MONITORING THE HEALTH OF THE RIVERS OF THE DURBAN METROPOLITAN AREA USING FRESH WATER INVERTEBRATES.

A PILOT STUDY

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Declaration

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Hereby declare that the dissertation entailed

Monitoring the health of the Rivers of the Durban Metropolitan Area using fresh water aquatic invertebrates.

is the result of my own investigation and research and that it has not been submitted in part or in full for any other degree or to any other University. A Pilot Study.

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ABSTRACT

This document is aimed at all parties involved with conservation, planning and management of rivers within the Greater Durban Metropolitan Area, South Africa. The intentions of this study were to provide information on the health of the rivers using freshwater invertebrates and to identify areas where investigative efforts should be focused. In doing so, this document incorporates two data processing methods or techniques used in biomonitoring, the South African Scoring System (SASS) Rapid Bioassessment Technique (RBA) version 4 and the Integrated Habitat Assessment System (IHAS version 2c). The history, current status and future prospects and potential benefits of biological indicators both globally and in South Africa are reviewed and discussed. The RBA (SASS4) involved the standardised collection of samples using the "kick and sweep" technique from defined habitat types at representative sites on river stretches using a standardised net following defined methods. The total score per site is calculated for each family represented in the sample, which is then summed to give the SASS4 score. Lower scores are given to families with a high level of tolerance for polluted waters. The Average Score Per Taxon (ASPT) computation is obtained by dividing the SASS4 total by the number of taxa (families) in the sample. Both scores were considered when determining water quality impairment. The number and abundance of the different taxa and the number of biotopes present were considered as other measures of the river condition. The presence of numerous families of highly tolerant organisms (sludge worms and leeches) usually indicated poor water quality as represented in the Umlaas River, iSipihingo River, Tongati River, and the Ohlanga River. Several different types (or taxa) of stoneflies, mayflies and caddisflies (higher biodiversity) indicated a healthy site for example the iLovu River. Moderate river sites were characterized by declination in invertebrate diversity. Invertebrate diversity declines as the degradation of water quality increases. The manner in which SASS4 scores varied with "degree of anthropogenic impact" showed that the assessment does yield results, which follow water quality changes, provided that when SASS4 scores are less than 50, little attention is given to ASPT. At intermediate and high impacted sites ASPT did not follow habitat quality. However at low impacted water quality sites both SASS and ASPT tended to be greatest where habitat quality was the best. This study has identified that water quality "appears" to have a greater effect on macro invertebrate communities than the physical habitat and SASS distinguished sites with differing levels of water quality. This method was not designed to enable the exact nature of the disturbance to be determined, and it was intended that once an impairment of water quality had been established, it would be further assessed via intensive chemical and other studies. The use of more ecological indicators for example the inclusion of IHAS (version 2c) allowed a more comprehensive assessment of river health and more confidence could be linked to the outcome.

Key Words rapid bioassessment, macro-invertebrates, human impacts, monitoring, water quality.

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Sites Abbreviation	Parameter/site
DMA	Durban Metropolitan Area
RBA	Rapid Biological Assessment
BMWP	British Monitoring Working Party
SASS	South African Scoring System
IHAS	Integrated Habitat Assessment System
ASPT	Average Score Per Taxon
R-BABA-01	Umgababa below dam wall at Mnini
R-BABA-02	Umgababa at Sports field, Mnini
R-MBAZI –01	Msimbazi close to Alpha
R-MBAZI-02	Msimbazi at Karridene
R-LOVU-01	iLovu above Sugar Mill
R-LOVU-02	iLovu below Sugar Mill
R-LTOTI-01	Little Manzimtoti at Kingsway
R-LTOTI-02	Little Manzimtoti at Sports Club
R-TOTI-01	Manzimtoti at N2 Highway
R-TOTI-02	Manzimtoti at Riverside Road
R-MBOKO-01	iziMbokodweni below Sewage Works1
R-MBOKO-02	iziMbokodweni at AECI Purification Plant
R-MBOKO-03	iziMbokodweni at Amanzimtoti Country Club
R-SPING-01	iSiphingo at Road 2123
R-SPING-02	iSiphingo at Flambouyant Road Sports field
R-MLASS-01	uMlazi at Sports field
R-MLASS-02	uMlazi below informal settlement
R-ZANA-01	Mhlathuzana at Clairwood Quarry Compound Road
R-ZANA-02	Mhlathuzana at South Coast Road SWD
R-MGENI-01	uMngeni at Siripat Road
R-MGENI-02	uMngeni North end of Connaught Bridge
R-UBILO-01	Umbilo at Paradise Valley Nature Reserve below waterfall
R-UBILO-02	Umbilo at Edenweg Road, Sarnia
R-HLOTI-01	uMdloti above Verulam SW
R-HLOTI-02	uMdloti above Sewage Works
R-OHL-01	Ohlanga below PWWTW Ponds
R-OHL-02	Ohlanga above Umhlanga Sewage Works
R-TONG-01	Tongati at Sugar Mill
R-TONG-02	Tongati below Central Sewage Works

CHAPTER 1

BIOASSESSMENT OF THE RIVERS IN THE DURBAN METROPOLITAN AREA

1.1 INTRODUCTION

South Africa is facing a water supply crisis caused by a combination of low rainfall and high evaporation rates. In a water scarce country such as this, where there are rapidly growing informal settlements generally possessing poor sanitation services together with high population growth, deteriorating water quality is a serious problem.

Domestic and industrial waste disposal, agricultural runoff, catchment degradation (through the loss of vegetation and erosion) and the introduction of exotic species, are some of the factors changing rivers in South Africa (O'Keeffe, 1986). The impoundment, extraction and transfer of waters from South African rivers, represent another form of exploitation. In other aspects such as species diversity and community dynamics change has been so subtle as to be more often assumed than measured (O'Keeffe, 1986). This problem is further aggravated by a shortage of capital for infrastructure development resulting in pollution of watercourses often beyond their capacity as an effective purifying agent. Most developments are unavoidable and the priority must be to understand their consequences to minimise their effects on the aquatic ecosystem.

Research into and conservation of rivers and streams has to be planned within the context of these pressures. One of the sound water management practices (corrective actions) nowadays taken, include monitoring the 'health' of the natural systems using surrogates of natural systems as indicators of ecosystem health. Although theoretically any organism is good enough for bioassay, sensitive species or indicator species like the aquatic invertebrates are proving to be useful pollution monitors

(Metcalfe-Smith, 1989). In reviewing the practice of biological indicators of aquatic "health" some general points emerge. The most striking of these is the relative neglect of biological compared with chemical methods of assessment (Dallas *et al.*, 1994). The reason for this negligence may be due in part to a lack of understanding of biological data but in many cases it is due to the non-quantitative nature of much of the information (Dallas *et al.*, 1994). Another general point is the tendency to regard biological and chemical methods of assessment as alternatives (Metcalfe-Smith, 1989). This view does not consider the different kinds of information that the above-mentioned assessments provide. Biological indicators show the degree of ecological imbalance that has been caused whilst chemical methods measure the concentration of pollutants responsible (Dallas *et al.*, 1994). In addition, biological methods of water quality assessment measure actual effects on biota, whereas physical and chemical methods must eventually be interpreted on a biological basis (Metcalfe-Smith, 1989). The purpose of biological monitoring is to protect and preserve the biological integrity of natural ecosystems, assessing the degree of ecological impact and taking preventive measures (Dallas *et al.*, 1994).

