998). More generally, a high degree of correlation has been shown to exist between species richness and family richness for a variety of groups of terrestrial biota (Williams & Gaston 1994). Family-level identification or reduced family-level identification (e.g. BMWP taxa or SASS taxa, as used in this assessment) is thus appropriate for rapid or large-scale bioassessments, where time and cost-effectiveness are important factors.

For the current assessment, the sample from each biotope group was analysed for 15 minutes (or until no additional SASS taxa had been identified for 5 minutes), after which collected organisms were returned to the river. Specimens for which there was uncertainty about the identification in the field were transferred into labelled vials and preserved with a 70% solution of ethanol. In the laboratory, uncertain family-level identifications were confirmed using optical microscopes and the SASS identification guides (Gerber & Gabriel n. d., Gerber & Gabriel 2002), and the aquatic macroinvertebrate identification guides/keys of Davies & Day (1998, pp. 418–460), McCafferty & Provonsha (1983) and/or Quigley (1977) where necessary.

At each sampling site, a standard SASS-5 score-sheet (Appendix 2.1) was completed, entering the estimated abundance of all the pre-defined taxa present in each biotope group. Abundance estimates were recorded according to a categorised, approximate log-scale as follows: 1 = single individual present; A = 2–10 individuals; B = 11–100 individuals; C = 101–1 000 individuals; and D = >1 000 individuals. The SASS-5 Score, Number of Taxa and Average Score per Taxon (ASPT), none of which take the abundance estimates into account, were calculated for each biotope group present at a sampling site and for all the biotope groups combined. Using a relatively large data set from Western Cape rivers, Dallas (2002, Appendix B), concluded that the weighting of SASS scores[4] by means of rank abundance estimates does not greatly alter the detection of disturbance at a sampling site. Vos *et al*. (2002), using data from a single river in KwaZulu-Natal, concluded that qualitative family-level SASS data provided an adequate classification of sites for use in routine biomonitoring but obtained ambiguous results regarding the importance of abundance

[4] SASS Score (upper-case ‘S’) refers specifically to the sum of the sensitivity scores of the macroinvertebrate taxa recorded at a sampling site, while SASS scores (lower-case ‘s’) refers more generally to the SASS indices (i.e. SASS-4/5 Score, Number of Taxa and ASPT).

estimates in SASS biomonitoring surveys. Brown (2001), on the other hand, found that including abundance estimates improved the ability to detect impacts by means of multivariate analyses of family-level macroinvertebrate data.

Macroinvertebrate sampling was undertaken on three occasions at each site along the Lourens, Palmiet and Hout Bay Rivers, to represent different seasons: during autumn (April/May 2002; April 2003 for Site 3 on the Lourens River[5]), spring (September/October 2002) and summer (February 2003). No sampling was undertaken during winter, as this is the rainfall period in the SW Cape when riverine macroinvertebrates are naturally sparse and difficult to collect due to high water flow.

Replicate samples were not collected during this investigation, as this is the norm for SASS assessments and, for that matter, for most rapid bioassessment methods (Resh *et al*. 1995). Samples from different seasons can, however, be regarded as replicates for the purposes of data analysis (Furse *et al*. 1984; Mackey *et al*. 1984; Norris & Georges 1993; pers. comm., Dr M. Kidd, Statistics Department, University of Stellenbosch). It has been shown that replication of samples or a longer time period for sampling than that specified by the SASS protocol is necessary to capture 75% to 95% of the SASS taxa present, especially at minimally-impacted sites (Dallas *et al*. 1994, Dallas 1995). Although this causes the SASS Score and Number of Taxa recorded at a site to differ from the achievable maxima, it does not significantly affect the ASPT metric or the ability of SASS results to distinguish between impacted and minimally-impacted sampling sites (Dallas *et al*. 1994, Dallas 1995, Chutter 1998). Furthermore, evidence suggests that combining three separate qualitative samples can provide over 85% of the macroinvertebrate taxa that would be captured by multiple-replicate sampling (e.g. Frost *et al*. 1971, Furse *et al*. 1981, Armitage *et al*. 1983, Stark 1993), while a single sample can provide over 70% of the families (Kay *et al*. 1999).

Assessment of invertebrate habitat

At each sampling site, on each sampling occasion, an assessment of the diversity and quality of the habitat available for aquatic macroinvertebrates was undertaken using the Integrated Habitat Assessment System (IHAS) (McMillan 1998). The standard IHAS score-sheet (Appendix 2.1) was completed on each occasion and the various scores (for SIC, Vegetation, Other Habitat, Habitat Total, Stream Characteristics and Total IHAS Score) were computed. Under the SIC section of the form, “Total length of broken water (riffles/rapids)” and “Total length of submerged stones in current (run)” were scored according to the length of the relevant biotope actually sampled, as opposed to

[5] After the first round of sampling (autumn 2002), it was decided that the original Site 3 for the Lourens River (at Radloff Park) was not representative of the relevant river reach and was too close to Site 2. The new Site 3, selected during the second round of sampling (spring 2002), was sampled in April 2003 to obtain an autumn sample.

the total length present at a sampling site. This method of scoring is the norm amongst SASS biomonitoring practitioners in the SW Cape.

Supplementary data collection

The geographical coordinates of each sampling site were recorded during the first round of sampling (autumn 2002) and confirmed during the second round of sampling (spring 2002), using a Garman III hand-held Geographic Positioning System (GPS). All coordinates (see Tables 2.1, 2.2 and 2.3) were geo-referenced relative to the WGS 84 (World Geodetic Survey, 1984) datum.

Daily rainfall data, for a three-week time period prior to each sampling day, were obtained from a series of rain gauging stations along the length of each selected river. Data were obtained from two stations nearby the Lourens and Hout Bay Rivers, respectively, and from three stations in the vicinity of the Palmiet River. Most of the rainfall data were retrieved from the South African Weather Service, except the data for one station along the upper-to-middle part of the Lourens River that were obtained from Lourensford Estate.

A field-based data sheet from the Field Manual of the Ecological Reference Condition Project for the RHP (Dallas 2000a) was filled in at each sampling site on each sampling occasion. This data sheet (Appendix 2.1) includes, *inter alia*, visual estimates of the water level, water turbidity, riparian canopy cover, stream dimensions and substratum composition.

In addition to the data collected by the author of this thesis, complementary data on the following aspects were obtained by other members of the study team, as indicated:

- River profiles and river zonation – Ms E. Dawson, University of Stellenbosch (Dawson 2003);
- Water chemistry, including the measurement of water temperature, pH, dissolved oxygen, electrical conductivity (EC) and total dissolved solids (TDS) – Ms E. Dawson (Dawson 2003) and, for summer sampling, personnel of the DWAF and the Scientific Services Department of the CMC Administration: City of Cape Town;
- Habitat integrity (instream and riparian) and the IHI – Ms E. Dawson (Dawson 2003);
- Riparian vegetation and the RVI – Ms M. Withers, University of Stellenbosch (Withers 2003); and
- Fish communities and the FAII – Mr J. Hayes, University of Stellenbosch (Hayes 2002) and, for summer sampling, Mr D. Impson of CapeNature (Jonkershoek).

Data analysis

Aquatic invertebrate data

The SASS-5 Score and ASPT recorded at each sampling site during autumn, spring and summer (biotope groups combined) were used to categorise the ecological integrity along the three rivers, using 'biological bands' of SASS Score vs. ASPT generated from reference sites for the Fynbos Bioregion of the SW Cape (Dallas *et al*. 1998, Dallas 2002). The interpretation of SASS results according to these biological bands (Table 2.4) is, however, based on SASS-4 scores (see Appendix 2.2). Therefore, prior to categorising each sampling site using the biological bands, SASS-5 scores (SASS-5 Score and ASPT) were converted to SASS-4 scores by transferring data collected during the current investigation onto SASS-4 score-sheets (Appendix 2.1)[6]. A linear regression analysis was undertaken to determine the relationships for converting between SASS-4 and SASS-5 scores.

Table 2.4: Categories for SASS biological bands (after Dallas 2002)

Biological band	Status of sampling site
X	Richer than reference: potential biodiversity 'hot-spot'.
A	Reference: SASS-4 Score and ASPT-4 within range of 85% of reference sites.
B	Below reference: potential impairment of water quality and/or habitat, with loss of pollution-sensitive taxa.
C	Well below reference: substantial impairment of water quality and/or habitat, with major loss of pollution-sensitive taxa.
D	Impoverished: severe impairment, with hardy and pollution-tolerant taxa remaining.

The SASS-5 Score and ASPT recorded for each biotope group (*viz*. Stones, Vegetation and GSM) during autumn, spring and summer were analysed separately by means of scatter plots for the three rivers. No biological bands have been generated for separate biotope groups. Therefore, comparisons were made by analysing SASS-5 Scores and ASPT values relative to the median values for each biotope group calculated by Dallas (2002) from reference sites in the SW Cape. Reference median values for the SASS Score and ASPT from each biotope group were first converted from SASS-4 scores to SASS-5 scores, using the equations obtained through the linear regression analysis.

[6] Six taxa accounted for in the SASS-5 are excluded in Version 4, and the scores allocated to ten taxa are different. Furthermore, except for Hyroptilidae, cased caddisflies are not identified with SASS-4; instead, they are scored according to the number of case types observed.

The distribution of SASS-5 scores amongst the taxa collected from each site along the three study rivers during autumn, spring and summer were analysed by comparing the respective proportions of sensitive invertebrate taxa (SASS-5 sensitivity scores = 11 – 15) versus intermediate taxa (SASS-5 sensitivity scores = 6 – 10) and tolerant taxa (SASS-5 sensitivity scores = 1 – 5). Results were presented as pie-charts (for combined biotopes) to provide a visual aid for interpretation and as comparative tables (for combined biotopes and for each SASS-5 biotope group separately).

The percentage of air-breathing taxa (as indicated on the SASS-5 score-sheet) at each sampling site was calculated for each sampling occasion. This measure provides an indication of the proportion of macroinvertebrate taxa present that are tolerant of low dissolved oxygen concentrations, which is a characteristic of organic pollution and nutrient enrichment.

Multivariate analyses

Multivariate analyses of the macroinvertebrate community data collected during this investigation were performed using the PRIMER Version 5 (Clarke & Gorley 2001) computer software package. Community structure at sampling sites was compared by means of the Bray-Curtis Coefficient of Similarity (Bray & Curtis 1957), which is regarded to be one of the most robust similarity coefficients for biological community applications (Field *et al*. 1982, Clarke & Warwick 1994). Patterns in community structure were represented in two-dimensional space by means of cluster analysis (classification) and ordination, both based on the triangular matrix of similarity/dissimilarity coefficients computed between pairs of samples for each data set analysed.

Classification involved hierarchical, agglomerative clustering with group-average linking, as recommended by Field *et al*. (1982) and Clarke & Warwick (1994), and results were displayed as dendrograms. As cluster analysis may force data into artificially distinct classes when, in reality, continua exist, a complementary method of analysis is advisable to confirm groupings (Field *et al*. 1982). Ordination by means of non-metric multi-dimensional scaling (MDS), which was used in this investigation, is one such method. Advantages of MDS include its flexibility and its basis on very few underlying assumptions (see Field *et al*. 1982 and Clarke & Warwick 1994 for a thorough discussion of MDS). All MDS ordinations were generated using 25 restarts. Distortions of the underlying data in two-dimensional MDS ordinations (and the subsequent reliability of the ordinations) were determined by the respective 2-D stress values (Table 2.5).

Table 2.5: Guidelines for interpretation of 2-D stress values for MDS diagrams (from Clarke & Warwick 1994)

2-D stress value	Interpretation
< 0.05	Excellent representation with no prospect of misinterpretation
0.05 – 0.1	Good ordination with no real prospect of misleading interpretation
0.1 – 0.2	Potentially useful 2-D ordination, but too much reliance should not be placed on the plot for values at upper end of range
0.2 – 0.3	2-D ordination should be treated with great deal of scepticism and discarded in upper half of range, especially with <50 data points
> 0.3	Points close to being arbitrarily placed in a 2-D ordination

Following the recommendation of Brown (2001) for the multivariate analysis of family-level community data, where possible, cluster and MDS analyses were undertaken using rank abundance estimates of SASS taxa collected. Abundance estimates were ranked as follows: 0 = no individuals; 1 = 1–9 individuals; 2 = 10–99 individuals; 3 = 100–999 individuals; 4 = ≥1 000 individuals.

Cluster and MDS analyses were conducted to compare the macroinvertebrate community structure at all sampling sites during the three sampling seasons with one another (for all biotope groups combined and for each SASS biotope group separately). Composite community data for sampling sites, based on all three seasons combined, were also compared (again, for all biotope groups together and for each SASS biotope group separately). These composite analyses, which have been recommended (Mackey *et al*. 1981, Furse *et al*. 1984) and are often used for multi-season bioassessment studies (e.g. Wright *et al*. 1984, Marchant *et al*. 1997, Turak *et al*. 1999), are based on the presence/absence of macroinvertebrate taxa. Finally, cluster and MDS analyses were undertaken for each of the three study rivers individually (for all biotope groups combined and for each SASS biotope group separately) to highlight localised differences between the sampling sites along each river.

Invertebrate habitat assessment data

For each river, the Total IHAS Score, Habitat Total and Stream Characteristics Scores from the IHAS score-sheet completed for each sampling site during autumn, spring and summer were compared by means of stacked bar graphs. Results were compared against the guideline values for excellent (Total IHAS Score >75) and good (Total IHAS Score >65<75) habitat, according to McMillan (1998), and against the constrained maximum Habitat Total (=55).

The Total IHAS Score includes a Stream Characteristics (or Stream Condition) Score, which provides an indication of the general make-up and condition of a site. Therefore, the Habitat Total provides a better indication of the quality of invertebrate habitat at a site than the Total IHAS Score. Bar graphs of the unconstrained Habitat Total, which has a maximum attainable value of 74 but is usually constrained to a maximum of 55 to enable the Total IHAS Score to be expressed as a percentage, were used to compare the autumn, spring and summer values at the sampling sites for each river.

The Habitat Score for the Stones biotope group was calculated by summing the scores for SIC, SOOC and bedrock from the IHAS score-sheet (Appendix 2.1). The Vegetation Habitat Score was taken directly from the sub-total of the Vegetation section of the score-sheet, and the GSM Habitat Score was calculated by summing the scores for the amount of gravel, sand and mud sampled from the 'Other Habitat' section of the score-sheet. For each sampling site and season, Habitat Scores for Stones, Vegetation and GSM were expressed as a percentage of the respective maximum obtainable scores.

Supplementary data

The daily rainfall figures (mm/day) from each of the rain gauging stations for which data were obtained were summed for both the three-day and three-week time periods prior to each sampling occasion. This was done to determine whether any high river flow was likely to have occurred immediately or relatively shortly before sampling was undertaken. Sampling aquatic macroinvertebrates during periods of high river flow can result in the collection of unrepresentative samples, as many invertebrates migrate into the benthos under these conditions (e.g. King 1983), while significant numbers of certain taxa (e.g. surface-dwelling hemipterans) may be washed downstream or seek refuge in marginal vegetation and, once the flow begins to subside, it can take some time for populations to return to the pre-spate situation.

RESULTS

Rainfall and general site observations

Cumulative rainfall before sampling

Cumulative rainfall data for the three-week and three-day periods before sampling are presented in Appendix 2.3. The highest rainfall over the three-week period before sampling was generally recorded in autumn 2002, up to 118 mm at Nuweberg (upper Palmiet River) and 80 mm at Woodhead Dam (upper Hout Bay River). Over the three-day period before sampling in autumn, a particularly significant amount of rainfall was recorded along the Hout Bay River (23 – 54 mm), while there was no rainfall along the Palmiet River during the three-day period before autumn sampling. In the case of the Lourens River, between 30 mm and 60 mm of rainfall was recorded over the three-week period before autumn 2002 sampling, while 14 mm was recorded at Lourensford Estate (situated along the upper to middle reaches of the river) for the three-day period before sampling in autumn.

During spring, the most significant amount of rainfall for the three-week period before sampling was at Lourensford Estate (90 mm), although no rainfall was recorded along the Lourens River over the three-day period before sampling. The only significant amount of rainfall recorded for the three-day period before spring sampling was at Oudebosch (14 mm), along the middle to lower reaches of the Palmiet River.

As expected, the lowest amount of rainfall was generally recorded during summer, with no rainfall measured at any of the gauging stations for the three-day period before sampling. However, a relatively significant amount of rainfall (79 mm) was recorded at Woodhead Dam (upper Hout Bay River) over the three-week period before summer sampling, with 16 mm recorded towards the lower end of the catchment. Between approximately 18 mm and 50 mm of rainfall was recorded at the rain gauging stations along the Palmiet River over the three-week period before summer sampling, while less than 10 mm was recorded along the Lourens River over this time period.

Physical site observations

Visual observations/estimates of the substrate embededness, average stream width, average deep-water depth, average shallow-water depth, stream velocity, water clarity and riparian canopy cover recorded at each sampling site during autumn, spring and summer are presented in Table A2.4-1 (Appendix 2.4). For each river, pie charts of the estimated proportional composition of the substrate at each sampling site for the three sampling seasons are presented in Figures A2.4-1 to A2.4-3 (Appendix 2.4).

Water chemistry data

Recorded measurements of pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen concentration, temperature and dissolved nutrient concentrations (nitrate, nitrite, ammonium, phosphate and total inorganic nitrogen) recorded at each sampling site are presented in Appendix 2.5 (autumn and spring data from Dawson 2003; summer data from the DWAF and CMC Administration: Scientific Services Department). A comprehensive discussion of these data, with respect to the water quality of the Lourens, Palmiet and Hout Bay Rivers during autumn and spring, is provided by Dawson (2003).

Biotope groups sampled and macroinvertebrate taxa collected

The SASS-5 biotope groups sampled at sampling sites along the Lourens, Palmiet and Hout Bay Rivers are outlined in Table 2.6, while a list of macroinvertebrate taxa collected from the different biotope groups is provided for each river in Appendix 2.6.

Table 2.6: SASS-5 biotope groups (Stones, Vegetation, GSM) sampled during each sampling season

River	Sampling site	Stones	Vegetation	GSM
Lourens	Site 1	ALL	-	-
	Site 2	ALL	ALL	-
	Site 3	ALL	ALL	aut
	Site 4	ALL	ALL	ALL
Palmiet	Site 1	ALL	ALL	sum
	Site 2	ALL	ALL	spr+sum
	Site 3	ALL	ALL	-
	Site 4	ALL	ALL	ALL
	Site 5	ALL	ALL	aut
Hout Bay	Site 1	ALL	ALL	-
	Site 2	ALL	spr+sum	-
	Site 3	ALL	ALL	aut
	Site 4	-	ALL	ALL

GSM = gravel, sand and mud
ALL = autumn, spring and summer; aut = autumn; spr = spring; sum = summer
- = Not sampled in any season

SASS results: combined biotope groups

The SASS-5 Scores and ASPT values recorded along the Lourens, Palmiet and Hout Bay Rivers (all biotopes combined), before converting to SASS-4 scores, are presented in Appendix 2.7.

Conversion of SASS-5 scores to SASS-4 scores

Full results of the linear regression analyses undertaken to determine the relationships between SASS-4 and SASS-5 Scores and between ASPT-4 and ASPT-5 are presented in Appendix 2.8. The correlation between SASS-5 and SASS-4 Scores and between ASPT-5 and ASPT-4 was very highly significant with $R > 0.98$ ($n = 39$, $p \ll 0.0005$). The following linear equations (see Appendix 2.8 for standard errors and probability values associated with the respective coefficients and constants) were generated to convert from SASS-4 to SASS-5 scores and *vice-versa*:

$$SASS\text{-}4 = 0.97(SASS\text{-}5) + 3.08$$
$$ASPT\text{-}4 = 1.16(ASPT\text{-}5) - 0.65$$

$$SASS\text{-}5 = 1.02(SASS\text{-}4) - 1.64$$
$$ASPT\text{-}5 = 0.83(ASPT\text{-}4) + 0.78$$

Scatter plots of biological bands

Scatter plots of SASS-4 Score vs. ASPT-4 are presented below for upland and rejuvenated sites (Figure 2.8) and for lowland sites (Figure 2.9) during autumn, spring and summer (combined biotopes) for all three rivers together, indicating the respective biological bands. Upland sites include those in the Mountain Stream and Foothill: Cobble-bed Zones, while lowland sites include the Foothill: Gravel-bed and Lowland Floodplain Zones. The only lowland sites were Site 4 on the Lourens and Hout Bay Rivers, respectively.

Interestingly, plotting SASS-5 scores relative to the SASS-4 biological bands resulted in 11 misclassifications (out of 39 data points), of which only two were not borderline cases. Sampling sites near the borderline between two biological bands during a particular season included Lourens River Site 3, Palmiet River Sites 1, 4 and 5, and Hout Bay River Site 1 in autumn; and Sites 1, 2 and 3 on the Lourens River in spring.

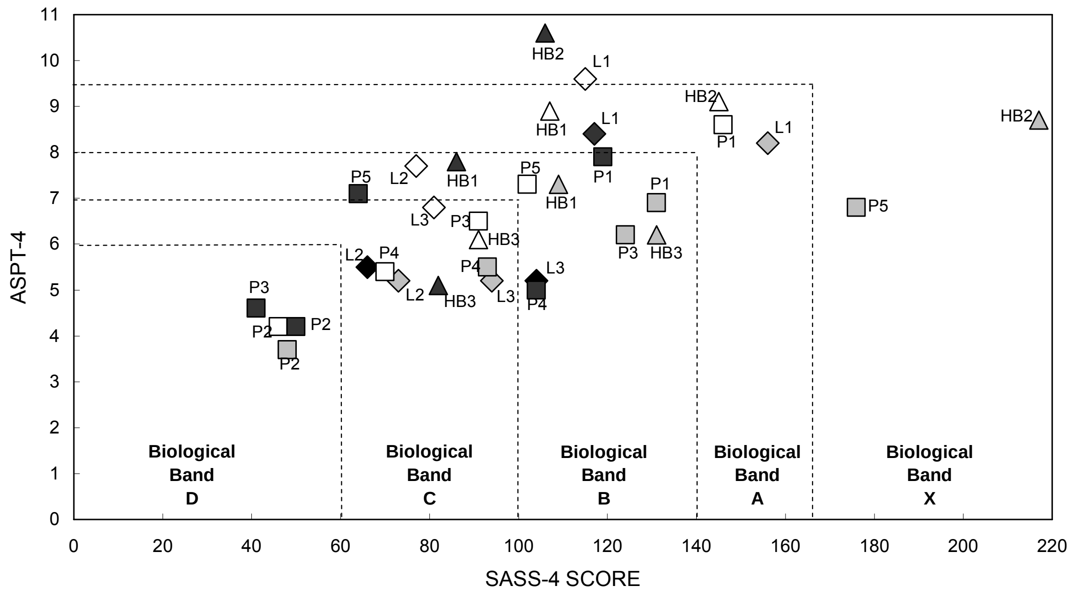

Figure 2.8: Scatter plot of SASS-4 scores for upland and rejuvenated sites (combined biotopes, seasons separate) relative to relevant biological bands (from Dallas 2002). Lourens River (L) represented by diamonds, Palmiet River (P) by squares and Hout Bay River (HB) by triangles; site numbers shown. Autumn samples indicated by solid shapes, spring samples by open shapes, and summer samples by grey-shaded shapes

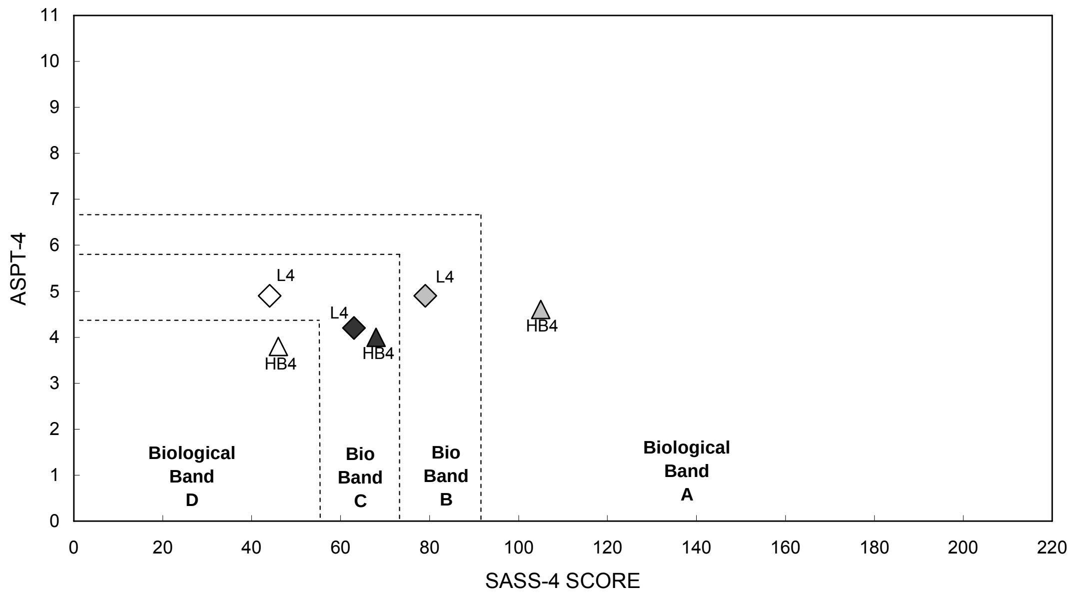

Figure 2.9: Scatter plot of SASS-4 scores for lowland sites (combined biotopes, seasons separate) relative to relevant biological bands (from Dallas *et al*. 1998). Lourens River (L) represented by diamonds, and Hout Bay River (HB) by triangles; site numbers shown. Autumn samples indicated by solid shapes, spring samples by open shapes, and summer samples by grey-shaded shapes

Along the Lourens River, Site 1 was consistently classified into Biological Band A (autumn and summer) or X (spring). Site 2 was classified into Biological Band C during autumn and summer, with an improvement to Band B (borderline Band A) in spring due to a relatively high ASPT. The categorisation of Sites 3 and 4 fluctuated between Biological Band B (during autumn for Site 3 and summer for Site 4) and Band C (for all other sampling occasions).

Along the Palmiet River, Site 1 was classified into Biological Band B during autumn (borderline Band A) and summer, and into Band A during spring. Site 2 was consistently classified into Biological Band D. Site 3, situated below the Arieskraal Dam, improved from Biological Band D in autumn (with only 9 mostly low-scoring taxa recorded) to Band C in spring and, further, to Band B in summer. The condition at Site 4 fluctuated between Biological Band B (during autumn, borderline Band C) and Band C (spring and summer). Site 5 was classified into Biological Band B during autumn (borderline Band C) and spring, improving markedly to Band X in summer as a result of a very high SASS Score (SASS-5 Score >180).

Along the Hout Bay River, Site 1 fluctuated between Biological Band A (spring) and Band B (autumn and summer), while Site 2 was consistently located in Band A (spring, borderline Band X) or Band X. Site 3 improved from Biological Band C in autumn and spring to Band B in summer, as a result of a significantly higher SASS Score being recorded. Although the ASPT at Site 4 was always below 5, varying SASS Scores caused the categorisation of this site to vary from Biological Band C in autumn to Band D in spring, improving markedly to Band A in summer.

Proportions of sensitive, tolerant and air-breathing taxa

Pie-charts of the distribution SASS-5 scores amongst the taxa collected from the three rivers during autumn, spring and summer (all biotopes combined) are presented in Figures A2.9-1 to A2.9-3 (Appendix 2.9). A comparative table of the proportion of sensitive taxa (SASS-5 score >10) versus the proportion of tolerant taxa (SASS-5 score ≤5) is presented below (Table 2.7), also showing the total number of taxa sampled on each occasion. The proportions of air-breathing taxa recorded at each sampling site are shown in Table 2.8.

Table 2.7: Percentages of sensitive (S) and tolerant (T) taxa collected at sampling sites (combined biotopes) during autumn, spring and summer. Proportions of sensitive taxa ≥25% and tolerant taxa ≥50% highlighted in bold

River	Sampling site	Autumn			Spring			Summer		
		%S	%T	n	%S	%T	n	%S	%T	n
Lourens	Site 1	21%	21%	14	**50%**	25%	12	**25%**	30%	20
	Site 2	8%	**58%**	12	**27%**	45%	11	7%	**64%**	14
	Site 3	5%	**60%**	20	17%	42%	12	6%	**61%**	18
	Site 4	7%	**87%**	15	11%	**67%**	9	6%	**69%**	16
Palmiet	Site 1	19%	38%	16	21%	32%	19	24%	38%	21
	Site 2	0	**83%**	12	0	**82%**	11	0	**100%**	13
	Site 3	0	**78%**	9	14%	43%	14	10%	48%	21
	Site 4	9%	**64%**	22	8%	**62%**	13	0	**59%**	17
	Site 5	22%	33%	9	**25%**	**50%**	16	11%	32%	28
Hout Bay	Site 1	**27%**	36%	11	**31%**	38%	13	19%	**50%**	16
	Site 2	**36%**	18%	11	**33%**	33%	18	**26%**	33%	27
	Site 3	6%	**69%**	16	13%	**56%**	16	13%	43%	23
	Site 4	0	**65%**	17	0	**67%**	12	4%	**70%**	23

n = Total number of taxa sampled

Table 2.8: Percentages of air-breathing taxa collected at sampling sites (combined biotopes) during autumn, spring and summer. Proportions ≥40% highlighted in bold

River	Sampling site	Autumn	Spring	Summer
Lourens	Site 1	14%	0	10%
	Site 2	33%	18%	29%
	Site 3	35%	17%	33%
	Site 4	33%	22%	**50%**
Palmiet	Site 1	25%	26%	33%
	Site 2	**42%**	36%	**62%**
	Site 3	11%	7%	19%
	Site 4	36%	23%	24%
	Site 5	33%	6%	21%
Hout Bay	Site 1	27%	23%	31%
	Site 2	9%	17%	19%
	Site 3	**44%**	25%	30%
	Site 4	**53%**	**50%**	**52%**

Along the Lourens River, Site 1 had the greatest percentage of sensitive taxa in all three seasons (varying from 21% in autumn to 50% in spring). The percentage of sensitive taxa collected at all four sampling sites was significantly higher in spring than in autumn or summer, with the difference gradually decreasing downstream (from 25–30% at Site 1 to 4–5% at Site 4). At Sites 2, 3 and 4, in autumn and summer, less than 10% of the taxa recorded were sensitive, while there was a high proportion (58% to 87%) of tolerant taxa. Less than 30% of the taxa recorded at Site 1 during all three seasons were tolerant, with less than 15% air-breathing. Similar proportions of air-breathing taxa were generally collected at Sites 2, 3 and 4 during autumn and summer (approximately 30–35%), except for the summer sample at Site 4 (50%), while slightly lower proportions (approximately 20%) were collected at these sites during spring.

Along the Palmiet River, the highest proportions of sensitive taxa were recorded at Sites 1 and 5 during autumn and spring (19% to 25%), and at Site 1 in summer (24%). The proportion of tolerant taxa was generally below 40% at Sites 1 and 5 (except during spring at Site 5, where it was 50%). No sensitive taxa were recorded at Site 2 during any sampling season or at Site 3 in autumn and Site 4 in summer, with the proportion of tolerant taxa at Site 2 being greater than 80% in all three seasons (100% in summer). The general trend in the proportion of air-breathing taxa collected along the Palmiet River was an increase from Site 1 to the highest value at Site 2 (reaching 62% in summer), a decrease to the lowest value at Site 3 (except during spring, when Sites 3 and 5 had similar values), an increase to Site 4 and a marginal decrease to Site 5 (except in spring, when the decrease in proportions between Sites 4 and 5 was significant).

In the case of the Hout Bay River, during all three seasons, the highest proportions of sensitive taxa were recorded at Site 2 (varying from 26% in summer to 36% in autumn), followed by Site 1 (varying from 19% in summer to 31% in spring). Less than 15% of the taxa recorded at Site 3 were sensitive during all sampling seasons (<10% in autumn), while less than 10% of the taxa were sensitive at Site 4 (zero in autumn and spring). At Site 3 during autumn and spring, and Site 4 during all three sampling seasons, more than 50% of the recorded taxa were tolerant. The general trend for the proportion of air-breathing taxa collected along the Hout Bay River was a decrease from Site 1 to the lowest value at Site 2 (9% to 19%), then to increase again at Site 3 with a further increase to the highest value at Site 4 (always ≥50%).

Invertebrate habitat assessment: combined biotope groups

Lourens River

Total IHAS Scores recorded along the Lourens River (Figure A2.10-1, Appendix 2.10) ranged from 64 (Site 1, summer) to 80 (Site 2 and Site 4, summer). IHAS Habitat Totals (Figure 2.10) ranged from 23 (Site 1, autumn) to 45/46 (Site 3, autumn and Site 4, summer) and was lowest at Site 1 (<30) for all three sampling seasons.

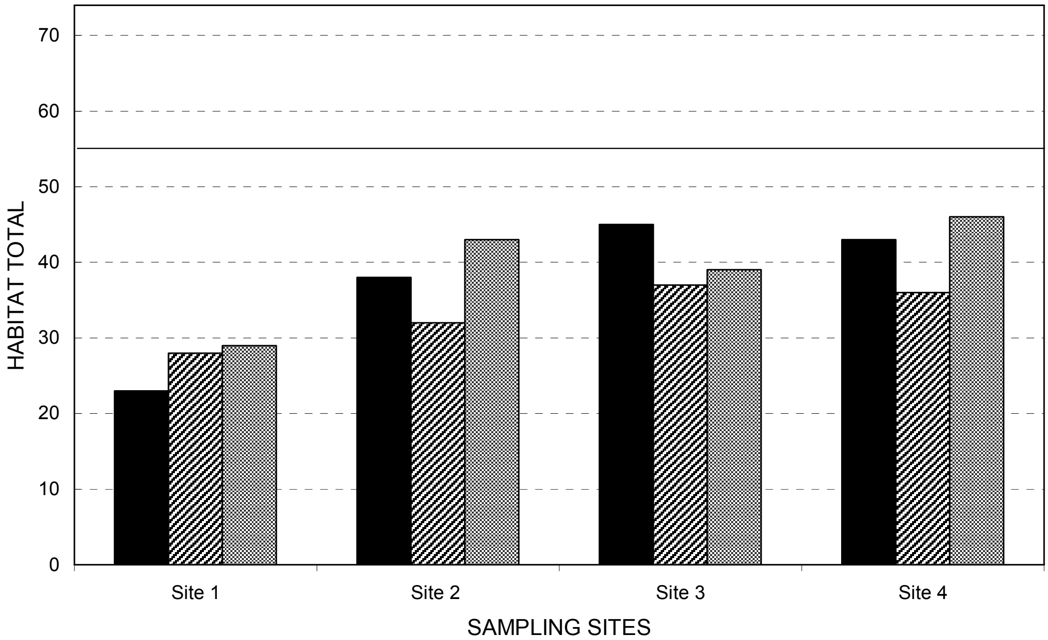

Figure 2.10: IHAS Habitat Totals (unconstrained) along the Lourens River (combined biotopes) on each sampling occasion. Autumn represented by black bars, spring by cross-hatched bars and summer by grey-shaded bars. Solid horizontal grid-line indicates maximum attainable constrained Habitat Total; top of graph indicates maximum attainable unconstrained Habitat Total

Palmiet River

Total IHAS Scores along the Palmiet River (Figure A2.10-2, Appendix 2.10) ranged from 66 (Site 2, autumn) to 90 (Site 4, summer), with Sites 1 and 4 having the highest values (between 74 and 90) in all three seasons. IHAS Habitat Totals (Figure 2.11) ranged from 33 (Site 2, autumn) to 51 (Site 4, summer), with the highest value (45–51) recorded at Site 4 in all three seasons. The lowest Habitat Totals were recorded at Site 2 in autumn (33), at Sites 3 and 5 in spring (34), and at Sites 2 and 5 in summer (42–43).

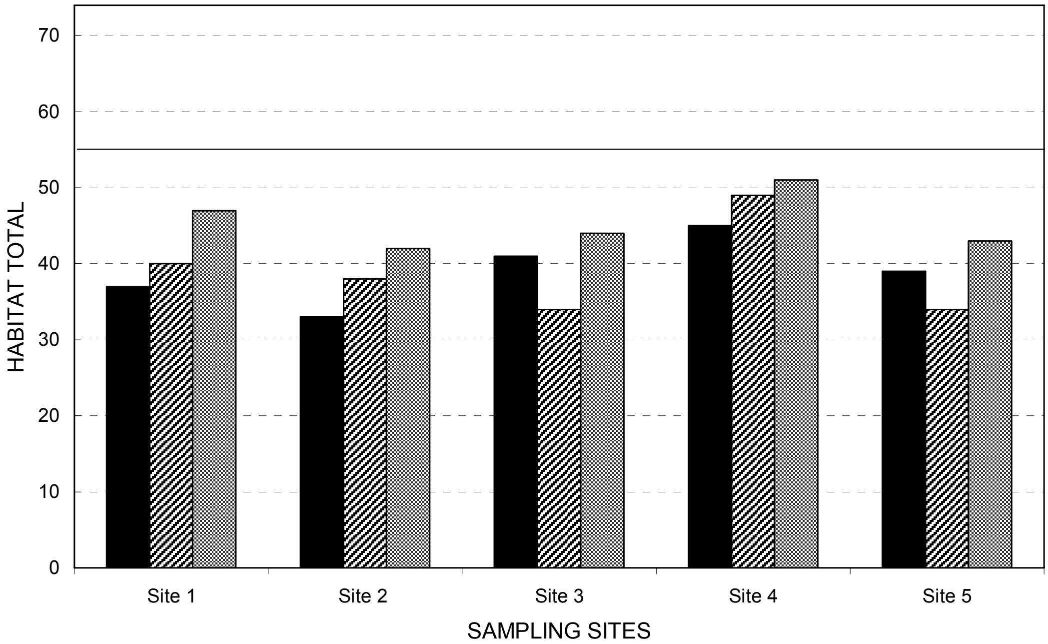

Figure 2.11: IHAS Habitat Totals (unconstrained) along the Palmiet River (combined biotopes) on each sampling occasion. Autumn represented by black bars, spring by cross-hatched bars and summer by grey-shaded bars. Solid horizontal grid-line indicates maximum attainable constrained Habitat Total; top of graph indicates maximum attainable unconstrained Habitat Total

Hout Bay River

Total IHAS Scores along the Hout Bay River (Figure A2.10-3, Appendix 2.10) ranged from 38 (Site 4, autumn) to 83 (Site 3, autumn), with the lowest value in all three seasons recorded at Site 4 (varying from 38 in autumn to 50 in spring). IHAS Habitat Totals (Figure 2.12) ranged from 21 (Site 4, autumn) to 44 (Site 3, summer). Generally, the highest Habitat Totals during all three sampling seasons were recorded at Site 3 (varying from 36 in spring to 44 in summer) and the lowest Totals at Site 4 (varying from 21 in autumn to 25 in spring), although in spring similar highest and lowest Habitat Totals were recorded at Site 1 and Site 2, respectively.