Of the potential biotic components available for biomonitoring, macroinvertebrates are most commonly used. They act as continuos monitors of the water they inhabit, enabling long term analysis of both regular and intermittent discharges. The macro-invertebrates component utilises the rapid bioassessment technique, SASS4 (SASS, version 4). The South African Scoring System (SASS) Rapid Bioassessment Technique (version 4) is used in this thesis to provide a preliminary survey of the rivers of the Greater Durban Metropolitan Area (DMA). This technique is used describe general patterns and to determine those rivers which appear to be most degraded (to determine the effects and consequences of pollution in the rivers of the Greater Durban Metropolitan Area), particularly through changes in the freshwater macro-invertebrate fauna. Looking at the importance of biological indicators in response to environmental degradation, (water quality to be specific in this case), this thesis also incorporates the Integrated Habitat Assessment System (habitat evaluation) (IHAS version 2c) methods of analysis

This study is aimed at all parties involved with the planning, management and utilisation of the rivers in the Metropolitan Area of Durban. It is envisaged that the conclusions and inferences from this study may be useful in forward planning so that the anthropogenic threats to water and the environment are reduced.

1.2 CURRENT STATUS OF THE FRESH WATER RESOURCES OF THE GREATER DURBAN METROPOLITAN AREA (DMA).

If land use planning in Durban Metropolitan Area does not take into account the environmentally sensitive nature of its fourteen river systems (Fig.1), the value of these ecological systems will become damaged or diminished. The economic and social opportunities of the river catchment systems may even be lost due to the reduced water quality which have resulted in an increased pressure in the DMA rivers.

Most of the rivers of the DMA are influenced by changes in watershed outside Durban boundaries and are further reduced and degraded, as the rivers travel eastwards, especially downstream as they get closer to the sea, by catchment malpractices within the City of Durban. The rivers of the DMA are under pressure from a range of anthropogenic activities (sandwinning, flooding, soil erosion, siltation, acidification, agricultural runoff, wastewater discharge and the occasional accidental or illegal discharges from industrial activities) and as such have become significantly modified. As more of the rivers of the DMA are disturbed, habitats are becoming smaller and more altered. The organisms in this altered environment struggle to survive and so the rivers of the DMA are now threatened.

1.3 Water Quality Management of the Durban Metropolitan Area

The need for high quality water requires increased vigilance to be exercised in the prevention and abatement of pollution to ensure that what little water there is, is maintained in a state fit for use. The question of equity and responsibility of the present water allocation demands attention (DWAF, 1995). Concern about the ecological status of water resources has been raised in various regulatory statutes and public awareness forums in South Africa. Freshwater ecosystems are being managed through national and local policies and Durban Metro Water Services programmes. At a local level, the Durban Metro Water Services policy initiative sets out policy statements and implementation strategies for the sustainable use of fresh water resources. At provincial level responsibility for bulk water supply for the Durban Metropolitan Area lies with Umgeni Water, a statutory body. At national level a crucial step towards sustainable management of South African water resources was taken with the release of the National Water Act, Act 36 of 1998.

The new water Law demands that South Africa's water management process be more "transparent, co-operative and equitable". Act 36 of 1998 establishes that there is no such thing as "private water"–all water is said to be for "public good" with the responsibility to manage and authorise use of the nation's water resources vesting in the Minister of Water Affairs and Forestry. The Act's aims are to ensure that the nation's water resources are "protected, used, developed, conserved, managed and controlled" in ways which take into account amongst other factors "protecting aquatic and associated ecosystems and their biological diversity, as well as reducing and preventing pollution and degradation of water resources".

As far as catchment management strategies are concerned the Act requires that "every catchment management agency progressively develop a catchment strategy for the water resource within its water management area". A catchment management strategy must set principles for "allocating water to existing and prospective users, taking into account all matters revelant to the protection, use, development, conservation management and control of water resources". Community participation, water conservation and appropriate landuse are important aspects of making Act 36 work.

1.4 Users of Fresh Water in the DMA

Ideally it would be desirable for every river to be unpolluted, full of fish and invertebrates and aesthetically pleasing. However in a semi-industrialised country such as South Africa it becomes economically impossible to prevent river pollution. It is therefore necessary to take an overall view of water and to classify rivers as suitable for particular purposes. The principal users of fresh water are listed below:

1.4.1 Municipal (Domestic water supply):

The main use is for public water (drinking, personal hygiene, sewage disposal and drainage).

1.4.2 Industry

Substantial amounts of water are used in a variety of industrial processes. Mondi in the DMA is one of the big user of fresh water within the DMA. Competition for the water resources within the DMA also comes from several large industries outside the

DMA such as the Illovo Sugar Estates, SA Rubber Manufacturing Company Ltd based at Howick and Sappi – Saiccor (Pty) Ltd.

1.4.3 Agriculture

Irrigation practices are developed in several river catchments in the DMA.

1.4.4 Recreation and Amenity

Some of the rivers in DMA are used for water sports, swimming and fishing. Particularly important for recreation purposes is the estuary of the uMngeni River.

1.4.5 Environment

The Umbilo River system integrates aesthetic enjoyment of water dependant landscapes and wildlife and is an example of a river with a natural balance of plants and animals, some are interdependent, some competing and some independent.

According to Patrick (1949) a 'healthy' river or stream, is classified as an 'undamaged' one, one which supports a diverse balanced fauna and flora, with all trophic levels proportionally represented and no obvious population imbalance. "Any downward change from that state constitutes biological 'damage' and does not bear any relation to use, economics or aesthetics" (Patrick, 1949). In making this evaluation, the physical structure and available habitats must be considered as well as background studies of similar stream or river sections whose sources and amounts of contaminants are known (Hart and Fuller, 1974).

1.5 TYPES OF MEASUREMENTS OF WATER QUALITY

1.5.1 Chemical Measures of Water Quality

Monitoring, assessing and regulating aquatic ecosystems was previously based largely on traditional measures of water quality i.e. physical and chemical measures (Metcalfe-Smith, 1991). This type of assessment, although essential for determining the type and concentration of pollutants entering a river, is limited to the period of sample collection and therefore requires large numbers of measurements for an accurate assessment (Metcalfe-Smith, 1991). "Unless these sample collections are continuous over time, pulsed releases of effluents that result in an alteration of water quality may not be recorded" (Warren, 1971). Warren stated that "organisms living in water provide a more sensitive and reliable measure of the conditions than do physical and chemical measurements of water quality and may detect pollution problems that may no longer be evident in the water sample". Chemical measures allow one to determine the levels of chemicals in the water sample but do not provide adequate information for sound management of aquatic resources because they tell little about the direct effects of pollution on living organisms (Warren, 1971). "In addition the cost of such chemical analyses in a country where socio-economic considerations are of increasing significance, should also be taken into account" (Dallas *et al.*, 1994).

1.5.2 Biological Measures of Water Quality

Since water pollution results in biological impact, it would be logical that it ought to be measured biologically. "Biological methods can integrate responses to combinations of all contaminants and to other sources of environmental stress, thereby indicating overall effects in a water body" (Plafkin *et al.*, 1989). "By making an inventory of the invertebrate communities and comparing results of invertebrate communities with those found in pollution free areas, it is possible to determine whether or not pollution is causing ecological effects such as loss of sensitive groups of organisms" (Plafkin *et al.*, 1989).