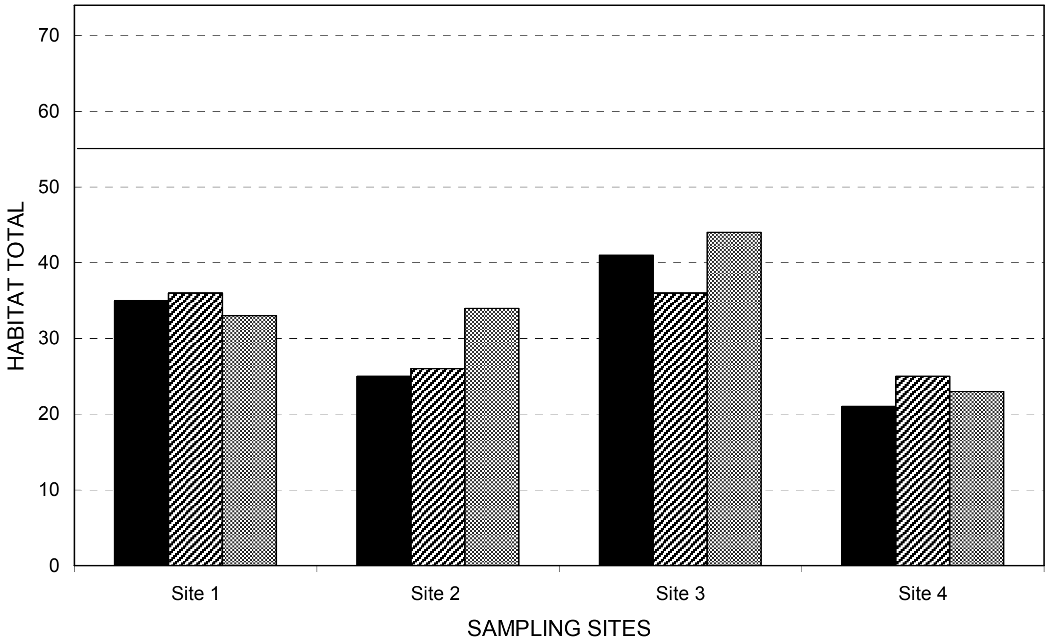

Figure 2.12: IHAS Habitat Totals (unconstrained) along the Hout Bay River (combined biotopes) on each sampling occasion. Autumn represented by black bars, spring by cross-hatched bars and summer by grey-shaded bars. Solid horizontal grid-line indicates maximum attainable constrained Habitat Total; top of graph indicates maximum attainable unconstrained Habitat Total

SASS results: separate biotope groups

Scatter plots of SASS-5 Score and ASPT

For each SASS biotope group (i.e. Stones Vegetation and GSM), median SASS-4 Scores and ASPT-4 values have been determined for reference sites in the SW Cape (Dallas 2002). These SASS-4 reference values were converted to SASS-5 values (SASS-5 Score and ASPT-5) using the regression equations developed during the current investigation (discussed above). Scatter plots of SASS-5 Scores and ASPT values recorded for each biotope group could then be compared against the relevant median scores for reference sites, to determine the degree of impairment at sampling sites.

Stones biotope group

A scatter plot of SASS-5 Score vs. ASPT for the Stones biotope group (seasons separate) is presented in Figure 2.13, with the median SASS-5 Score (=130) and ASPT (=8.0) for reference sites indicated. The SASS-5 Score and/or ASPT were greater than or approximately equal to the respective median values for reference conditions at Site 1 (all seasons) and at Sites 2 and 3 in spring on the Lourens River, at Site 1 (all seasons) and at Site 5 in summer on the Palmiet River, and at Site 1 (during autumn and spring) and Site 2 (all seasons) on the Hout Bay River.

Recorded scores for the Stones biotope group were also relatively close to reference conditions (SASS-5 Scores >80 and ASPT ≥~6.5) at Site 5 on the Palmiet River in spring and at Sites 1 and 3 on the Hout Bay River in summer. Relatively high SASS-5 Scores (80–100, but with ASPT <6.0) were recorded at Site 3 on the Lourens River in autumn and at Site 3 on the Palmiet River in summer, while relatively high ASPT values (6.0–6.5, but with SASS-5 Score <60) were recorded at Site 5 on the Palmiet River in autumn and at Site 3 on the Hout Bay River in spring. The SASS results from the remaining sampling sites/occasions for the Stones biotope group indicated conditions that were significantly impaired compared to reference sites in the SW Cape. Particularly low scores were recorded at Site 4 on the Lourens River in autumn and spring and, on the Palmiet River, at Site 2 (all seasons) and at Sites 3 and 4 in autumn. No stones were present at Site 4 on the Hout Bay River (Table 2.6).

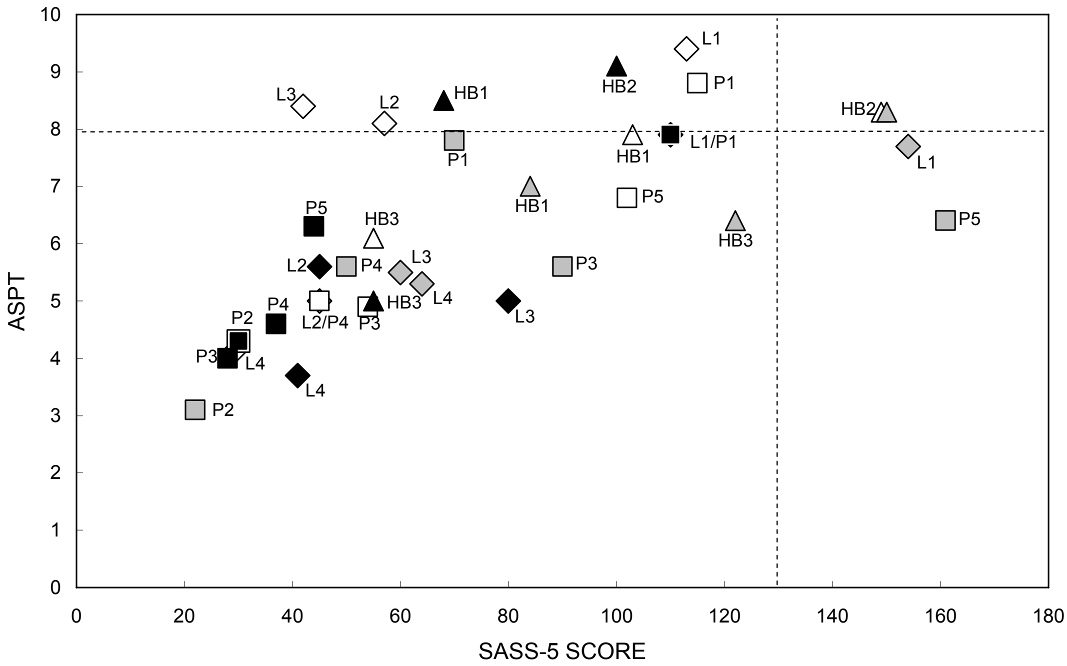

Figure 2.13: Scatter plot of SASS-5 Score vs. ASPT for the Stones biotope group (seasons separate) relative to median values from South Western Cape reference sites (indicated by dashed lines, from Dallas 2002). Lourens River (L) represented by diamonds, Palmiet River (P) by squares, and Hout Bay River (HB) by triangles; site numbers shown. Autumn samples indicated by solid shapes, spring samples by open shapes, and summer samples by grey-shaded shapes

Vegetation biotope group

A scatter plot of SASS-5 Score vs. ASPT for the Vegetation biotope group (seasons separate) is presented in Figure 2.14, with the relevant median values from reference sites (SASS-5 Score = 80, ASPT = 6.7) shown. The Vegetation biotope group was absent at Site 1 on the Lourens River, and in autumn it was not sampled at Site 2 on the Hout Bay River (Table 2.6). The SASS-5 Score and/or ASPT were greater than or approximately equal to the respective median reference values at Site 3 on the Lourens River in spring and summer (but with relatively low ASPT = 5.0 in summer). Along the Palmiet River, this was the case at Sites 1 and 5 during all sampling seasons, at Site 3 in spring, and at Site 4 in autumn. Reference or near-reference scores were recorded at Sites 1 and 2 on the Hout Bay River (all sampled seasons), and at Site 4 in summer (but with a relatively low ASPT <5.0).

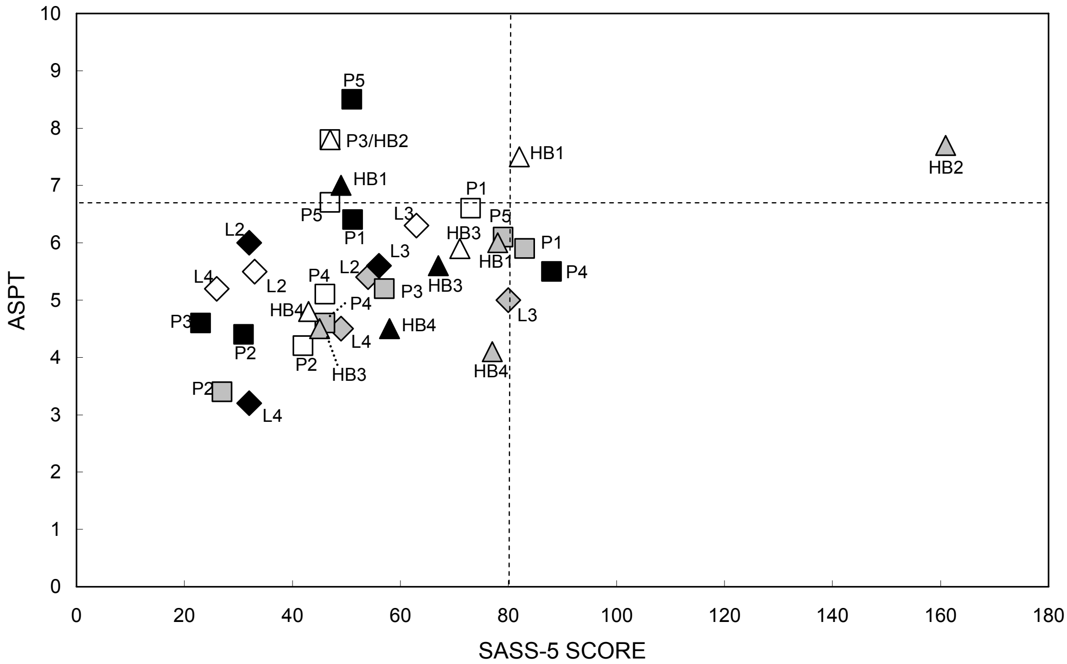

Figure 2.14: Scatter plot of SASS-5 Score vs. ASPT for the Vegetation biotope group (seasons separate) relative to median values from South Western Cape reference sites (indicated by dashed lines, from Dallas 2002). Lourens River (L) represented by diamonds, Palmiet River (P) by squares, and Hout Bay River (HB) by triangles; site numbers shown. Autumn samples indicated by solid shapes, spring samples by open shapes, and summer samples by grey-shaded shapes

Intermediate scores (SASS-5 Score >50, ASPT ≥~5.2) for samples from the Vegetation biotope group were recorded at Site 2 on the Lourens River in summer and at Site 3 in autumn, at Site 3 on the Palmiet River in summer, and at Site 3 on the Hout Bay River in autumn and spring. The only other scores not indicative of significantly impaired conditions relative to the reference state for the Vegetation biotope group were recorded at Site 2 on the Lourens River in autumn and spring and at Site 4 in spring where, despite relatively low SASS-5 Scores (<50), the ASPT was ≥~5.2.

Gravel-Sand-Mud (GSM) biotope group

A scatter plot of SASS-5 Score vs. ASPT for the GSM biotope group (seasons separate) relative to the median SASS-5 Score (=25) and ASPT (=4.8) from SW Cape reference sites is presented in Figure 2.15. The GSM biotope group was only sampled at Site 4 during all seasons and at Site 3 in autumn along the Lourens River, while along the Palmiet River, this biotope group was only sampled at Site 4 during all three sampling seasons, and at Site 5 in autumn, Site 2 in spring, and Sites 1 and 2 in summer (Table 2.6). In the case of the Hout Bay River, the GSM biotope group was only sampled at Site 4 (all seasons) and at Site 3 in autumn.

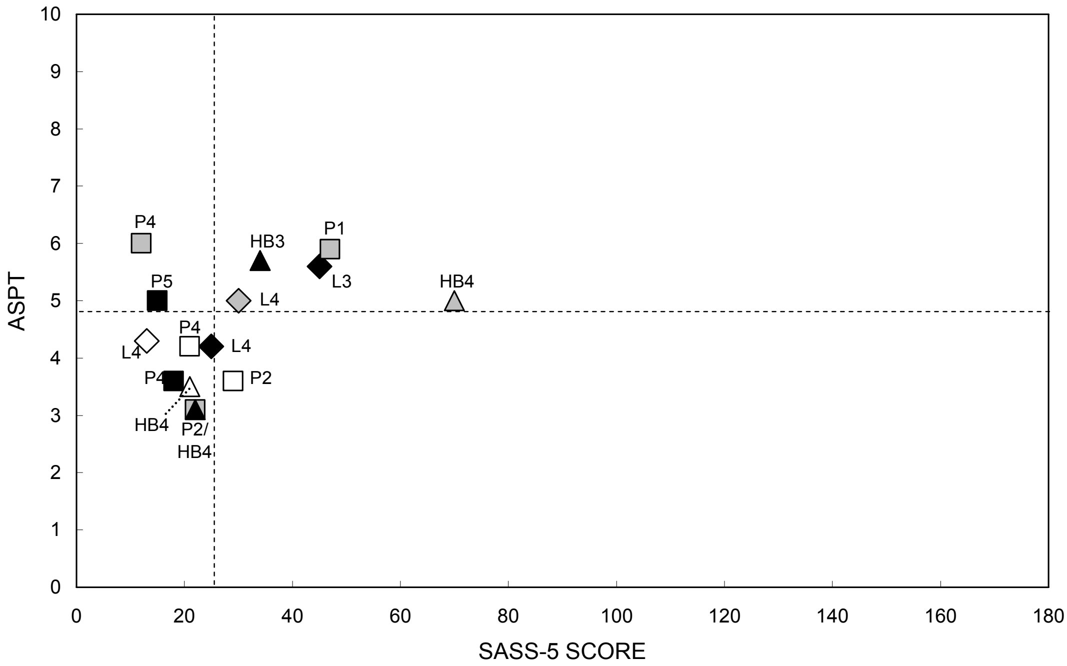

Figure 2.15: Scatter plot of SASS-5 Score vs. ASPT for the GSM biotope group (seasons separate) relative to median values from South Western Cape reference sites (indicated by dashed lines, from Dallas 2002). Lourens River (L) represented by diamonds, Palmiet River (P) by squares, and Hout Bay River (HB) by triangles; site numbers shown. Autumn samples indicated by solid shapes, spring samples by open shapes, and summer samples by grey-shaded shapes

The SASS-5 Score and ASPT were both greater than the GSM reference values for the autumn sample from Site 3 and the summer sample from Site 4 on the Lourens River, for the summer sample from Site 1 on the Palmiet River, and for the autumn sample from Site 3 and the summer sample from Site 4 on the Hout Bay River. Although the autumn sample from Site 4 on the Lourens River and the spring sample from Site 2 on the Palmiet River had SASS-5 Scores comparable to or greater than the reference score, these samples had low ASPT values (<4.5). The relatively high ASPT values (5.0 to 6.0) for the GSM biotope group at Site 4 in summer and Site 5 in spring along the Palmiet River, with very low SASS-5 Scores (<20), should also be treated with caution because only two or three macroinvertebrate taxa were collected in these cases.

Proportions of sensitive and tolerant taxa

Comparative tables showing the percentages of sensitive taxa (SASS-5 sensitivity score >10) versus the percentage of tolerant taxa (SASS-5 sensitivity score ≤5) collected during each sampling season are presented for the Stones, Vegetation and GSM biotope groups in Appendix 2.11 (Tables A2.11-1 to A2.11-3). The results are summarised for each biotope group, in turn, below.

Stones biotope group

Along the Lourens River, the highest proportions of sensitive taxa (>40%) were recorded for the Stones biotope group at Sites 1, 2 and 3 during spring, with relatively high proportions of sensitive taxa (20–25%) recorded at Site 1 during autumn and summer. At Sites 2 and 3, no sensitive taxa were recorded for the Stones biotope group during autumn or at Site 2 in summer, with more than 50% of the taxa being tolerant and <10% sensitive at Site 3 in summer. At Site 4, a high proportion of taxa were tolerant (55–85%) during all three sampling seasons, with no or very low proportions (<10%) sensitive taxa.

For the Stones biotope group along the Palmiet River, the greatest proportions of sensitive taxa were recorded at Site 1 during spring and summer (>30%), with relatively high proportions of sensitive taxa (20–30%) also recorded at Site 1 in autumn and at Site 5 in spring. At Site 5, 10–15% of the taxa recorded during autumn and summer were sensitive, with 30–50% tolerant taxa recorded. No sensitive taxa were recorded for the Stones biotope group at Site 2 during any season, or at Site 3 in autumn, with >70% tolerant taxa collected. At Sites 3 and 4, less than 15% of the collected taxa were sensitive during all three seasons and, except for Site 3 during summer (44% tolerant taxa), more than 50% of the taxa were tolerant.

In the case of the Hout Bay River, the highest proportions of sensitive taxa from the Stones biotope group were recorded at Site 2 (>30% in all seasons), followed by Site 1 (25–30% in all seasons). At Site 3, less than 10% of the taxa collected from the Stones biotope group during autumn were sensitive (55% tolerant), while 15–22% of the taxa collected from this biotope group during spring and summer were sensitive, with relatively high proportions of tolerant taxa recorded (>55% in spring and ~40% in summer). No stones were present at Site 4 along the Hout Bay River.

Vegetation biotope group

For the Vegetation biotope group along the Lourens River, which was absent at Site 1, 50% or more of the taxa were tolerant at all the other sites during all three seasons, except at Site 3 during spring (40%). Concurrently, less than 10% of the taxa sampled from this biotope group along the Lourens River were sensitive, except at Site 2 during autumn and spring and at Site 4 during spring (15–20% sensitive in these cases).

Along the Palmiet River, relatively high proportions of sensitive taxa (>30%) were recorded for the Vegetation biotope group at Site 3 in spring and at Site 5 in autumn. Besides these cases and proportions of 10–15% sensitive taxa recorded at Sites 4 and 5 in spring, very low proportions of sensitive taxa (<10%) were recorded for all other sampling sites and occasions. The proportion of tolerant taxa collected from the Vegetation biotope was generally ≥50% along the Palmiet River, except at Site 5 (<20% in autumn, ~40% in spring and summer) and during spring at Sites 1 and 3 (30–40%).

In the case of the Hout Bay River, 50% of the taxa collected from the Vegetation biotope group were sensitive (and 50% tolerant) at Site 2 in spring, while 20–30% of the taxa recorded at Site 1 in spring and at Site 2 in summer were sensitive. Approximately 15% of the taxa were sensitive at Site 1 in autumn, dropping to <10% in summer. No vegetation was sampled at Site 2 in autumn (Table 2.6). At Sites 3 and 4, for all three sampling seasons, <10% of the taxa collected from the Vegetation biotope group were sensitive (zero at Site 3 in summer and at Site 4 during all three seasons) and ≥50% tolerant.

Gravel-Sand-Mud (GSM) biotope group

Very few samples were collected from the GSM biotope group, particularly along the Lourens and Hout Bay Rivers (Table 2.6). In the case of the Lourens River, this biotope group was only sampled at Site 4 during all three seasons and at Site 3 in autumn, with high proportions (>50%) of tolerant taxa always recorded (15–20% sensitive taxa at Site 4 in autumn and summer).

Along the Palmiet River, the GSM biotope group was only sampled at Site 1 in summer, at Site 2 in spring and summer, at Site 4 in autumn and spring, and at Site 5 in autumn. No sensitive taxa were collected at any of the sampling sites, except for a low proportion (<15%) recorded at Site 1 during summer. Generally, the proportion of tolerant taxa was ≥80%, except at Site 1 in summer and at Site 5 in autumn (30–40% tolerant taxa recorded).

In the case of the Hout Bay River, the GSM biotope group was not sampled at Sites 1 and 2 during any season or at Site 3 in spring and summer. At Site 3, which was only sampled in autumn, ~15% of the taxa collected from this biotope group were sensitive and 50% tolerant. At Site 4, <10% of the taxa were sensitive (zero in autumn and spring) and >60% tolerant (>70% in autumn and spring).

Proportions of air-breathing taxa

The respective proportions of air-breathing taxa collected from each of the three biotope groups (seasons separate) are shown in Table 2.9.

Table 2.9: Percentages of air-breathing taxa collected from the Stones, Vegetation and GSM biotope groups during each sampling season. Proportions ≥40% highlighted in bold

River	Sampling site	Stones			Vegetation			GSM		
		aut	spr	sum	aut	spr	sum	aut	spr	sum
Lourens	Site 1	14%	0	10%	-	-	-	-	-	-
	Site 2	13%	14%	11%	**50%**	17%	**40%**	-	-	-
	Site 3	31%	0	27%	30%	20%	38%	38%	-	-
	Site 4	27%	14%	**42%**	**50%**	20%	**64%**	33%	0	33%
Palmiet	Site 1	29%	0	**44%**	38%	**45%**	**50%**	-	-	38%
	Site 2	14%	29%	**43%**	**57%**	30%	**63%**	-	**50%**	29%
	Site 3	0	0	13%	20%	17%	27%	-	-	-
	Site 4	13%	11%	22%	**50%**	33%	**40%**	0	20%	-
	Site 5	14%	7%	20%	33%	14%	31%	33%	-	-
Hout Bay	Site 1	13%	23%	25%	**43%**	0	38%	-	-	-
	Site 2	9%	17%	17%	-	0	19%	-	-	-
	Site 3	27%	22%	21%	**50%**	25%	**60%**	33%	-	-
	Site 4	-	-	-	**69%**	**67%**	**47%**	29%	33%	**64%**

aut = autumn; spr = spring; sum = summer

Along the Lourens River, the general trend for all three biotope groups was for the lowest proportions of air-breathing taxa to be recorded during spring, with similar proportions recorded during autumn and summer (except at Site 4, where a significantly greater proportion of air-breathing taxa were collected from the Stones biotope in summer compared to autumn, and at Site 3 where almost 40% of the taxa collected from the GSM biotope group in autumn were air-breathers compared to zero in summer). Relatively high proportions of air-breathing taxa (>40%) were recorded most frequently for the Vegetation biotope group along the Lourens River, particularly at Sites 2 and 4.

Along the Palmiet River, during all three seasons, the highest proportions of air-breathing taxa were generally collected from the Vegetation biotope group. The only exceptions were at Site 2 in spring, when the GSM biotope group had the highest proportion of air-breathing taxa, and at Site 5 in autumn when the same proportion of air-breathers were recorded for the Vegetation and GSM biotope groups.

Relatively high proportions of air-breathing taxa (>40%) were collected most frequently from the Vegetation biotope group along the Hout Bay River, as in the case of the Lourens and Palmiet Rivers. However, the Vegetation biotope group did not have the highest proportion of air-breathers at Site 1 on the Hout Bay River in spring (Stones highest), at Site 2 in autumn and spring (Stones highest), or at Site 4 in summer (GSM highest). Furthermore, at Site 2 in summer and at Site 3 in spring, the proportion of air-breathing taxa for the Vegetation biotope group was only marginally higher than it was for the Stones biotope group.

Invertebrate habitat assessment: separate biotope groups

The IHAS Habitat Scores for the Stones, Vegetation and GSM biotope groups (as percentages of the respective maximum scores attainable) are presented for all sampling sites and seasons in Table 2.10. Generally, the highest Habitat Score was most frequently recorded for the Vegetation biotope group, except at Site 1 on the Lourens River during all sampling seasons (where only stones were sampled), at Sites 3 and 4 on the Lourens River in summer, at Sites 1, 3 and 5 on the Palmiet River in spring (and Site 5 in autumn), and along the Hout Bay River at Site 1 in spring and Site 2 during all seasons. For all these exceptions, Habitat Scores were greatest for the Stones biotope group (or the same for the Stones and Vegetation biotope groups). Habitat Scores for the GSM biotope group (as a percentage of the maximum attainable) were always the lowest, with relatively significant scores only recorded consistently at Site 4 on the Lourens Palmiet and Hout Bay Rivers, respectively.

Table 2.10: Habitat Scores (% of maximum) for the Stones, Vegetation and GSM biotope groups during each sampling season. Percentages ≥65% highlighted in bold

River	Sampling site	Stones			Vegetation			GSM		
		aut	spr	sum	aut	spr	sum	aut	spr	sum
Lourens	Site 1	50%	**65%**	**65%**	-	-	-	-	-	-
	Site 2	59%	47%	62%	61%	61%	**72%**	8%	8%	8%
	Site 3	**65%**	53%	**65%**	**67%**	61%	44%	25%	8%	8%
	Site 4	59%	41%	**65%**	**67%**	**67%**	56%	33%	25%	50%
Palmiet	Site 1	50%	**65%**	56%	56%	56%	**89%**	8%	8%	33%
	Site 2	50%	47%	62%	61%	**78%**	**83%**	8%	33%	17%
	Site 3	59%	56%	59%	**72%**	56%	**83%**	8%	8%	8%
	Site 4	59%	**68%**	59%	61%	**83%**	**89%**	42%	33%	58%
	Site 5	56%	59%	**68%**	56%	33%	**78%**	25%	8%	-
Hout Bay	Site 1	56%	59%	38%	**67%**	39%	**67%**	-	-	-
	Site 2	53%	56%	59%	0	17%	33%	8%	-	-
	Site 3	50%	47%	59%	**72%**	56%	**89%**	33%	8%	8%
	Site 4	-	-	-	56%	**72%**	**83%**	25%	33%	42%

Multivariate analyses of macroinvertebrate data

Combined biotope groups

Seasons separate

The results of the cluster analysis for all sampling sites and seasons (combined biotopes), with groupings delineated at a Bray-Curtis Similarity level of 40% (Figure 2.16), indicate that the macroinvertebrate community structure was similar at Site 1 on the Lourens River (all seasons), Site 1 on the Palmiet River (all seasons), Site 5 on the Palmiet River in summer, and Sites 1 and 2 on the Hout Bay River (all seasons, with autumn and summer communities at Site 1 forming a sub-group at a similarity level of ~35%). The remaining sites/seasons formed another group, separating into three sub-groups at Bray-Curtis Similarity levels of 30–40%. The MDS ordination of the above data (not shown) had a stress value of 2.0, indicating that the groupings should be treated with caution (Table 2.5).

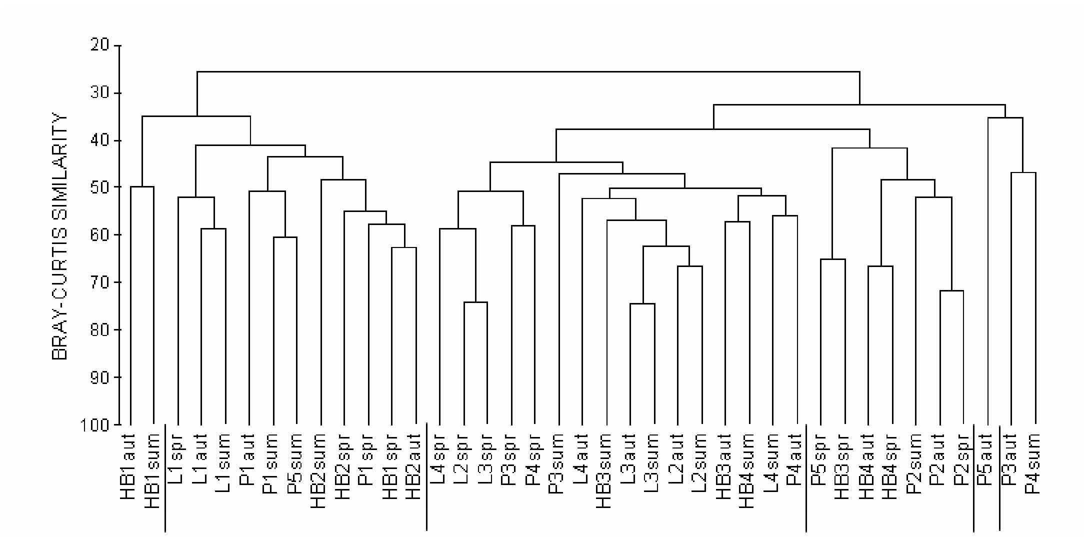

Figure 2.16: Dendrogram of sampling sites along the Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from all biotope groups

The MDS ordination for the Lourens River (combined biotopes, seasons separate), which is considered to be a reliable 2-D representation (stress value <0.1), is presented in Figure 2.17. Three groups have been delineated on the 2-D ordination, according to the groupings generated by the respective cluster analysis at a Bray-Curtis Similarity level of 50% with sub-groups at a Similarity level of 60% (Figure A2.12-1, Appendix 2.12). One of the primary groupings consisted exclusively of Site 1, with the spring sample separating out as a sub-group, while another primary group consisted of the spring samples from Sites 2, 3 and 4. The third main group comprised the autumn and spring samples from Sites 2, 3 and 4. At a Similarity level of 50–60%, Site 4 separates from the main groupings into which it was classified during each season.

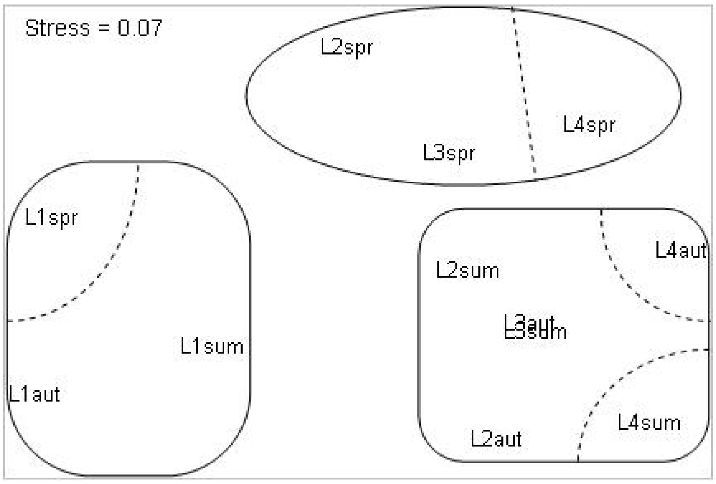

Figure 2.17: Ordination diagram of sampling sites along the Lourens River (site numbers given) during autumn (aut), spring (spr) and summer (sum) based on rank-abundance macroinvertebrate data from all biotope groups. 2-D stress value shown; site groupings delineated according to results of cluster analysis

The MDS ordination for the Palmiet River (combined biotopes, seasons separate) is shown in Figure 2.18, with groups and sub-groups outlined according to the results of the cluster analysis (Figure A2.12-2, Appendix 2.12) at Bray-Curtis Similarity levels of 40% and 50%, respectively. There is a chance of misinterpretation of data on the basis of the ordination, as the stress value is close to 0.2 (Table 2.5). Three main groups were delineated, with the autumn sample for Site 5 classified as an outlier. One group consisted exclusively of Site 2 (all sampling seasons), while another consisted of Site 1 (all sampling seasons) together with the summer sample from Site 5. The third group comprised all seasonal samples from Sites 3 and 4, and the spring sample from Site 5.

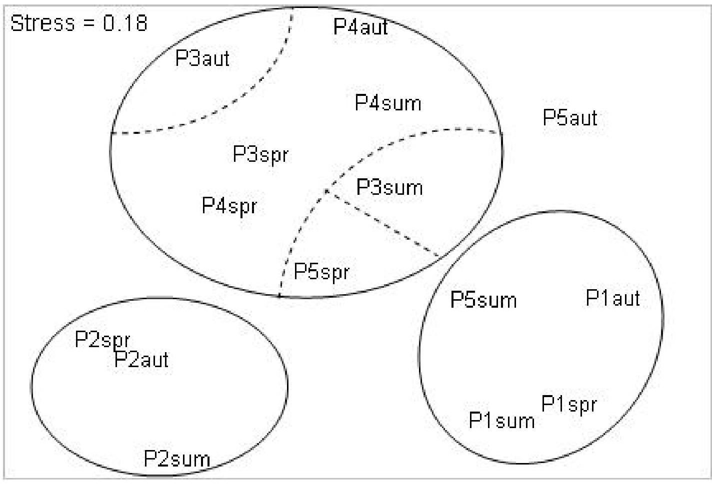

Figure 2.18: Ordination diagram of sampling sites along the Palmiet River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from all biotope groups. 2-D stress value shown; site groupings delineated according to results of cluster analysis

In the case of the Hout Bay River (combined biotopes, seasons separate), the MDS ordination (Figure 2.19) was considered to be a reliable representation (2-D stress value = 0.1). According to the results of the cluster analysis (Figure A2.12-3, Appendix 2.12), two main groups formed at a Bray-Curtis Similarity level of 40%, one consisting of Sites 1 and 2 and the other of Sites 3 and 4. Sub-groups formed at a Similarity level of ~50% on the basis of the cluster analysis (dashed lines in Figure 2.19) do not agree very well with the natural groupings that would be formed according to the MDS ordination. On the basis of the MDS ordination, one would tend to split Site 1 and Site 2 from one another, and the spring samples from Sites 3 and 4 would be separated from the autumn and summer samples.

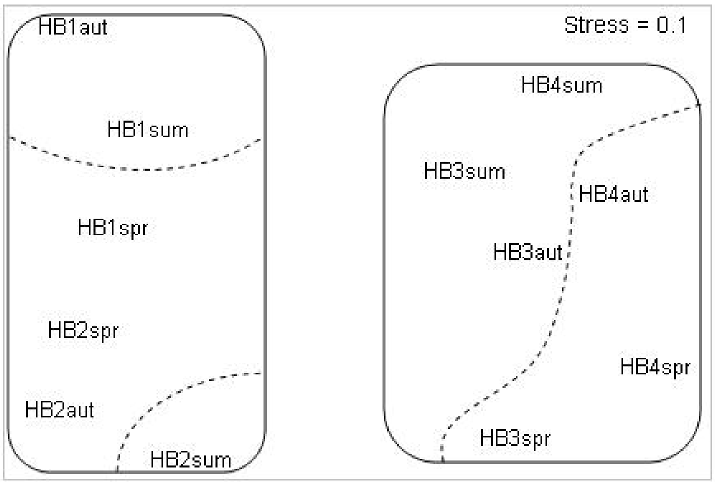

Figure 2.19: Ordination diagram of sampling sites along the Hout Bay River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from all biotope groups. 2-D stress value shown; site groupings delineated according to results of cluster analysis

Seasons combined

The MDS ordination for composite samples (combined seasons, combined biotopes) from all three rivers is presented in Figure 2.20, with main groupings (at 60% Bray-Curtis Similarity) and sub-groupings (at 65% Similarity) indicated according to the results of the cluster analysis (Figure A2.12-4, Appendix 2.12). The ordination has a 2-D stress value of 0.1, indicating that it is a useful two-dimensional representation of the underlying patterns in the data (Table 2.5). Site 1 on the Palmiet River grouped with Sites 1 and 2 on the Hout Bay River, with Hout Bay River Site 1 being the least similar of these three sites. A second group consisted of Sites 2 and 4 on the Palmiet River, Site 4 on the Lourens River and Site 4 on the Hout Bay River, with Palmiet River Site 4 separating from the other three sites at a Similarity level of 65%. A third grouping consisted of the remaining sampling sites (i.e. Sites 1, 2 and 3 on the Lourens River, Sites 3 and 5 on the Palmiet River, and Site 3 on the Hout Bay River), with Lourens River Site 1 splitting from the other sites at a 65% Similarity level.

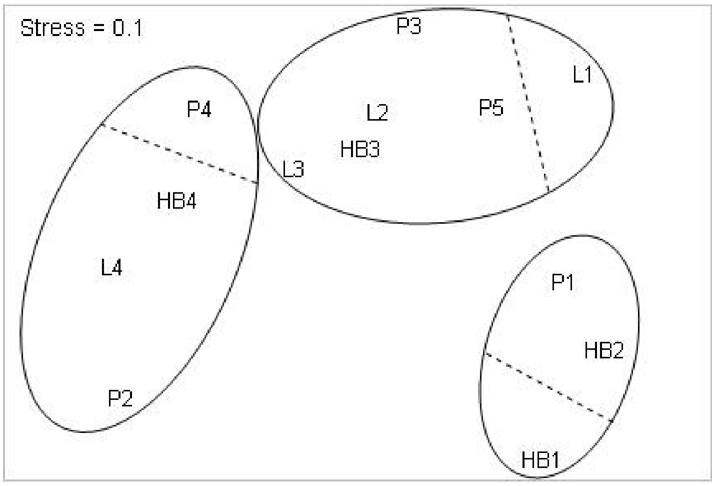

Figure 2.20: Ordination diagram of sampling sites along the Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given), based on combined-season presence/absence macroinvertebrate data from all biotope groups. 2-D stress value shown; site groupings delineated according to results of cluster analysis

Separate biotope groups

Seasons separate

The results of the cluster analyses for all sampling sites from the three rivers (seasons separate) are presented as dendrograms for the Stones, Vegetation and GSM biotope groups in Figures A2.12-5 to A2.12-7 (Appendix 2.12), respectively. Groups and sub-groups formed at Bray-Curtis Similarity levels of 25/30% and 35%, respectively, are indicated. However, this classification should be treated with caution because the 2-D stress values of the respective MDS ordinations ranged from 0.17 to 0.24, indicating unreliable representations of the data (Table 2.5).

MDS ordination diagrams for the Stones and Vegetation biotope groups along the Lourens River are presented in Figure 2.21, with groups delineated according to the cluster analyses (Figures A2.12-8 and 2.12-9, Appendix 2.12) at 50% Bray-Curtis Similarity level for Stones and at 45% Similarity for Vegetation. Both ordinations are potentially useful, with stress values of 0.12 (Table 2.5). The MDS ordination for the GSM biotope group is not shown, as there were too few data points to generate any meaningful groupings (dendrogram presented in Figure A2.12-10, Appendix 2.12).

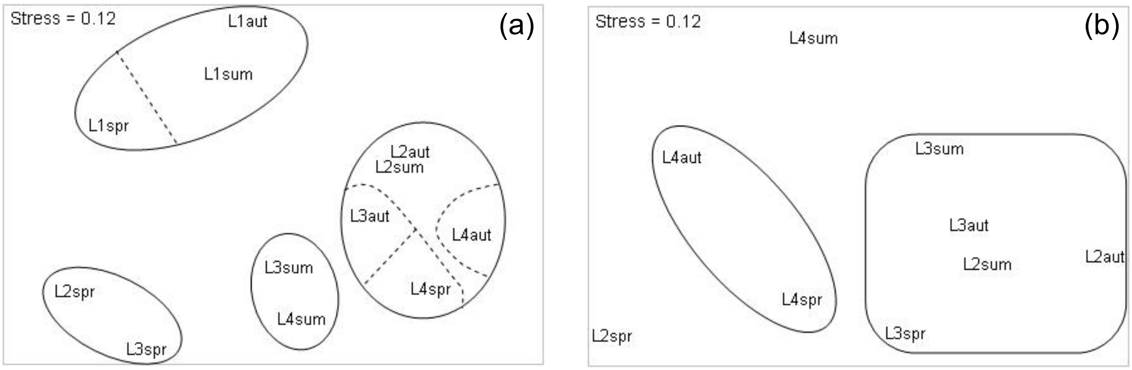

Figure 2.21: Ordination diagrams of sampling sites along the Lourens River (site numbers given) during autumn (aut), spring (spr) and summer (sum) based on rank-abundance macroinvertebrate data from (a) Stones and (b) Vegetation biotope groups. 2-D stress values shown; site groupings delineated according to results of cluster analyses

For the Stones biotope group along the Lourens River (Figure 2.21a), all the samples from Site 1 formed a grouping, with the spring sample separating out at a Bray-Curtis Similarity level of 50–55%. A second group consisted of the spring samples from Sites 2 and 3, while a third group consisted of the summer samples from Sites 3 and 4. The remaining samples formed a fourth group, with the autumn and summer samples from Site 2 separating out at a Similarity level of ~60%. For the Vegetation biotope group (Figure 2.21b), the autumn and spring samples from Site 4 were classified into a group. A second grouping consisted of all the samples from Site 3, together with the autumn and summer samples from Site 2. The spring sample from Site 2 and the summer sample from Site 4 were classified as outliers.

MDS ordination diagrams for the Stones, Vegetation and GSM biotope groups from the Palmiet River are presented in Figure 2.22. Groupings are shown according to the results of the relevant cluster analyses (Appendix 2.12), at Bray-Curtis Similarity levels of 35% for the Stones biotope group (Figure A2.12-11), 30% for the Vegetation biotope group (Figure A2.12-12) and 20% for the GSM biotope group (Figure A2.12-13). The ordinations for the Stones and Vegetation biotope groups had 2-D stress values of 0.15–0.20 and should therefore be treated with caution, while the ordination for the GSM biotope group had a stress value <0.1 and is therefore considered to be very reliable (Table 2.5).

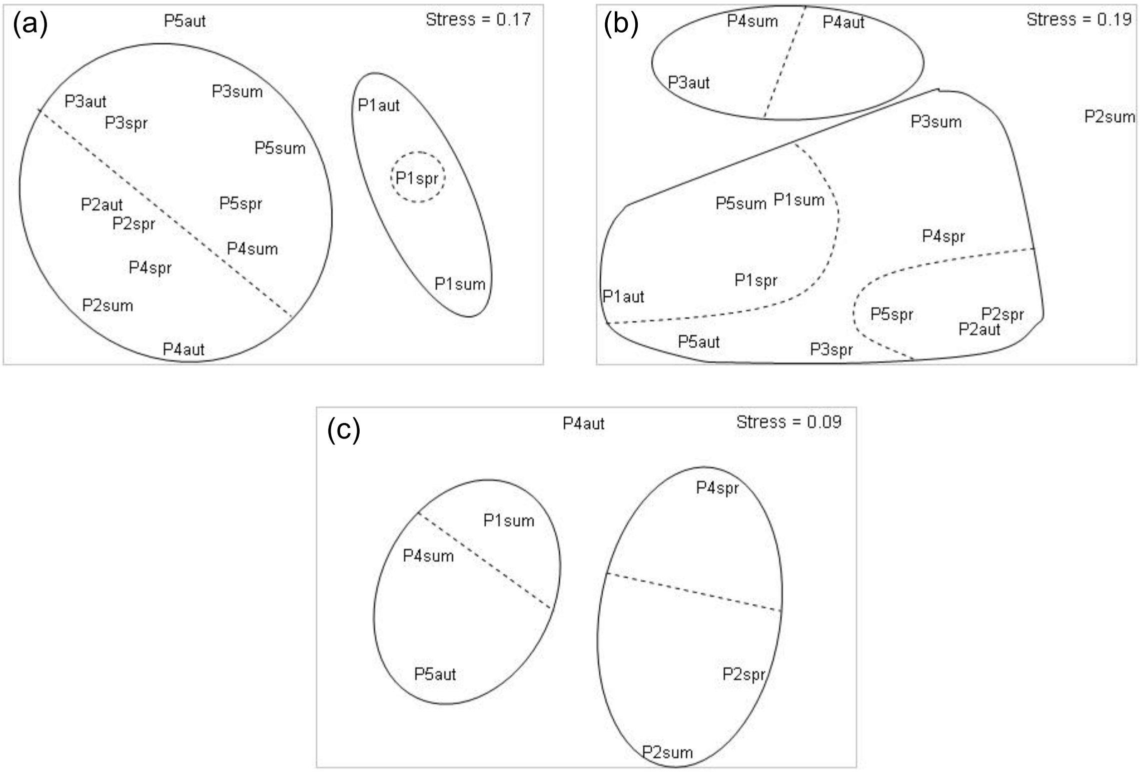

Figure 2.22: Ordination diagrams of sampling sites along the Palmiet River (site numbers given) during autumn (aut), spring (spr) and summer (sum) based on rank-abundance macroinvertebrate data from (a) Stones, (b) Vegetation and (c) GSM biotope groups. 2-D stress values shown; site groupings delineated according to results of cluster analyses

For the Stones biotope group along the Palmiet River (Figure 2.22a), the three samples from Site 1 were classified into a group, with all the samples from the other sites (except the autumn sample from Site 5) forming a second group. A sub-group consisting of all the samples from Site 2 and the autumn and spring samples from Site 4 separated out at a Bray-Curtis Similarity level of ~40%. No clear patterns were generated for the Vegetation biotope group from the Palmiet River (Figure 2.22b), which had an MDS ordination with a high stress value (~0.2). For the GSM biotope group (Figure 2.22c), two distinct groups were delineated – one consisting of the spring and summer samples from Site 2 (no autumn sample collected) and the spring sample from Site 4, and the other consisting of the summer samples from Sites 1 and 4 together with the autumn sample from Site 5. The autumn sample from Site 4 was classified as an outlier, while the spring sample from Site 4 and summer sample from Site 1 separated out from their respective groups at Similarity levels of 25–30%.

MDS ordination diagrams for the Stones and Vegetation biotope groups along the Hout Bay River are presented in Figure 2.23, with groups delineated according to the results of the cluster analyses (Appendix 2.12), at a Bray-Curtis Similarity level of 40% for the Stones biotope group (Figure A2.12-14) and 35% for the Vegetation biotope group (Figure A2.12-15). The MDS ordination for the GSM biotope group is not shown as it had too few data points (dendrogram presented in Figure A2.12-16, Appendix 2.12), while the ordinations for Stones and Vegetation are both considered to be reliable with stress values ≤0.1 (Table 2.5).

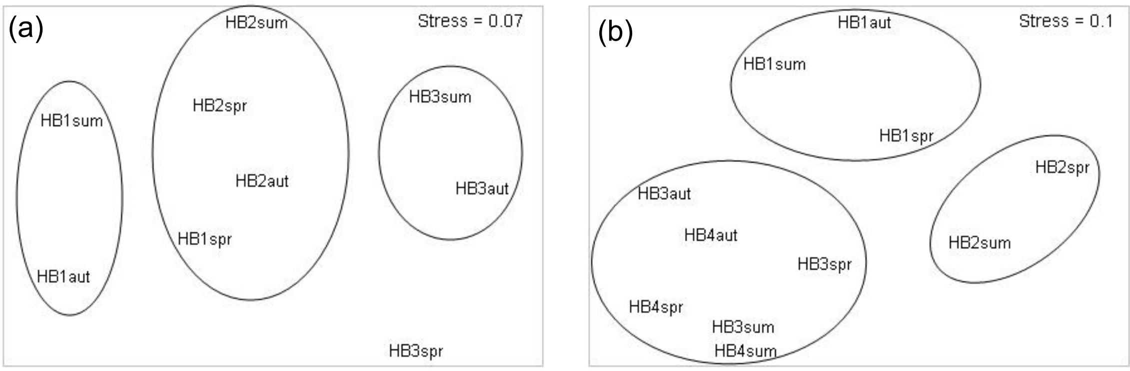

Figure 2.23: Ordination diagrams of sampling sites along the Hout Bay River (site numbers given) during autumn (aut), spring (spr) and summer (sum) based on rank-abundance macroinvertebrate data from (a) Stones and (b) Vegetation biotope groups. 2-D stress values shown; site groupings delineated according to results of cluster analyses

For the Stones biotope group (Figure 2.23a), three main groupings were generated and one sample (Site 3 in spring) was classified as an outlier. One group consisted of the autumn and summer samples from Site 1, while a second group consisted of all the samples from Site 2 together with the spring sample from Site 1. The third grouping comprised the autumn and summer samples from Site 3. Three groups were also generated for the Vegetation biotope group (Figure 2.23b). In this case, all the samples from Site 1 formed one group and all the samples from Site 2 (no autumn sample collected) another, while the third group consisted of all samples from Sites 3 and 4.

Seasons combined

MDS ordination diagrams of composite samples from each biotope group along all three rivers are presented in Figure 2.24. Groups have been outlined according to the results of the respective cluster analyses (Figures A2.12-17 to A2.12-19, Appendix 2.12), at Bray-Curtis Similarity levels of 50% for the Stones and Vegetation biotope groups (55% Similarity for sub-groups) and 35% for the GSM biotope group (45% Similarity for sub-groups). All three ordination diagrams were considered to be relatively reliable, with stress values varying from 0.09 to 0.12 (Table 2.5).

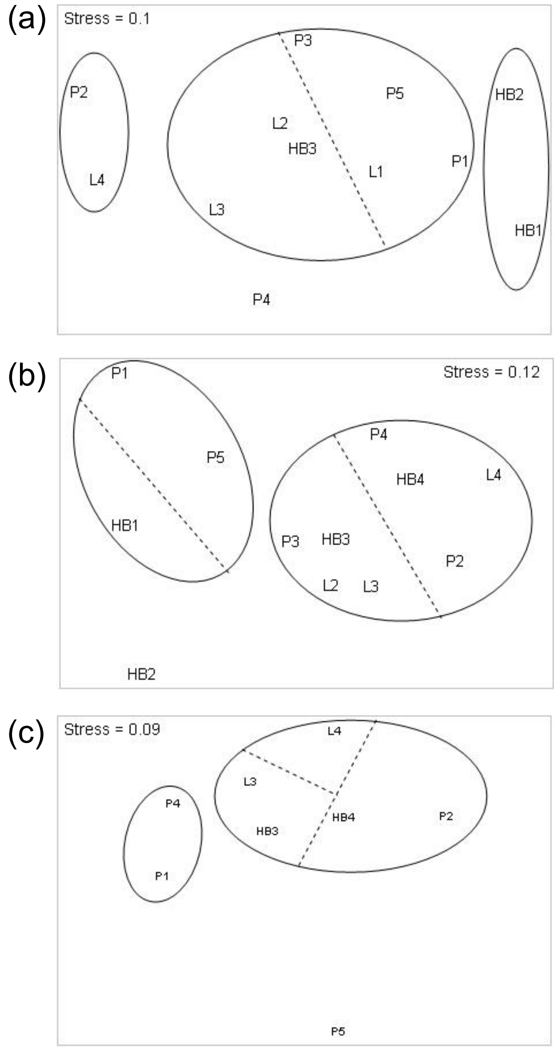

Figure 2.24: Ordination diagrams of sampling sites along the Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given), based on combined-season presence/absence macroinvertebrate data from (a) Stones, (b) Vegetation and (c) GSM biotope groups. 2-D stress values shown; site groupings delineated according to results of cluster analyses

The composite samples from the Stones biotope group (Figure 2.24a) were classified into three groups, with Site 4 on the Palmiet River identified as an outlier. One group consisted of Sites 1 and 2 on the Hout Bay River, another of Site 2 on the Palmiet River and Site 4 on the Lourens River, while the remaining sites formed the third group. For the Vegetation biotope group (Figure 2.24b), two main groups were delineated, with Site 2 on the Hout Bay River classified as an outlier. One of these groups comprised Sites 1 and 5 on the Palmiet River together with Site 1 on the Hout Bay River, while the other group consisted of the remaining sites where vegetation was sampled. Composite samples from the GSM biotope group (Figure 2.24c) also formed two main groups with one outlier (Site 5 on the Palmiet River, in this case). Sites 1 and 4 on the Palmiet River formed one group, while the second group comprised the remaining sites where GSM was sampled.

DISCUSSION

Assessment based on combined biotope groups with seasons separate

Reference sites

As expected, upper sites in the Mountain Stream Zone of the Lourens, Palmiet and Hout Bay Rivers (i.e. Site 1 on all three rivers, plus Site 2 on the Hout Bay River) generally had the least disturbed macroinvertebrate communities during the current investigation.

In terms of biological bands based on SASS-4 scores for combined biotopes, during summer and autumn, macroinvertebrate communities represented conditions that were below the reference state at Site 1 on the Palmiet and Hout Bay Rivers (Figure 2.8, Table 2.4). During autumn, however, these sites placed only marginally outside the reference bands, possibly as a result of fairly significant amounts of rainfall during the three-week period before sampling in the case of the Palmiet River and the three-day period before sampling in the case of the Hout Bay River (Table A2.3-1). The sub-reference SASS scores at these sites during summer, particularly for the Hout Bay River (50% tolerant taxa recorded – Table 2.7), were possibly the result of naturally harsh conditions at this time of year (associated with relatively low flows, high water temperatures, very acid water and low dissolved oxygen concentrations – Tables A2.4-1 and A2.5-1) and the subsequent loss of certain sensitive taxa at these exposed, high-altitude sites with no riparian trees providing shade. Alternatively, the sub-reference results could have been due to a greater proportion of lentic habitat being prevalent in the low-flow summer season than in autumn or spring, as lentic habitats generally support fewer sensitive taxa (Dallas 2002, Bonada 2003).

During summer, at Site 5 on the Palmiet River, the macroinvertebrate community from all biotopes combined also represented reference conditions in terms of SASS biological bands (Figure 2.8), mainly as a result of a large number of taxa (n =28) and subsequently high SASS4/5 Score being recorded. According to the results of the multivariate analyses based on samples from all biotopes combined, the Mountain Stream sites from the three rivers always separated clearly from other sites and, for the Palmiet River, the summer sample from Site 5 (Rejuvenated Foothill Zone) joined with the samples from Site 1 (Figures 2.16 to 2.19). This confirms that the Mountain Stream sites from all three rivers are consistently good reference sites, while reference conditions are at times reached, but not maintained, at Site 5 on the Palmiet River.

The summer sample from Site 4 along the Hout Bay River represented the reference state for lowland sites (Figure 2.9, Table 2.4), mainly as a result of a relatively large number of taxa (n =23) and correspondingly high SASS Score being recorded. However, the macroinvertebrate community at this site represented conditions that were well below the reference state in autumn and spring (Figure 2.9).

Generally, according to the macroinvertebrate communities recorded during this investigation, there was a significant deterioration in the ecological integrity of the Lourens, Palmiet and Hout Bay Rivers downstream of the Mountain Stream Zone.

Lourens River

All sampling sites downstream of Site 1 on the Lourens River were in Biological Band C (well below reference) during two of the three sampling seasons, with an improvement to Band B (below reference) in spring at Site 2, in autumn at Site 3 and in summer at Site 4 (Figures 2.8 and 2.9). The reduction in the integrity of the macroinvertebrate communities below Site 1 was due to a drastic decrease in the proportion of sensitive taxa and an increase in the proportion of tolerant (and air-breathing) taxa (Tables 2.7 and 2.8), as indicated by a significant decline in ASPT values. For example, along the Lourens River, pollution-sensitive stonefly nymphs (Order: Plecoptera) and blepharocerid larvae (Order: Diptera) were only recorded at Site 1 (Table A2.6-1).

As the invertebrate habitat was less diverse at Site 1 (where only the Stones biotope group was present) than at the downstream sites (Figure 2.10), a reduction in water quality is the most likely reason for the observed decline in biotic integrity. This is confirmed by the increased EC/TDS values (more than double) and the drastic (more than ten-fold) increase in nitrate and inorganic nitrogen concentrations at sampling sites downstream of Site 1 (Table A2.5-1, see Dawson 2003 for details), as well as the opaque or discoloured water observed (Table A2.4-1). A previous investigation along the Lourens River (Tharme *et al*. 1997) had similar findings, with drastic increases in TDS and nutrient concentrations (and TSS) recorded downstream of Site 1 together with a radical reduction in the biotic integrity of the macroinvertebrate communities present (collected using the SASS-4 rapid bioassessment method). Pesticide-contaminated runoff from farms adjacent to the river (in the upper-to-middle reaches) is undoubtedly one of the major sources of water quality problems along the Lourens River, with other studies having shown that the TSS and pesticide levels entering the river from contaminated runoff after rainfall events exceed national guidelines and toxic thresholds (Schultz 2001, Schultz *et al*. 2001, Dabrowski *et al*. 2002). Lower down the river, water quality has been reduced largely as a result of stormwater runoff from urban, industrial and commercial areas (Tharme *et al*. 1997, Dawson 2003, RHP 2003).

Flow reduction downstream of Site 1, largely as a result of off-stream farm dams and water abstraction by riparian landowners, is also a major problem along the Lourens River (Tharme *et al*. 1997, Dawson 2003, RHP 2003), exacerbated by the dominance of alien vegetation and the loss of indigenous riparian species downstream of the Hottentots Holland and Helderberg Nature Reserves (Tharme *et al*. 1997, Dawson 2003, RHP 2003, Withers 2003). The impact of reduced flows on the macroinvertebrate communities along the Lourens River during this investigation may have been offset during spring, when a fairly significant amount of rainfall (~90 mm at Lourensford) was recorded over the three-week period before sampling (Table A2.3-1), perhaps resulting in the drift of invertebrates from the Mountain Stream Zone into the lower reaches of the river. The ASPT at Sites 1 to 3 was generally higher during spring (Figure 2.8, Table A2.7-1) because greater proportions of sensitive taxa were recorded (Table 2.7), some of which may have drifted to these sampling sites from upstream. Spring samples at all four sites also separated clearly from the autumn and summer samples in the multivariate analyses undertaken for the Lourens River, particularly at Sites 2 and 3 (Figure 2.17)[7]. Despite these findings, the cause/s of the observed differentiation of spring samples from autumn and summer samples along the Lourens River may not necessarily be related to the flow regime.

Palmiet River

Along the Palmiet River, the macroinvertebrate communities observed at Site 2 (near Grabouw town centre) consistently represented impoverished conditions (Biological Band D) according to the SASS Scores and ASPT values recorded (Figure 2.8). No sensitive taxa were collected at this site during any season, with >80% tolerant taxa recorded in all three sampling seasons (Table 2.7) and it always had the highest proportion of air-breathing taxa (Table 2.8), indicating possible organic enrichment. Furthermore, Site 2 separated clearly from other sampling sites along the Palmiet River in the multivariate analyses undertaken (Figure 2.18). The opaque or discoloured water, low dissolved oxygen concentrations (particularly in summer), and elevated EC/TDS levels and nutrient concentrations (particularly nitrate, ammonium and total inorganic nitrogen) recorded during this investigation (Table A2.5-1, see Dawson 2003 for details) confirm that water quality impairment is a major problem at this site.

At Site 3 (downstream of Arieskraal Dam), the macroinvertebrate community was impoverished (Biological Band D) during autumn (Figure 2.8) with less than 10 taxa recorded, none of which were sensitive (Table 2.7). This coincided with a relatively high flow rate, resulting from a significant amount of rainfall (>100 mm at Nuweberg) over the three-week period before autumn sampling (Table A2.3-1). The macroinvertebrate community at this site in spring represented improved conditions (Biological Band C, still well below reference), with further improvement in summer (Biological Band B, below reference), as a result of more taxa and correspondingly higher SASS Scores being recorded on each successive sampling occasion. In an earlier study with replicated bimonthly sampling undertaken using a modified box sampler over approximately one year, the number of macroinvertebrate taxa collected below Arieskraal Dam (identified to the

[7] When based on presence/absence (instead of rank abundance, as in Figure 2.17), the spring samples from Sites 2 and 3 still formed a separate group and the spring sample from Site 1 a sub-group, but the spring sample from Site 4 grouped with the autumn sample from this site.

lowest taxonomic unit possible) was generally found to be drastically reduced up to at least the position of Site 3 (Gale 1992), similar to the situation during spring and, especially, autumn in the current investigation. Although water is apparently released at a constant rate from the bottom of Arieskraal Dam, the high flow rate experienced during autumn sampling for the current investigation (Table A2.4-1) suggests that the dam overtopped at this time. Whatever the case, from this investigation and previous studies (e.g. Byren & Davies 1989, Gale 1992, Brown & Day 1998), it is evident that the Arieskraal Dam is exerting a negative impact on the ecological integrity of the Palmiet River for at least a few kilometres downstream. Although the current investigation showed that some recovery of the macroinvertebrate community does occur at this site after disturbance, conditions always remained below the reference state (Figure 2.8, Table 2.4).

Rather surprisingly, according to the SASS results from this investigation (Figure 2.8), the macroinvertebrate community at Site 4 (in the heart of the Kogelberg Nature Reserve) indicated conditions below or well below the reference state (Biological Band B or C). Less than 10% of the taxa recorded at this site during any season were sensitive (zero in summer), while 60% or more tolerant taxa were present (Table 2.7), resulting in low ASPT values (<6.0). Site 4 had the highest Total IHAS Score and Habitat Total relative to the other sampling sites along the Palmiet River (Figure 2.11) with relatively pristine riparian vegetation (Withers 2003), indicating that the impaired conditions are due to water quality problems. The relatively low dissolved oxygen concentrations (during spring and summer) and elevated EC/TDS values and nitrate concentrations recorded at this site (Table A2.5-1, see Dawson 2003 for details), together with the observation of algae coating the rock surfaces during summer sampling, confirm that water quality, and nutrient enrichment in particular, is an issue of concern. A previous study undertaken to assess the ecological flow requirements of the river (Brown & Day 1998) revealed similar results. The high turbidity (silty water) observed in autumn (Table A2.4-1) indicates that sedimentation is a problem at this site, with the presence of reed-invaded sandbanks along this part of the river that would not have been as prolific under natural conditions providing further evidence of a poor water quality. The fact that no increased turbidity was observed upstream at Site 3 during autumn suggests that the water quality problems at Site 4 originate from the heavily agriculturalised Huis and/or Krom River tributaries (Figure 2.4).

While the EC/TDS levels at Site 5 (near the southern boundary of the Kogelberg Nature Reserve) were still significantly elevated, the dissolved oxygen and nutrient concentrations were approaching the expected natural range (Table A2.5-1). However, during autumn, the silty conditions under relatively high flow rates observed at Site 4 were also present at this site (Table A2.4-1). At this time, less than 10 macroinvertebrate taxa were recorded, resulting in a low SASS Score (<70) but a relatively high ASPT (>7.0) because more than 20% of the taxa were sensitive (Table 2.7), including, for example, heptageniid mayflies (recorded in all three sampling seasons –

Table A2.6-2). In autumn and spring, the macroinvertebrate community at this site indicated conditions below the reference state (Biological Band B), approaching well below reference in autumn, but improved to better than reference (Biological Band X) in summer (Figure 2.8). Therefore, although negative impacts relating primarily to water quality problems originating upstream do result in periodic disturbances to the macroinvertebrate community at Site 5 on the Palmiet River, the relatively long distance over which the river flows through the Kogelberg Nature Reserve above this site enables subsequent recovery to the reference state.

Hout Bay River

Reference conditions generally prevailed at Site 1 (in the Table Mountain National Park, above the Hely-Hutchinson Dam) and Site 2 (in the Orange Kloof Reserve, below the Hely-Hutchinson and Woodhead Dams) along the Hout Bay River (Figure 2.8). According to the SASS results for Site 2, where a relatively large number of sensitive taxa were sampled (including barbarochthonid caddisflies and relatively rarely-encountered aquatic caterpillars of the Pyralidae family – Table A2.6-3), the relatively undisturbed parts of the Orange Kloof Reserve have conditions that are richer than the average reference state for the Fynbos Bioregion of the SW Cape (Biological Band X). This area is, therefore, a potential biodiversity 'hot-spot' for aquatic macroinvertebrates where more detailed species-level studies should be undertaken. Indeed, this area falls within one of the hot-spots of invertebrate endemism in the Cape Peninsula (Picker & Samways 1996).

Downstream of the Table Mountain National Park and Orange Kloof Reserve, a significant deterioration in the ecological integrity of the Hout Bay River was observed. At Site 3, on the peri-urban fringe of Hout Bay Village in the Foothill: Cobble-bed Zone of the river, conditions were well below reference (Biological Band C) in autumn and spring, improving to below reference in summer (Biological Band B) as a result of a relatively large number of taxa (n =23) and correspondingly higher SASS Score being recorded (Figure 2.8). Low proportions of sensitive taxa and relatively high proportions of tolerant taxa were recorded at this site in all three sampling seasons (Table 2.7), resulting in consistently suppressed ASPT values (<6.5). As this site had the highest invertebrate habitat scores (in the 'good' category, according to Total IHAS Scores – Figure A2.10-3) compared to the other sampling sites along the Hout Bay River (Figure 2.12), the decline in ecological integrity was most likely due to water quality impairment. This was confirmed to some extent by elevated pH values, EC/TDS levels and concentrations of ammonium and total inorganic nitrogen, relative to Sites 1 and 2 (Table A2.5-1, Dawson 2003). Possible sources of the water quality problems at this sampling site include organically-enriched runoff (from surrounding gardens, horse paddocks and stables), the discharge of contaminated stormwater into the river and seepage from septic tanks in the area (Dawson 2003, RHP 2003).

At Site 4, in a largely residential area on the outskirts of the Hout Bay town centre, variable SASS results were obtained, indicating conditions that fluctuated from well below reference (Biological Band C, in autumn) or impoverished (Biological Band D, in spring) to a reference state (Biological Band A, in summer) for rivers in the Lowland Floodplain Zone (Figure 2.9). However, the categorisation of this site into the reference band in summer is somewhat misleading, as it is purely the result of a relatively large number of taxa (n = 23) and correspondingly high SASS Score (>100) being recorded. In all three sampling seasons, less than 5% of the recorded taxa were sensitive (zero in autumn and spring) and more than 65% were tolerant (Table 2.7), leading to consistently low ASPT values (<5.0), which are often a more robust indicator of ecological integrity than SASS Scores (Dallas 1995).

The reduction in ecological integrity at Site 4 is possibly partly due to habitat degradation, which has occurred largely as a result of extensive channel modification in the lower reaches of the Hout Bay River (Dawson 2003, RHP 2003). However, water quality is also a problem here, with relatively high pH values and significantly elevated EC/TDS levels recorded in all three seasons (Table A2.5-1, Dawson 2003). Of particular concern are the low dissolved oxygen concentrations recorded in autumn (6.2 mg/l) and, especially, summer (5.0 mg/l) which, together with the dominance of air-breathing taxa (≥50% in all three seasons) (Table 2.8), indicate that organic enrichment is occurring at this sand-bed site. A drastic reduction in flow levels between Site 3 and 4 indicate that water abstraction by riparian landowners is also a potential problem along the lower reaches of the Hout Bay River (Dawson 2003).

Assessment based on combined biotope groups and seasons

Results from the multivariate analyses based on composite data (i.e. combined biotopes and combined seasons) generally agreed with the results based on separate seasons (Figure 2.20). Sites 1 and 2 on the Hout Bay River were similar to each other and to Site 1 on the Palmiet River in terms of macroinvertebrate community structure, forming a reference group. Although Site 1 on the Lourens River did not join with this reference group, the reason is more than likely because only the Stones biotope group was present at this site and not because it was ecologically impaired. Another grouping of similar sites consisted of Sites 1, 2 and 3 on the Lourens River, Sites 3 and 5 on the Palmiet River and Site 3 on the Hout Bay River, with Lourens River Site 1 separating at a Bray-Curtis Similarity level of 65%. Besides Site 1 on the Lourens River, this group of sites were generally in an intermediate (below reference) state of ecological integrity according to SASS results. A third grouping consisted of largely degraded (well below reference) sites, namely, Site 4 on the Lourens River, Sites 2 and 4 on the Palmiet River and Site 4 on the Hout Bay River, with Palmiet River Site 4 separating out at a Similarity level of 65%.

Assessment based on separate biotope groups and seasons

According to the SASS results for the Stones biotope group, reference or near-reference conditions were generally recorded at sampling sites in the Mountain Stream Zone during all three seasons (Figure 2.13). The only exception was Site 1 on the Hout Bay River during summer, where a relatively low ASPT was recorded as a result of a high proportion (50%) of tolerant taxa being collected in this season that were not collected in other seasons (Table A2.11-1), including turbellarian flatworms, notonectid hemipterans and culicid dipterans (mosquito larvae) (Table A2.6-3). The increased proportion of tolerant taxa at this site in summer may have been the result of low flows and a corresponding decrease in the proportion of lotic habitat available for invertebrates. The proportion of sensitive taxa recorded for the Stones biotope group at this site was consistently ≥25% (Table A2.11-1), indicating a relatively good condition. Furthermore, the results of the relevant multivariate analyses (Figure 2.23a) grouped the autumn and summer samples from Site 1 together, which were collected under relatively high and low flow conditions respectively, while the spring sample (which, unlike the other seasons, included relatively sensitive larvae of teloganodid mayflies, leptocerid caddisflies and athericid dipterans – Table A2.6-3) formed a group with the samples from Site 2. This confirms that the reference state was attained for the Stones biotope group at Site 1 on the Hout Bay River, as at Site 2, except under naturally high- or low-flow conditions which are probably mitigated at Site 2 by the two dams upstream. The multivariate analyses for the Stones biotope group along the Lourens and Palmiet Rivers (Figures 2.21a and 2.22a) confirmed that Site 1 on these rivers were both consistently good reference sites for this biotope group.

In addition to the Mountain Stream sites, reference conditions were also obtained for the Stones biotope group at Sites 2 and 3 on the Lourens River during spring and at Site 5 on the Palmiet River in summer, according to the SASS results (Figure 2.13). The conditions at Sites 2 and 3 on the Lourens River during autumn and summer, however, fell well below reference as a result of very low proportions of sensitive taxa being recorded (Table A2.11-1). At Site 5 on the Palmiet River, samples from the Stones biotope group were classified below reference in spring and well below reference in autumn (Figure 2.13), as a result of decreased numbers of taxa being recorded (Table A2.11-1). While the separation of the spring samples from the Stones biotope group at Sites 2 and 3 on the Lourens River was evident in the multivariate analyses undertaken (Figure 2.21a), this was not the case for the summer sample at Site 5 on the Palmiet River (Figure 2.22a).

It is interesting to note that the relatively strong seasonal signal detected along the Lourens River, with the greatest proportion of sensitive taxa occurring in spring, was most evident in the Stones biotope group, particularly at Sites 1, 2 and 3 (Table A2.11-1). Such a pattern was not clearly seen in the Vegetation or GSM biotope groups, except for the proportion of air-breathing taxa generally being less in spring than in autumn or summer for the Vegetation biotope group (Table 2.9).

Reference or near-reference SASS scores were recorded for the Vegetation biotope group during all sampling seasons at Sites 1 and 5 on the Palmiet River and at Sites 1 and 2 on the Hout Bay River (Figure 2.14), with no vegetation sampled at Site 1 on the Lourens River (Table 2.6). All the samples from the Vegetation biotope group at Site 1 on the Palmiet River and at Sites 1 and 2 on the Hout Bay River grouped together in the respective multivariate analyses (Figures 2.22b and 2.23b), while Site 5 on the Palmiet River did not consistently separate from impacted sites indicating that reference conditions were not maintained in the Vegetation biotope group at this site. Although reference or near-reference SASS scores were obtained on one or two sampling occasions for the Vegetation biotope group at Site 3 on the Lourens River, Sites 3 and 4 on the Palmiet River and Site 4 on the Hout Bay River (Figure 2.14), these samples did not separate out in the respective multivariate analyses undertaken (Figures 2.21b, 2.22b and 2.23b). Therefore, it is difficult to categorise the ecological condition of these sites on the basis of the macroinvertebrate data obtained from the Vegetation biotope group, which included sampling from both lotic and lentic vegetation habitats.

Invertebrate Habitat Scores for the Vegetation biotope group were generally very good (Table 2.10), but the proportions of sensitive taxa collected from this biotope group were generally relatively low and the proportions of tolerant taxa consistently high (Table A2.11-2) with relatively high proportions of air-breathing taxa recorded (Table 2.9). Many air-breathing macroinvertebrates, which are generally low-scoring tolerant taxa, would be expected to favour the Vegetation biotope group, as observed, but it would be useful to differentiate between the lotic and lentic vegetation habitats, as suggested by Dallas (2002).

It is interesting to note that the increase in SASS4/5 Scores from autumn/spring to summer that was observed for the combined-biotope analysis at Sites 3 and 5 on the Palmiet River (Figure 2.8, Table A2.7-1), largely as a result of increased numbers of taxa being recorded, was evident in the separate analyses for both the Stones and, to a slightly lesser degree, Vegetation biotope groups (Figures 2.13 and 2.14). The relatively high Vegetation ASPT values recorded for the spring sample at Site 3 and the autumn sample at Site 5 (Figure 2.14) are somewhat misleading, however. At Site 3 in spring, this was a result of more than two types of baetid mayfly nymphs being recorded (SASS-5 Score = 12) for the Vegetation biotope group compared to one type in autumn (SASS-5 Score = 4) (Table A2.6-2), with a correspondingly low total number of taxa. At Site 5 in autumn, it was the result of a single heptageniid mayfly larva (Table A2.6-2), which is a characteristic inhabitant of the stones-in-current biotope, being collected from the Vegetation biotope group.

The GSM biotope group was poorly represented during this investigation, particularly at undisturbed sites (Table 2.6). Where it was present, the Habitat Score for this biotope group was generally relatively low (Table 2.10), mainly because gravel and mud were absent from most sampling sites (which is fairly typical for rivers in the SW Cape) and sand, when present, was often mostly under stones. Generally, as expected, low proportions of sensitive taxa were collected from the GSM biotope group (Table A2.11-3), with relatively high proportions of tolerant and air-breathing taxa recorded on most occasions (Table 2.9). Very little, if any, additional information was obtained from separate analyses of the GSM biotope group during this investigation, as was the case for the characterisation of reference sites in the SW Cape (Dallas 2002).

Assessment based on separate biotope groups with seasons combined

The multivariate analyses for each of the SASS-5 biotope groups based on combined seasons' data (Figure 2.24) provided a somewhat muted representation of the results of this investigation, with some aspects detected by means of the separate seasons' analyses not being evident.

For the Stones biotope group, a gradient could be observed in the MDS ordination diagram (Figure 2.2.4a) from the right-hand-side to the left-hand-side, with Sites 1 and 2 on the Hout Bay River forming a group of least-disturbed sites on the right (Site 1 on the Palmiet River was relatively similar to these sites). Site 1 on the Lourens River formed a sub-group together with Sites 1, 3 and 5 on the Palmiet River. As such, the disturbances of the macroinvertebrate communities observed during autumn and spring for the Stones biotope group at Sites 3 and 5 on the Palmiet River (according to SASS results) were not evident in the combined analysis based on the accumulated taxa sampled over three seasons. Another sub-group of sites consisted of Sites 2 and 3 on the Lourens River and Site 3 on the Hout Bay River, all of which had an intermediate (below reference) ecological integrity according to the SASS results (Figure 2.13), while Site 4 on the Palmiet River was classified as an outlier to this sub-group. A final grouping on the left-hand-side of the ordination diagram for the Stones biotope group (Figure 2.24a) consisted of Site 4 on the Lourens River and Site 2 on the Palmiet River, which were the most ecologically disturbed sites from this biotope group in terms of SASS results (Figure 2.13).

For the Vegetation biotope group, the combined seasons' ordination diagram (Figure 2.24b) also showed some sort of gradient from one side to the other. In this case, Sites 1 and 5 on the Palmiet River and Site 1 on the Hout Bay River formed a group on the left-hand-side, with Site 2 on the Hout Bay River classified as an outlier to this group. Again, as in the case of the combined seasons' analysis for the Stones biotope group, the seasonal variation observed at Site 5 on the Palmiet River, with reference conditions only attained in summer in terms of the SASS-5 Score

(Figure 2.14) and according to the ordination diagram with seasons separate (Figure 2.22b), was lost. All the other sites where vegetation was sampled formed a second group, which could be split into two sub-groups at a Bray-Curtis Similarity level of 55%. One sub-group (near the middle of the ordination diagram – Figure 2.24b) consisted of Sites 2 and 3 on the Lourens River, Site 3 on the Palmiet River and Site 3 on the Hout Bay River, all of which could be regarded as sites of intermediate (below reference) ecological integrity for the Vegetation biotope group in terms of SASS results (Figure 2.14). The other sub-group (towards the right-hand-side of the ordination diagram – Figure 2.24b) contained sites where SASS results represented degraded conditions for the Vegetation biotope group (Figure 2.14), namely Site 4 on the Lourens River, Sites 2 and 4 on the Palmiet River and Site 4 on the Hout Bay River.

The multivariate analyses for the GSM biotope group were based on very few data, with many of the sites shown in the ordination diagram (Figure 2.24c) only having been sampled in one or two of the three sampling seasons (Table 2.6). Therefore, although the ordination has a low 2-D stress value, the picture should be interpreted with extreme caution and provides very little useful information.

CONCLUSIONS

General findings of ecological assessment

According to the results of this bioassessment of the Lourens, Palmiet and Hout Bay Rivers, the ecological integrity of sampling sites in the Mountain Stream Zone of the three rivers was consistently good. The ecological integrity of the Hout Bay River in the upper portions of the Orange Kloof Reserve (Site 2 in this investigation) was particularly near-pristine, with this area having been identified in this study as a potential biodiversity ‘hot spot’ for aquatic macroinvertebrates. Downstream of the Mountain Stream Zone, however, a significant deterioration in the ecological integrity of all three rivers was observed, which is generally the case for most rivers in the SW Cape (Dallas 2002).