Biological studies can serve an early warning function by detecting intermittent pollution and subtle disruptions, which would likely be missed by conventional chemical surveys (Howmiller and Scott, 1977; Reynoldson, 1984). It must be recognised that not all impacts are chemical in nature, and biological assessments may also be able to detect habitat destruction, overharvesting of biological resource and current velocity (Karr, 1991). This approach relies on the great diversity of macro-invertebrate life in rivers and streams and to determine how suitable a waterbody is for the support of aquatic life (Karr, 1991).

It can therefore be stated that the main purpose of biological assessment is to characterise the status of the water resource and to monitor trends in the condition of biological communities that are associated with anthropogenic perturbation (Karr, 1991). "The concept of biological community health is a valuable assessment tool within the broader management context and has an important role to play in the integrated management of water resources because the general public can more readily comprehend the information obtained" (Hellawell, 1986). Biological assessments of water resources provide the public with more familiar expressions of ecological health than the results produced by chemical and toxicity tests. According to Roux *et al.* (1994) "biological communities have regained their acceptability as an integrated measure, which responds to environmental changes in a river".

1.6 Indicator Species

"In order to detect environmental disturbance using biota it is important that organisms reflect the situation at the site from which they are collected" (Rosenberg and Resh, 1993). Changes in these conditions can result in reduction in species numbers, a change in species dominance or a total loss of sensitive species by death or migration.

"In order to assess water quality on the basis of ecosystem health, it would be best to study the response of the entire aquatic community to stress" (Metcalfe-Smith, 1989). "As this is obviously impractical, most workers focussed on a particular sector of the ecosystem, such as periphyton, plankton, macrobenthos or fish" (Metcalfe-Smith, 1989).

The presence or absence of certain species in relation to particular water quality characteristics has been exploited in the development of ecological methods based on 'indicator species' (Rosenberg and Resh, 1993). An "indicator species is defined as a species (or species assemblage), that has particular requirements with respect to known sets of physical or chemical variables" (Rosenberg and Resh, 1993). "The presence or absence of indicators or an indicator community reflects certain kinds of habitats and water quality and whether the given physical or chemical variables are outside its preferred limits" (Rosenberg and Resh, 1993). "The presence of large numbers of indicator organisms signifies that their physical, chemical, habitat as well as the water requirements are being met" (Rosenberg and Resh, 1993). "Therefore if the environmental factors that are most commonly limiting to the species concerned are known then the presence or absence of the organisms will indicate specific environmental conditions" (Rosenberg and Resh, 1993).

Absence of a species is also equally important but not as meaningful as it might seem, as there may be reasons other than pollution that may have resulted in its absence (e.g. predation, competition, or geographical barriers). According to Rosenberg and Resh (1993) "the absence of multiple species of different orders with similar tolerance levels that were present previously at the same site, is more indicative of pollution than the absence of a single species". Studies using indicator species will always be needed for example where the precise quantification of the impact of a major development is required or where the conservation of a rare species is of concern. "It is clearly necessary to know which species should be found at the site or in a system in order to assist in understanding the system" (Rosenberg and Resh, 1993).

1.7 Rapid Assessment Techniques for Biological Monitoring (SASS4 and IHAS)

Several organism assemblages are used to assess the condition of biological communities, however approaches to biological monitoring using macro-invertebrates have diversified in the recent decades (Hellawell, 1986; Rosenberg and Resh, 1993). "A technique for low cost rapid assessment was required because of the need to survey a large number of sites using limited resources, and provide timely feedback to water resource and wastewater managers" (Chutter, 1994). "For macro-invertebrates these procedures generally involve qualitative or semi–quantitative sampling and reduce the biological information to a metric or biotic index which is easily interpreted by natural resource managers" (Chutter, 1994).

Macro-invertebrates have for some time been used as indicators of biological health of flowing waters in South Africa. The most recent in this respect is the SASS community index (South African Scoring System: Chutter, 1998), which has become a national standard for biomonitoring of rivers and streams of South Africa. This technique was modified for South African conditions from the Biological Monitoring Working Party (BMWP) score system (Chesters, 1980) and is based on the sensitivities of key families of invertebrates to pollution (Armitage *et al.*, 1983).

A characteristic of rapid bioassessment programmes used in South Africa has been the inclusion and evaluation of habitat structure. The interpretation of results does require the careful recording of the habitats from which the invertebrate were taken, as each species also requires specific physical conditions (Chutter, 1994, 1998). Habitat structure incorporates geomorphological features such as gradient, channel morphology, channel width and depth and substratum, in addition to factors related to riparian vegetation, canopy cover and bank stability (McMillan, 1998). In the rocky bed of a river, for instance, a few species will live on the upper surfaces of the stones in fast-flowing currents, while others live under the stones in quiet backwaters, and others prefer the protection of submerged plants (Chutter, 1994, 1998). Chutter went on to say that "wherever the impact of small-scale habitat variation on SASS was considered it has been found that there was little change in ASPT". Indeed this is the basis for interpreting relatively low SASS4 scores and correspondingly relatively high ASPT scores as indicating a limitation in habitat diversity, rather than deterioration in water quality. "The cases where the large-scale properties of the river habitat have an apparent direct impact on the SASS4 scores are limited, and may be picked up through their impact on small-scale habitat diversity" (Chutter, 1994).

Both techniques (IHAS and SASS4) primarily make use of indices for measuring biological and habitat "health" to enable integrated assessment of the condition of the river as a whole. Rapid bioassessment techniques are appropriate when a preliminary survey is required over a wide area and at a large number of sites (Chutter, 1994). In such cases rapid assessment can be used to describe general patterns and to pick out those sites which appear to be most degraded (Chutter, 1994). Such sites can then be subjected to more detailed studies, in order to confirm or modify the preliminary findings, determine cause and effect relationships and provide firmer basis for remedial management (Chessman, 1995). The second main use of rapid techniques is when a preliminary assessment of the condition of a waterway is needed immediately for management purpose (Chessman, 1995).

"It should be emphasised that the rapid techniques are not advocated as a substitute for detailed quantitative studies at species level" (Chessman, 1995). "Such studies will always be needed for example where the precise quantification of the impact of a major development is required or where the conservation of a rare species is of concern" (Chessman, 1995). The SASS4 method is intended to be a rapid technique for the detection of water quality degradation or for revealing trends of water quality change over periods of time (Chutter, 1994). It is not intended to categorise the degree of degradation in any detail nor to identify the nature of the degradation (Chutter, 1994). The role of SASS4 is to guide chemical water investigations to areas where ecosystem health is poor and where, therefore, investigative efforts should be focussed (Chutter, 1994).

1.8 REASONS FOR THE SELECTION OF THE STUDY AREA

The Greater Durban Metropolitan Area (Fig 1) was selected as the study area because of the following factors:

- No previous investigation using SASS version 4 and IHAS version 2c methods of analysis had been conducted on the rivers of the DMA.
- The area had known point sources of effluents.
- The area had a mixture of agricultural and other sources of pollution dominated by extensive urbanisation.