Along the Lourens River (Figure 2.2), impaired water quality was shown to be a major problem downstream of the Mountain Stream Zone (Site 1), most likely resulting largely from contaminated runoff from agricultural areas in the upper to middle reaches of the river and, further downstream in the middle to lower reaches, largely from contaminated stormwater runoff from urban, commercial and industrial areas. Water abstraction was also identified to be a problem impacting on the ecological integrity of the river, particularly during the low-flow season, exacerbated by the proliferation of water-thirsty alien vegetation in the riparian zone below the Hottentots Holland and

Helderberg Nature Reserves. Generally, the Lourens River was found to be in a very poor ecological state below the Nature Reserve areas in the Mountain Stream Zone and, bearing in mind that the river has been declared a PNE along its entire course, urgent action is required (see Dawson 2003 and RHP 2003 for recommended management actions).

There was a significant deterioration in the ecological integrity of the Palmiet River (Figure 2.4) between the Nuweberg Nature Reserve (Site 1) and the town of Grabouw (Site 2), with water quality problems severely impacting on the macroinvertebrate communities in the river. The main sources of the impacts were identified to be the extensive fruit farming and related activities along this stretch of the river (Dawson 2003, RHP 2003), although Nuweberg and Eikenhof Dams are undoubtedly also exerting a negative influence on the ecological functioning of the river (see, for example, Gale 1992). There was a significant improvement in the ecological state of the river between Grabouw and the Kogelberg Nature Reserve, but Arieskraal Dam was shown to be a source of periodic disturbance to the macroinvertebrate communities a few kilometres downstream of the dam (Site 3 in this investigation). The ecological integrity of the Palmiet River in the Kogelberg Nature Reserve (Site 4) was unexpectedly impaired, seemingly as a result of water quality problems arising from the Huis and/or Krom River tributaries. Further investigations into the exact sources of the problem and follow-up actions are critical because, from an ecological perspective, the Kogelberg Reserve is an extremely sensitive and valuable natural asset in the heart of an internationally recognised Biosphere Reserve, demanding maximum protection from adverse impacts. Although the macroinvertebrate communities were found to have, during certain sampling seasons, recovered from upstream disturbances by the point at which the river flows out of the Kogelberg Reserve, this was not always the case. The impaired integrity of the instream communities in the Palmiet River recorded at the downstream end of the Kogelberg Reserve (Site 5) highlights the severity of the upstream impacts and the need for urgent action to prevent (unknown) critical thresholds of disturbance from being reached beyond which recovery is no longer possible.

Along the Hout Bay River (Figure 2.6), a drastic decline in ecological integrity was observed downstream of the Orange Kloof Reserve (Site 2). Water quality problems were found to be impacting on the integrity of the macroinvertebrate communities where the river flows through large tracts of peri-urban land immediately downstream of the Reserve (Site 3 in this investigation). Further downstream (towards Site 4), as the river enters Hout Bay Village, additional impacts are caused by drastic habitat alteration and fairly intensive water abstraction by riparian landowners. Suggested management actions to improve the ecological integrity of the middle and lower reaches of the Hout Bay River are provided by Dawson (2003) and RHP (2003).

Generally, the integrity of the macroinvertebrate communities observed along the Lourens, Palmiet and Hout Bay Rivers during the current investigation was similar to that found during other relatively recent studies undertaken along these rivers using similar methods based on the SASS. For example, on the basis of SASS results, previous studies along all three rivers (Lourens: Tharme *et al*. 1997; Palmiet: Dallas 1998; Hout Bay: Brown *et al*. 1997, Catchment Management Department 2000) revealed a sharp decline in ecological integrity downstream of the Mountain Stream Zone, with an increase in macroinvertebrate community integrity in the rejuvenated lower reaches of the Palmiet River (Dallas 1998). The reported reasons for the observed changes in the macroinvertebrate community structure along the three rivers during these previous studies were similar to those suggested during the current study.

Comparison of results using different methods of data analysis

In the current assessment, results based on recorded SASS Scores and ASPT values, using 'biological bands' generated from reference sites in the SW Cape (Dallas *et al*. 1998, Dallas 2002), were generally similar to and supported by the corresponding multivariate analyses (classification and ordination) undertaken. This reinforces the usefulness of the SASS indices in categorising the ecological integrity of sampling sites, at least where regional reference conditions have been established. It is recommended that SASS indices (SASS Score and ASPT) are used in combination with multivariate methods for macroinvertebrate-based bioassessments within the RHP, as discrepancies in the results from the different types of analysis highlight potential aspects warranting further investigation.

Analyses based on separate biotope groups revealed where certain patterns were most evident, compared to analyses based on combined biotopes. However, the patterns and results based on separate biotope groups were sometimes difficult to interpret, particularly for the Vegetation and GSM biotope groups. For the Stones and Vegetation biotope groups, interpretation may have been improved if lotic and lentic flow-habitats were sampled and analysed separately, as in the GUADALMED protocol for the IBMWP in Spain (Bonada 2003). The GSM biotope group, which was often not present at a sampling site (Table 2.6), generally provided very little additional information during this investigation. Therefore, as suggested previously (Dallas 2002), it seems that the GSM biotope group can safely be left out of macroinvertebrate-based rapid assessments without losing any valuable information regarding the ecological integrity of sampling sites, at least for rivers in the SW Cape.

Combined seasons' multivariate analyses undertaken during this investigation masked important seasonal variations in the ecological integrity at certain sampling sites (e.g. Site 5 on the Palmiet River), especially in the analyses based on combined biotopes, with sites of an intermediate or variable ecological state being classified as similar to reference sites in certain cases. Therefore, the use of combined seasons' analyses is not recommended for future bioassessment studies within RHP. However, these analyses would be very useful in conservation-oriented studies where the main aim is to analyse sampling sites with respect to the total inventory of aquatic fauna present.

From the results of the various analyses undertaken in this investigation and some of the problems encountered in interpreting the data, the following recommendations are made regarding future bioassessment studies based on the SASS within the RHP:

- Multi-season sampling (excluding the rainy season) should be undertaken, with data from different seasons kept separate in analyses. No preferable season for bioassessments was identified through this investigation, as some impacts were only apparent in certain seasons.
- Environmental data should be collected together with macroinvertebrate data, so that the possible causes of disturbances to macroinvertebrate communities can be identified.
- Lotic (in-current) and lentic (out-of-current) habitats within the Stones and Vegetation biotope groups should be sampled and analysed separately, while the GSM biotope group can be left out of assessments. This will enable better interpretation of results, and scores can still be generated for lotic and lentic habitats together to enable comparison with current SASS-5 assessments.
- Biological bands of SASS Score vs. ASPT should be used to interpret results, where these have been generated, together with multivariate techniques (classification and ordination). It is strongly recommended that biological bands are generated for separate biotope groups, so that conditions at a site can be categorised according to the biotopes sampled.

Potential research and development areas identified

The current assessment on the basis of SASS-4 biological bands suggested that it may be acceptable to classify sites using unconverted SASS-5 scores, with relatively few misclassifications occurring compared to when SASS-4 scores were used. However, for more accurate results, it is recommended that SASS-5 scores are converted to SASS-4 scores before classifying sites according to the biological bands. In this regard, a potential area for research and development within the RHP is the collation of as many SASS-5 data as possible from the various regions of the country, and the completion of regression analyses to determine statistically reliable equations for converting between SASS-4 and SASS-5 scores for each region. Once this has been done, SASS-5 biological bands can be compiled for future use by biomonitoring practitioners.

A critical need within the RHP is the development of SASS-5 biological bands based on reference sites for regions where these have not yet been generated. Separate biological bands should be generated for each biotope group, not just for combined biotopes. In the case of certain regions, such as Mpumalanga and the Fynbos Bioregion of the SW Cape, the primary research for the development of separate biological bands for the different biotope groups has already been undertaken (Dallas 2000b, 2002) and additional data analysis is all that is required. For other regions, the primary research on reference conditions must still be undertaken, and should be prioritised within the RHP.

Another area for potential research and development with regards to the SASS is the exploration of the possibility of modifying the current sampling protocol (Version 5) to keep the lotic and lentic habitats within the Stones and Vegetation biotope groups separate. At the same time, consideration should be given to the exclusion of the GSM biotope group. It is recommended that this whole topic be discussed in a workshop of SASS biomonitoring practitioners and researchers from around the country, as in the development of SASS to date (see, for example, Chutter 1998) and the initial design of the RHP (see, for example, Brown *et al*. 1996, DWAF 1996, Roux 1997).

The scientific testing and validation of the IHAS is still an important area requiring further research (Dallas 2000b, Dickens & Graham 2002). A preliminary investigation of this topic has been initiated (see **Chapter 3** of this thesis), which has highlighted the need for more research to be undertaken.

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APPENDICES TO CHAPTER 2

APPENDIX 2.1: BLANK DATA SHEETS

The following data sheets are provided:

1) SASS-5 score sheet (from RHP website: http://www.csir.co.za/rhp)

2) SASS-4 score sheet (from Chutter 1998)

3) IHAS score sheet (from McMillan 1998)

4) Field-based data sheets (from Dallas 2000a)

May 2001

River Health Programme - SASS 5 Score Sheet

Date: / /200__

Grid References:
S: ° ' , "
E: ° ' , "

WGS-84 | Cape datum

Site code:……………………

River:…………………………………………

Site description:……………………………………

Weather Condition:…………………………………

Temp:……………°C pH:………………

DO:………………mg/l Cond:…………mS/m

Biotopes sampled:

SIC ……………… Time……………minutes

SOOC……………

Bedrock…………

Aquatic veg'n……… Dom. sp………………………

MvegIC…………… Dom. sp………………………

MvegOOC………Dom. sp………………………

Gravel………… Sand……………

Mud………………

Hand picking/Visual observation……………

Flow: Low/Medium/High/Flood

Turbidity: Low/Medium/High

Riparian land use:

Disturbance in the river: eg. sandwinning, cattle drinking point, floods etc.

Signs of pollution: eg. smell and colour of water, petroleum, dead fish, etc.

Other observations:

Taxon		S	VG	GSM	TOT
PORIFERA	5				
COELENTERATA	1				
TURBELLARIA	3				
ANNELIDA					
Oligochaeta	1				
Leeches	3				
CRUSTACEA					
Amphipoda	13				
Potamonautidae*	3				
Atyidae	8				
Palaemonidae	10				
HYDRACARINA	8				
PLECOPTERA					
Notonemouridae	14				
Perlidae	12				
EPHEMEROPTERA					
Baetidae 1sp	4				
Baetidae 2 sp	6				
Baetidae > 2 sp	12				
Caenidae	6				
Ephemeridae	15				
Heptageniidae	13				
Leptophlebiidae	9				
Oligoneuridae	15				
Polymitarcyidae	10				
Prosopistomatidae	15				
Teloganodidae SWC	12				
Tricorythidae	9				
ODONATA					
Calopterygidae ST,T	10				
Chlorocyphidae	10				
Chlorolestidae	8				
Coenagrionidae	4				
Lestidae	8				
Platycnemidae	10				
Protoneuridae	8				
Zygoptera juvs.	6				
Aeshnidae	8				
Corduliidae	8				
Gomphidae	6				
Libellulidae	4				
LEPIDOPTERA					
Pyralidae	12				

Taxon		S	VG	GSM	TOT
HEMIPTERA					
Belostomatidae*	3				
Corixidae*	3				
Gerridae*	5				
Hydrometridae*	6				
Naucoridae*	7				
Nepidae*	3				
Notonectidae*	3				
Pleidae*	4				
Veliidae/M...veliidae*	5				
MEGALOPTERA					
Corydalidae	8				
Sialidae	6				
TRICHOPTERA					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphoce	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA					
Dytiscidae*	5				
Elmidae/Dryopidae*	8				
Gyrinidae*	5				
Haliplidae*	5				
Helodidae	12				
Hydraenidae*	8				
Hydrophilidae*	5				
Limnichidae	10				
Psephenidae	10				

Taxon		S	VG	GSM	TOT
DIPTERA					
Athericidae	10				
Blephariceridae	15				
Ceratopogonidae	5				
Chironomidae	2				
Culicidae*	1				
Dixidae*	10				
Empididae	6				
Ephydridae	3				
Muscidae	1				
Psychodidae	1				
Simuliidae	5				
Syrphidae*	1				
Tabanidae	5				
Tipulidae	5				
GASTROPODA					
Ancylidae	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae*	3				
Physidae*	3				
Planorbinae*	3				
Thiaridae*	3				
Viviparidae* ST	5				
PELECYPODA					
Corbiculidae	5				
Sphaeriidae	3				
Unionidae	6				
Sass score					
No. of taxa					
ASPT					

IHAS

Other biota:

Comments:

Procedure: Kick stones in current & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock +/- 1m2. Sweep vegetation (IC & OOC) for 2m total. Stir & sweep gravel, sand, mud for 30 secs total. * = airbreathers

Hand picking & visual observation for 1 min - record in biotope where found. Tip net contents into tray. Remove leaves, twigs & trash. Check taxa present for 15 mins and stop if no new taxa seen after 5 mins.

Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000 S = Stone and rock; VG = All vegetation; GSM = Gravel, sand, mud SWC = South Western Cape, T = Tropical, ST = Sub-tropical

Rate invertebrate biotope sampled: 1=very poor (i.e. limited diversity), 5=highly suitable (i.e. wide diversity)

SASS4

River. . . . . Date . . . . . . Time . . . .

Sampling point . . . .

Temp °C . . . . . pH . . . . . Cond.(mSm^{-1}) . . . .

Biotopes sampled:

SIC . . . (Type/time . . . .)

Marg veg . . . Dom. sp . . . .

Aq veg . . . Species . . . .

SOOC . . . . Sand . . . . Mud . . . . gravel . . . .

Other . . . .

Procedure Protocols:

1. If stones in current (SIC) all kickable, sample for 2 min., otherwise for maximum of 5 min.
2. Gravel - 1/2 min.
2. Marg/Aq veg, back & forward sweep 2 m.
3. Stones out of current (SOOC) kick +/- 1 m^2.
4. Sand/mud stir with feet & sweep net over disturbed area for 1/2 minute.
5. Any other biotopes - 1/2 min.
6. Complete top of form.
7. Tip net contents into tray. Remove leaves, twigs & trash.
8. Check taxa present on above list FOR THE LESSER of 15 minutes or 5 minutes since the last taxon was found.
9. Estimate & record taxon abundances on scale:
   A - 1 to 10; B - 10 to 100;
   C - 100 to 1000; D - >1000
10. **BEFORE LEAVING THE SAMPLING POINT CHECK THAT THIS FORM HAS BEEN FULLY COMPLETED!**

A* - score allocated to taxon.

Taxon	A*			
Porifera	5			
Coelenterata				
Hydra sp.	1			
Turbellaria				
Planarians	5			
Annelida				
Oligochaeta	1			
Hirudinea				
Leeches	3			
Crustacea				
Amphipoda	15			
Crabs	3			
Shrimps	8			
Hydracarina				
Hydrachnellae	8			
Plecoptera				
Notonemouridae	12			
Perlidae	12			
Ephemeroptera				
Polymitarcyidae	10			
Ephemeridae	15			
Baetidae 1 sp or	4			
2 spp or	6			
> 2 spp	12			
Oligoneuridae	15			
Heptgeniidae	10			
Leptophlebiidae	13			
Ephemerellidae	15			
Tricorythidae	9			
Prosopistomatidae	15			
Caenidae	6			
Odonata				
Chlorolestidae	8			
Lestidae	8			
Protoneuridae	8			
Platycnemidae	10			
Coenagriidae	4			
Calopterygidae	10			
Chlorocyphidae	10			
Zygoptera juvs.	6			
Gomphidae	6			

Aeshnidae	8			
Corduliidae	8			
Libellulidae	4			
Hemiptera				
Notonectidae	3			
Pleidae	4			
Naucoridae	7			
Nepidae	3			
Belostomatidae	3			
Corixidae	3			
Gerridae	5			
Veliidae	5			
Megaloptera				
Corydalidae	8			
Trichoptera				
Hydropsychidae: 1 sp	4			
or 2 spp	6			
or > 2 spp	12			
Philopotamidae	10			
Polycentropodidae	12			
Psychomyiidae	8			
Ecnomidae	8			
Hydroptilidae	6			
Other movable case larvae:				
case types score fam.				
1 8 1	8			
2 15 1	15			
3 20 1	20			
4 30 2	30			
5 40 2	40			
>5 50 3	50			
Lepidoptera				
Nymphulidae	15			
Coleoptera				
Dytiscidae	5			
Elmidae/Dryopidae	8			
Gyrinidae	5			
Haliplidae	5			
Helodidae	12			
Hydraenidae	8			
Hydrophilidae	5			
Limnichidae	8			

Psephenidae	10			
Diptera				
Blepharoceridae	15			
Tipulidae	5			
Psychodidae	1			
Culicidae	1			
Dixidae	13			
Simuliidae	5			
Chironomidae	2			
Ceratopogonidae	5			
Tabanidae	5			
Syrphidae	1			
Athericidae	13			
Empididae	6			
Ephydridae	3			
Muscidae	1			
Gastropoda				
Lymnaeidae	3			
Melaniidae	3			
Planorbidae	3			
Physidae	3			
Ancylidae	6			
Hydrobiidae	3			
Pelecypoda				
Sphaeriidae	3			
Unionidae	6			

Sample score				
No. of families				
Score/taxon (ASPT)				

Other families present/
notes & comments

INTEGRATED HABITAT ASSESSMENT SYSTEM (IHAS)

version 2.0c peter mac 12/98	River Name:	
	Site Name:	Date:

SAMPLING HABITAT

Stones In Current (SIC)

	0	1	2	3	4	5
Total length of white water rapids (ie: bubbling water) (in metres)	none	0-1	>1-2	>2-3	>3-5	>5
Total length of submerged stones in current (run) (in metres)	none	0-2	>2-5	>5-10	>10	
Number of separate SIC area's kicked (not individual stones)	0	1	2-3	4-5	6+	
Average stone sizes kicked (in cm's) (<2 or >20 = <2 >20) (gravel <2: bedrock >20)	none	<2>20	2-10	11-20	2-20	
Amount of stone surface clear (of algae, sediment etc.) (in percent) *	n/a	0-25	26-50	51-75	>75	
PROTOCOL: time spent actually kicking SIC's (in minutes) (gravel/bedrock=0min)	0	<1	>1-2	2	>2-3	>3

(* NOTE: up to 25% of stone is usually embedded in the stream bottom)

(E=SIC boxes total; F.=adjustment to equal 20; G=final total) **SIC Scores:** actual E | adj. ± F | max. 20 G

Vegetation

	0	1	2	3	4	5
Length of fringing vegetation sampled (banks) (in metres)	none	0-½	>½-1	>1-2	2	>2
Amount of aquatic vegetation/algae sampled (underwater) (in square metres)	none	0-½	>½-1	>1		
Fringing vegetation sampled in: (none, pool or still only, run only, mixture of both)	none		run	pool		mix
Type of veg. (percent leafy veg. as opposed to stems/shoots) (aq. veg. only=49)	none	0	1-25	26-50	51-75	>75

(H=Veg. boxes total; I=adjustment to equal 15; J=final total) **Veg. Scores:** actual H | adj. ± I | max. 15 J

Other Habitat / General

	0	1	2	3	4	5
Stones Out Of Current (SOOC) sampled: (PROTOCOL - in square metres)	none	0-½	>½-1	1	>1	
Sand sampled: (PROTOCOL - in minutes) (present, but only below stones)	none	under	0-½	>½-1	1	>1
Mud sampled: (PROTOCOL - in minutes) (present, but only below stones)	none	under	0-½	½	>½	
Gravel sampled: (PROTOCOL - in minutes) (if all, SIC stone size=<2) **	none	0-½	½	>½**		
Bedrock sampled: (all=no SIC, sand, gravel) (if all, SIC stone size=>20) **	none	some			all**	
Algal presence: (1-2m²=algal bed, rocks=on rocks, isol.=isolated clumps)	>2m²	rocks	1-2m²	<1m²	isol.	none
Tray identification: (PROTOCOL - using time: corr=correct times)		under		corr		over

(** NOTE: you must still fill in SIC section)

(K=O.H./G boxes total; L=adjustment to equal 20; M=final total) **O.H.Scores:** actual K | adj. ± L | max. 20 M

(S=total adjustment [F+I+L]; N= total habitat [G+J+M]) **Habitat Totals:** adj. ± S | max. 55 N

STREAM CONDITION

Physical

	0	1	2	3	4	5
River make-up: (pool=pool/still/dam only; run only; rapid only; 2 mix=2 types etc.)	pool		run	rapid	2 mix	3 mix
Average width of stream: (metres)		>10	>5-10	<1	1-2	>2-5
Average depth of stream: (metres)	>2	>1-2	1	>½-1	½	<½
Approximate velocity of stream: (slow=<½m/s, fast=>1m/s)	still	slow	fast	med.		mix
Water colour: (disc.=discoloured with visible colour but still clearish)	silty	opaque		discol		clear
Recent disturbances due to: (constr.=construction)	flood	fire	constr	other		none
Bank / riparian vegetation is: (grass=includes reeds, shrubs=includes trees)	none		grass	shrubs	mix	
Surrounding impacts: (erosn=erosion/shear banks, farm=farmland/settlements)	erosn.	farm	trees	other		open
Left bank cover (rocks and vegetation): (in percent)	0-50	51-80	81-95	>95		
Right bank cover (rocks and vegetation): (in percent)	0-50	51-80	81-95	>95		

(P=Physical boxes final total) **Stream Conditions Total:** max. 45 P

Total IHAS Score: (N+P) % T

SECTION C: FIELD-BASED DATA FOR EACH SAMPLING VISIT

GENERAL

1. GENERAL SITE VISIT INFORMATION

Assessor Name(s):	
Organisation:	
Date:	
Time:	

Water level at time of sampling (tick appropriate category)

Dry	Isolated pools	Low flow	Moderate flow	High flow	Flood

Rainfall in the last 4 days ?

Yes	No	Comment:

Water turbidity (tick appropriate category)

Clear	Discoloured	Opaque	Silty	Comment:

Vegetation sampling instructions:

Canopy Cover (tick appropriate category)

Open	Partially Open	Closed	Comment:

Impact on channel flow

Rate impacts on a scale of 0 to 3: 0 – no impact; 1- limited impact; 2 – extensive impact; 3 – channel blocked

	Score	**Source: local / upstream**
Coarse woody debris		
Other:		

2. STREAM DIMENSIONS (estimate widths, heights and depths)

		(m)		**Comments**
Macro-channel width				
Active-channel width				
Water surface width				
Bank Height	**LB:**			**RB:**
		Depth (m)		**Comments (specify physical biotope type)**
Deep-water physical biotope (e.g. pool)	Average			
	Minimum			
	Maximum			
Shallow-water physical biotope (e.g. riffle)	Average			
	Minimum			
	Maximum			

3. SUBSTRATUM COMPOSITION

Material	% Cover Bed	% Cover Bank	Riparian
Bedrock			
Boulder			
Cobble			
Pebble			
Gravel			
Sand			
Silt / mud / clay			
Soil (Riparian only)			
TOTAL % =	**100**		**100**

Degree of embeddedness of substratum (%)	0-25	26-50	51-75	76-100

INVERTEBRATES

4. BIOTOPES PRESENT (tick appropriate combinations and estimate relative percentages for each SASS biotope).
Note the percentages for each specific biotope should equal 100%.

		Specific Biotope (% of general)								Total = 100%
SASS Biotope	**%**		**%**		**%**		**%**		**%**	
SIC		Cobble riffle		Run		Bedrock Rapid		Chute		
		Cascade		Waterfall		Other				
SOOC		Backwater		Slackwater		Pool		Other		
Mg. Veg		Grasses		Reeds		Shrubs		Palmiet		
		Sedges		Other						
Aq. Veg		Sedges		*Isolepis*		Other				
Gravel		Backwater		Slackwater		In channel				
Sand		Backwater		Slackwater		In channel				
Silt/mud/clay		Backwater		Slackwater		In channel				
TOTAL	**100**									

APPENDIX 2.2: SASS-4 BIOLOGICAL BANDS FOR FYNBOS BIOREGION

Table A2.2-1: Critical values of Biological Bands (SASS-4 Score and ASPT) for upland and lowland sites in the Fynbos Bioregion, Western Cape

Biological band	**Upland sites** (values from Dallas 2002)		**Lowland sites** (values from Dallas *et al*. 1998)	
	SASS-4 Score	ASPT	SASS-4 Score	ASPT
X	>166	>9.5	-	-
A	140–166	8.0–9.5	>91	>6.7
B	100–139	7.0–7.9	73–91	5.8–6.7
C	60–99	6.0–6.9	55–72	4.3–5.7
D	<60	<6.0	<55	<4.3

- = No criteria stipulated.

APPENDIX 2.3: RAINFALL DATA

Table A2.3-1: Cumulative rainfall data for Lourens, Palmiet and Hout Bay Rivers (3-week cumulative rainfall >75 mm and 3-day cumulative rainfall >10 mm highlighted in bold)

			Rainfall (mm) before sampling							
River	**Rain station**	**Alt. (m)**	Autumn '02		Spring '02		Summer '02/'03		Autumn '03	
			3 weeks	3 days	3 weeks	3 days	3 weeks	3 days	3 weeks	3 days
LOURENS	Lourensford	~120	61	**14**	**90**	0	10	0	19.5	0
	Strand	10	31.8	2.8	48	0	6.6	0	5.8	1.6
PALMIET	Nuweberg	535	**118**	0	26	0	20	0	-	-
	Grabouw	258	63.3	0	37.9	5	18.8	0	-	-
	Oudebosch	55	**75.5**	0.5	29.1	**14.3**	50.4	0	-	-
HOUT BAY	Woodhead Dam	747	**79.9**	**54**	43	4	**79**	0	-	-
	Houtbaai	300	34.1	**23.1**	22.6	0	16	0	-	-

- = Not applicable.

APPENDIX 2.4: PHYSICAL SITE OBSERVATIONS

Table A2.4-1: Summary of physical site observations

River	Sampling site	Season	% substrate embedded	Avg. stream width (m)	Avg. deep-water depth (m)	Avg. shallow-water depth (m)	Estimated stream velocity	Water clarity	Canopy cover
Lourens River	Site 1	Autumn	12.5	3	0.3	0.15	medium	clear	open
		Spring	12.5	3.5	0.9	0.1	medium	clear	"
		Summer	12.5	3	1.5	0.1	slow	clear	"
	Site 2	Autumn	37.5	8	0.25	0.15	slow	discoloured	partial
		Spring	-	9	0.35	0.2	medium	opaque	"
		Summer	62.5	7.5	0.2	0.05	slow	clear	"
	Site 3	Autumn	37.5	7	0.8	0.15	slow	opaque	partial
		Spring	12.5	7	0.75	0.1	fast	opaque	"
		Summer	12.5	5	0.5	0.15	still	discoloured	"
	Site 4	Autumn	62.5	4	1.5	0.15	slow	opaque	partial
		Spring	37.5	7.5	1.5	0.2	fast	discoloured	"
		Summer	62.5	1.5	1.5	0.08	still	discoloured	"
Palmiet River	Site 1	Autumn	12.5	4	0.5	0.15	slow	clear	open
		Spring	12.5	4	0.5	0.1	slow	clear	"
		Summer	12.5	3	0.5	0.2	still	clear	"
	Site 2	Autumn	12.5	3	1.5	0.2	fast	discoloured	open
		Spring	-	10	2	0.3	medium	discoloured	"
		Summer	-	2	1	0.3	slow	opaque	"
	Site 3	Autumn	12.5	18	1	0.2	fast	clear	open
		Spring	12.5	16	0.8	0.1	medium	clear	"
		Summer	-	10	1.5	0.3	slow	discoloured	"
	Site 4	Autumn	12.5	15	1.8	0.3	fast	silty	open
		Spring	12.5	15	2	0.3	medium	clear	"
		Summer	87.5	6	1.5	0.3	slow	clear	"
	Site 5	Autumn	12.5	4	0.5	0.2	fast	silty	open
		Spring	12.5	6	1	0.2	medium	clear	"
		Summer	37.5	10	1	0.4	slow	clear	"

Table A2.4-1 (cont.)

River	Sampling site	Season	% substrate embedded	Avg. stream width (m)	Avg. deep-water depth (m)	Avg. shallow-water depth (m)	Estimated stream velocity	Water clarity	Canopy cover
Hout Bay River	Site 1	Autumn	12.5	3	0.5	0.1	slow	clear	open
		Spring	12.5	3	0.8	0.2	slow	clear	"
		Summer	12.5	2	1	0.05	still	clear	"
	Site 2	Autumn	12.5	3	0.4	0.1	slow	clear	closed
		Spring	-	-	-	-	medium	clear	"
		Summer	62.5	1.5	0.2	0.05	still	clear	"
	Site 3	Autumn	62.5	3	0.4	0.1	slow	clear	open
		Spring	12.5	4	0.3	0.1	still	clear	"
		Summer	12.5	3	0.3	0.1	slow	clear	"
	Site 4	Autumn	n/a	5	0.75	0.5	still	silty	open
		Spring	n/a	5	1	0.1	still	silty	"
		Summer	n/a	5	1	0.5	still	discoloured	"

- = Not recorded.

On the following three pages, pie-charts of the estimated substrate composition at sampling sites during autumn, spring and summer are presented for each river.

Figure A2.4-1: Lourens River

Figure A2.4-2: Palmiet River

Figure A2.4-3: Hout Bay River

Figure A2.4-1

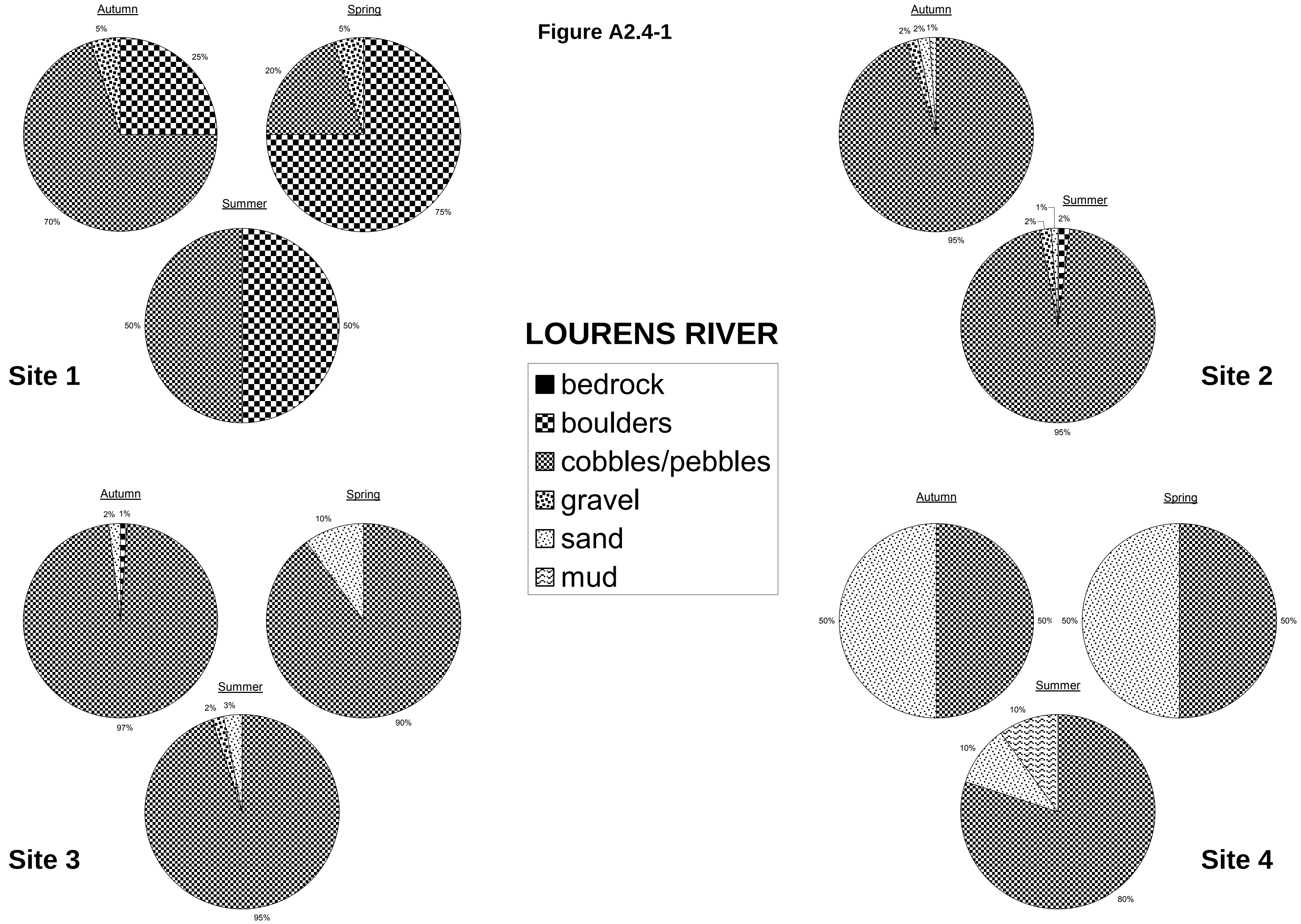
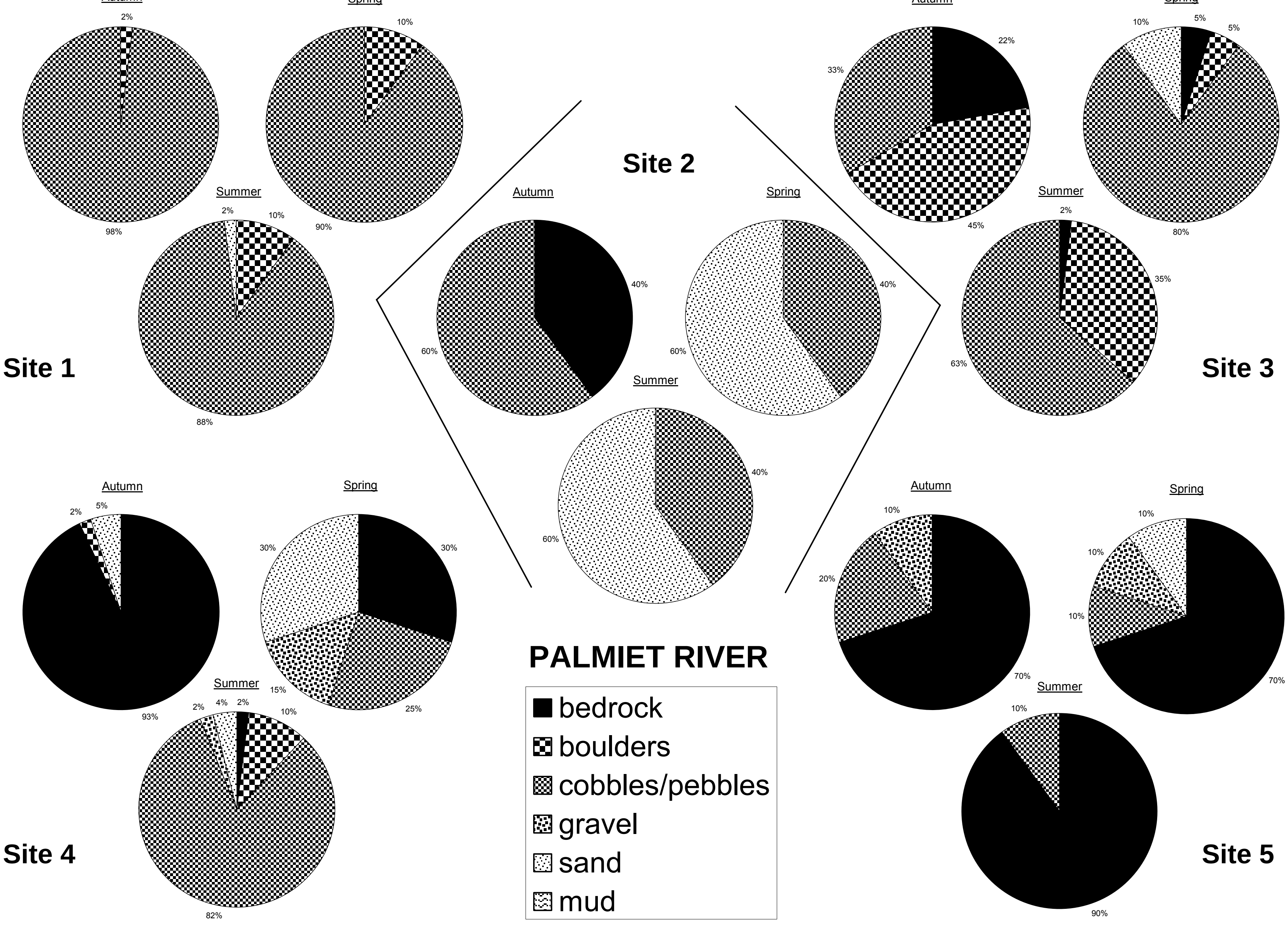
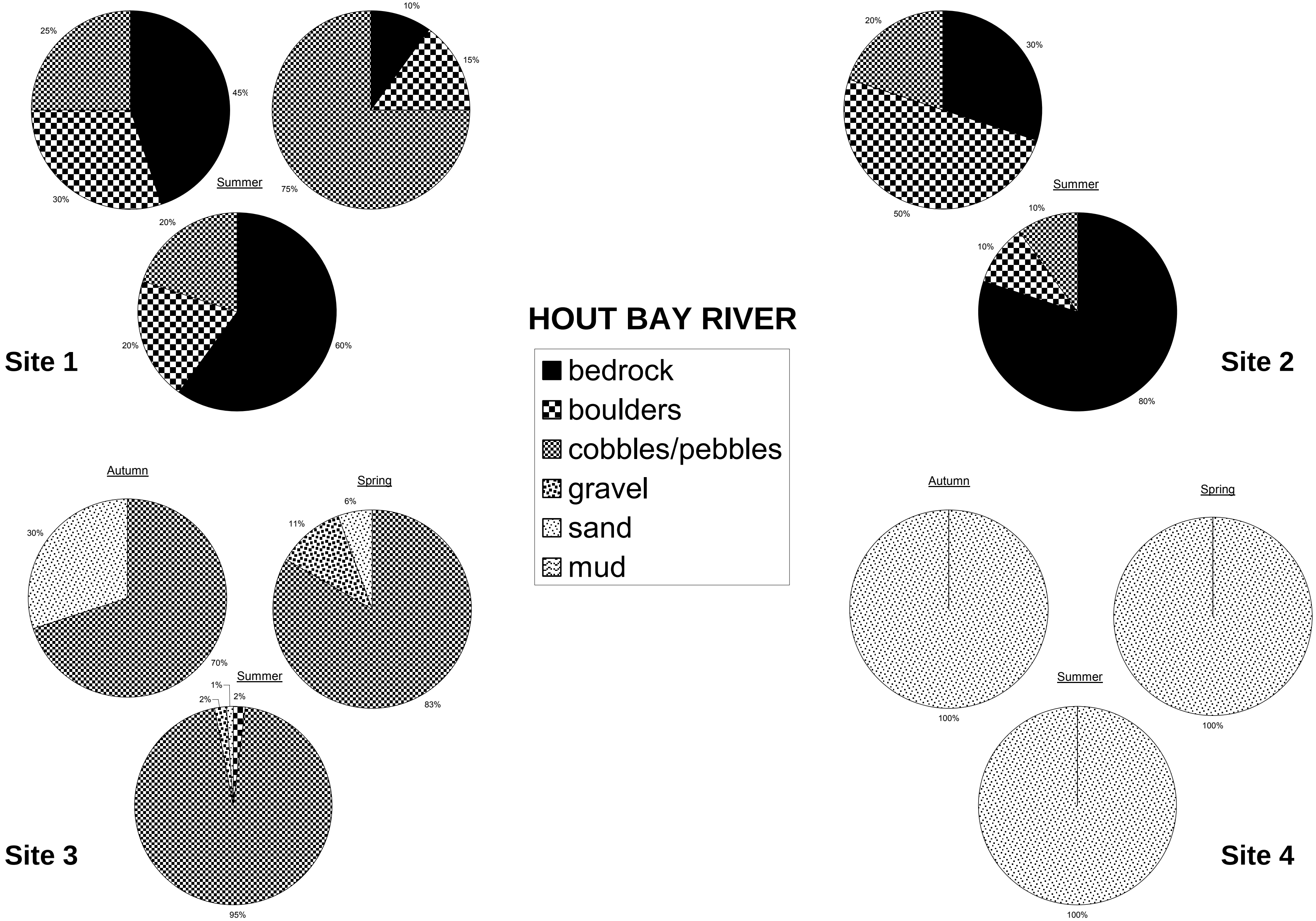