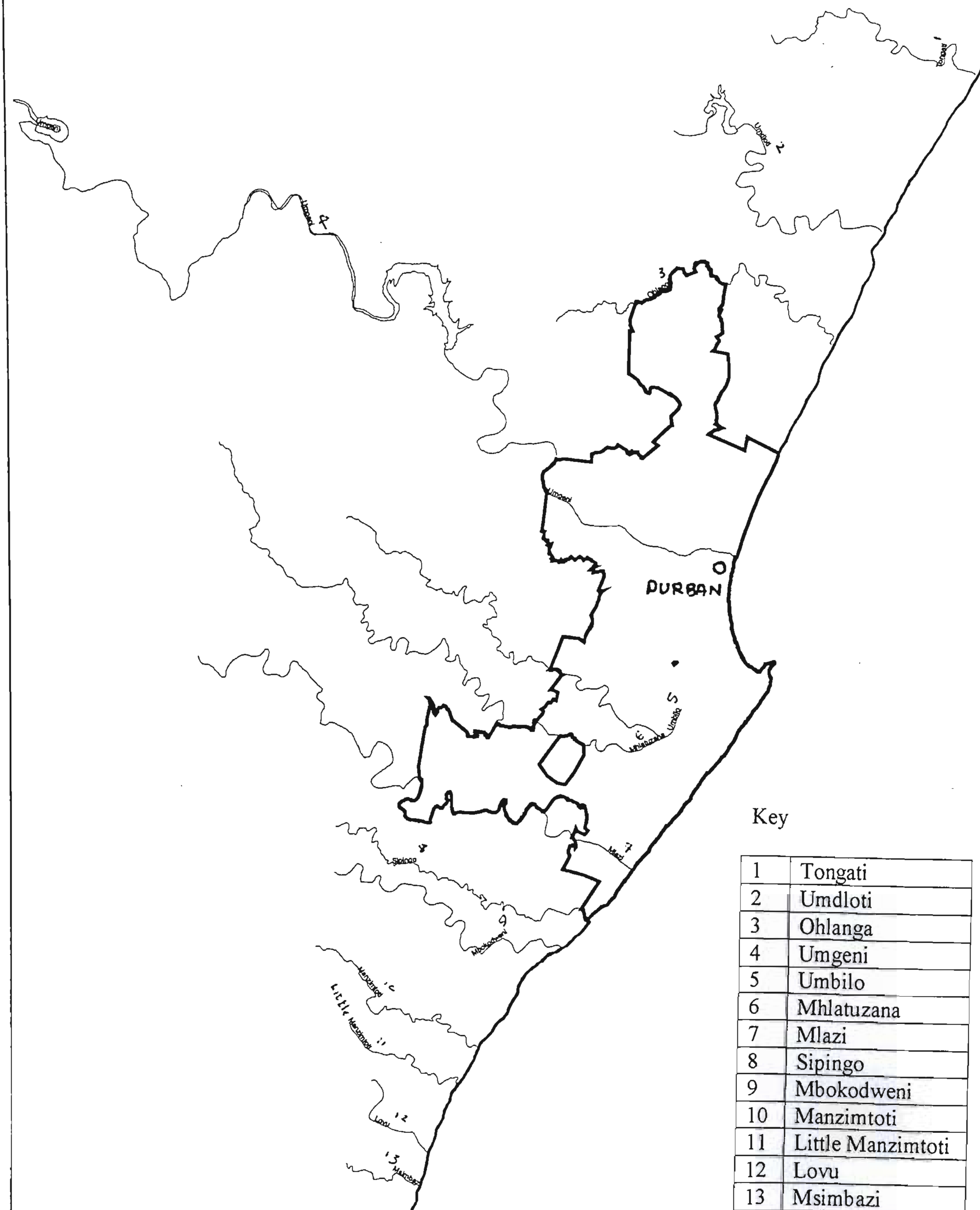
- Rapid development is currently occurring within the region, and the results of this study may be used in the planning and development projects, to reduce the effects of pollutants.

1.9 Aim of Study

The aim of the ecological research on the rivers of the DMA was to determine, using SASS4 and IHAS methods of analysis: (a) the status of the rivers of the DMA (pick out those sites which appear most degraded) and

(b) Determine the effect of the impactors on the on the aquatic invertebrates.

Unfortunately due to time constraints of the study, seasonal effects were not accounted for. Consequently, the effect of flow could also not be realised due to the typical low flow time of the year in which the study was performed.



Key

1	Tongati
2	Umdloti
3	Ohlanga
4	Umgeni
5	Umbilo
6	Mhlatuzana
7	Mlazi
8	Sipingo
9	Mbokodweni
10	Manzimtoti
11	Little Manzimtoti
12	Lovu
13	Msimbazi

Project Title:

Fig. Location of rivers in the Durban Metropolitian Areas, South Africa

Scale: 1: 250000

Date: 24/12/2001

3 Prior Road
Tel: 3024673

LEGEND:
Rivers.shp
Durban

Notes: The Metropolitan Council accepts no liability or responsibility whatsoever for the correctness or accuracy of information supplied, or for the stability or efficacy of any structure or design shown hereon. In the case of Council services, the information supplied must be used as a guide only. Details should therefore where possible, be physically checked on site.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter briefly considers in Section (A) the history and development of biological water quality assessment using aquatic invertebrates and review the ecological studies carried out in different parts of the world, which have established the effects of different types of discharges on freshwater communities, which are generally regarded as affecting water quality. Section (B) describes first the development of freshwater biological research in South Africa and then reviews the SASS and IHAS methods of rapid biological assessment studies conducted in South African rivers and streams.

Section A

2.1.1 A BRIEF HISTORY OF THE GLOBAL PERSPECTIVE ON FRESHWATER ECOLOGICAL RESEARCH USING BIOLOGICAL INDICATORS.

It is well established that environmental disturbances such as pollution induce change in the structure and function of biological systems. Although biological methods of assessing water quality had been used in Europe since early in the 20^{st} century, and later in America, it was only in the later half of the 21 th century that the possibility of using river organisms as indicators of pollution received serious attention in Britain. Forbes (1913) recognised the value of organisms as environmental indicators when Forbes stated, "it is quite possible to arrange the plants and animals of a stream in the order of their preference for, or tolerance of, organic impurities in such a way that a graded list of them may serve as an index to grades of contamination".

He remarked that "biological observations are more dependable in certain ways than chemical determinants since they show cumulative effects of the present and past conditions, while chemical tests apply only to the moment of sampling". He also stated that sludge worms were common in polluted areas whilst mayflies and caddisflies were not found in areas receiving sewage pollution. Purdy (1930) clearly recognised the value of biological indicators when he stated that "if it be true that the biological life of a stream is distinctly and profoundly affected by the numerous factors which form the environment, it follows that the organisms in a stream constitute in a general way a reflection of the prevailing environmental condition of the stream".

The first critical use of benthos in ecological assessment was the 'Saprobien System' developed by Kolkwitz and Marsson (1909) assign scores to benthos as affected by organic pollution. In some way the majority of score systems subsequently used are modifications or refinements of this fundamental concept. The Saprobien system incorporates all trophic levels. However, much of the taxonomy, particularly for micro-organisms was, and still remains, unavailable. Furthermore the pollution sensitivity of many species is unknown and the system suffers from a lack of community integration. "The original system was geographically specific and was only appropriate for sewage pollution" (Chutter, 1972). Hynes (1960) and Hawkes (1962) agree on the limited usefulness of the Saprobien system and its later modification, because of its rigidity and because all indicator organisms, including those associated with the most severely polluted water, occur in natural waters.

The second major innovation in utilising benthic invertebrates in ecological assessment was the advent of diversity indices (Wilhm and Dorris, 1968). "Diversity indices use three components of community structure, abundance (total numbers) richness (numbers of species) and evenness (distribution of individuals among species) to produce a single number" (Wilhm and Dorris, 1968). However, the recent decline in the frequency of their use suggests that the inherent disadvantages (reviewed by Wilhm and Dorris, 1968) of using diversity indices outweigh their benefits. "These disadvantages are as follows: the reduction of information on individual species to a single number and the disregard of known data on pollution tolerances of various species results in the loss of information on the composition of the community" (Winget and Mangum, 1979). "The response of a community to stress is not normally linear and the level of taxonomic detail and other conditions can markedly affect the index value" (Wilhm and Dorris, 1968).

It has been reported by Cook (1976) both the Saprobic index and the Diversity index calculated according to Simpson's formula (Simpson, 1949) of water quality had little practical application. "A major reason for this decline in use is that, historically people who developed the indices were not always the ones who had to use them" (Chutter, 1998).

Most indices and assessment techniques are based on the response of the entire aquatic invertebrate benthic community to pollution. It has been demonstrated, however, that certain components or assemblages are more suitable for assessing lakes versus rivers or water versus sediment quality, or for investigating specific types of pollution.

The biotic approach to biological assessment, as defined by Tolkamp (1985) is one, which combines "the benefits of the Saprobic system with those of diversity indices into a single score that can be statistically analysed has received the most attention in recent years". This type of index where families are assigned a pollution sensitivity score has an advantage in that it allows rapid interpretation of the conditions of the monitoring site. "Possibly the most advanced system to date is the Biological Monitoring Working Party (BMWP) score system, which is based on the sensitivities of key families of invertebrates to pollution" (Armitage *et al.*, 1983). All organisms from a site to be scored are identified to the family level and each family is assigned a value according to its pollution tolerance. The values for all families present are summed to arrive at a site score.

Although the Biological Monitoring Working Party (BMWP) score (Armitage *et al.*, 1983) and its associated 'average score per taxon' (ASPT) were developed in Britain, this score has been modified for use in several countries including Spain, India, Australia and South Africa. According to Thorne and Williams (1997) the adaptation of an index to suit local fauna can greatly enhance its performance. Numerous biotic indices and scores have since been developed for use in different countries (reviewed by Metcalfe-Smith, 1989) and new research directions aimed at improving the performance of bioassessment techniques are being explored (Metcalfe–Smith, 1989).

2.2 REVIEW OF INTERNATIONAL EXPERIENCE OF THE USE OF BIOLOGICAL INDICATORS OF WATER POLLUTION.

2.2.1 A BRIEF DESCRIPTION OF THE POSSIBLE NATURAL SOURCES OF CONTAMINANTS AFFECTING AQUATIC INVERTEBRATES

Natural sources of environmental stress are noted by several authors. Natural inputs of organic matter can enter some defined area of an ecosystem from multiple sources and can change community structure resulting in the detritus feeding blackflies (Simuliidae) and midges (Chironomidae) increasing in abundance. The main contributors of natural sources of water quality degradation are primarily, excreta, falling leaves, pollen and decayed vegetation. Natural events such as torrential rainfall and hurricanes lead to excessive erosion and landslides, which in turn increase the content of suspended material in affected rivers and lakes. An increase in enrichment that causes increased productivity in lakes, rivers, streams and estuaries can come from natural processes such as earthquakes, forest fires and other factors, and result in periods of high enrichment. The representation of certain species of freshwater invertebrates is often a sensitive indicator of the trophic state (Welch, 1980).

2.3. CULTURAL SOURCES OF CONTAMINANTS AFFECTING BIOTA

Literature concerning cultural sources of environmental stress on aquatic systems cites diffuse and point sources of pollution and these may be situated in urban or rural areas. Point source of pollution is best thought of as "discharges from fixed sites, such as a factory or a sewage treatment plant, which if the process involved was stopped so would the discharge" (Metcalfe-Smith, 1989). "Generally speaking a modification to the nature of the process or treatment of the discharge will change the composition of a point discharge" (Metcalfe-Smith, 1989). Diffuse pollution is defined as "that which comes in over the length of the river and originates from the widespread use of substances, for example agricultural runoff would be considered a diffuse source" (Metcalfe- Smith, 1989).

2.3.1 POINT SOURCES OF POLLUTION

2.3.1.1 EFFECTS OF ORGANIC WASTE ON AQUATIC INVERTEBRATES

"The responses of aquatic invertebrates to organic pollution are the best documented and most thoroughly understood of all groups in freshwater organisms" (Hynes, 1960) and form the basis of a large number of systems or indices for classifying stages and degrees of this and other forms of pollution. Most authors have generalised the tolerance of aquatic invertebrates to organic waste into three principal groups. The intolerant groups include mayflies, stoneflies, caddisflies and riffle beetles; the tolerant groups include sludge worms, certain midges, leeches and certain snails; the moderately tolerant groups include most snails, bugs, blackflies, dragonflies and some midges.

"In heavily polluted streams planarians are absent though other faunal constituents (tubificid oligochaetes, Ephemeroptera and gammarid amphipods) may still be found" (Hart and Fuller, 1974). Most workers report a definite clean–water association of fauna which is upset by even mild organic pollution and which is re-established at the end of the "recovery zone" after all traces of the organic pollution have disappeared (Chutter, 1972). In addition, other Australian studies (Chessman, 1995) investigated the effects of organic waste on stream aquatic invertebrate communities revealed in particular an increased abundance of Dipterans especially Chironomidae. "Leeches can reach tremendously high densities in regions of organic enrichment as revealed in a case study of the Illinois River in 1925 where this population reached an abundance of 29,107 individuals / m^{2}" (Sawyer, 1947). According to work done by Harrison (1958) in the Black River, South African rivers receive large volumes of effluent from sewage works and polysaproic conditions occur with characteristic fauna of *Tubifex* species, red *Chironomus* larvae and abundant ciliates. Harrison (1958) report that "Ephemeroptera and Trichoptera are characteristic clean water groups that are absent even if mild organic pollution is present whilst Plecoptera (stoneflies) and Elmidae (riffle beetles) are sensitive to organic pollution".

"The overall effect is that in environments stressed by organic wastes, the community generally responds with a decrease in diversity as sensitive organisms are lost, and an increase in the population of those able to tolerate the enriched food source" (Dallas *et al.*, 1994).

2.3.1.2 EFFECTS OF INDUSTRIAL EFFLUENT ON AQUATIC INVERTEBRATES

Pollution of waters by metals such as copper, zinc and lead sometimes found in industrial effluents brings about obvious changes in the flora and fauna" (Surber, 1953). Williams and Feltmate (1992) consider the majority of factory effluents to be important point source pollutants. A discharge of toxic materials generally eliminates some taxa altogether and reduces the numbers of other taxa (Surber, 1953). Resistant groups include many insect orders such as Diptera and Trichoptera, while oligochaetes are intermediate and molluscs and malacostracans (Crustacea) are recognised to be the most sensitive. According to the literature reviewed there appeared to be a relationship between the aquatic invertebrate community at a river and the type of effluent entering the riverine system. On the other hand, Carpenter (1924) stated that leeches are more tolerant of lead than of zinc and some species of stoneflies that are most sensitive to organic enrichment are highly tolerant of zinc. According to Sawyer (1947) tubificids, leeches and molluscs are among the most sensitive to heavy metals. Winner *et al.* (1980) assessed the response of aquatic insect communities to heavy metal pollution (Cu, Cr and Zn) in two Ohio streams. When metal stress was very severe and overwhelmed other environmental features, chironomid populations were consistently dominant. Winner *et al.* (1980) therefore proposed that the ratio of chironomids to the total insect population was a useful index of heavy metal pollution.