LOURENS RIVER
bedrock
boulders
cobbles/pebbles
gravel
sand
mud
Site 1
Autumn
5%
25%
70%
Spring
5%
20%
75%
Summer
50%
50%
Site 2
Autumn
2%
2%
1%
95%
Summer
1%
2%
2%
95%
Site 3
Autumn
2%
1%
97%
Spring
10%
90%
Summer
2%
3%
95%
Site 4
Autumn
50%
50%
Spring
50%
50%
Summer
10%
10%
80%

Figure A2.4-2



PALMIET RIVER
Site 1
Autumn
2%
98%
Spring
10%
90%
Summer
2%
10%
88%
Site 2
Autumn
40%
60%
Spring
40%
60%
Summer
40%
60%
Site 3
Autumn
22%
33%
45%
Spring
10%
5%
5%
80%
Summer
2%
35%
63%
Site 4
Autumn
2%
5%
93%
Spring
30%
30%
15%
25%
Summer
2%
4%
2%
10%
82%
Site 5
Autumn
10%
20%
70%
Spring
10%
10%
10%
70%
Summer
10%
90%
bedrock
boulders
cobbles/pebbles
gravel
sand
mud

Figure A2.4-3


HOUT BAY RIVER
bedrock
boulders
cobbles/pebbles
gravel
sand
mud
Site 1
Autumn
25%
45%
30%
Spring
10%
15%
75%
Summer
20%
20%
60%
Site 2
Autumn
20%
30%
50%
Summer
10%
10%
80%
Site 3
Autumn
30%
70%
Spring
6%
11%
83%
Summer
1%
2%
2%
95%
Site 4
Autumn
100%
Spring
100%
Summer
100%

APPENDIX 2.5: WATER CHEMISTRY DATA

Table A2.5-1: Summary of water chemistry measurements* (autumn and spring data from Dawson 2003; summer data from the DWAF and CMC Administration: Scientific Services Department)

River	Sample site	Season	pH	EC (mS/m)	TDS (mg/l)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (%)	Temp (^oC)	Nitrate (mg/l)	Nitrite (mg/l)	Ammonium (mg/l)	Phosphate (mg/l)	Inorganic N (mg/l)
Lourens River	Site 1	Autumn	7.1	4.5	22.0	7.2	76.0	17.2	0.1	0.1	-	0.1	-
		Spring	6.7	4.0	17.5	8.9	87.8	16.4	0.1	0.1	0.1	0.1	0.0
		Summer	5.5	3.4	-	7.5	-	17.4	-	-	-	-	-
	Site 2	Autumn	6.9	10.0	56.3	8.0	88.0	19.0	3.7	0.1	-	0.1	-
		Spring	6.4	10.1	51.5	9.0	94.0	18.8	4.7	0.1	0.3	0.1	1.3
		Summer	6.0	10.1	-	8.1	-	17.5	-	-	-	-	-
	Site 3	Autumn	6.8	bdr	bdr	11.4	133.0	17.8	-	-	-	-	-
		Spring	6.4	17.8	82.7	9.4	92.0	16.8	4.4	0.1	0.1	0.1	1.1
		Summer	6.5	15.7	-	6.8	-	23.6	-	-	-	-	-
	Site 4	Autumn	6.9	11.5	54.9	9.4	97.0	18.9	1.6	0.1	-	0.1	-
		Spring	6.3	17.2	84.6	6.2	63.5	18.5	4.5	0.1	0.5	0.1	1.4
		Summer	7.0	20.9	-	7.0	-	22.6	-	-	-	-	-
Palmiet River	Site 1	Autumn	5.8	4.6	25.7	8.5	85.0	18.8	0.1	0.1	-	0.1	-
		Spring	6.3	3.8	9.9	8.9	94.5	17.0	0.1	0.1	0.1	0.1	0.1
		Summer	4.0	4.0	-	5.1	-	25.3	-	-	-	-	-
	Site 2	Autumn	6.3	10.4	59.5	6.8	66.0	19.2	1.0	0.1	-	0.1	-
		Spring	5.6	19.2	87.4	6.0	62.7	15.6	0.6	0.1	0.7	0.1	0.7
		Summer	5.7	11.0	-	1.3	-	19.1	-	-	-	-	-
	Site 3	Autumn	6.4	9.0	40.2	9.8	100.0	16.8	0.1	0.1	-	0.1	-
		Spring	6.4	8.6	45.0	7.9	82.5	19.1	0.2	0.1	0.6	0.1	0.5
		Summer	6.2	8.6	-	8.2	-	18.8	-	-	-	-	-
	Site 4	Autumn	7.2	17.8	80.0	10.3	99.0	16.4	1.5	0.1	-	0.1	-
		Spring	6.8	17.2	86.7	6.3	76.0	16.1	1.5	0.1	0.3	0.1	0.6
		Summer	6.2	15.0	-	6.1	-	24.2	-	-	-	-	-
	Site 5	Autumn	7.2	20.0	82.0	9.8	101.0	17.8	0.1	0.1	-	0.1	-
		Spring	7.0	15.1	75.3	8.1	89.0	18.5	0.7	0.1	0.1	0.1	0.3
		Summer	5.0	10.2	-	7.1	-	24.3	-	-	-	-	-

Table A2.5-1 (cont.)*

River	Sample site	Season	pH	EC (mS/m)	TDS (mg/l)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (%)	Temp (^{o}C)	Nitrate (mg/l)	Nitrite (mg/l)	Ammonium (mg/l)	Phosphate (mg/l)	Inorganic N (mg/l)
Hout Bay River	Site 1	Autumn	4.2	11.0	-	9.0	89.0	12.8	0.1	0.1	-	0.1	-
		Spring	4.2	11.1	55.5	13.3	112.5	12.9	0.1	0.1	0.3	0.1	0.3
		Summer	4.5	12.6	-	6.9	-	16.6	-	-	-	-	-
	Site 2	Autumn	4.5	12.0	-	9.0	88.0	13.2	0.1	0.1	-	0.1	-
		Spring	-	13.3	62.6	-	-	11.9	0.1	0.1	0.0	0.1	0.0
		Summer	4.5	8.7	-	7.5	-	15.5	-	-	-	-	-
	Site 3	Autumn	7.0	17.0	-	8.7	89.0	17.1	0.1	0.1	-	0.1	-
		Spring	6.6	22.3	111.7	9.6	96.8	19.2	0.1	0.1	0.7	0.1	0.5
		Summer	6.0	17.7	-	6.3	-	24.3	-	-	-	-	-
	Site 4	Autumn	7.3	26.0	-	6.2	66.0	17.2	0.1	0.1	-	0.1	-
		Spring	6.3	25.9	138.3	7.5	82.6	18.3	0.1	0.1	0.2	0.1	0.2
		Summer	7.0	34.0	-	5.0	-	21.9	-	-	-	-	-

- = Not recorded

bdr = Below detection range of instrument

* EC = Electrical conductivity; TDS = Total dissolved solids; Inorganic N = Inorganic nitrogen

APPENDIX 2.6: MACROINVERTEBRATE TAXA COLLECTED

Table A2.6-1: Macroinvertebrate taxa collected from Stones (S), Vegetation (V) and Gravel-Sand-Mud (G) biotope groups along the Lourens River during autumn (aut), spring (spr) and summer (sum)

		Site 1			Site 2			Site 3			Site 4		
		aut	spr	sum	aut	spr	sum	aut	spr	sum	aut	spr	sum
TURBELLARIA				S			V						
ANNELIDA	Oligochaeta				S	S	S	S	S	V	SVG	SG	
	Hirudinae										SV	SV	
CRUSTACEA	Potamonautidae*			S	S	V	SV	SV	V	SV	SVG	S	SVG
HYDRACARINA				S	S								
PLECOPTERA	Notonemouridae	S	S	S									
EPHEMEROPTERA	Baetidae 1sp											G	
	Baetidae 2sp	S			S	V	S	S			S	S	
	Baetidae >2sp		S	S	V	S	V	VG	SV	SV	G	V	SVG
	Caenidae						SV	G	V	SV			
	Leptophlebiidae	S	S	S		S							
	Teloganodidae	S	S			SV			S				
	Tricorythidae		S						SV				
ODONATA	Coenagrionidae			S	V	V	V	V	V	V	SVG	V	VG
	Zygoptera juvs.							SV					
	Aeshnidae			S	S		SV	SV	SV	S	S	SG	S
	Corduliidae									V			
	Gomphidae							SG		S			SG
	Libellulidae			S				S			V		
HEMIPTERA	Corixidae*						V	G		SV	V		
	Gerridae*									V			V
	Nepidae*												V
	Pleidae*										V		
	Veliidae*				V		V	SVG		V			SV
MEGALOPTERA	Corydalidae	S	S	S	S		S						
TRICHOPTERA	Hydropsychidae 1sp		S			S		S		SV			
	Hydropsychidae 2sp	S		S			S						
	Hydropsychidae >2sp												
	Philopotamidae	S		S				S		V			S
	Polycentropodidae		S										
	Psychomyiidae	S											
Cased caddis:	Glossosomatidae		S			S							
	Hydroptilidae			S									
	Leptoceridae	S		S		V			V				
	Petrothrincidae			S									
COLEOPTERA	Dytiscidae*				V			G					
	Elmidae/Dryopidae*	S		S		S		S	V				
	Gyrinidae*						V	SV		SV	V	V	
	Helodidae			S									
DIPTERA	Blepharoceridae	S	S	S									
	Ceratopogonidae												
	Chironomidae	S	S	S		V	S	SVG	V	SV	SVG	SV	SVG
	Culicidae*	S			V			S		V	S		S
	Simuliidae	S	S	S	SV		SV	SV	V	SV	S		S
	Tipulidae										S		
GASTROPODA	Ancylidae				S			SVG		SV		S	SV
	Lymnaeidae*												SV
	Physidae*										SVG		VG
	Planorbidae*												SV

* Air breathers

Table A2.6-2: Macroinvertebrate taxa collected from Stones (S), Vegetation (V) and Gravel-Sand-Mud (G) biotope groups along the Palmiet River during autumn (aut), spring (spr) and summer (sum)

		Site 1			Site 2			Site 3			Site 4			Site 5		
		aut	spr	sum	aut	spr	sum	aut	spr	sum	aut	spr	sum	aut	spr	sum
TURBELLARIA							VG	S	S	SV			S		S	S
ANNELIDA	Oligochaeta				S	SVG	SVG	S	S	S	SG	SV		SG	S	S
	Hirudinae					VG	SG									
CRUSTACEA	Potamonautidae*				S					SV						
HYDRACARINA			S										V			V
PLECOPTERA	Notonemouridae	S		V												
EPHEMEROPTERA	Baetidae 1sp	V						SV	S		G		V			
	Baetidae 2sp		SV		SV	SVG				A	V			S	SV	SV
	Baetidae >2sp								V	V	S	SV		V		
	Caenidae			G								G				S
	Heptageniidae													SV	S	S
	Leptophlebiidae	SV	SV							S			S		SV	S
	Teloganodidae		S						SV						SV	
	Tricorythidae															S
ODONATA	Chlorocyphidae															S
	Chlorolestidae	SV	SV	SV												S
	Coenagrionidae				V	V		V	V		SV	SVG	V		V	
	Zygoptera juvs.			V						V			S			V
	Aeshnidae	S			S	SV		S	S	S	V	S	S	S	S	SV
	Gomphidae										G					
	Libellulidae			VG				SV		V	SV	SG	SV		S	SV
HEMIPTERA	Corixidae*		V	VG			V				V					
	Gerridae*						V				V					
	Hydrometridae*										V					
	Naucoridae*	SV	V	SVG										V		SV
	Nepidae*										V					SV
	Notonectidae*			VG	V		VG									
	Pleidae*					G										
	Veliidae*						V			V	V		SV			
MEGALOPTERA	Corydalidae	S	S	V					S	S						S
TRICHOPTERA	Ecnomidae								S							
	Hydropsychidae 1sp	S										S			S	
	Hydropsychidae 2sp								S	S						S
	Philopotamidae		S							S						
	Psychomyiidae										V					
Cased caddis:	Glossosomatidae		S	S											S	
	Hydroptilidae									1						1
	Leptoceridae	S	V	VG				SV	V	V	V	V	VG	SVG	SV	SV
	Petrothrincidae	S	SV	S												SV
	Sericostomatidae			S						S	V				S	S
COLEOPTERA	Dytiscidae*	SV	V	SV	V	VG	G	V						S		V
	Elmidae/Dryopidae*	SV	V	SV					V		SV	V	SV	VG		SV
	Gyrinidae*	S	V	SV	V	SVG	SV			V		SVG			SV	S
	Helodidae	S		G												
	Hydrophilidae*						S						V			
DIPTERA	Athericidae		S													
	Blepharoceridae		S													
	Chironomidae		S	S	S	SVG	SVG	S	S	SV	SG	SVG	S		S	SV
	Culicidae*			V			S				V		V			S
	Muscidae								S	S						
	Psychodidae										S		V			
	Simuliidae	SV	SV	V	SV	SV	SG		SV	SV	S	SV	S	SV	SV	SV
	Tabanidae										V					
	Tipulidae	V			S						G					
GASTROPODA	Ancylidae									SV						S
	Lymnaeidae*									S	V					
	Physidae*				V	SVG						V				

* Air breathers

Table A2.6-3: Macroinvertebrate taxa collected from Stones (S), Vegetation (V) and Gravel-Sand-Mud (G) biotope groups along the Hout Bay River during autumn (aut), spring (spr) and summer (sum)

		Site 1			Site 2			Site 3			Site 4		
		aut	spr	sum	aut	spr	sum	aut	spr	sum	aut	spr	sum
TURBELLARIA				S		SV	SV			S			
ANNELIDA	Oligochaeta						V	S	S	S	G	G	V
	Hirudinae										G		V
CRUSTACEA	Amphipoda	S	SV	SV	S		SV						
	Potamonautidae*							SV	S	SV	V	V	VG
HYDRACARINA				SV			V			S	V		
PLECOPTERA	Notonemouridae	SV	SV	S	S	SV	SV						
EPHEMEROPTERA	Baetidae 1sp											G	
	Baetidae 2sp								SV	V	V	V	V
	Baetidae >2sp							SVG		S			G
	Caenidae									SV	G		VG
	Leptophlebiidae				S	S	V						
	Teloganodidae		SV		S	SV	SV		SV				
	Tricorythidae								V				
ODONATA	Chlorolestidae	S	SV	SV	S	S							
	Coenagrionidae							V	V		V	V	V
	Zygoptera juvs.												V
	Aeshnidae						V			S			V
	Corduliidae						S						
	Gomphidae							SVG	V	S	G	G	G
	Libellulidae	SV	SV	SV						V			V
LEPIDOPTERA	Pyralidae					S	S						
HEMIPTERA	Corixidae*							SVG		SV	VG	VG	VG
	Gerridae*			V				V		V			VG
	Hydrometridae*									V	V	V	
	Nepidae*												V
	Notonectidae*	V		SV				V					VG
	Pleidae*										V		
	Veliidae*						SV	V	V	SV	V	V	V
MEGALOPTERA	Corydalidae					S	SV						
TRICHOPTERA	Hydropsychidae 1sp								S				
	Hydropsychidae 2sp									S			
	Philopotamidae	V					V						
	Psychomyiidae	S											
Cased caddis:	Barbarochthonidae				S	SV	SV						
	Glossosomatidae						S			S			
	Hydroptilidae									S			VG
	Leptoceridae		SV	V	S		SV	SG	SV	S			
	Petrothrincidae	S	S	B		S							
	Pisuliidae					S	SV						
	Sericostomatidae					S			S	S			
COLEOPTERA	Dytiscidae*	SV	SV	SV		S		VG	V		V	V	G
	Elmidae/Dryopidae*	V	SV	SV	S	A	SV			S	V		G
	Gyrinidae*		SV				V		SV	V		VG	VG
	Helodidae						V						
	Hydraenidae*						V						
	Hydrophilidae*						S						
DIPTERA	Athericidae		S	V	S	S	S	SV		S			
	Ceratopogonidae			SV									
	Chironomidae		SV	SV	S	SV	SV	SG	V	SV	VG	G	VG
	Culicidae*			V		S		S			VG		V
	Muscidae						V						
	Simuliidae	SV	SV		S	SV	SV	SV	SV	S			
	Tipulidae					S	S						
GASTROPODA	Ancylidae							SV	V			V	
	Lymnaeidae*												G
	Physidae*										V		VG

* Air breathers

APPENDIX 2.7: SASS-5 RESULTS (COMBINED BIOTOPES)

Table A2.7-1: Number (#) of taxa, SASS-5 Score and ASPT recorded at each sampling site along the Lourens, Palmiet and Hout Bay Rivers during autumn, spring and summer

River	Sampling site	**# Taxa**			**SASS-5 Score**			**ASPT**		
		aut	spr	sum	aut	spr	sum	aut	spr	sum
Lourens	Site 1	14	12	20	110	113	154	7.9	9.4	7.7
	Site 2	12	11	14	66	72	71	5.5	6.5	5.1
	Site 3	20	12	18	104	76	94	5.2	6.3	5.2
	Site 4	15	9	16	63	44	79	4.2	4.9	4.9
Palmiet	Site 1	16	19	21	119	149	144	7.4	7.8	6.9
	Site 2	12	11	13	50	46	46	4.2	4.2	3.5
	Site 3	9	14	21	37	84	122	4.1	6	5.8
	Site 4	22	13	17	114	68	85	5.2	5.2	5
	Site 5	9	16	28	65	106	183	7.2	6.6	6.5
Hout Bay	Site 1	11	13	16	89	103	106	8.1	7.9	6.6
	Site 2	11	18	27	100	149	212	9.1	8.3	7.9
	Site 3	16	16	23	77	92	142	4.8	5.8	6.2
	Site 4	17	12	23	74	52	105	4.4	4.3	4.6

APPENDIX 2.8: SASS-5 vs. SASS-4 REGRESSION ANALYSIS

A] SASS-5 Score (X) vs. SASS-4 Score (Y)

Regression Statistics	
Multiple R	0.992
R Square	0.985
Adjusted R Square	0.984
Standard Error	4.844
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	55245.419	55245.419	2354.886	0.000
Residual	37	868.017	23.460		
Total	38	56113.436			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	3.078	2.077	1.482	0.147
X Variable 1	0.969	0.020	48.527	0.000

SASS-4 = 0.969*SASS-5 + 3.078

B] ASPT-5 (X) vs. ASPT-4 (Y)

Regression Statistics	
Multiple R	0.980
R Square	0.960
Adjusted R Square	0.959
Standard Error	0.365
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	118.450	118.450	889.717	0.000
Residual	37	4.926	0.133		
Total	38	123.376			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0.645	0.242	-2.665	0.011
X Variable 1	1.155	0.039	29.828	0.000

ASPT-4 = 1.155*ASPT-5 - 0.645

C] SASS-4 Score (X) vs. SASS-5 Score (Y)

Regression Statistics	
Multiple R	0.992
R Square	0.985
Adjusted R Square	0.984
Standard Error	4.961
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	57968.884	57968.884	2354.886	0.000
Residual	37	910.808	24.616		
Total	38	58879.692			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1.635	2.173	-0.752	0.457
X Variable 1	1.016	0.021	48.527	0.000

SASS-5 = 1.016*SASS-4 - 1.635

D] ASPT-4 (X) vs. ASPT-5 (Y)

Regression Statistics	
Multiple R	0.980
R Square	0.960
Adjusted R Square	0.959
Standard Error	0.310
Observations	39

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	85.247	85.247	889.717	0.000
Residual	37	3.545	0.096		
Total	38	88.792			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.778	0.184	4.229	0.000
X Variable 1	0.831	0.028	29.828	0.000

ASPT-5 = 0.831*ASPT-4 + 0.778

APPENDIX 2.9: DISTRIBUTION OF SASS-5 SCORES AMONGST TAXA COLLECTED (COMBINED BIOTOPE GROUPS)

The pie-charts on the following three pages indicate, for each river in turn, the proportions of tolerant taxa (SASS-5 scores of 1 – 5), intermediate taxa (SASS-5 scores of 6 – 10) and sensitive taxa (SASS-5 scores of 11 – 15) recorded at each sampling site during each season (combined biotope groups).

Figure A2.9-1: Lourens River

Figure A2.9-2: Palmiet River

Figure A2.9-3: Hout Bay River

Figure A2.9-1

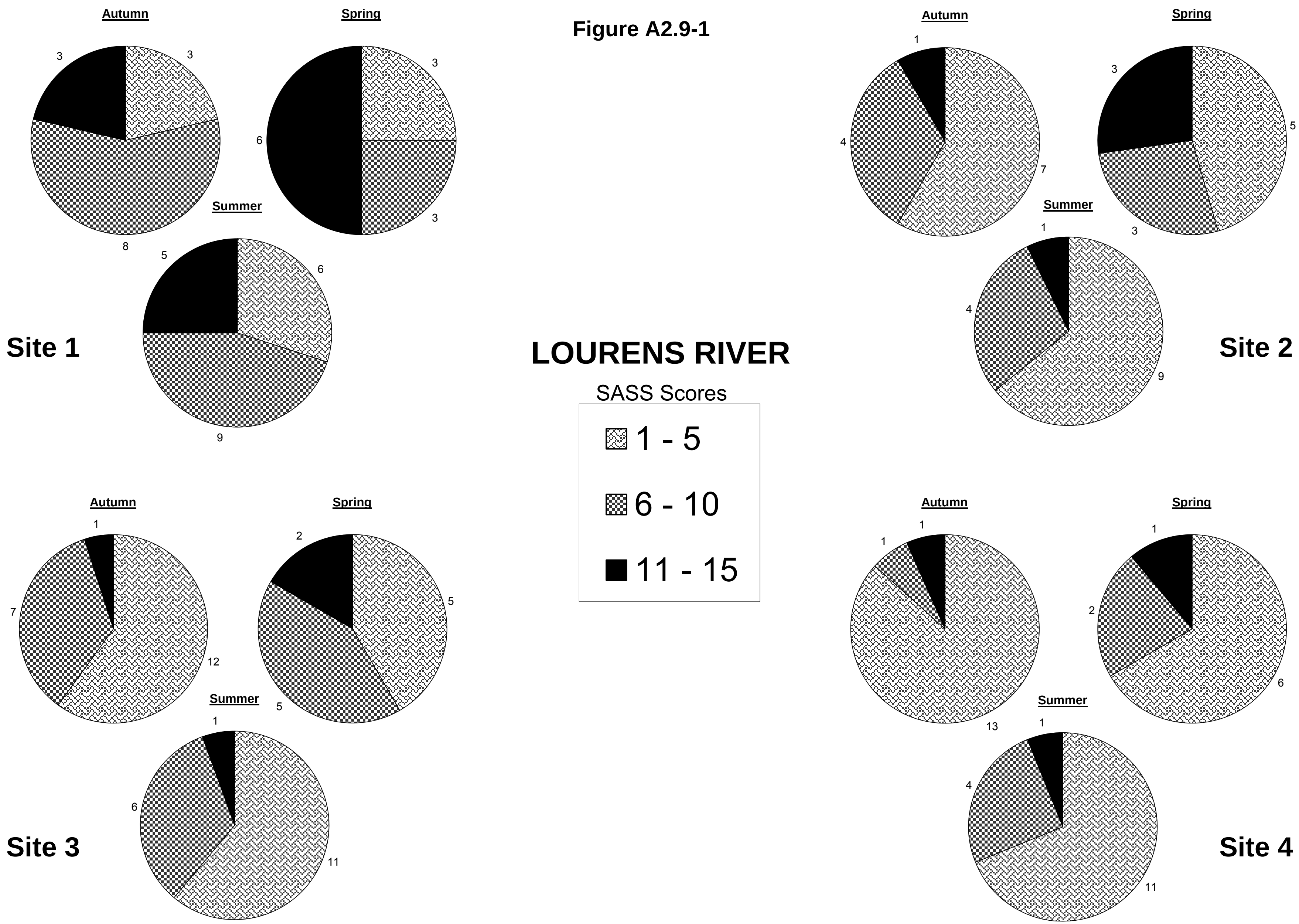

LOURENS RIVER
SASS Scores
1 - 5
6 - 10
11 - 15
Site 1
Autumn
3
3
8
Spring
3
6
3
Summer
5
6
9
Site 2
Autumn
1
4
7
Spring
3
5
3
Summer
1
4
9
Site 3
Autumn
1
7
12
Spring
2
5
5
Summer
1
6
11
Site 4
Autumn
1
1
13
Spring
1
2
6
Summer
1
4
11

Figure A2.9-2

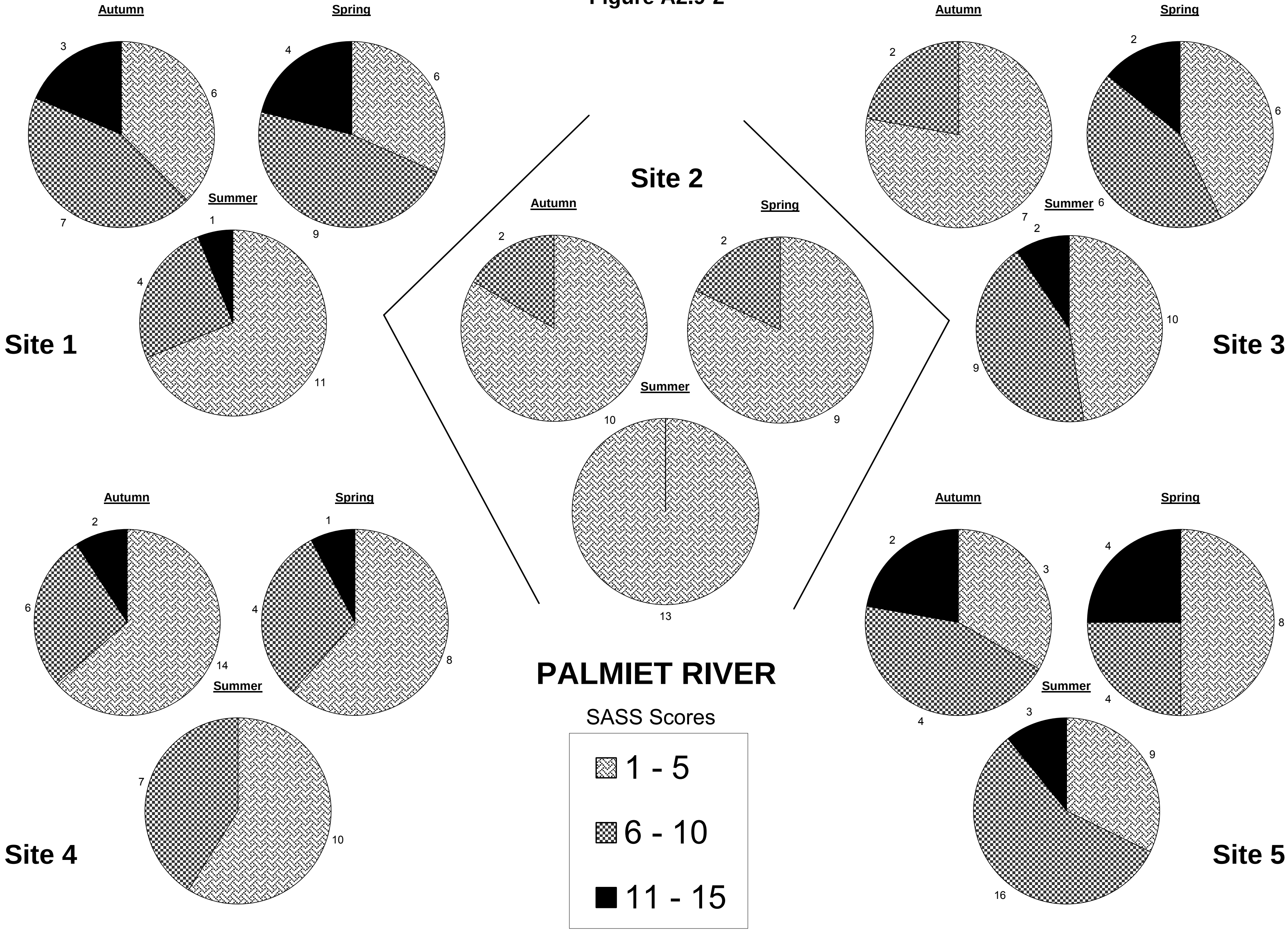
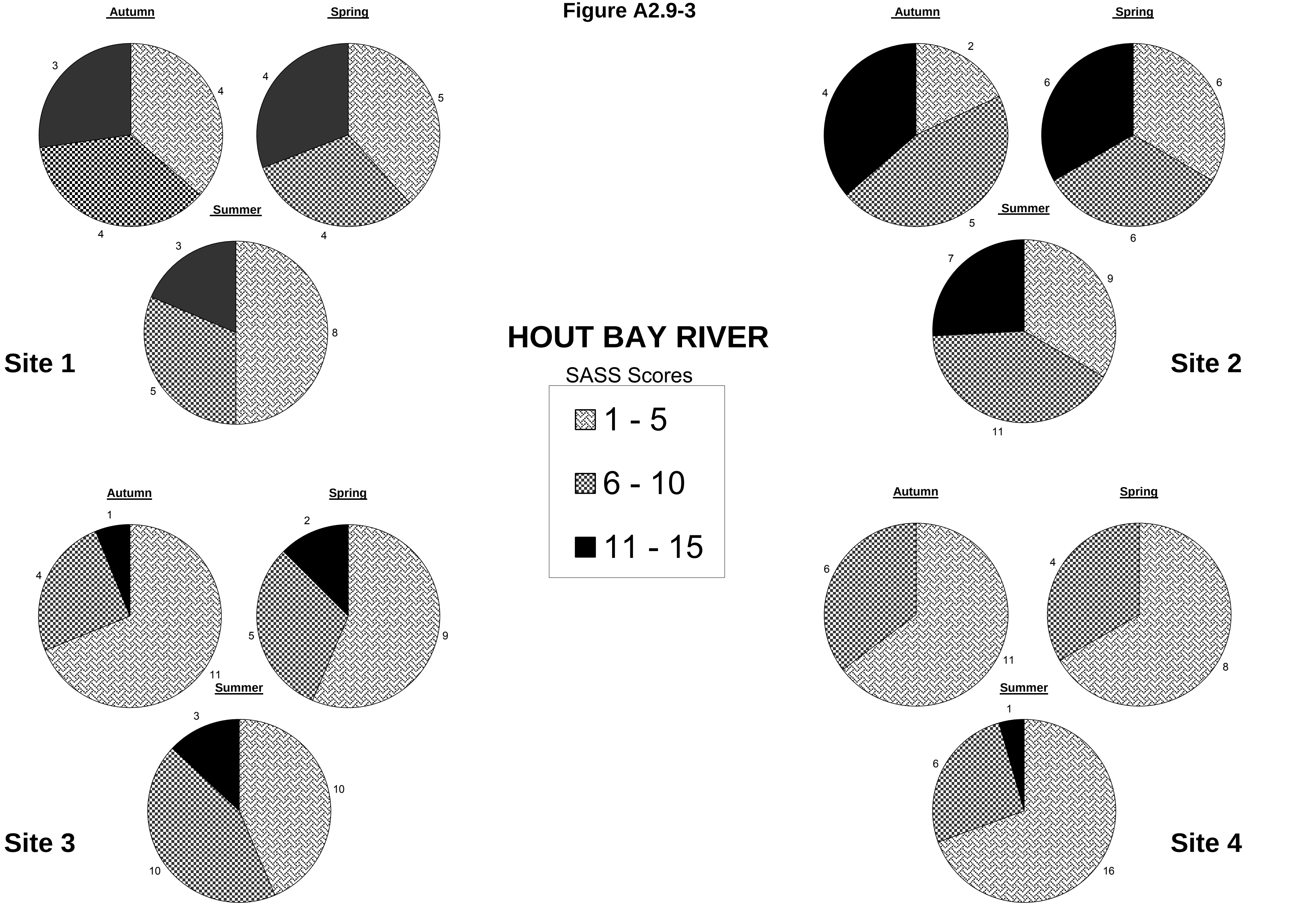
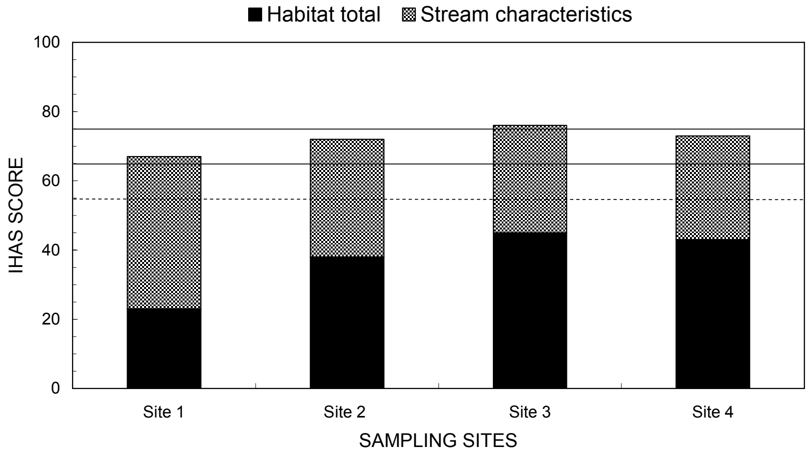

Site 1
Autumn
3
6
7
Spring
4
6
9
Summer
1
4
11
Site 2
Autumn
2
10
Spring
2
9
Summer
13
Site 3
Autumn
2
7
Spring
2
6
6
Summer
2
10
9
Site 4
Autumn
2
6
14
Spring
1
4
8
Summer
7
10
Site 5
Autumn
2
3
4
Spring
4
8
4
Summer
3
9
16
PALMIET RIVER
SASS Scores
1 - 5
6 - 10
11 - 15

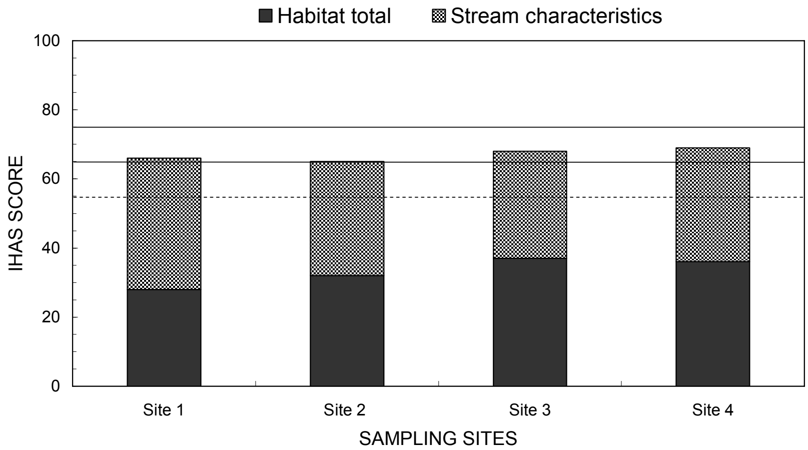
Figure A2.9-3


HOUT BAY RIVER
SASS Scores
1 - 5
6 - 10
11 - 15
Site 1
Autumn
3
4
4
Spring
4
5
4
Summer
3
8
5
Site 2
Autumn
2
4
5
Spring
6
6
6
Summer
7
9
11
Site 3
Autumn
1
4
11
Spring
2
5
9
Summer
3
10
10
Site 4
Autumn
6
11
Spring
4
8
Summer
1
6
16

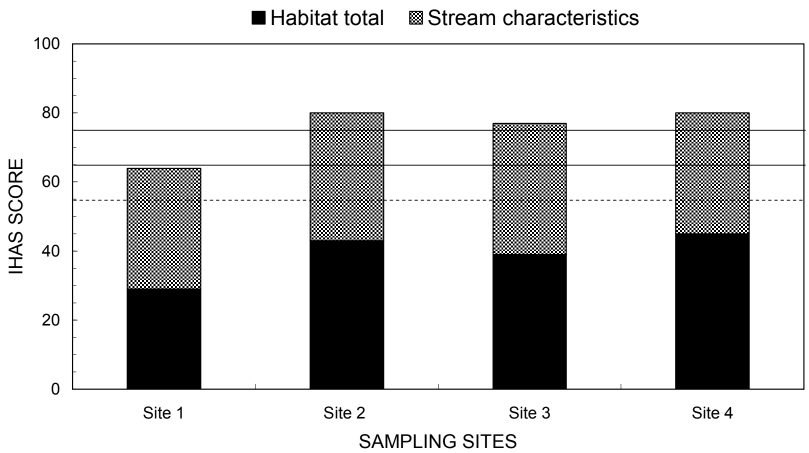
APPENDIX 2.10: IHAS SCORES (COMBINED BIOTOPE GROUPS)



a) Autumn

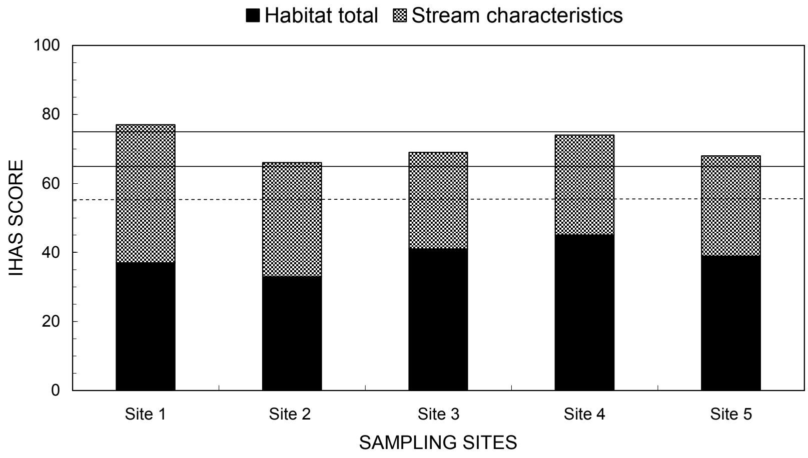


b) Spring

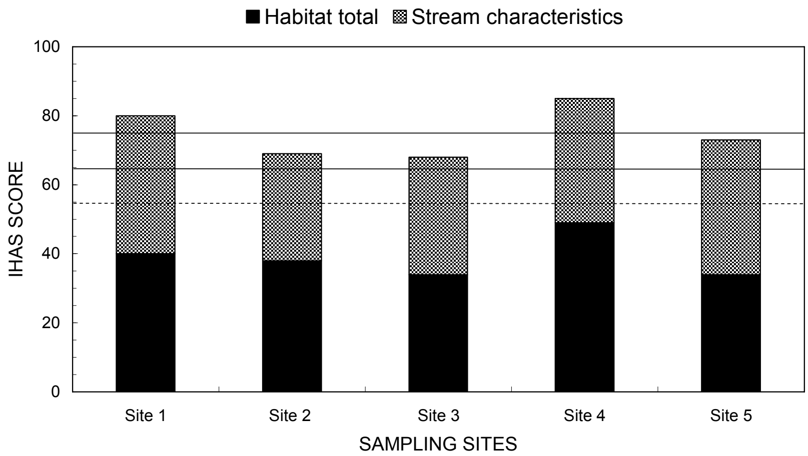


c) Summer

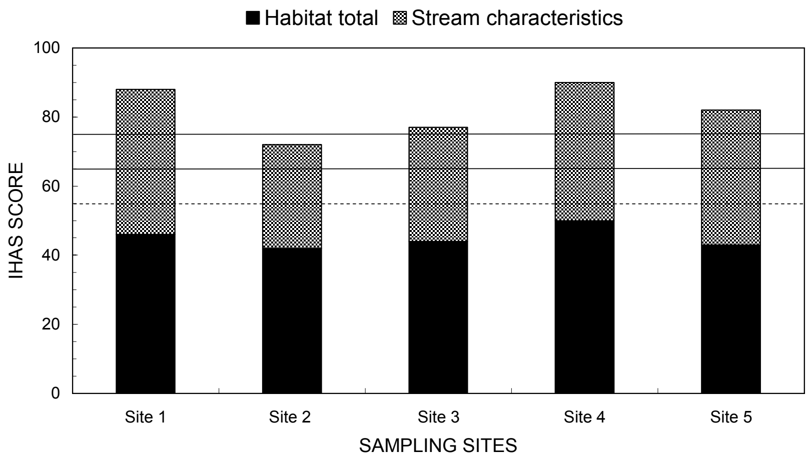
Figure A2.10-1: IHAS Scores along Lourens River (combined biotopes) during each sampling season. Dotted horizontal grid-line indicates maximum attainable Habitat Total; solid horizontal grid-lines indicate critical IHAS Scores for good (lower line) and excellent (top line) invertebrate habitat



a) Autumn



b) Spring



c) Summer

Figure A2.10-2: IHAS Scores along Palmiet River (combined biotopes) during each sampling season. Dotted horizontal grid-line indicates maximum attainable Habitat Total; solid horizontal grid-lines indicate critical IHAS Scores for good (lower line) and excellent (top line) invertebrate habitat

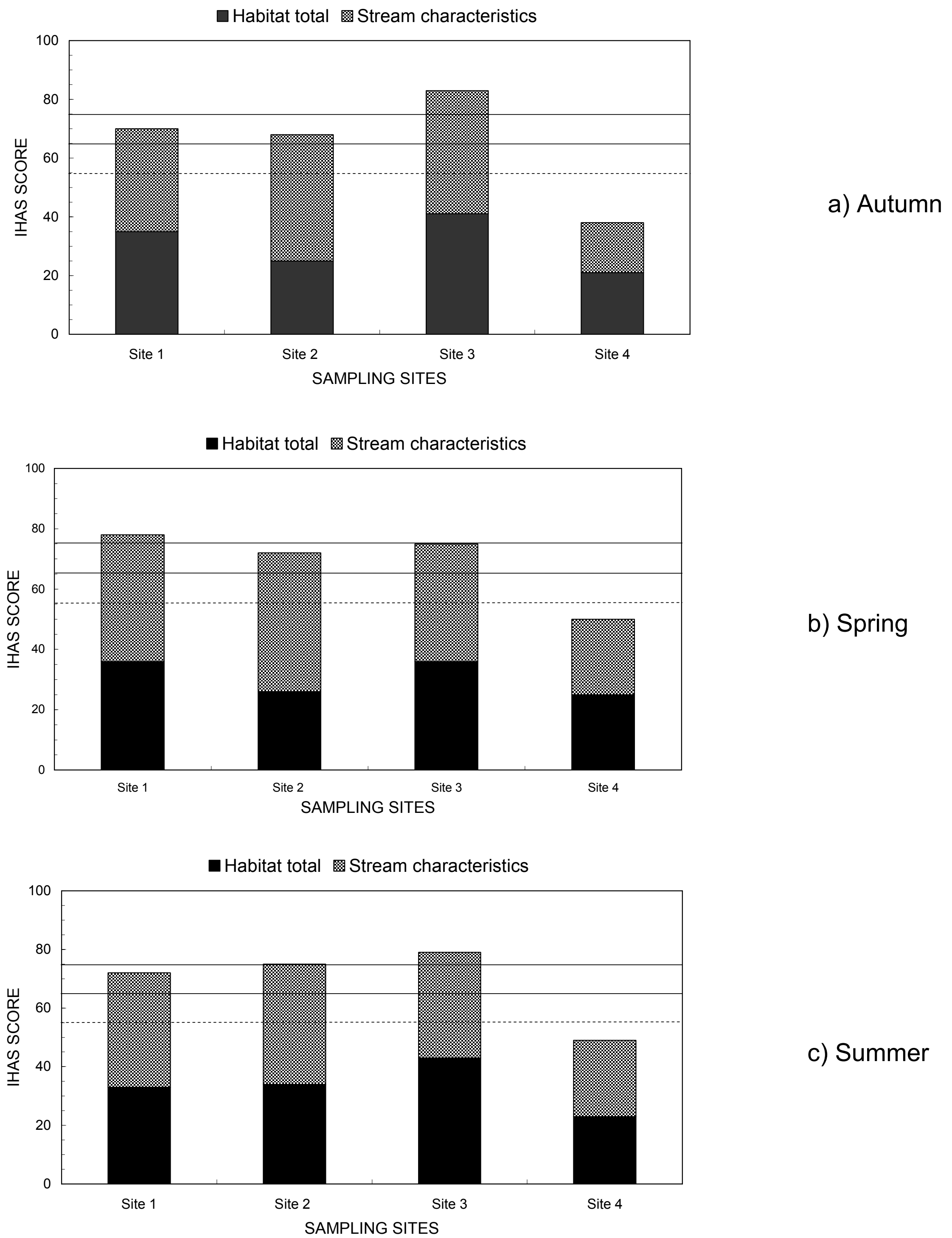


Figure A2.10-3: IHAS Scores along Hout Bay River (combined biotopes) during each sampling season. Dotted horizontal grid-line indicates maximum attainable Habitat Total; solid horizontal grid-lines indicate critical IHAS Scores for good (lower line) and excellent (top line) invertebrate habitat

APPENDIX 2.11: DISTRIBUTION OF SASS-5 SCORES AMONGST TAXA COLLECTED (SEPARATE BIOTOPE GROUPS)

Tables A2.11-1 to A2.11-3 indicate, for each SASS-5 biotope group in turn, the proportions of sensitive (S) taxa (SASS-5 scores of 11 – 15) and tolerant (T) taxa (SASS-5 scores of 1 – 5), together with the total number of taxa sampled (n), at each sampling site during autumn, spring and summer.

Table A2.11-1: Proportions of sensitive (S) and tolerant (T) taxa recorded for Stones biotope group during each sampling season. Proportions of sensitive taxa ≥25% and tolerant taxa ≥50 highlighted in bold

River	Sampling site	Autumn			Spring			Summer		
		%S	%T	n	%S	%T	n	%S	%T	n
Lourens	Site 1	21%	21%	14	**50%**	25%	12	**25%**	30%	20
	Site 2	0	38%	8	**43%**	29%	7	0	44%	9
	Site 3	0	**56%**	16	**40%**	20%	5	9%	**55%**	11
	Site 4	0	**82%**	11	0	**57%**	7	8%	**58%**	12
Palmiet	Site 1	21%	29%	14	**31%**	15%	13	**33%**	33%	9
	Site 2	0	**71%**	7	0	**71%**	7	0	**100%**	7
	Site 3	0	**71%**	7	9%	**55%**	11	6%	44%	16
	Site 4	13%	**75%**	8	11%	**78%**	9	0	**56%**	9
	Site 5	14%	43%	7	**27%**	47%	15	12%	32%	25
Hout Bay	Site 1	**25%**	38%	8	**31%**	38%	13	**25%**	**50%**	12
	Site 2	**36%**	18%	11	**33%**	33%	18	**33%**	33%	18
	Site 3	9%	**55%**	11	22%	**56%**	9	16%	37%	19
	Site 4	-	-	-	-	-	-	-	-	-

n = Total number of taxa collected
- = No taxa recorded

Table A2.11-2: Proportions of sensitive (S) and tolerant (T) taxa recorded for Vegetation biotope group during each sampling season. Proportions of sensitive taxa ≥25% and tolerant taxa ≥50 highlighted in bold

River	Sampling site	Autumn			Spring			Summer		
		%S	%T	n	%S	%T	n	%S	%T	n
Lourens	Site 1	-	-	-	-	-	-	-	-	-
	Site 2	17%	**83%**	6	17%	**50%**	6	10%	**70%**	10
	Site 3	10%	**60%**	10	10%	40%	10	6%	**69%**	16
	Site 4	0	**100%**	10	20%	**80%**	5	9%	**82%**	11
Palmiet	Site 1	0	**50%**	8	9%	36%	11	7%	**50%**	14
	Site 2	0	**86%**	7	0	**80%**	10	0	**100%**	8
	Site 3	0	**80%**	5	**33%**	33%	6	9%	**64%**	11
	Site 4	6%	**56%**	16	11%	**67%**	9	0	**70%**	10
	Site 5	**33%**	17%	6	14%	43%	7	8%	38%	13
Hout Bay	Site 1	14%	**57%**	7	**27%**	45%	11	8%	**54%**	13
	Site 2	-	-	-	**50%**	**50%**	6	24%	33%	21
	Site 3	8%	**67%**	12	8%	**50%**	12	0	**70%**	10
	Site 4	0	**69%**	13	0	**67%**	9	0	**74%**	19

n = Total number of taxa collected.
- = No taxa recorded.

Table A2.11-3: Proportions of sensitive (S) and tolerant (T) taxa recorded for GSM biotope group during each sampling season. Proportions of sensitive taxa ≥25% and tolerant taxa ≥50 highlighted in bold

River	Sampling site	Autumn			Spring			Summer		
		%S	%T	n	%S	%T	n	%S	%T	n
Lourens	Site 1	-	-	-	-	-	-	-	-	-
	Site 2	-	-	-	-	-	-	-	-	-
	Site 3	13%	**50%**	8	-	-	-	-	-	-
	Site 4	17%	**83%**	6	0	**67%**	3	17%	**67%**	6
Palmiet	Site 1	-	-	-	-	-	-	13%	38%	8
	Site 2	-	-	-	0	**88%**	8	0	**100%**	7
	Site 3	-	-	-	-	-	-	-	-	-
	Site 4	0	**80%**	5	0	**80%**	5	0	0	2
	Site 5	0	33%	3	-	-	-	-	-	-
Hout Bay	Site 1	-	-	-	-	-	-	-	-	-
	Site 2	-	-	-	-	-	-	-	-	-
	Site 3	17%	**50%**	6	-	-	-	-	-	-
	Site 4	0	**71%**	7	0	**83%**	6	7%	**64%**	14

n = Total number of taxa collected.
- = No taxa recorded.

APPENDIX 2.12: DENDROGRAMS FROM MULTIVARIATE CLUSTER ANALYSES

Combined biotopes

Lourens River

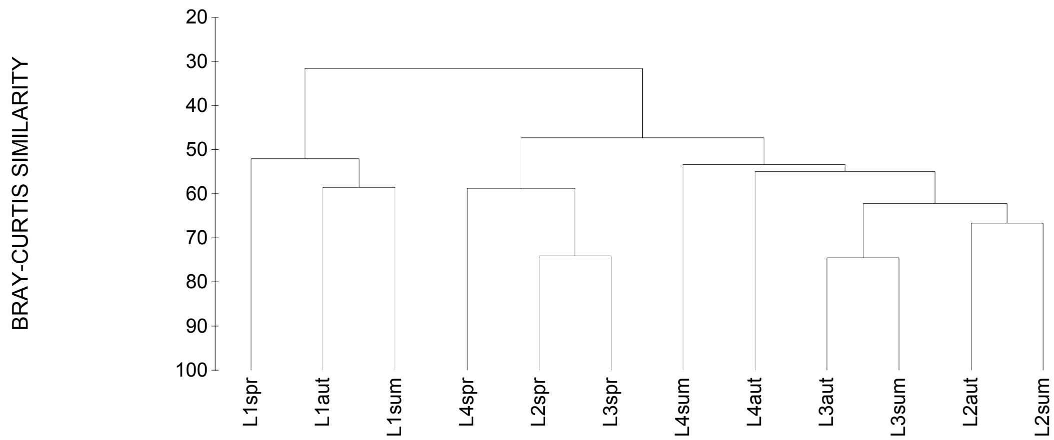


Figure A2.12-1: Dendrogram of sampling sites along Lourens River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data for combined biotope groups

Palmiet River

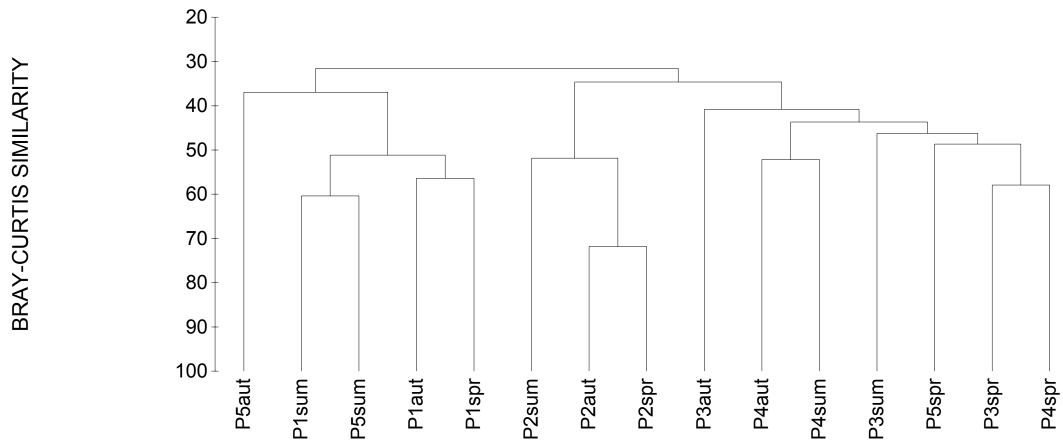


Figure A2.12-2: Dendrogram of sampling sites along Palmiet River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data for combined biotope groups

Hout Bay River

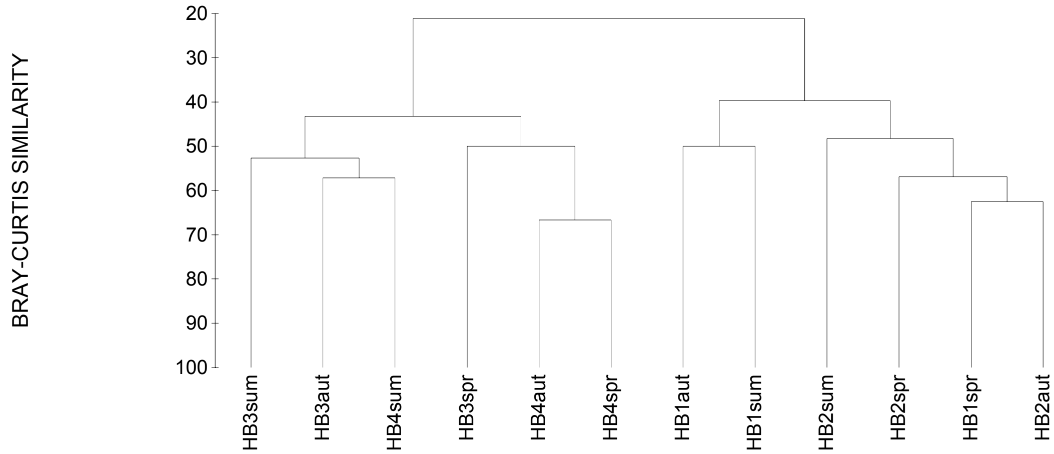


Figure A2.12-3: Dendrogram of sampling sites along Hout Bay River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data for combined biotope groups

All rivers (combined seasons)

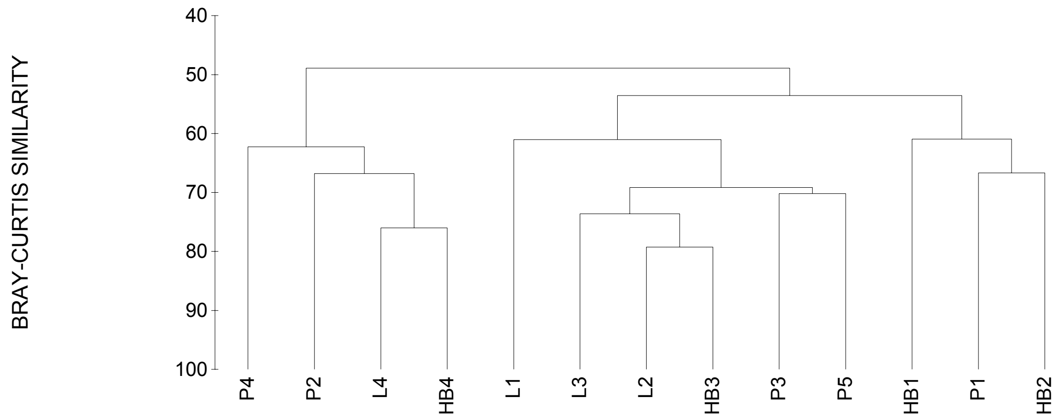


Figure A2.12-4: Dendrogram of sampling sites along Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given), based on combined-season presence/absence macroinvertebrate data for combined biotope groups

Separate biotope groups with seasons separate

All rivers

Stones biotope group

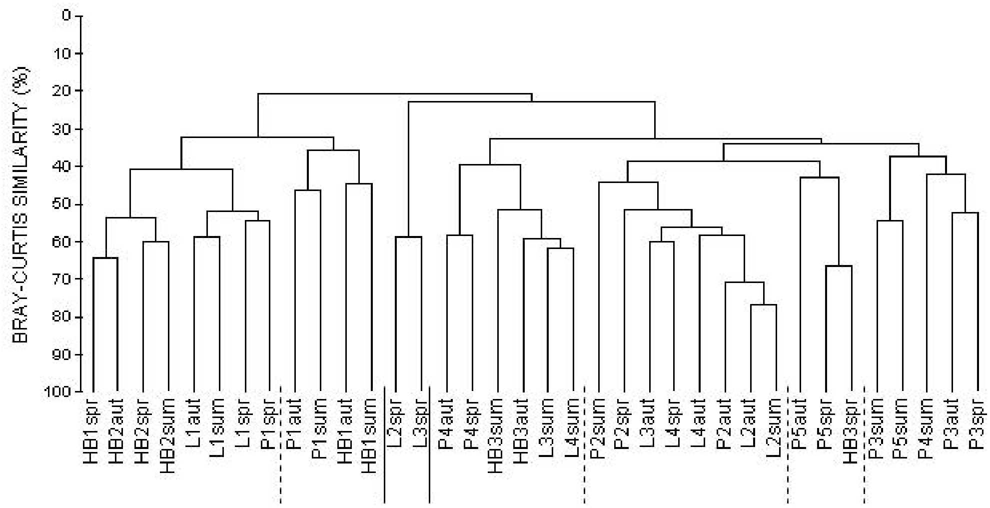


Figure A2.12-5: Dendrogram of sampling sites along Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from Stones biotope group. Groupings shown at 30% Bray-Curtis Similarity level and sub-groupings at 35%

Vegetation biotope group

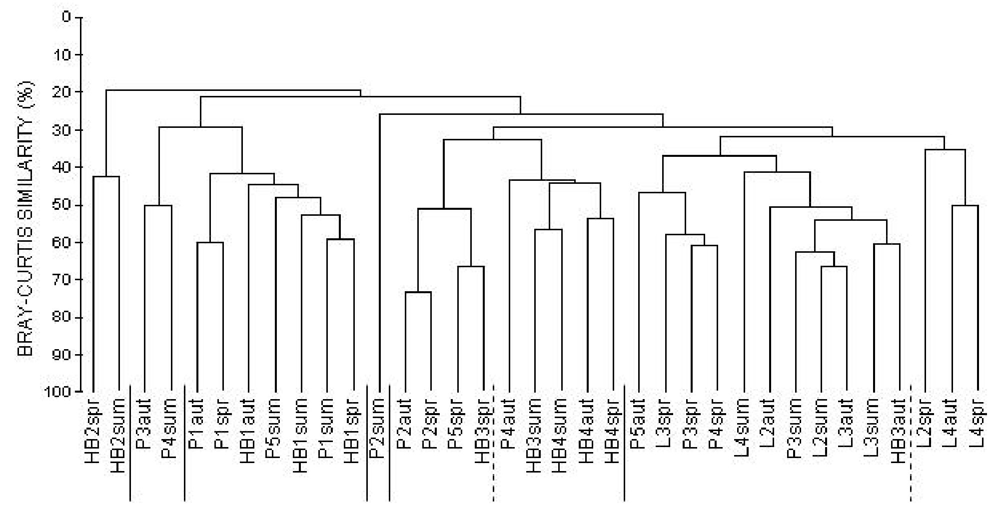


Figure A2.12-6: Dendrogram of sampling sites along Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from Vegetation biotope group. Groupings shown at 30% Bray-Curtis Similarity level and sub-groupings at 35%

Gravel-Sand-Mud (GSM) biotope group

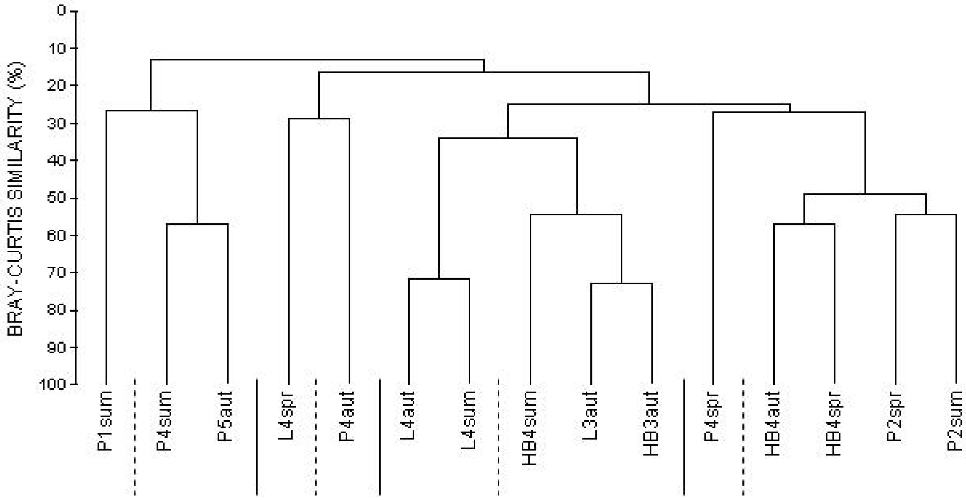


Figure A2.12-7 Dendrogram of sampling sites along Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from GSM biotope group. Groupings shown at 25% Bray-Curtis Similarity level and sub-groupings at 35%

Lourens River

Stones biotope group

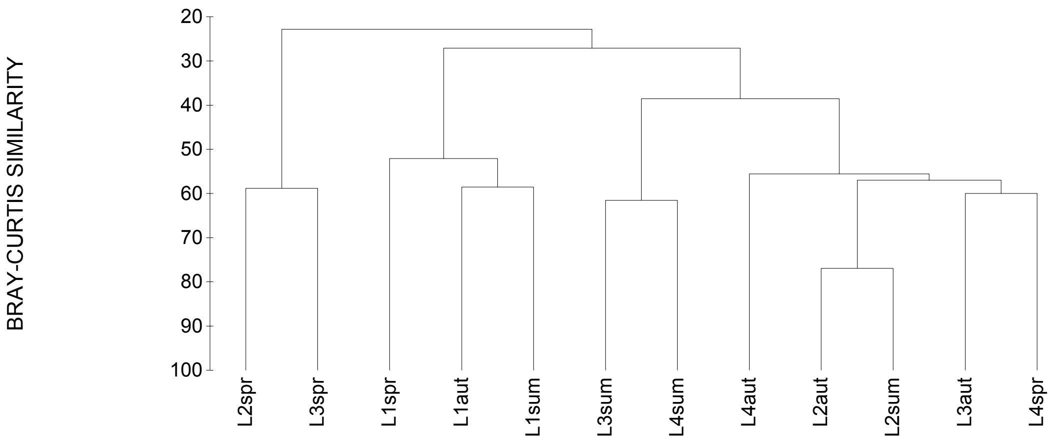


Figure A2.12-8: Dendrogram of sampling sites along Lourens River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from Stones biotope group

Vegetation biotope group

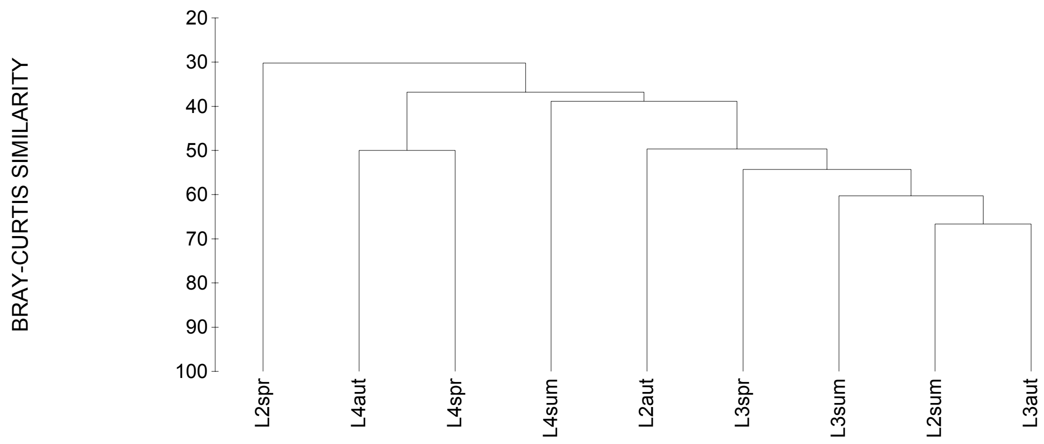


Figure A2.12-9: Dendrogram of sampling sites along Lourens River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from Vegetation biotope group

Gravel-Sand-Mud (GSM) biotope group

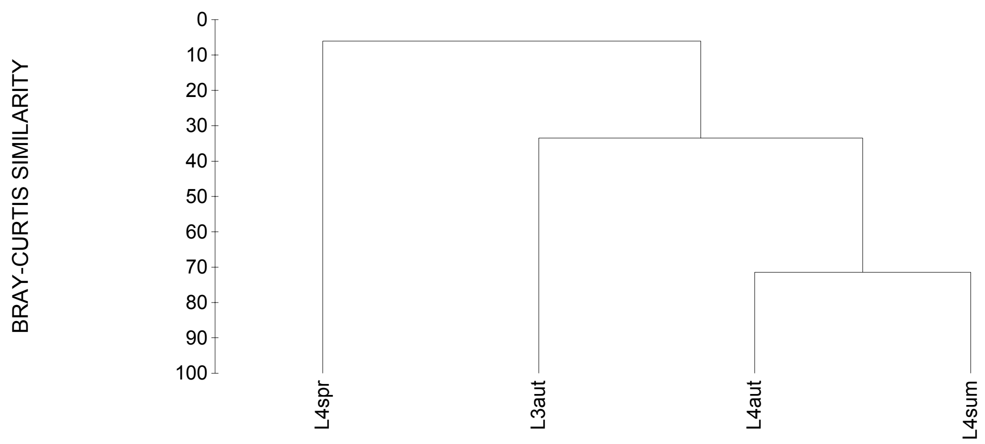


Figure A2.12-10: Dendrogram of sampling sites along Lourens River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from GSM biotope group

Palmiet River

Stones biotope group

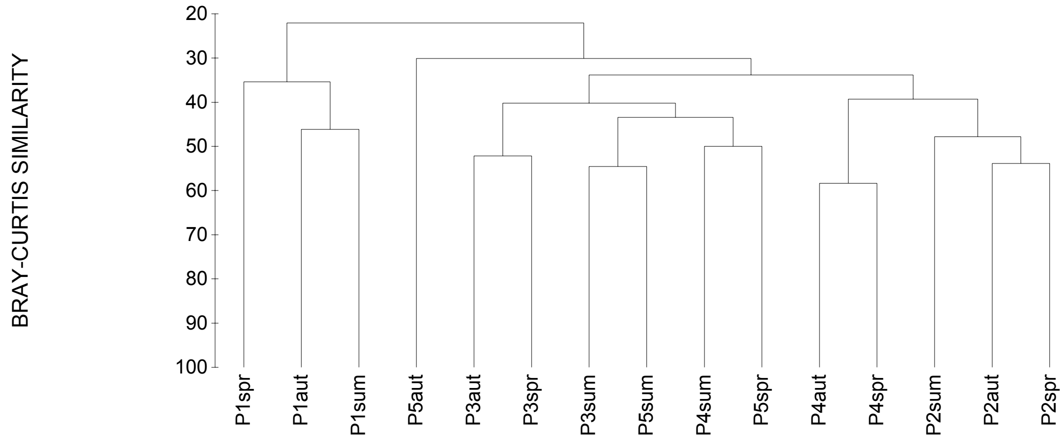


Figure A2.12-11: Dendrogram of sampling sites along Palmiet River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from Stones biotope group

Vegetation biotope group

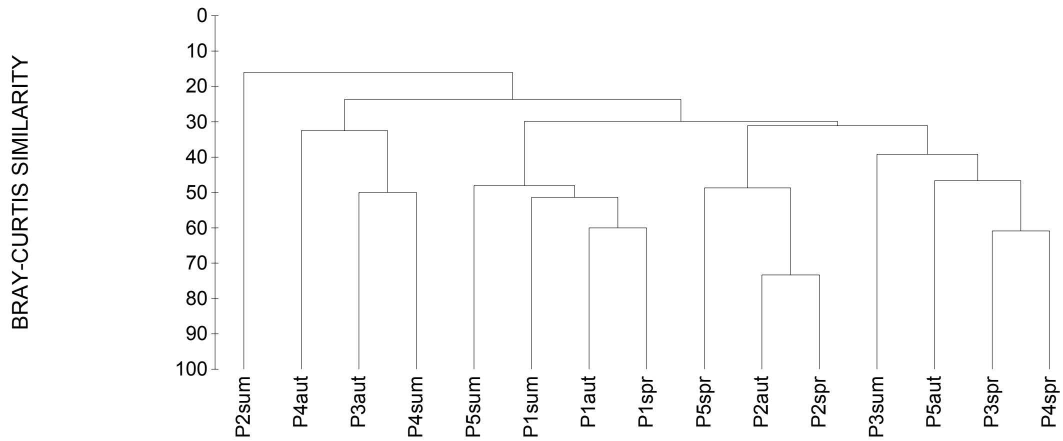


Figure A2.12-12: Dendrogram of sampling sites along Palmiet River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from Vegetation biotope group

Gravel-Sand-Mud (GSM biotope group)

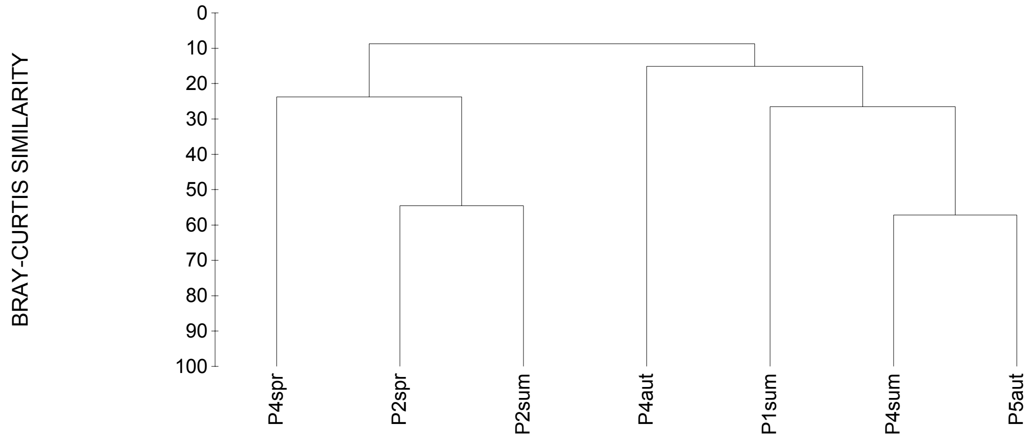


Figure A2.12-13: Dendrogram of sampling sites along Palmiet River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from GSM biotope group

Hout Bay River

Stones biotope group

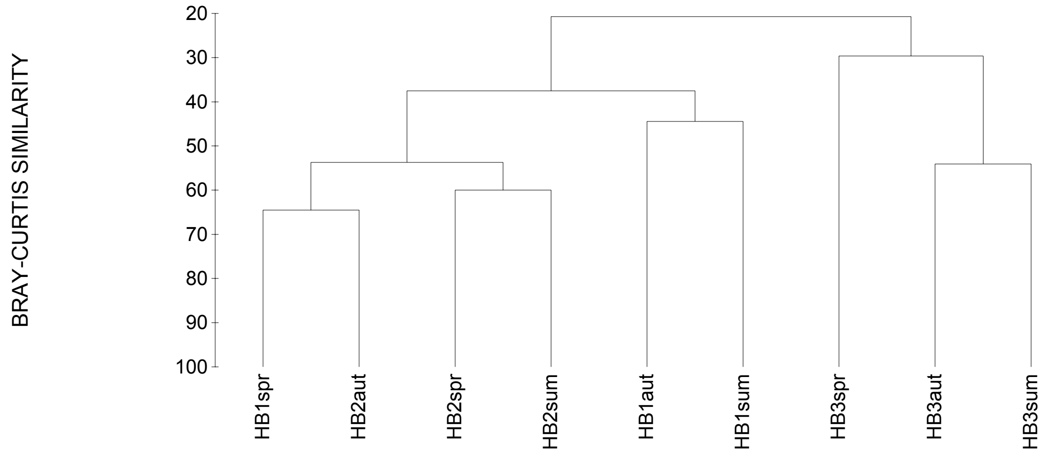


Figure A2.12-14: Dendrogram of sampling sites along Hout Bay River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from Stones biotope group

Vegetation biotope group

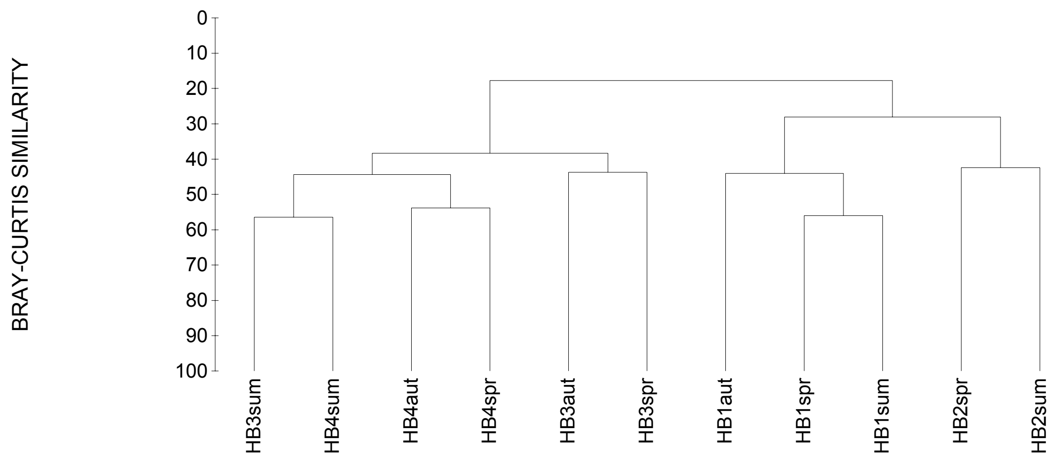


Figure A2.12-15: Dendrogram of sampling sites along Hout Bay River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from Vegetation biotope group

Gravel-Sand-Mud (GSM) biotope group

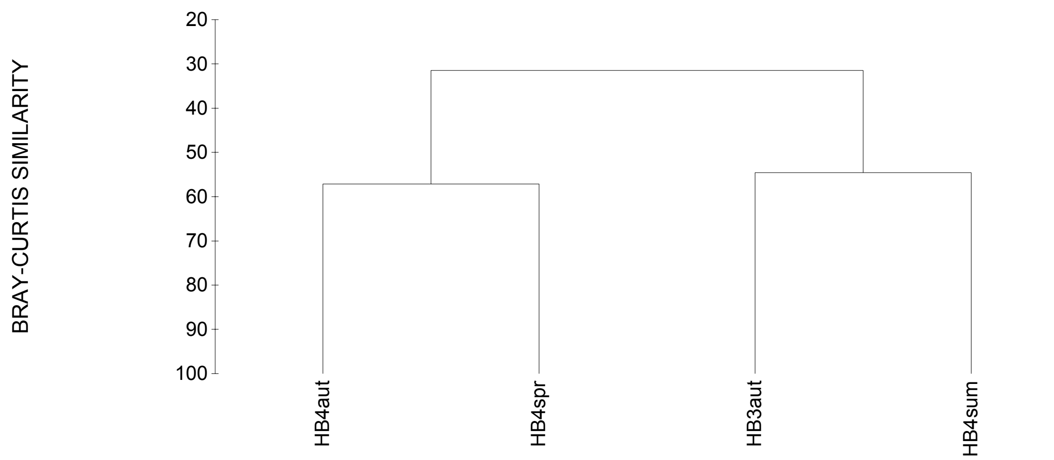


Figure A2.12-16: Dendrogram of sampling sites along Hout Bay River (site numbers given) during autumn (aut), spring (spr) and summer (sum), based on rank-abundance macroinvertebrate data from GSM biotope group