The response of aquatic invertebrates to non-degradable toxic pollution is a decrease in both diversity and abundance of the sensitive organisms, and there is no additional food source for the remaining tolerant forms. The natural food sources may be more limited than normal, and there may be sub-lethal stresses on the survivors, which can affect productivity (Persoone and De Pauw, 1979).

2.4 DIFFUSE SOURCES OF CONTAMINANTS

Diffuse pollution arises from a lack of adequate infrastructure, management and/or maintenance of land-use practices including crop production, de-vegetation and deforestation, sanitation and refuse. Some diffuse sources of possible pollution events are described in this section.

2.4.1 EFFECTS OF URBAN RUNOFF ON AQUATIC INVERTEBRATES

The effects of urban runoff on the biota of receiving waters have not been extensively studied but recently it have been recognised as an important source of pollution in receiving waters (Whiting and Clifford, 1983). "The total weight of material released annually into receiving waters by water runoff is roughly equivalent to that of secondarily treated domestic sewage" (Whiting and Clifford, 1983). Total solids may be 10 to 20 times greater in urban runoff than domestic sewage. It often consists of a poisonous "cocktail" of petrol, tyre spread, hydrocarbons and other organic products and heavy metals. These contaminants enter the receiving waters mainly via storm sewer discharge, although little is known about the importance of direct overland flow (Whiting and Clifford, 1983).

According to work done by Whiting and Clifford (1983) on the Whitemud Creek in Canada, it was suggested that "organic enrichment, a component of urban runoff, resulted in two tubificid species dominating the urban fauna". "These worms are typically found in association with organic enrichment" (Brinkhurst and Kennedy, 1965). Increased siltation, another component of urban runoff, may also have been responsible for some observed faunal changes. Animals such as gastropods and tubificids are tolerant of siltation as well as organic enrichment. "Some chironomid groups were dominant and have been previously associated with siltation or siltation plus organic enrichment" (Brinkhurst and Kennedy, 1965). Toxic substances usually reported from urban runoff in the form of pesticides, result in tubificids, chironomids and oligochaetes being absent because they are intolerant of pesticides. Williams and Feltmate (1992) found that runoff associated with motor vehicles imposed an additional stress on aquatic insects. The higher values of carbon oxygen demand (COD) in urban surface waters were due to hydrocarbon leaked from motor vehicles.

2.4.2 EFFECTS OF AGRICULTURAL LAND USE ON AQUATIC INVERTEBRATES

Degradation of the ecological health of running waters is common place wherever significant human settlement has occurred. Conversion of native vegetation to agricultural croplands has transformed large land areas. Loss or reduction of riparian vegetation is another common consequence of maximising tillable land. This results in a number of changes, including higher temperatures, altered channel structure due to reduced woody debris and fewer inputs of leaf litter. These changes may be less dramatic when the riparian vegetation is left unaltered. Together these habitat alterations profoundly affect key qualities of the stream ecosystem.

Dance and Hynes (1980), for example, observed characteristic changes in a variety of insect orders due to the combined stresses of agricultural landuse. Rae (1989) found that "several groups of chironomid genera were indicative of certain chemical conditions in the Scioto River Basin in Ohio". He strongly recommended "focussing on indicator taxa rather than studying the entire benthic community because little information is gained by examining the distributions of facultative organisms".

Whitten and Goodnight (1966) investigated the effects of toxicity of organochlorine insecticides to invertebrates, stating that "invertebrates are highly sensitive to insecticides". Muirhead and Thompson (1987) observed that "even with concentration as low as 5 to 10 l^{-1} of organoclorine over 95 % of aquatic invertebrate test organisms were killed, so that application of insecticide to, for example Simuliidae would not kill fish directly although their food organisms would clearly be at risk". Oligochaeta and some other soft-bodied forms (flatworms and leeches) are more tolerant of pesticides than arthropods. As is expected, less tolerant species disappear and the biological communities become dominated by a smaller number of species that tolerate these degraded conditions.

2.4.3 Effect of Sedimentation on aquatic invertebrates

Perhaps the most obvious outcome of environmental stress in a semi-arid country such as South Africa is the considerable load of sediment carried by rivers. The increased silt loads have already been seen to be due to the effect of man upon natural erosion rates (Fuggle and Rabie, 1983). The response of benthic aquatic invertebrates to suspended sediment will depend on both concentration and duration of exposure, which is a response similar to that caused by other environmental contaminants (Fuggle and Rabie, 1983).

The deleterious effects of suspended high solid loads and sedimentation on riverine habitats have been well documented. Cordone and Kelly (1961) report on the deleterious effects of fine sediment suspension and deposition on benthic invertebrates. Dudgeon (1994) reported on "invertebrate fauna that will predominate as a result of the mobilisation of large volumes of sediments into rivers". Nutall (1972) provides "a useful list of the reaction of sand mining on different invertebrates showing those which were enhanced in numbers eliminated, or unaffected by sand deposition".

Hart and Fuller (1974) observed the diversity and abundance of species associated with riffles, pools and runs changed significantly in Ozarks streams (in the United States of America) as accumulation of fine sediments reduced differences between these habitats types.

According to case studies conducted by Williams and Feltmate (1992) "higher levels of sedimentation can affect aquatic insects by altering biochemical conditions, food resources, respiratory diffusion gradients and habitat space". Chutter (1969) discussed the effects of sand and silt deposition on invertebrates in South African streams. His investigations concluded that increased sand and silt in a stony biotope reduced diversity of aquatic invertebrates and the abundance of certain groups but did not necessarily change the overall faunal diversity. In several cases it was found that reductions in densities of aquatic insects in areas of the rivers exposed to heavy siltation were related to increases in catastrophic and behavioural drift. "The effect of deposition of solids on benthic community diversity was the disappearance or marked reduction in biomass and numbers of certain sensitive species, and the replacement fauna consisted of burrowing forms, typical of soft, depositing substrates, provided the deposits were not excessive" (Hawkes, 1962). "When this occurs in a riffle, the lithophilous fauna such as the mayflies, stoneflies and caddisflies are seriously affected and may be replaced by silt communities including oligochaetaes, pulmonate snails and chironomid larvae" (Hawke, 1962).

Species richness, density and biomass decrease as inert sediment loading increases (Hellawell, 1986). In general, burrowing tubicolous oligochaetes and chironomid larvae predominate in habitats where depositing sediments accumulate (Hellawell, 1986, Armitage, 1984).

2.4.4 EFFECT OF EUTROPHICATION ON AQUATIC INVERTEBRATES

Along its length a river gains nutrients naturally from the land-which may increase its trophic status. This is regarded as natural eutrophication paralleling the natural eutrophication of lakes with time. Intensification of land use by human activity (sowing and harvesting of certain crop species, application of fertilisers, management of animals and their wastes, domestic sewage, rural runoff, urban storm runoff and detergents) inevitably disturbs the naturally conservative cycling of nutrients in the terrestrial ecosystem and increases their concentration in runoff resulting in what is referred to as cultural eutrophication (Harper, 1992).

The terms cultural eutrophication and organic pollution or artificial enrichment are often interrelated (Harper, 1992). First, one must make sure confusion does not exist between artificial enrichment and ephemeral seasonal characteristics of the environment, natural succession in lotic environments, or the effect of rich soil and allochthonous vegetation (Hynes, 1970). Secondly, there appears to be no easily obtained chemical, physical or biological parameter that can be quantitatively measured to indicate exclusively that organic pollution exits although an assessment of carbon oxygen demand levels may provide an indicator of the current conditions in the riverine habitat (Hynes, 1970).

It has been stated by Harper, (1992) artificial eutrophication of rivers is a more widespread phenomenon than that of lakes. However, the effects of increased nutrient concentration on rivers have received far less attention (Harper, 1992). The effect of eutrophication upon rivers increases the primary production and biomass of algae (under slow flowing conditions) which is the direct result of raised nutrient influx. The indirect effects such as the loss of plants and concomitant loss of invertebrate species occur as a result of the altered habitat or reduced oxygen concentrations (Harper, 1992).

2.5 Habitat Manipulation

2.5.1 Introduction

Major water projects constitute an important set of forces causing modification of rivers and streams. Biological communities may suffer when their habitat is subjected to environmental manipulation. Hawkes and Davies (1971) reported on the effects of abstraction and channelisation on rivers and their observed impact on aquatic ecosystems. These activities hardly qualify as pollution, but their consequences can be just as serious (Hellawell, 1986).

2.5.2 CHANNEL MODIFICATION

The biological effects of water diversions are not as well documented as those of dams (Allan, 1995). River channel modifications are undertaken to enlarge its carrying capacity and thereby reduce the frequency of flooding. The channel may be realigned or constrained in order to prevent erosion. Canal systems facilitate invasion of non-native species, surely one of the most serious consequences. Engineering works may result in changes in the physical and chemical dimension of the habitat, resulting in the removal of biota. This activity may also submerge the substrate downstream. This change in habitat affects the invertebrate fauna and flora resulting in changes in species composition (Allan, 1995).

According to O' Keeffe and De Moor (1988) "prior to an interbasin transfer from the Orange River, completed in 1977, the Great Fish River of South Africa was characterised by irregular seasonal flow of water of high mineral content". "Inflow from the Orange River converted the Fish River to perennial flow and reduced the concentrations of sodium, magnesium, chloride, and sulphate, but not calcium or total alkalinity" (O' Keeffe and De Moor, 1988). Invertebrate communities of riffles changed substantially, although the overall densities apparently were not altered. The dominant simuliids were replaced by a blood-feeding pest of livestock (*Simulium chutteri*) and the dominant species of hydropsychids and chironomids also changed.

More permanent flow and increased area of erosional habitats in the Fish River were the likely causes of these changes (O' Keeffe and De Moore, 1988).

Channel modification therefore produces another kind of river and an unnatural one at that, and so it is only to be expected that the changes will have ecological significance. Fortunately, the natural forces that moulded the original configuration continue to operate and the river often reverts in time to its former state, or something very similar (Allan, 1995).

"It should be noted that although it appears convenient to place each of the contaminants or categories of environmental manipulation into its own compartment and then document its characteristics properties and effects, in reality it is rarely so simplistic" (Hellawell, 1986). Human influences on the rivers are often superimposed and as such combined effluents may enter regulated rivers. In summary it is envisaged that the use of an indicator potential of biological systems to identify or measure environmental stress, may provide some indication of the effect of pollution source(s) on ecosystems.

2.6 SECTION B

2.6.1 A BRIEF HISTORY OF ECOLOGICAL RESEARCH IN SOUTH AFRICAN RIVERS.

Between 1900 and 1930 the scientific literature on rivers in South Africa deals almost exclusively with taxonomic descriptions (Stander, 1952). From 1930s to 1950s taxonomic contributions continued dealing with insect orders (Diptera, Plecoptera, Ephemeroptera, Odonata, Trichoptera) fish, snails and algae (Stander, 1952).

The early 1930's saw the publication of the first attempts to investigate aquatic ecology (Stander, 1952). The early 1950's saw the first official expression of concern for the degradation of rivers and the deterioration of water quality (Stander, 1952).

Chutter (1970) reviewed the effects of the past exploitation of South African rivers, in the light of information from previous surveys and predicted likely future trends. He discussed the reasons for attempting to maintain rivers in a viable state, and suggested that apart from intrinsic values, recreation, aesthetics the prevention of disease and pest species and the protection of river ability to self purify were the main justifications for research and conservation.

Chutter's biotic index of water quality in South African streams and rivers (Chutter, 1972) was based on the assumption that the faunal communities of rivers and streams for flowing water of stones-in-current habitat are definable. These communities would change in a predictable way as organic matter was added, and that the addition of more oxidizable organic matter would cause greater faunal change. He suggested that species composition and ecology are the most important criteria in assessing water quality. This required detailed taxonomic analysis and counting of invertebrate samples collected using a fine-meshed net. "This analysis took twelve hours per sample and required the attention of technicians with advanced level of taxonomic expertise" (Chutter, 1998). "However this index was not regularly used" (Chutter, 1998).

"Twenty years later it was apparent that the reasons were that the method was too costly and stones-in-current biotopes were not available at every point where water quality information was required" (Chutter, 1998).

Numerous biotic indices and scores have since been developed for use in Europe (reviewed by Metcalfe-Smith 1989). The most advanced system to date is the Biological Monitoring Working Party (BMWP) score system. The BMWP scores for families were adapted by Chutter (1994) to local conditions by the addition of taxa found only in South Africa and the deletion of the taxa not found here. In some families it was necessary to change scores, as the South African representatives are known to have sensitivities to pollution, which differ from those in the Northern Hemisphere. The acronym SASS (South African Scoring System) evolved and successive versions (SASS1, SASS2 SASS3 and SASS4) were named. SASS data are now widely applied by user agencies. The development of SASS is described in Chutter (1998), who presents results of field research from rivers and streams in South Africa as case studies to demonstrate the validity of SASS.

The initiation of the national biomonitoring programme for riverine ecosystems in South Africa reinforced the potential usefulness of the inclusion of physical and chemical parameters of the associated waterbody. This would provide useful information for ascertaining the characteristics of waterbodies with respect to biota and water chemistry. The initial concern of how SASS scores will be affected by habitat availability is now addressed by the development of the habitat quality index (IHAS). The habitat quality index (IHAS) is described in McMillan (1998). This index allows comparisons of SASS scores between sites which are different in terms of substrate heterogeneity (McMillan, 1998).

2.6.2 EVIDENCE FROM FIELD STUDIES IN SOUTH AFRICA BASED ON SASS BIOASSESSMENT AND THE HABITAT QUALITY INDEX (IHAS 2C)

SASS has been tested and used widely in South Africa as a biological index of water quality (Dallas, 1995, 1997; Thirion, 1998). The Berg River in the southern-western Cape was selected as a "test river" for SASS because of the extensive historical data collected in the 1950's, because of its increasing importance and utilization as a water resource (Dallas *et al.*, 1994). It was suggested that SASS effectively differentiated between the three sites with differing water quality. The results revealed that sites with impaired water quality had low variance in SASS scores suggesting a single SASS sample would be adequate. According to Dallas *et al.* (1994) "seasonal changes are almost to occur; they will affect total score and not ASPT value, which might remain relatively constant"

Roux *et al.*(1999) stated that the best index scores usually obtained at the least impacted sites were regarded as the benchmarks for particular segments. This was for SASS index score and ASPT score. Dickens and Graham (1998) reported "the effect of wastewater works effluent on the receiving streams within the province of KwaZulu Natal". In this study it was noted that a significant deterioration in the numbers of benthic invertebrates were observed downstream of most treatment works. Biomonitoring using SASS gave a clear indication of the impact of the effluent on a number of downstream rivers. "SASS4 scores respond to many types of changes to water quality such as pH, heavy metal pollution, organic pollution, silt and turbidity and increases in the total dissolved solids, as well as urban and industrial effluent" (Chutter, 1998). In fact SASS4 is sensitive to all forms of pollution which are recognised as having an impact on aquatic invertebrates.