Separate biotope groups with seasons combined

Stones biotope group

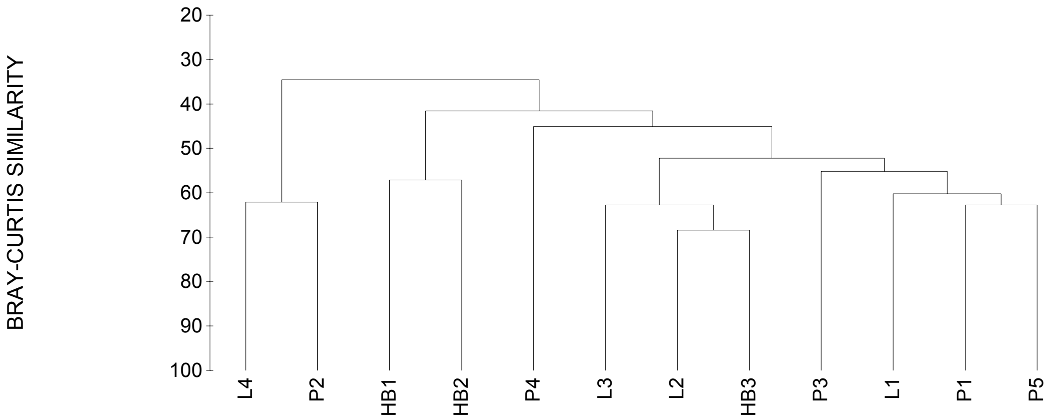


Figure 2.12-17: Dendrogram of sampling sites along Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given), based on combined-season presence/absence macroinvertebrate data from Stones biotope group

Vegetation biotope group

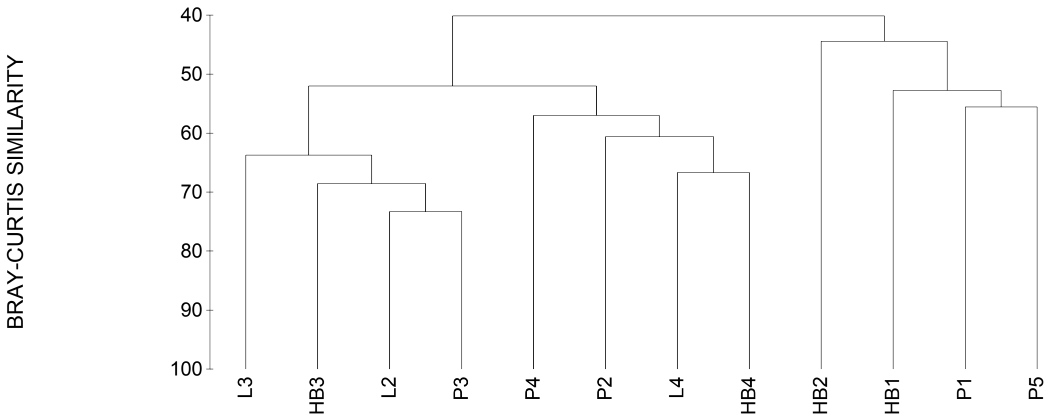


Figure 2.12-18: Dendrogram of sampling sites along Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given), based on combined-season presence/absence macroinvertebrate data from Vegetation biotope group

Gravel-Sand-Mud (GSM) biotope group

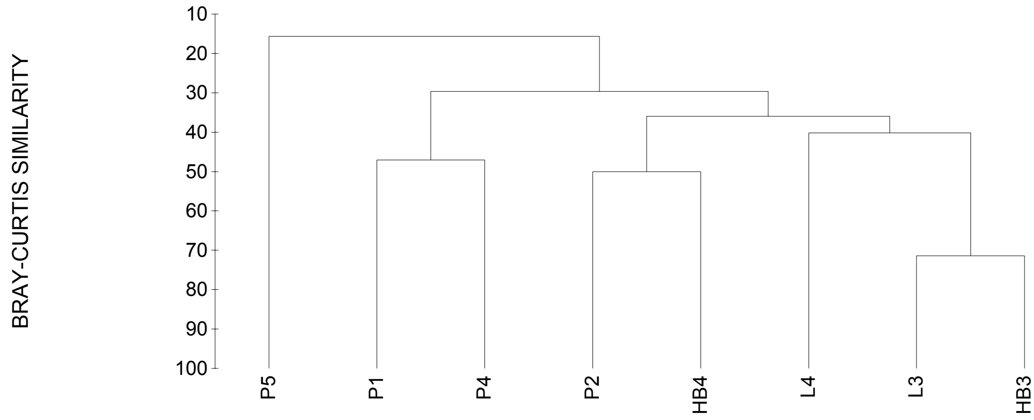


Figure 2.12-19: Dendrogram of sampling sites along Lourens (L), Palmiet (P) and Hout Bay (HB) Rivers (site numbers given), based on combined-season presence/absence macroinvertebrate data from GSM biotope group

CHAPTER 3:

PRELIMINARY TESTING OF THE INTEGRATED HABITAT ASSESSMENT SYSTEM (IHAS) FOR AQUATIC MACROINVERTEBRATES

Preliminary testing of the Integrated Habitat Assessment System (IHAS), a widely used aquatic invertebrate habitat assessment method in South Africa, was undertaken. The IHAS generates a Habitat Total and Stream Condition Score, which are summed to give the Total IHAS Score. Based on the sensitivity of the South African Scoring System (SASS) to biotope availability and assuming that SASS Scores at reference sites are the highest scores attainable, one would expect to find a positive relationship between SASS Scores and IHAS Habitat Totals at reference sites. The preliminary testing undertaken in the current investigation is based on the assumption that this relationship should be linear. For data obtained from reference sites in the Mpumalanga and Western Cape Provinces, non-parametric correlation analyses were undertaken between SASS-4/5 Scores and IHAS scores, using Kendall's Rank-correlation Coefficient. Separate analyses were undertaken for different geomorphological zones and biotope groups. Correlations between SASS Scores and IHAS scores were generally unsatisfactory, with no significant correlations ($p < 0.05$) found for two-thirds of the data sets analysed. The performance of the IHAS was found to vary between geomorphological zones and biotope groups, with the Foothill: Gravel-bed Zone in Mpumalanga showing the best results, particularly when the stones-in-current biotope group was analysed separately. Further testing of the IHAS is required to confirm its relative performance in different bioregions/ecoregions, geomorphological zones and biotope groups.

Keywords: invertebrate habitat assessment, South African Scoring System (SASS), river assessment, Mpumalanga, Western Cape, South Africa

INTRODUCTION

The need for invertebrate habitat assessment

In lotic ecosystems, physical habitat structure is of critical importance to the composition, diversity and abundance of resident biological communities (Karr & Dudley 1981, Roux *et al*. 1993, Maddock 1999, Norris & Thoms 1999), as the quantity and quality of the habitat available for biota is a primary determinant of aquatic community potential (Karr & Dudley 1981, Roux *et al*. 1993, Muhar & Jungwirth 1998, Barbour *et al*. 1999, Norris & Thoms 1999). Consequently, physical habitat structure has been identified as one of the major factors affecting the ecological integrity of an aquatic ecosystem (see Figure 1.1, **Chapter 1**) and all bioassessment studies should include some form of habitat assessment to enable the accurate interpretation of results (Chutter 1994, 1995, 1998; Rankin 1995; Thirion *et al*. 1995; Uys *et al*. 1996; Dallas 1997, 2000; McMillan 1998; Barbour *et al*. 1999; Dickens & Graham 2002; Vos *et al*. 2002). Without an assessment of available physical habitat, it is not possible to determine with certainty whether or not any biological impairment detected at a sampling site is attributable to water quality impacts as opposed to physical impacts (Hawkes 1979, Rosenberg & Resh 1993, Collier *et al*. 1998, Barbour *et al*. 1999).

Habitat assessment has become an important component in evaluating the ecological integrity of river ecosystems internationally (Maddock 1999), with habitat assessments on a larger spatial scale, in particular, being used to an increasingly greater extent (Muhar & Jungwirth 1998). Broad-scale habitat assessments are now a regular part of many nationwide or regional monitoring programmes. Examples include the Qualitative Habitat Evaluation Index (QHEI) in Ohio and a number of other habitat assessment systems across North America (Rankin 1995), the River Habitat Survey (RHS) in the United Kingdom (Raven *et al*. 1998, 2000) and similar habitat assessment methods in other European countries including Austria, Germany and Switzerland (Muhar & Jungwirth 1998). Broad-scale habitat assessment systems used in Australia include a method developed for the assessment of the environmental condition of rivers in the state of Victoria (Mitchell 1990, cited by Ladson & White 2000), a rapid technique for assessing the physical and environmental condition of rivers in the state of Queensland for their 'State of Rivers Project' (Anderson 1993, cited by Ladson & White 2000; Jackson & Anderson 1994) and the Physical Form Sub-index of the Index of Stream Condition (ISC) developed for river assessments in the state of Victoria (CEAH and ID&A 1997, Ladson *et al*. 1999, Ladson & White 2000), while in South Africa the Index of Habitat Integrity (IHI) is used (Kleynhans 1996). At the other end of the spectrum, microhabitat assessments that analyse small-scale variables to determine the physical habitat characteristics of selected target species have been used extensively over the past two decades (Maddock 1999), especially for Environmental Flow Assessment studies.

Unfortunately, with regard to bioassessment based on macroinvertebrates, most habitat assessment systems for streams and rivers have been developed either for use by geomorphologists, hydrologists and engineers or for the classification of fish habitat (Campbell 1994). The development of habitat assessment systems for bioassessment that take into account the requirements of aquatic macroinvertebrates is hampered by a lack of autecological information on many of the taxa, and by a relatively poor understanding of the relationships between macroinvertebrate species and the physical environment in rivers (Campbell 1994, Resh *et al*. 1995). Nevertheless, invertebrate habitat assessment systems have been developed and are used specifically for bioassessment applications.

Current use of invertebrate habitat assessment in bioassessment

Although a number of multimetric indices based on macroinvertebrates that are used in the USA, such as the Invertebrate Community Index (ICI) and the Benthic Index of Biotic Integrity (B-IBI), do not include any form of habitat assessment (Maddock 1999), the Rapid Bioassessment Protocols (RBPs) for fish, macroinvertebrates and periphyton developed by the United States Environmental Protection Agency (USEPA) (Plafkin *et al*. 1989, Barbour *et al*. 1999) include a habitat assessment that must be completed with all biological sampling that is undertaken. With the multivariate approach to bioassessment (e.g. RIVPACS and AusRivAS[8]), habitat assessment is implicit in that a number of physical habitat parameters are measured when macroinvertebrates are collected at sampling sites so that sites with similar characteristics can be grouped together for comparison.

In South Africa, it has been recognised that the results of bioassessments undertaken using the South African Scoring System (SASS) (Chutter 1998, Dickens & Graham 2002), particularly the SASS-4/5 Score (as opposed to the Average Score Per Taxon, or ASPT), can be significantly affected by the quality and diversity of invertebrate habitat available at a sampling site. Indeed, of all the extraneous factors affecting SASS Scores, invertebrate habitat diversity is considered to have the greatest impact after water quality (Chutter 1998). Therefore, an assessment of invertebrate habitat should be undertaken together with these bioassessments (Chutter 1994, 1995, 1998; Thirion *et al*. 1995; Uys *et al*. 1996; Dallas 1997, 2000; McMillan 1998; Dickens & Graham 2002; Vos *et al*. 2002).

Currently, the most widely used method for invertebrate habitat assessment in South Africa is the Integrated Habitat Assessment System[9] (IHAS, Version 2) developed by McMillan (1998). However, in contrast to the SASS and despite its widespread use, the IHAS has not to date been tested and validated scientifically (Dallas 2000, Dickens & Graham 2002).

[8] RIVPACS is the Riverine Invertebrate Prediction and Classification System, and AusRivAS is the Australian River Assessment Scheme. These systems and the differences between the multivariate and multimetric approaches to bioassessment are discussed in **Chapter 1**.

[9] Within the River Health Programme (RHP), the IHAS is referred to as the Invertebrate (as opposed to Integrated) Habitat Assessment System.

History of invertebrate habitat assessment systems in South Africa

The first invertebrate habitat assessment system designed for use with the SASS was the Habitat Quality Index (HQI) (Moore & McMillan 1992), which was a modification of the habitat assessment system for RBPs developed by the USEPA (Plafkin *et al*. 1989). Subsequently, two more habitat assessment systems were independently developed for use with the SASS. The Habitat Assessment Matrix (HAM) (Roux 1993, cited by Dallas 2000) was a further modification of the USEPA's habitat assessment system for RBPs, while the Habitat Score – Version 1 (HABS1) was developed by Chutter (1994). The HABS1 was simply based on the combination of SASS biotopes sampled at a site. The HQI and HAM, on the other hand, included an evaluation of *inter alia* the substrate composition, the degree of substrate embeddedness, velocity/depth categories, area of bottom affected by scouring and deposition, pool/riffle and run/bend ratios, bank erosion potential, bank vegetation stability and streamside cover at a site, together with a categorisation of biotope diversity.

All three of the above habitat assessment systems (HQI, HAM and HABS1) were used interchangeably when SASS assessments were undertaken (Thirion *et al*. 1995) in a rather *ad hoc* fashion, with no consistency or standardisation amongst biomonitoring practitioners until the development of the IHAS. Furthermore, these habitat assessments were often neglected and, when undertaken, often produced unreliable results (McMillan 1998; pers. comm. Dr. H. Dallas, Freshwater Research Unit, University of Cape Town). As such, there was a clear need for the development of a reliable invertebrate habitat assessment system to accompany SASS bioassessments, prompting the formulation of the IHAS (McMillan 1998). The IHAS underwent a number of revisions (see McMillan 1998 for more details) before being released as Version 2 for widespread application and testing.

Brief description of the IHAS

The ultimate aim of the IHAS is to summarise and numerically reflect the quantity, quality and diversity of biotopes available for habitation by invertebrates at a sampling site (McMillan 1998, Dallas 2000). The scoring system is based on a total of 100 points, split into two sections: Sampling Habitat (55 points) and Stream Condition/Characteristics (45 points). The Sampling Habitat section is further divided into three sub-sections: Stones-In-Current (20 points), Vegetation (15 points), and Other Habitat (20 points) including stones-out-of-current, gravel, sand and mud. The Stream Condition section provides an evaluation of a site in terms of its physical characteristics and the degree of disturbance present, including estimates of aspects such as stream width, depth and velocity.

A site assessment involves the completion of an IHAS score-sheet (Figure 3.1), which contains a number of questions with up to five possible answers in each case. Each answer chosen on the form provides an integer value between zero and five, which are then summed to generate three indices: a Habitat Total (with sub-indices for the different habitat groups), a Stream Condition Score and a Total IHAS Score (sum of Habitat Total and Stream Condition Score). For convenience, by constraining the maxima for the various sub-indices, the system has been designed so that the maximum Total IHAS Score obtainable is 100 (representing a percentage). Total IHAS Scores over 75 are thought to indicate excellent invertebrate habitat, with Total Scores between 65 and 75 indicating adequate habitat conditions (McMillan 1998).

INTEGRATED HABITAT ASSESSMENT SYSTEM (IHAS)

River Name:	
Site Name:	Date:

SAMPLING HABITAT	0	1	2	3	4	5
Stones In Current (SIC)						
Total length (m) of broken water (riffles/rapids)	none	0-1	>1-2	>2-3	>3-5	>5
Total length (m) of submerged stones in current (run)	none	0-2	>2-5	>5-10	>10	
Number of separate SIC areas kicked	0	1	2-3	4-5	6+	
Average size (cm) of stones kicked (gravel<2; bedrock>20)	none	<2, >20	2-10	11-20	2-20	
Amount of stone surface clear (of algae, sediment, silt, etc.) (%)	n/a	0-25	26-50	51-75	>75	
Protocol: Time (mins) spent actuallly kicking SIC (gravel/bedrock=0)	0	<1	>1-2	2	>2-3	>3
SIC Scores: (A=SIC boxes total; B=adjustment to equal 20; C=final total)	*actual*	A	*adj.*	B	*max. 20*	C
Vegetation						
Length (m) of fringing vegetation sampled (banks)	none	0-½	>½-1	>1-2	2	>2
Amount (m^2) of aquatic vegetation/algae sampled	none	0-½	>½-1	>1		
Fringing vegetation sampled in:	none		run	pool		mix
Type of veg. (% leafy veg. vs. stems/shoots) (aq. veg. only=49)	none	0	1-25	26-50	51-75	>75
Veg Scores: (D=Veg boxes total; E=adjustment to equal 15; F=final total)	*actual*	D	*adj.*	E	*max. 15*	F
Other Habitat						
Stones Out Of Current (SOOC) sampled (m^2) (protocol=$1m^2$)	none	0-½	>½-1	1	>1	
Sand sampled (mins) (protocol=1min) (under=present below stones)	none	under	0-½	>½-1	1	>1
Mud sampled (mins) (protocol=½min) (under=present below stones)	none	under	0-½	½	>½	
Gravel sampled (mins) (protocol=½min) (if all, SIC stone size=<2)*	none	0-½	½	>½*		
Bedrock sampled (all=no SIC/sand/gravel) (if all, SIC stone size=>20)*	none	some			all*	
Algal presence (1-$2m^2$=algal bed; rocks=on rocks; isol.=isolated clumps)	>$2m^2$	rocks	1-$2m^2$	<$1m^2$	isol.	none
Tray identification (using time as per protocol)		under		correct		over
Other Habitat Scores: (G=Other Habitat boxes total; H=adjustment to equal 20; I=final total)	*actual*	G	*adj.*	H	*max. 20*	I
HABITAT TOTALS: (J=total adjustment [B+E+H]; K=Habitat Total [C+F+I])			*adj.*	J	*max. 55*	K
STREAM CONDITION						
Physical						
River make-up (2/3 mix = 2/3 types)	pool		run	rapid	2 mix	3 mix
Average stream width (m)		>10	>5-10	<1	1-2	>2-5
Average stream depth (m)	>2	>1-2	1	>½-1	½	<½
Approximate stream velocity (slow=<½m/s; fast=>1m/s)	still	slow	fast	med.		mix
Water colour (disc.=visibly discoloured but still clearish)	silty	opaque		discol.		clear
Recent disturbances due to: (constr.=construction)	flood	fire	constr.	other		none
Bank/riparian vegetation is: (grass=incl. reeds; shrubs=incl. trees)	none		grass	shrubs	mix	
Surrounding impacts (erosn.=erosion/shear banks; farm=farmland)	erosn.	farm	trees	other		open
Left bank cover (%) (rocks and vegetation)	0-50	51-80	81-95	>95		
Right bank cover (%) (rocks and vegetation)	0-50	51-80	81-95	>95		
Stream Condition Total:					*max. 45*	L
Total IHAS Score: (K+L)	%					

Figure 3.1: Integrated Habitat Assessment System (IHAS) score-sheet (from McMillan 1998)

Testing of the IHAS

Some initial testing of the primary indices generated by the IHAS was undertaken by Dallas (2000), using SASS-4 data collected from reference sites in the Mpumalanga Region of South Africa. This preliminary work has been taken further in the current investigation.

For reference sites from rivers in the Western Cape and Mpumalanga Regions of South Africa, it has been shown that the percentage contribution of the SASS-4 Scores from individual biotope groups to the total SASS-4 Score for a sampling site varies significantly between different biotope groups, whereas individual percentage contributions to the ASPT for a site are generally relatively similar (Dallas 1997, 2000, 2002). This is largely due to the fact that certain macroinvertebrate taxa show a preference for particular biotope groups (Dallas 2002), and it indicates that biotope availability will generally significantly influence SASS Scores (and the number of taxa) but not ASPT values at reference sites, at least in the Western Cape and Mpumalanga Regions. These findings highlight the importance of undertaking some form of invertebrate habitat assessment that accounts for the biotope availability at a sampling site, and it indicates that SASS Scores (and/or number of taxa), as opposed to ASPT values, should be used to evaluate the effectiveness such a habitat assessment system.

Assuming that SASS Scores at reference sites are the highest scores attainable, based on the demonstrated sensitivity of the SASS to biotope diversity (Dallas 1997, 2000, 2002), one would expect to find a positive relationship between SASS Scores and IHAS Habitat Totals at reference sites. This is because sites with higher Habitat Totals should be more suitable for habitation by a greater diversity of invertebrates, leading to increased SASS Scores. If this relationship does not hold true, it would suggest that IHAS scores[10] are not adequately reflecting the actual suitability of the biotopes available at a site for habitation by riverine invertebrates (Dallas 2000). The preliminary testing of IHAS undertaken in the current investigation (and in the initial testing undertaken by Dallas 2000) revolves around the assumption that the relationship between SASS Scores and IHAS scores should be linear.

METHODS

The main aim of the current investigation was to examine the degree of correlation between SASS Scores and IHAS scores at reference sites, based on the above-mentioned assumptions. Data were obtained from SASS (Versions 4 and 5) assessments undertaken in the Mpumalanga and

[10] "IHAS scores" (with lower-case 's') refers to the IHAS indices in general (including Total IHAS Score and Habitat Total) and the scores for individual entries (or groups of entries) recorded on the IHAS score-sheet.

Western Cape Provinces of South Africa, for which IHAS assessments were also completed. Mpumalanga data were retrieved from the Rivers Database (Fowler *et al*. 2000, River Health Programme 2003), while the Western Cape data were obtained from a variety of sources (including the Department of Water Affairs and Forestry, CapeNature and the Scientific Services Department of the City of Cape Town). A list of the sampling sites for which data were obtained is provided in Appendix 3.1, indicating the river and geomorphological zone (sub-region) for each site, together with the sampling dates.

Separate analyses were undertaken for Mpumalanga and the Western Cape, with SASS-4 (Mpumalanga only) and SASS-5 data analysed separately. In addition, where sufficient data were available, separate analyses were undertaken for sampling sites in different geomorphological zones. All data analyses were undertaken using either the Analyse-it (Version 1.71) for Microsoft Excel or Statistica (Version 6) computer software packages.

Correlation analyses

For the data obtained, correlation analyses were undertaken between SASS-4/5 Scores and (adjusted) Total IHAS Scores, and between SASS-4/5 Scores and (adjusted) Habitat Totals[11]. Furthermore, to determine the reliability of the different components of the IHAS scoring system, the SASS and IHAS scores for separate biotope groups were correlated against one another. For SASS-4 data, biotope groups included Stones-In-Current (SIC), Stones-Out-Of-Current (SOOC), Marginal Vegetation, and Gravel, Sand and Mud (GSM). SASS-5 data, on the other hand, distinguish between Stones, Vegetation and GSM biotope groups. Although the IHAS score-sheet only includes sections (with total scores generated) for the SIC and Vegetation biotope groups (Figure 3.1), scores can be computed for other biotope groups. For example, SOOC (a SASS-4 biotope group) is included as one of the entries under the 'Other Habitat' section of the IHAS score-sheet. The SOOC habitat score was added to the SIC habitat score to obtain a habitat score for the (SASS-5) Stones biotope group. The GSM habitat score was obtained by adding the individual scores for the amount of gravel, sand and mud sampled, each of which are separate entries under the 'Other Habitat' section of the IHAS score-sheet.

As the sampling distribution of biotic indices such as the SASS is generally unknown, parametric statistics should not be used to analyse such data (Norris & Georges 1993, Dallas 1995). Kolmogorov-Smirnov tests for normality (significance level: $p < 0.05$) were undertaken on the data obtained, and these confirmed that, at least for separate biotope groups, the data for SASS Scores

[11] Adjusted (i.e. constrained) IHAS scores were used in the correlation analyses because, in practice, these are the scores that are ultimately recorded and used to interpret IHAS results.

and (more often) IHAS scores could not consistently be assumed to be normally distributed. Therefore, non-parametric correlation analyses were undertaken in the current study, using Kendall's Rank-correlation Coefficient (τ) as opposed to Pearson's Product-moment Correlation Coefficient (r).

Multiple regression analyses

In addition to the non-parametric correlation analyses, a linear multiple regression analysis was undertaken using SASS-4 and IHAS data from Mpumalanga for the SIC biotope group. The aim of this analysis was to determine the 'ideal' weightings for the various components of the SIC section of the IHAS score-sheet (length of rapids sampled, length of runs sampled, etc – see Figure 3.1) that would maximise the degree of correlation with the corresponding SASS-4 Score. The actual estimates for each variable were required for the multiple regression analysis, as opposed to the categorised scores entered on the IHAS score-sheet. As such, for the different variables, the median of the range of values for each categorised score was generally used, as follows:

1) Total length of white water rapids: 1 = 0.5 m; 2 = 1.5 m; 3 = 2.5 m; 4 = 4 m; 5 = 6 m.
2) Total length of submerged stones in current: 1 = 1 m; 2 = 3.5 m; 3 = 7.5 m; 4 = 12 m.
3) Number of separate SIC areas kicked: 1 = 1 area; 2 = 3 areas; 3 = 5 areas; 4 = 7 areas.
4) Average stone sizes kicked: categorised scores used.
5) Amount of stone surface clear: 1 = 12.5%; 2 = 37.5%; 3 = 62.5%; 4 = 87.5%.
6) Time spent actually kicking SIC: 1 = 0.5 min; 2 = 1.5 min; 3 = 2 min; 4 = 2.5 min; 5 = 3.5 min.

A non-linear multiple regression analysis (Multivariate Adaptive Regression Splines, or MARS) was also attempted, using the same data set that was used for the linear multiple regression analysis.

RESULTS

Non-parametric correlation analyses

Results of the non-parametric correlation analyses are presented below, first for the SASS-4 data (Mpumalanga only) and then for the SASS-5 data (Mpumalanga and Western Cape). For each data set, analyses were undertaken for all geomorphological zones combined and for each separate zone for which sufficient data were available. Geomorphological zones in Mpumalanga for which there were adequate data included the Mountain Stream, Foothill: Cobble-bed, Foothill: Gravel-bed and Rejuvenated Cascade Zones (see Table 1.2 in **Chapter 1** for descriptions of geomorphological zones). For the Western Cape, almost all of the available data were from the

Mountain Stream Zone (Appendix 3.1).

Mpumalanga (SASS-4 data)

Combined biotope groups

For the Mpumalanga SASS-4 data, the results of the correlation analyses for all geomorphological zones combined (combined biotope groups) indicate significant correlations between SASS-4 Scores and Total IHAS Scores ($p < 0.05$) and between SASS-4 Scores and Habitat Totals ($p < 0.01$), despite low Kendall Rank-correlation Coefficients ($\tau < 0.15$) (Table 3.1). The graph of SASS-4 Scores versus Habitat Scores (Figure 3.2) shows that there is a relatively large degree of scatter in these data, as pointed out by Dallas (2000).

Table 3.1: Values of Kendall's Rank-correlation Coefficient (τ) between SASS-4 Scores and total IHAS scores (Total Score and Habitat Total) for Mpumalanga data (combined biotope groups), with all geomorphological zones combined and for each zone separately. Significant correlations ($p < 0.05$) highlighted by * and highly significant correlations ($p < 0.01$) by **; number of samples (n) given in brackets

	Geomorphological zone^				
	All	MS	FH:CB	FH:GB	RC
Total IHAS Score	0.12* (169)	0.03 (57)	0.06 (69)	0.38** (29)	0.38 (12)
IHAS Habitat Total	0.14** (169)	0.01 (57)	0.10 (69)	0.31* (29)	0.39 (12)

^ MS = Mountain Stream; FH:CB = Foothill: Cobble-bed; FH:GB = Foothill: Gravel-bed; RC = Rejuvenated Cascade

No significant or strong correlations were recorded between SASS-4 Scores and Total IHAS Scores or Habitat Totals for combined biotope groups from the Mountain Stream, Foothill: Cobble-bed and Rejuvenated Cascade Zones in Mpumalanga (Table 3.1), with particularly low correlation coefficients recorded in the case of the Mountain Stream and Foothill: Cobble-bed Zones ($\tau \leq 0.10$). The results for combined biotope scores from the Foothill: Gravel-bed Zone (Table 3.1) indicated that there were significant correlations between SASS-4 Scores and Total IHAS Scores ($p < 0.01$) and between SASS-4 Scores and IHAS Habitat Totals ($p < 0.05$). Again, as in the case with all geomorphological zones combined, graphs of these data (not shown) revealed a relatively significant degree of scatter in the data points.

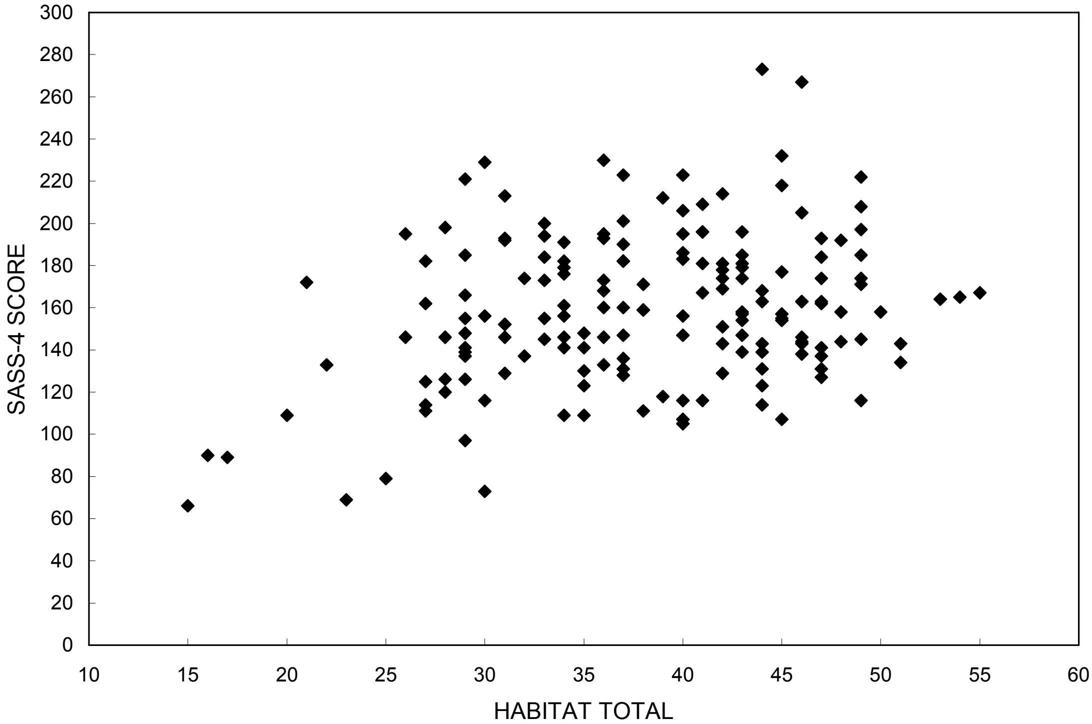


Figure 3.2: Scatter plot of SASS-4 Scores vs. IHAS Habitat Totals for Mpumalanga data from all geomorphological zones (combined biotopes)

Separate biotope groups

The results of the correlation analyses for separate biotopes (Table 3.2) reveal that, when considering all Mpumalanga geomorphological zones together, it is only for the SIC biotope that there is a significant correlation ($p < 0.01$) between SASS-4 Scores and the respective IHAS habitat scores. As in the case of the data for combined biotopes, a scatter plot of the data for the SIC biotope (not shown) revealed that there was a relatively significant amount of scatter in the data. The Kendall Rank-correlation Coefficient was zero or approaching zero for all the other biotopes sampled, with all zones considered together.

Table 3.2: Values of Kendall's Rank-correlation Coefficient (τ) between SASS-4 Scores and IHAS scores from separate biotope groups for Mpumalanga data, with all geomorphological zones combined and for each zone separately. Significant correlations ($p < 0.05$) highlighted by * and highly significant correlations ($p < 0.01$) by **; [zero] = division by zero in calculation; number of samples (n) given in brackets

Biotope group#	Geomorphological zone^				
	All	MS	FH:CB	FH:GB	RC
SIC	0.25** (161)	0.26* (57)	0.03 (68)	0.46** (26)	0.25 (8)
SOOC	0.00 (32)	[zero] (9)	0.15 (11)	0.45 (8)	0.00 (3)
MV	0.04 (150)	-0.08 (53)	0.01 (59)	0.27 (28)	0.67 (7)
GSM	-0.01 (87)	-0.04 (30)	-0.01 (32)	-0.40* (17)	-0.07 (6)

^ MS = Mountain Stream; FH:CB = Foothill: Cobble-bed; FH:GB = Foothill: Gravel-bed; RC = Rejuvenated Cascade
# SIC = Stones-In-Current; SOOC = Stones-Out-Of-Current; MV = Marginal Vegetation; GSM = Gravel, Sand and Mud

Although, in the Mountain Stream Zone of Mpumalanga, IHAS scores were not significantly correlated with SASS-4 Scores with all biotope groups combined (Table 3.1), the results of the analyses for separate biotope groups (Table 3.2) showed a significant correlation ($p < 0.05$) for the SIC biotope. A graph of SASS-4 Scores vs. IHAS scores for this biotope (not shown), however, revealed a significant degree of scatter in the data. Near-zero τ values were calculated for all other biotope groups for which data were analysed from the Mountain Stream Zone. No significant correlations were found between SASS-4 Scores and IHAS scores for any of the separate biotope groups from the Foothill: Cobble-bed and Rejuvenated Cascade Zones (Table 3.2), although it is important to note that relatively few data were available from the Rejuvenated Cascade Zone (n = 3 to 8).

The separate biotope analyses for the Foothill: Gravel-bed Zone of Mpumalanga (Table 3.2) showed that there was a highly significant ($p < 0.01$) and relatively strong ($\tau = 0.46$) correlation between SASS-4 Scores and IHAS scores for the SIC biotope. A graph of these data (Figure 3.3) revealed that, at least compared to the other data sets analysed during this investigation, there was a relatively low degree of scatter in the data. Although a significant correlation ($p < 0.05$) was found for the GSM biotope group, this was unexpectedly a negative correlation.

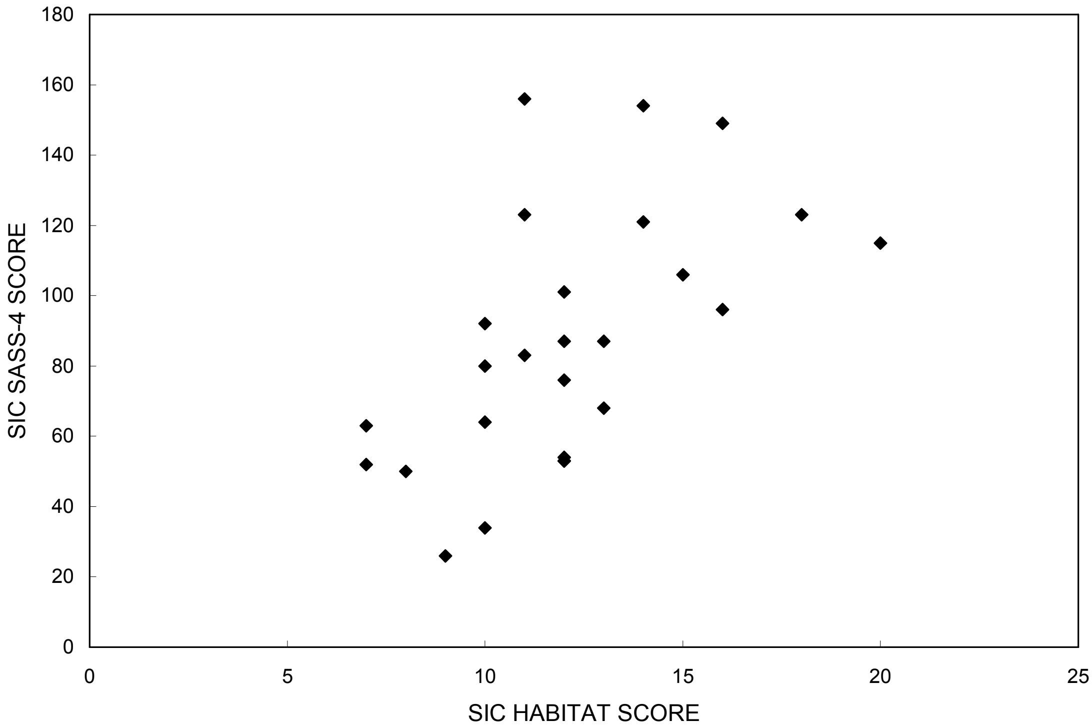


Figure 3.3: Scatter plot of SASS-4 Scores vs. IHAS habitat scores for the SIC biotope from the Foothill: Gravel-bed Zone of Mpumalanga

Mpumalanga and Western Cape (SASS-5 data)

Combined biotope groups

Significant ($p < 0.05$) and relatively strong ($\tau \approx 0.6$) correlations (but with a low sample size of 10) were found between SASS-5 Scores and Total IHAS Scores and between SASS-5 Scores and IHAS Habitat Totals for the Mpumalanga data from all geomorphological zones, while highly significant ($p < 0.01$) but not particularly strong ($\tau < 0.4$) correlations were found in both cases for the Western Cape data from all zones (Table 3.3). The graph of SASS-5 Scores versus Habitat Scores for the Western Cape data (Figure 3.4), however, indicates a relatively large degree of scatter in these data, as shown for the SASS-4 data from Mpumalanga.

Table 3.3: Values of Kendall's Rank-correlation Coefficient (τ) between SASS-5 Scores and total IHAS scores (Total Score and Habitat Total) for Mpumalanga and Western Cape data (combined biotope groups), with all geomorphological zones combined and for Western Cape Mountain Stream (MS) Zone separately. Significant correlations ($p < 0.05$) highlighted by * and highly significant correlations ($p < 0.01$) by **; number of samples (n) given in brackets

	Mpumalanga	Western Cape	
	All zones	All zones	MS Zone
Total IHAS Score	0.58* (10)	0.38** (38)	0.38** (36)
IHAS Habitat Total	0.60* (10)	0.38** (38)	0.39** (36)

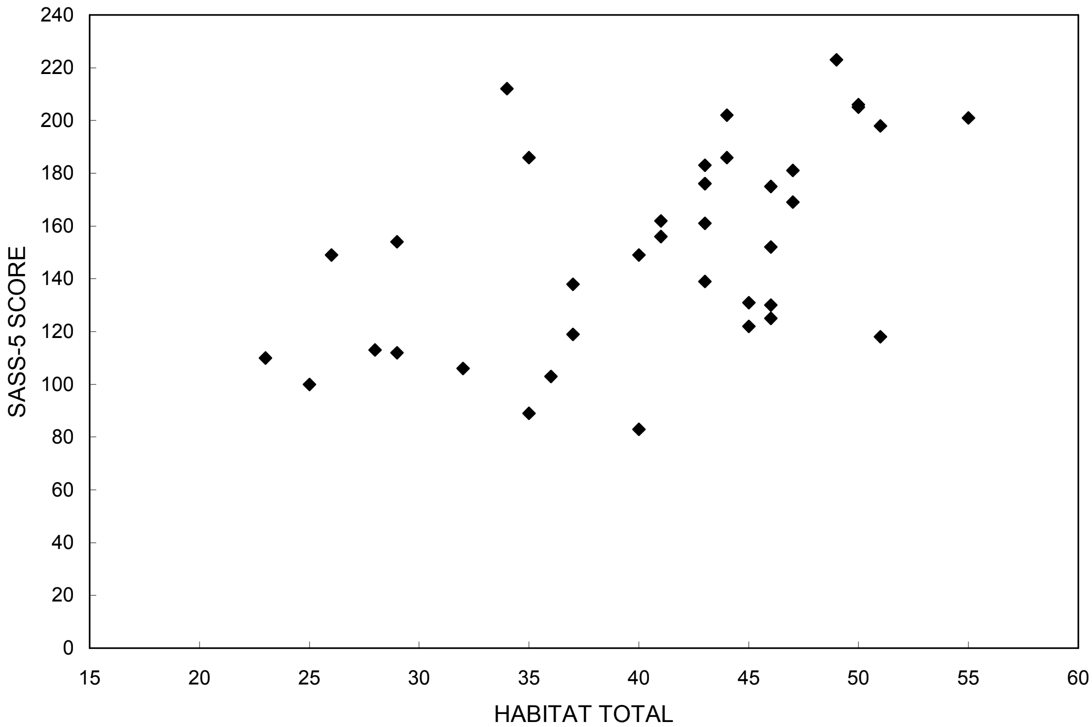


Figure 3.4: Scatter plot of SASS-5 Scores vs. IHAS Habitat Totals for Western Cape data from all geomorphological zones (combined biotopes)

For the Mountain Stream Zone in the Western Cape, which included most of the data that were analysed with all zones combined, the results of the correlation analyses between SASS-5 Scores and IHAS scores based on combined biotope groups were, not surprisingly, the same as those for all zones combined (Table 3.3), with highly significant correlations recorded. For correlation analyses based on SASS-5 data, very few data were available for sampling sites in Mpumalanga (n = 10). As such, the SASS-5 Mpumalanga data were not separated into geomorphological zones for further analysis.

Separate biotope groups

The results of the correlation analyses for separate biotope groups (Table 3.4) reveal that, for both the Mpumalanga and the Western Cape data, there were no significant ($p < 0.05$) and generally very weak correlations (with most τ-values less than 0.2) between SASS-5 Scores and the respective IHAS scores.

Table 3.4: Values of Kendall's Rank-correlation Coefficient (τ) between SASS-5 Scores and IHAS scores from separate biotope groups for Mpumalanga and Western Cape data, with all geomorphological zones combined and for Western Cape Mountain Stream (MS) Zone separately. No significant correlations ($p < 0.05$) recorded; number of samples (n) given in brackets

Biotope group	Mpumalanga	Western Cape	
	All zones	All zones	MS Zone
Stones	0.05 (10)	0.15 (38)	0.19 (36)
Vegetation	-0.21 (6)	0.10 (31)	0.10 (30)
GSM^	0.59 (8)	-0.05 (16)	0.01 (15)

^GSM = Gravel-Sand-Mud

Multiple regression analyses

The linear multiple regression analysis with SASS-4 and IHAS data from Mpumalanga for the SIC biotope group provided nonsensical results in that the weighting that was generated for one of the components of the SIC section of the IHAS score-sheet was negative. Further exploration of the data revealed that this was due to a number of the components being interrelated to one another (e.g. "length of white water rapids sampled" and "length of submerged stones in current sampled"). As such, the requirement of independent, uncorrelated x-values for linear multiple regression (e.g. Underwood 1997) was not met. This problem, which is known as collinearity, is quite common with ecological data (Quinn & Keough 2002). If collinearity is present in a data set, it is inappropriate to undertake a linear multiple regression analysis.

The non-linear MARS regression analysis that was attempted, which should not be hampered by the problem of collinearity, was unsuccessful. Although the exact reasons are not clear, it is more than likely because there were insufficient data to generate reliable results (pers. comm., Dr. M. Kidd, Statistics Department, University of Stellenbosch).

DISCUSSION

Non-parametric correlation analyses

Overall, the results of the (non-parametric) correlation analyses undertaken indicate that the degree of correlation between SASS Scores and IHAS scores is generally unsatisfactory. The only possible exception was for SASS-4 data from the SIC biotope in the Foothill: Gravel-bed Zone of Mpumalanga, for which a highly significant, relatively strong correlation ($p < 0.01$: $\tau = 0.46$, $n = 26$) was recorded and a relatively 'tight' scatter plot with an adequate number of data points was produced (Figure 3.3).

Although significant to highly significant correlations ($p < 0.05$ or $p < 0.01$) were recorded for a number of the data sets analysed (e.g. combined biotope groups with all geomorphological zones combined in Mpumalanga and the Western Cape), the correlations were often weak (low τ-values) and the respective scatter plots generally revealed a wide degree of scatter amongst data points (e.g. Figures 3.2 and 3.4). The main reason that this occurs is that, with large sample sizes, very small values of the τ correlation coefficient can be statistically significant (Campbell 1989). This highlights the importance of not blindly following the approach of the "p-value culture", whereby the primary concern is with formal statistical significance at a rather arbitrary predetermined limit (Underhill 2003). According to an alternative paradigm, results from ecological analyses must not only be demonstrated to be statistically discernable, but also ecologically consequential (Underhill 2003). In this case, it is tentatively argued that some of the statistically significant results obtained (at $p < 0.05$ or $p < 0.01$) in the current investigation are, in reality, of little consequence because of the high degree of scatter in the underlying data relative to the required precision for the application under scrutiny.

Even if statistical significance is not questioned, the results of the correlation analyses undertaken for this investigation still show that the IHAS is not providing reliable scores. Indeed, no significant correlations were found for the majority (two-thirds) of the data sets analysed. Furthermore, some of the findings were somewhat contradictory, such as significant correlations for the combined biotope groups but no significant correlations for any of the separate biotope groups in the Western Cape (Table 3.3 vs. Table 3.4), and the presence of a significant but negative correlation between SASS-4 Scores and IHAS scores for the GSM biotope group from the Foothill: Gravel-bed Zone of Mpumalanga (Table 3.2).

Generally, SASS Scores and IHAS scores were more closely correlated for combined biotope groups (Tables 3.1 and 3.3) than for individual biotope groups (Tables 3.2 and 3.4), except for the SIC biotope for SASS-4 data from Mpumalanga, particularly in the Mountain Stream and Foothill:

Gravel-bed Zones. More data are required from different geomorphological zones, however, especially in the Western Cape, before any reliable conclusions can be drawn with regard to the relative performance of the IHAS between zones for different biotope groups.

Multiple regression analyses

The problem of collinearity with the Mpumalanga IHAS data from the SIC section of the IHAS score-sheet will probably prevent the use, generally, of linear multiple regression in the testing of the IHAS or any of its component sections. Furthermore, as non-linear multiple regression analyses are generally numerically complex and generate results that are difficult to interpret accurately (Underwood 1997), the use of such techniques should probably also be avoided in any further testing of the IHAS.

Further testing of the IHAS

The results of the current investigation clearly show that further testing of the IHAS is required. This should be done separately for different bioregions or ecoregions across the country, with geomorphological zones analysed separately. Obtaining more SASS-5 data that is accompanied by IHAS data for different geomorphological zones within each bioregion or ecoregion, and using statistical correlation analyses to explore the underlying relationships further is one means of carrying out further testing. Alternatively, field data can be collected specifically to investigate various components of the IHAS.

One field-based approach that could be followed would be to collect replicated data for each individual variable on the IHAS score-sheet (Figure 3.1), covering the full range of possible values in each case, while keeping all the other variables constant as far as possible. This would have to be done section by section. For example, for the SIC section of the IHAS score-sheet, different lengths of white water rapids (say 0.5 m, 1.5 m, 3 m and 5 m) could be sampled for macroinvertebrates at a site, while attempting to keep the other SIC variables (length of runs sampled, number of individual SIC areas kicked, etc) constant. A few replicates would have to be collected for each different length of white water sampled and, for each replicate, the corresponding SASS Score would have to be calculated. The degree of correlation between the categorised IHAS scores for the different lengths of white water sampled and the corresponding SASS Scores obtained could then be computed. This approach would highlight which IHAS variables are correlating well with SASS Scores and which are not. For those variables that do not correlate well, the categorised IHAS scores could be adjusted to maximise the degree of correlation. Pursuing an approach such as this would generate valuable results for the refinement of the IHAS, but would require extensive, time-consuming data collection. An advantage of this approach would be that IHAS scores from past assessments could be retrospectively adjusted on the basis of the ‘corrected’ ranges of values that would be generated for the categorised scores of each IHAS variable.

Before embarking on the above-mentioned field-based approach, it is recommended that a preliminary investigation be undertaken to test the weightings of the IHAS scores for only two variables (“length of white water sampled” and “length of submerged stones in current sampled“) of the SIC section of the IHAS score-sheet (Figure 3.1). This investigation would involve the collection of macroinvertebrates from a range of lengths of both white water rapids and runs, sampled separately, with the corresponding SASS Score calculated for each length sampled. For each variable (i.e. length of white water sampled and length of runs sampled), three replicates should be collected for each length sampled, with at least five different lengths sampled in each case (pers. comm., Dr. M. Kidd, Statistics Department, University of Stellenbosch). This would enable one to construct a graph of the length of each habitat type sampled versus SASS Score, from which one could determine whether an asymptote in SASS Scores is reached. If an asymptote is reached for either habitat type, the length of habitat sampled that corresponds with the asymptote in SASS Scores would indicate the respective sampling length that should be used to represent the maximum score (=5) on the IHAS score-sheet. These ‘ideal maximum values’ for the length of white water sampled and the length of runs sampled could then be compared with the current maximum values on the IHAS score-sheet (5 m and 10 m, respectively), which will provide an indication of how well these variables are scored by the IHAS.

The field-based testing of IHAS would have to be undertaken separately for each bioregion or ecoregion and geomorphological zone, with all data collected from minimally-impacted reference sites (such as those established for Mpumalanga and the Western Cape by Dallas 2000 and Dallas 2002, respectively). Although this would be a time-consuming exercise, it would ensure that the further testing and refinement of the IHAS is undertaken within a scientifically defensible framework of analysis.

An important aspect requiring further investigation is the nature of the relationship between SASS Scores and IHAS scores that should be expected at reference sites. The assumption of the preliminary testing undertaken in the current investigation, that this relationship should be linear at reference sites, should be validated before any further testing of the IHAS is initiated.

CONCLUSIONS

The results of the current investigation revealed generally unsatisfactory correlations (τ-values mostly < 0.3, p > 0.5 for two-thirds of data sets analysed) and a consistently high degree of scatter between IHAS scores and SASS Scores. This indicates that the IHAS is not producing reliable scores with regards to the suitability of the habitat at sampling sites for aquatic macroinvertebrates. Furthermore, in Mpumalanga and the Western Cape, the performance of the IHAS was found to vary between geomorphological zones and between biotope groups, with the Foothill: Gravel-bed Zone in Mpumalanga showing the best results, particularly when the SIC biotope group was analysed separately. However, further testing of the IHAS is required to confirm its relative performance in different bioregions/ecoregions, geomorphological zones and biotope groups. Future testing could be undertaken by obtaining more SASS-5 and IHAS data from reference sites and completing further correlation analyses, or dedicated field-based testing of specific components of the IHAS could be undertaken with data collected from reference sites. Ultimately, data would have to be obtained from reference sites in different bioregions/ecoregions and geomorphological zones, with samples from different biotopes collected separately. The current investigation showed that the use of (linear and non-linear) multiple regression techniques should be avoided in any further testing of the IHAS.

The unsatisfactory and variable performance of the IHAS highlighted by the current investigation suggests that this invertebrate habitat scoring system cannot be used with a great deal of confidence in SASS-based bioassessment studies, and very little reliance should be placed on IHAS results produced. Until the IHAS has been scientifically validated, in order to prevent the misinterpretation of SASS data as a result of differences in invertebrate habitat, more emphasis should be placed on the ASPT than the SASS-5 Score in the interpretation of results because biotope availability has less effect on the former, except in cases where very low SASS Scores are recorded (Chutter 1998, Dallas 1997). Alternatively, and preferably, SASS data should be interpreted by plotting both SASS-5 Scores and ASPT values relative to 'biological bands' from reference sites, where these have been established (e.g. Dallas 2000, 2002; also see **Chapter 2** of this thesis), as this ensures that the variability in SASS results is taken into account (Dallas 2002). Unfortunately, biological bands for SASS scores have only been established for a limited number of regions in South Africa and, within these regions, biological bands have not been developed for all geomorphological zones.

A potential avenue for further research and development that could be explored with regard to invertebrate habitat assessment in South Africa is the determination of reference habitat conditions at minimally-impacted sampling sites for different geomorphological zones within different regions across the country, similar to the approach followed in the River Habitat Survey (RHS) assessment system in the United Kingdom (Raven *et al*. 1998, 2000) and the rapid assessment technique developed in the state of Queensland (Australia) for determining the physical and environmental condition of rivers as part of a regional 'State of Rivers Project' (Jackson & Anderson 1994, Ladson & White 2000). Such reference habitat conditions could be used together with SASS biological bands as a means of determining the degree of ecological degradation at sampling sites. The IHAS could be used, together with relevant components of the IHI (Kleynhans 1996), as a starting point for the development of a reference-based invertebrate habitat field-survey and scoring system.

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APPENDIX 3.1: LISTS OF SAMPLING SITES USED TO TEST THE IHAS

Mpumalanga

Table A3.1-1: Sampling sites in Mpumalanga for which SASS-4 and IHAS data were obtained, with river, sub-region and sampling dates indicated

River	Site^	Sub-region*	Sampling dates
Alexanderspruit	X2ALEX-LANGD	FH:CB	18/05/1999, 08/07/1999, 09/09/1999
Blyde	B6BLYD-GROOT	FH:CB	05/05/1999, 10/07/1999, 19/09/1999
	B6BLYD-PILGR	FH:CB	05/05/1999, 10/07/1999, 19/09/1999
Blystaanspruit	X2BLYS-UITSO	FH:CB	19/05/1999, 12/07/1999, 18/09/1999
Crocodile	X2CROC-GOEDE	FH:CB	06/05/1999, 07/07/1999, 08/09/1999
	X2CROC-INDEM	FH:CB	19/05/1999, 12/07/1999
	X2CROC-STERK	FH:CB	19/05/1999, 12/07/1999
	X2CROC-MONTR	RC	21/05/1999. 14/07/1999, 13/09/1999
	X2CROC-CROCB	FH:GB	04/05/1999, 07/07/1999, 31/08/1999
	X2CROC-KAAPM	FH:GB	20/05/1999, 14/07/1999, 14/09/1999
	X2CROC-LWAKA	FH:GB	05/05/1999, 07/07/1999, 31/08/1999
	X2CROC-MBYAM	FH:GB	05/05/1999, 07/07/1999, 31/08/1999
	X2CROC-NGONG	FH:GB	04/05/1999, 07/07/1999, 31/08/1999
Dorps	B4DORP-LYDEN	FH:CB	20/05/1999, 15/07/1999, 09/09/1999
Elands	X2ELAN-HEMLO	FH:CB	20/05/1999, 13/07/1999, 23/09/1999
	X2ELAN-MALAG	FH:CB	20/05/1999, 13/07/1999, 23/09/1999
Elandsfonteinspruit	X2ELFS-DLFBR	FH:CB	05/05/1999, 07/07/1999, 08/09/1999
	X2ELFS-DONKE	MS	05/05/1999, 07/07/1999, 08/09/1999
Ga-Selati	B7GASE-MIDDL	MS	04/05/1999, 08/07/1999, 16/09/1999
Grootfonteinspruit	B6GROO-GROOT	MS	05/05/1999, 10/07/1999, 19/09/1999
Houtbosloop	X2HOUT-ELAND	FH:CB	18/05/1999, 12/07/1999, 18/09/1999
Kareekraalspruit	X2KARE-KAREE	MS	05/05/1999, 09/07/1999, 31/08/1999
Kgwete	B6KGWE-KASPE	MS	06/05/1999, 08/07/1999, 16/09/1999
Klein-Sabie	X3KSAB-TWEEF	FH:CB	14/05/1999, 09/07/1999, 17/09/1999
Klip	B4KLIP-R555B	FH:CB	20/05/1999, 14/07/1999, 30/08/1999
Lunsklip	X2LUNS-KRUIS	FH:CB	05/05/1999, 09/07/1999, 31/08/1999
Mac-Mac	X3MACM-BRAND	RC	19/05/1999, 13/07/1999, 15/09/1999
	X3MACM-FALLS	FH:CB	14/05/1999, 09/07/1999, 21/09/1999
	X3MACM-VENUS	FH:CB	19/05/1999, 15/09/1999
Maritsane	X3MARIT-VERSA	MS	13/05/1999, 11/07/1999, 12/09/1999
Mohlomobe	X3MOHL-WELGE	MS	13/05/1999, 11/07/1999, 20/09/1999
Nelspruit	X2NELS-R40RO	RC	20/05/1999, 14/07/1999, 14/09/1999
	X2NELS-DOORN	MS	18/05/1999, 12/07/1999, 18/09/1999
Ohrigstad	B6OHRI-OHRIG	MS	06/05/1999, 08/07/1999, 16/09/1999

River	Site^	Sub-region*	Sampling dates
Sabie	X3SABI-LTPASS	MS	18/05/1999, 10/07/1999, 17/09/1999
	X3SABI-OLIFA	FH:CB	11/05/1999, 09/07/1999, 17/09/1999
Sabie	X3SABI-SEKUR	FH:GB	03/05/1999, 06/07/1999, 30/08/1999
	X3SABI-LUBYE	FH:GB	08/07/1999, 01/09/1999
	X3SABI-BRAND	FH:CB	20/05/1999, 13/07/1999, 15/09/1999
	X3SABI-BORDE	RFH	08/07/1999, 01/09/1999
	X3SABI-LEOPA	FH:GB	06/05/1999, 09/07/1999, 01/09/1999
	X3SABI-ZEEDE	RC	19/05/1999, 13/07/1999, 15/09/1999
Sand	X3SAND-HEBRO	MS	12/05/1999, 11/07/1999, 20/09/1999
	X3SAND-LONDO	FH:GB	07/05/1999, 06/07/1999, 16/09/1999
	X3SAND-SKUKU	FH:GB	06/05/1999, 06/07/1999, 31/08/1999
Spekboom	B4SPEK-FINSB	MS	07/05/1999, 08/07/1999, 21/09/1999
	B4SPEK-DEBAD	FH:CB	04/05/1999, 06/07/1999, 07/09/1999
Sterkspruit	B4STER-LYDEN	MS	07/05/1999, 07/07/1999, 21/09/1999
Tautesloop	X2TAUT-WINNA	MS	03/05/1999, 13/07/1999, 02/09/1999
Treu	B6TREU-R532B	FH:CB	06/05/1999, 10/07/1999, 19/09/1999
Unspecified	B4STRI-LYDEN	MS	03/05/1999, 07/07/1999, 21/09/1999
Unspecified F	X3BRID-BRIDA	MS	11/05/1999, 09/07/1999, 17/09/1999
Unspecified H	X3SAND-STRIB	MS	12/05/1999, 11/07/1999, 20/09/1999
Unspecified J	X3SADJ-HEBRO	MS	12/05/1999, 11/07/1999, 20/09/1999
Waterval	B4WATE-HADED	FH:CB	04/05/1999, 06/07/1999, 07/09/1999
	B4WATE-TWEEF	FH:CB	06/05/1999, 15/07/1999, 31/08/1999
Wilge	B2WILG-WASCH	FH:CB	17/05/1999, 13/07/1999, 30/08/1999
Wilgekraalspruit	X2WILG-WILGE	MS	06/05/1999, 07/07/1999, 07/09/1999

^ Site codes as used in Rivers Database (River Health Programme 2003)
* MS = Mountain Stream Zone; FH:CB = Foothill: Cobble-bed Zone; FH:GB = Foothill: Gravel-bed Zone; RC = Rejuvenated Cascade Zone; RFH = Rejuvenated Foothill Zone

Table A3.1-2: Sampling sites in Mpumalanga for which SASS-5 and IHAS data were obtained, with river, sub-region and sampling dates indicated

River	Site^	Sub-region*	Sampling dates
Blyde	B6BLYD-PONIE	MS	22/07/1999
	B6BLYD-VAALH	FH:GB	22/07/1999
	B6BLYD-MORIA	RFH	09/09/1999
Elands	B3ELAN-DETWE	FH:CB	22/06/1999
Ga-Selati	B7GASE-MIDDL	MS	12/08/1999
Spekboom	B4SPEK-FINSB	MS	21/07/1999
	B4SPEK-LEIDE	MS	21/07/1999
	B4SPEK-BURGE	FH:CB	20/07/1999
	B4SPEK-DEBAD	FH:CB	20/07/1999
Waterval	B4WATE-HADED	FH:CB	21/07/1999

^ Site codes as used in Rivers Database (River Health Programme 2003)
* MS = Mountain Stream Zone; FH:CB = Foothill: Cobble-bed Zone; FH:GB = Foothill: Gravel-bed Zone; RFH = Rejuvenated Foothill Zone

Western Cape

Table A3.1-3: Sampling sites in the Western Cape for which SASS-5 and IHAS data were obtained, with river, sub-region and sampling dates indicated

River	Site^	Sub-region*	Sampling dates
Elandspad	ELAND-WEIR	MS	12/10/2001
Paardeberg	PAARD-BRAK	MS	12/09/2001, ?/?/2002, 16/10/2002
Olifants	OLIFA-GROO	MS	09/12/2002
Dwars	DWARS-WEIR	MS	04/01/2003, 09/03/2003, 27/10/2003
Drakenstein	DRAKE-TWEM	MS	02/04/2003, 30/10/2003
Olifantsnek	OLIFN-TWEM	MS	02/04/2003, 30/10/2003
Klein Berg	KBERG-BPLA	MS	05/10/2001
Waterval	WATER-TKBE	MS	04/04/2003, 27/08/2003, 28/10/2003
Vier-en-twintigs	24RIV-WEIR	MS	04/03/2003, 28/08/2003, 29/10/2003
Lourens	LOURE-REDB	MS	21/11/2001, 09/01/2002, 24/02/2003
	LOURE-PICB	MS	22/04/2002, 17/09/2002, 24/02/2003
Palmiet	PALMI-NUWE	MS	12/05/2002, 30/09/2002, 26/02/2003
	PALMI-KOGE	RFH	27/02/2003
Hout Bay	HOUTB-HELY	MS	26/11/'01, 1/5/'02, 8/10/'02, 25/02/'03
	HOUTB-ORAN	MS	01/05/2002, 08/10/2002, 25/02/2003
Window Stream	WINDO-L03	MS	26/11/2001
Skeleton Gorge	SKELE-L01	MHS	31/12/2001

^ Site codes assigned by author
* MS = Mountain Stream Zone; RFH = Rejuvenated Foothill Zone, MHS = Mountain Headwater Stream Zone

CHAPTER 4:

GENERAL CONCLUSIONS

> *Macroinvertebrates have served as valuable indicators of degradation of streams, and as increasing demands are placed on our water resources, their value in assessments of these impacts will increase.*
> (Wallace & Webster 1996: 132)

BACKGROUND AND AIMS

As river ecosystems become increasingly threatened, and as the awareness of their importance as vital life-support systems grows, so does the realisation of the critical need to assess and conserve their ecological integrity. This is especially important in dry regions with existing or impending water shortages such as a large proportion of South Africa, including the South Western Cape (SW Cape) Region with its Mediterranean climate. Legislation that supports and, in certain cases, demands the assessment and protection of the ecological integrity of aquatic ecosystems now exists in this country, most notably the National Water Act (Republic of South Africa 1998). In addition, a national River Health Programme (RHP) has been initiated over the past 10 years.

It is globally accepted that the most effective way to assess the ecological integrity of aquatic ecosystems is by means of the biota. Macroinvertebrate communities are particularly effective as indicators of the ecological integrity of river ecosystems, and a number of bioassessment methods that use biotic indices based on aquatic macroinvertebrates have been developed. A comprehensive, comparative description of the more important or widely used indices and bioassessment methods is provided in **Chapter 1** of this thesis, together with a Summary Table. For each biotic index, a description is given of the habitats or biotopes sampled, the sampling equipment used, the sampling protocol followed, the level of taxonomic identification, whether identifications are laboratory- or field-based, the range of the final index value, and its current usage. The most widely used macroinvertebrate-based biotic index for river bioassessment in South Africa is the South African Scoring System (SASS) (Chutter 1998), currently in Version 5 (Dickens & Graham 2002).

Two independently-developed frameworks that are used for the interpretation of macroinvertebrate-based assessments of river ecosystems are the multimetric approach and the multivariate predictive approach, both of which are discussed and for which examples are provided in **Chapter 1**. Regardless of which framework for data interpretation is chosen, the establishment of regional reference conditions for aquatic macroinvertebrates, using either an *a priori* regional approach or an *a posteriori* multivariate approach, is critical for bioassessment programmes. The regional approach involves the initial classification of sites on the basis of geographic and physical attributes, while the multivariate approach involves the classification of sites by means of multivariate statistical analysis using site-specific biological data and supplementary environmental data as the starting point.

In South Africa, where a regional approach to the derivation of reference conditions has been adopted within the RHP (Brown *et al*. 1996; Eekhout *et al*. 1996; Roux 1997; Dallas 2000, 2002), three levels of classification have been prescribed as the spatial framework for bioassessment: a biogeographic or physiographic regional classification (Level I: bioregions or ecoregions), a sub-regional classification (Level II: geomorphological zones) and river types (Level III). Within the regional spatial framework for the RHP, protocols have been established for the selection of reference sites and monitoring sites (Eekhout *et al*. 1996) and for the derivation of ecological reference conditions for riverine macroinvertebrates (Dallas 2000). In addition, reference conditions for aquatic macroinvertebrates, with 'biological bands' based on SASS indices, have been developed for rivers in the province of Mpumalanga (Dallas 2000) and for upland rivers in the Fynbos Bioregion of the SW Cape (Dallas 2002). Furthermore, a geomorphological classification system for the longitudinal zonation of South African rivers has been developed (Rowntree & Wadeson 1999, Rowntree *et al*. 2000), which has been used widely throughout South Africa for the geomorphological classification of rivers when conducting bioassessments and Environmental Flow Assessments.

The primary aim of the current study was to assess and compare the ecological integrity of the Lourens, Palmiet and Hout Bay Rivers (SW Cape, South Africa) by examining the macroinvertebrate community structure at a series of representative sampling sites along the course of each river, using the SASS-5 rapid bioassessment method. Secondary aims included an examination of the effects of seasonal variability, biotope availability and site-specific environmental variables on the macroinvertebrate community structure at sampling sites, as well as the preliminary testing of the Integrated Habitat Assessment System (IHAS). The IHAS (McMillan 1998) is currently the most widely used method of invertebrate habitat assessment in South Africa, despite the fact that this system has not, to date, been tested and validated scientifically (Dallas 2000, Dickens & Graham 2002).

The Lourens, Palmiet and Hout Bay Rivers were selected as part of a broader project, initiated by the Provincial Implementation Team for the RHP in the Western Cape, to produce a 'State of Rivers Report' for these three rivers as well as for the Diep River (RHP 2003). Data collected for the current investigation contributed directly to the compilation of this State of Rivers Report.

SUMMARY OF FINDINGS

Bioassessment of Lourens, Palmiet and Hout Bay Rivers

According to the results of the macroinvertebrate-based bioassessment of the Lourens, Palmiet and Hout Bay Rivers, the ecological integrity of sampling sites in the Mountain Stream Zone of the three rivers was consistently good. The ecological integrity of the Hout Bay River in the upper portions of the Orange Kloof Reserve was particularly near-pristine, with this area having been identified in this study as a potential biodiversity 'hot-spot' for aquatic macroinvertebrates. Downstream of the Mountain Stream Zone, however, a significant deterioration in the ecological integrity of all three rivers was observed due to a number of probable causes (outlined in **Chapter 2**).

Results based on recorded SASS Scores and Average Score per Taxon (ASPT) values, using 'biological bands' generated from reference sites in the SW Cape (Dallas *et al*. 1998, Dallas 2002), were generally similar to and supported by the corresponding multivariate analyses (classification and ordination) undertaken. This reinforces the usefulness of the SASS indices in categorising the ecological integrity of sampling sites, at least where regional reference conditions have been established. It is recommended that SASS indices (SASS Score and ASPT) are used in combination with multivariate methods for macroinvertebrate-based bioassessments within the RHP, as discrepancies in the results from the different types of analysis highlight potential aspects warranting further investigation.

Analyses based on separate SASS-5 biotope groups (*viz*. Stones, Vegetation and Gravel-Sand-Mud or GSM) revealed where certain patterns were most evident, compared to analyses based on combined biotopes. However, the patterns and results based on separate biotope groups were sometimes difficult to interpret, particularly for the Vegetation and GSM biotope groups. For the Stones and Vegetation biotope groups, interpretation may have been improved if lotic and lentic flow-habitats were sampled and analysed separately, as in the GUADALMED protocol for the IBMWP in Spain (Bonada 2003). The GSM biotope group, which was often not present at sampling sites, generally provided very little additional information during this investigation. Therefore, as suggested previously (Dallas 2002), it seems that the GSM biotope group can safely be left out of macroinvertebrate-based rapid assessments without losing any valuable information regarding the ecological integrity of sampling sites, at least for rivers in the SW Cape.

Combined seasons' multivariate analyses undertaken during this investigation masked important seasonal variations in the ecological integrity at certain sampling sites (e.g. Site 5 on the Palmiet River), especially in the analyses based on combined biotopes, with sites of an intermediate or variable ecological state being classified as similar to reference sites in certain cases. Therefore, the use of combined seasons' analyses is not recommended for future bioassessment studies within RHP.

From the results of the various analyses undertaken in this investigation and some of the problems encountered in interpreting the data, the following recommendations are made regarding future bioassessment studies based on the SASS within the RHP:

- Multi-season sampling (excluding the rainy season) should be undertaken, with data from different seasons kept separate in analyses. No preferable season for bioassessments was identified through this investigation, as some impacts were only apparent in certain seasons.
- Environmental data should be collected together with macroinvertebrate data, so that the possible causes of disturbances to macroinvertebrate communities can be identified.
- Lotic (in-current) and lentic (out-of-current) habitats within the Stones and Vegetation biotope groups should be sampled and analysed separately, while the GSM biotope group can be left out of assessments. This will enable better interpretation of results, and scores can still be generated for lotic and lentic habitats together to enable comparison with current SASS-5 assessments.
- Biological bands of SASS Score vs. ASPT should be used to interpret results, where these have been generated, together with multivariate techniques (classification and ordination). It is strongly recommended that biological bands are generated for separate biotope groups, so that conditions at a site can be categorised according to the biotopes sampled.

Preliminary testing of the Integrated Habitat Assessment System (IHAS)

The results of an investigation concerned with the preliminary testing of the IHAS are presented in **Chapter 3** of this thesis. Assuming that SASS Scores at reference sites are the highest scores attainable, one would expect to find a positive relationship between SASS Scores and IHAS scores at reference sites. The assumption in this investigation was that this relationship should be linear. For data obtained from reference sites in the Mpumalanga and Western Cape Provinces of South Africa, non-parametric correlation analyses were undertaken between SASS-4/5 Scores and IHAS scores, using Kendall's Rank-correlation Coefficient (τ). Separate analyses were undertaken for different geomorphological zones and biotope groups. Correlations between SASS Scores and IHAS scores were generally weak (τ-values mostly < 0.3) and unsatisfactory, with no significant correlations ($p < 0.05$) for two-thirds of the data sets analysed and a wide degree of scatter generally observed amongst data points in the respective scatter plots. The performance of the IHAS was found to vary between geomorphological zones and biotope groups, with the Foothill: Gravel-bed Zone in Mpumalanga showing the best results, particularly when the stones-in-current biotope group was analysed separately.

Further testing of the IHAS is required to confirm its relative performance in different bioregions/ecoregions, geomorphological zones and biotope groups. Attempts to test the IHAS by means of multiple regression analyses were unsuccessful, suggesting that such techniques should be avoided in any further testing of the IHAS. It is recommended that further testing of the IHAS be undertaken as a priority for research and development within the RHP, with different bioregions/ecoregions across the country and different geomorphological zones analysed separately. Obtaining more SASS-5 data that is accompanied by IHAS data for different geomorphological zones within each bioregion/ecoregion, and using statistical correlation analyses to explore the underlying relationships further is one means of carrying out further testing. Alternatively, and preferably, field data can be collected specifically to investigate various components of the IHAS. An important aspect requiring further investigation is the nature of the relationship between SASS Scores and IHAS scores that should be expected at reference sites.

In light of the unsatisfactory performance of the IHAS shown in the preliminary testing undertaken and until the IHAS can be scientifically validated, it is recommended that, in order to prevent the misinterpretation of SASS data as a result of differences in invertebrate habitat, more emphasis should be placed on the ASPT than the SASS-5 Score in the interpretation of results because biotope availability has less effect on the former, except in cases where very low SASS Scores are recorded (Chutter 1998, Dallas 1997). Alternatively, and preferably, SASS data should be interpreted by plotting both SASS-5 Scores and ASPT values relative to 'biological bands' from reference sites, where these have been established (e.g. Dallas 2000, 2002), as this ensures that the variability in SASS results is taken into account (Dallas 2002).

POTENTIAL AVENUES FOR FUTURE RESEARCH IDENTIFIED

Through the work undertaken for this thesis, a number of potential avenues for future research and development have been identified with regard to macroinvertebrate-based river bioassessment studies in South Africa.

As previously suggested by Dallas (1995, 2000), there is huge scope for the development of multivariate approaches to the bioassessment of river ecosystems in this country along the lines of the Riverine Invertebrate Prediction and Classification System (RIVPACS) and the Australian River Assessment System (AusRivAS) (see **Chapter 1** for descriptions), which can incorporate the SASS as a data collection and analysis tool.

A critical need within the RHP and for river bioassessment in South Africa generally is the development of SASS-5 biological bands based on reference sites for regions where these have not yet been generated. Separate biological bands should be generated for each biotope group (i.e. Stones, Vegetation and GSM), not just for combined biotopes. In the case of certain regions, such as Mpumalanga and the Fynbos Bioregion of the SW Cape, the primary research for the development of separate biological bands for the different biotope groups has already been undertaken (Dallas 2000, 2002) and additional data analysis is all that is required. For other regions, the primary research on reference conditions must still be undertaken, and should be prioritised within the RHP.

Another research need within the RHP is the collation of as many SASS-5 data as possible from the various regions of the country, and the completion of regression analyses to determine statistically reliable equations for converting between SASS-4 and SASS-5 scores for each region (as undertaken in **Chapter 2** of this thesis, using data from the Lourens, Palmiet and Hout Bay Rivers). Once this has been done, SASS-5 biological bands can be compiled for future use by biomonitoring practitioners where SASS-4 biological bands currently exist.

A further area for potential research and development with regards to the SASS is the exploration of the possibility of modifying the current sampling protocol (Version 5) to keep the lotic and lentic habitats within the Stones and Vegetation biotope groups separate. At the same time, consideration should be given to the exclusion of the GSM biotope group. It is recommended that this whole topic be discussed in a workshop of SASS biomonitoring practitioners and researchers from around the country.

Many river systems in South Africa are non-perennial, either naturally or because they have been impacted to such a degree that they no longer flow all year round. In relation to this, research should be initiated to develop an assessment system similar to the SASS for naturally non-perennial river types, in addition to assessing the reliability of SASS results in river systems forced into becoming non-perennial as a result of anthropogenic disturbances.

Internationally, it has been recognised that research is needed on the development of physical habitat assessment methods that incorporate and integrate the range of spatial and temporal scales affecting the ecological integrity of river ecosystems, to bridge the gap that currently exists between broad-scale and micro-scale habitat assessments (Maddock 1999). Furthermore, additional research is required to test many of the assumptions of current habitat assessment systems and to establish closer links between habitat characteristics and biota (Resh *et al*. 1995). In South Africa, in this regard, there is a critical need for further testing and refinement of the IHAS (following on from the preliminary work presented in **Chapter 3** of this thesis) to ensure that a rapid but robust invertebrate habitat assessment method is developed for river bioassessments.

Another potential avenue for further research and development that could be explored with regard to invertebrate habitat assessment in this country is the determination of reference habitat conditions at minimally-impacted sampling sites for different geomorphological zones within different regions across the country, similar to the approach followed in the River Habitat Survey (RHS) assessment system in the United Kingdom (Raven *et al*. 1998, 2000) and the rapid assessment technique developed in the state of Queensland (Australia) for determining the physical and environmental condition of rivers (Jackson & Anderson 1994, Ladson & White 2000). Such reference habitat conditions could be used together with SASS biological bands as a means of determining the degree of ecological degradation at sampling sites. The IHAS could be used, together with relevant components of the Index of Habitat Integrity (IHI) (Kleynhans 1996), as a starting point for the development of such a reference-based invertebrate habitat field-survey and scoring system.

Finally, an important aspect requiring further research, which was not examined during the current investigation due to the nature of the data collected (with impacted sampling sites included and macroinvertebrates only identified to family level), is the exploration of the implications of 'catchment signatures' and 'river signatures' (*sensu* King & Schael 2001) to river bioassessment. King & Schael (2001) found that macroinvertebrate samples from minimally-impacted headwater-stream sites in the Western Cape grouped together according to individual catchments and rivers, instead of according to geomorphological longitudinal zonation, at least with identifications taken to species level. These so-called catchment and river signatures were no longer apparent when the same data were analysed using family-level macroinvertebrate identifications.

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