Chutter (1998) records "the observations of case studies conducted on South African rivers defining the relationships between SASS4 derived data, ASPT scores and water quality". He reports that "the SASS4 score can be related to a habitat diversity index". The results from western Cape have confirmed other findings regarding the impact of missing habitats on SASS scores. Thus when stones-in- current or fringing vegetation habitats are not found at sampling points on unpolluted rivers, the SASS score is markedly lower, but ASPT does not change sufficiently for change to be recognised. It is not clear whether the absence of sand and mud habitats can be detected in either SASS4 or ASPT scores Chutter (1998). However it can therefore be interpreted that a low SASS score and a high ASPT score indicates a limitation in habitat diversity, rather than deterioration in water quality. A detailed explanation of the interpretation of SASS scores are provided in Chapter 5.

According to the literature reviewed it is envisaged that economic developments and an increase in informal settlements are likely to increase the contaminants reaching the rivers in the DMA. It is anticipated that this will impact on the health of the rivers resulting in significant changes in invertebrate composition and most possibly habitat degradation. More detailed descriptions and comparisons must be made to evaluate the importance of each source type and add it to the present database, using biological indicators of water quality for river research in South Africa.

CHAPTER 3

FRESH WATER INVERTEBRATES

3.1 INTRODUCTION

This chapter briefly describes the different kinds of invertebrates used in SASS4 biomonitoring, setting them out according to their classification, and then describing the various species found in different biotopes and finally describes their relationship to the environment.

The merits of other groups of organisms have not been considered in this thesis, but the reader should be aware that a wide variety of organisms including bacteria, protozoa, algae, macrophytes and fish have been used in biological assessment of water quality. Hellawell (1986) conducted a survey of the most frequently used groups of organisms in biological assessment. He noted that algae and macro invertebrates were the two most often recommended for use in assessing water quality.

In the past three decades the study of aquatic insects has been revolutionised. Insects are well suited in environmental impact assessment for several reasons. They offer an enormous potential choice of species to study. Insects occur in almost every imaginable habitat, and are often abundant and easily sampled. Not only have research studies shown the pivotal role played by aquatic insect species in the breakdown of terrestrial leaf litter and the pathways by which this plant energy is incorporated into the tissue of fishes, birds and other vertebrates but a host of more applied research has revealed the importance of aquatic insects in the spread of diseases and in the biological assessment of water quality (Hart and Fuller, 1974).

In fact, insects play roles, as predators, parasites, herbivores, saprophages, and pollinators, among others, which indicate the prevasive ecological and economic importance of this group of animals in both aquatic and terrestrial ecosystems. "Environmental perturbations impinge on those roles, and insects often respond to these perturbations in a characteristic fashion so that insects are useful objects of study in environmental impact assessment" (Rosenberg *et al.*, 1986). "There is a general consensus that benthic macro invertebrates are amongst the most sensitive components of aquatic ecosystems and are useful for assessing ecosystem integrity" (Metcalfe-Smith, 1991). In South Africa macro invertebrates and fish are the primary groups on which biological assessment work has been focused.

3.2 WHAT ARE FRESH WATER MACRO-INVERTEBRATES?

Freshwater aquatic macro-invertebrates constitute a heterogeneous assemblage of animal phyla. They are larger than 0.5 millimetres in size, visible to the naked eye and live a part or all of their lives in freshwater biotopes.

3.3 WHERE AND WHEN ARE FRESHWATER INVERTEBRATES FOUND IN RIVERINE SYSTEMS?

Invertebrates are widespread in their distribution occupying every kind of freshwater imaginable and various communities can be found in different biotopes. Hart and Fuller (1974) define "a biotope as a region in which conditions are of such uniformity that the plant and animal communities do not vary much; the stony substratum of a river, weed-beds and the open water are examples of biotopes". Habitat is defined as the space occupied by living organisms. "Macro-invertebrates are adapted to fast flowing mountain streams and ponds, the shallowest and deepest parts of the river, most pristine and polluted rivers, roadside ditches, marginal and aquatic vegetation, mud, gravel, bedrock, stones in current, and stones out of current as well as acidified and alkaline bodies of water" (Hart and Fuller, 1974). "Rivers can have different characteristics, so it can be expected that there will be different freshwater species common to different parts of the rivers" (Gerber and Gabriel, 2000b). Freshwater invertebrates need the shelter and food that these habitats provide and tend to congregate in areas that are suitable for their growth and development.

"The life history of macro-invertebrates includes either three or four stages in the case of the insects: egg, naiad (or nymph), and adult, or egg, larvae, pupa and adult" (Welch, 1980). "Although completion of more than one life cycle in a year is not uncommon, particularly with midges, many may require one or more years for completion" (Welch, 1980). Most aquatic invertebrates can be found throughout the year. "The Oligochaeta, Mollusca, and Crustacea have two-to three-stage life histories and have one or more generations per year" (Welch, 1980). Most of the insect's life is spent in the immature stage, with the adult terrestrial stage usually involved in reproduction. "Therefore, bottom substrate samples largely contain naids and larvae of insects, and major changes occur in the species composition through the spring and summer because emergence time varies among the populations with photo-period and temperature" (Welch, 1980).

3.4 WHAT ARE THE ECOLOGICAL IMPORTANCES OF THE FRESHWATER INVERTEBRATES?

Macro-invertebrates eat aquatic plants; algae and bacteria that are present in the stream whilst some eat leaves and grass that have naturally fall into the stream. Aquatic invertebrates serve as the 'middleman' in the aquatic food chain. Because of their abundance, position and diverse feeding habitats (Chessman, 1986) they form many key links in the aquatic food chain for example, macro invertebrates are a primary food source for fish. The maintenance of fish populations and conservation of threatened species requires not only an understanding of their individual species biology, but the identification of critical components of their habitats and the capacity to predict how perturbations will affect them. If a stream does not have a healthy population of stream invertebrates it cannot support good numbers of fish.

Invertebrates are pool sources of energy and nutrients, because as the invertebrates die, they decay, leaving nutrients that are used by aquatic plants and other animals in the food chain. Their diversity and abundance are therefore crucial to maintaining a balanced, functioning and healthy river ecosystem since they represent a significant source of food for aquatic and terrestrial animals. They also provide a wealth of evolutionary, ecological and biogeographical information.

3.5 WHAT ARE THE ADVANTAGES OF USING FRESHWATER INVERTEBRATES IN BIOMONITORING?

There are valid reasons for using invertebrates as part of any aquatic health assessment programme.

- Macro invertebrates are present in most aquatic habitats especially flowing water systems (Reynoldson, 1984).
- "Some form of benthic macro invertebrate life can be found in all but the most severely poisoned or disturbed habitats unlike fish, which may be absent due to a natural cause such as an obstruction to passage" (Cook, 1976).
- Freshwater invertebrates are relatively sedentary and therefore representative of local conditions being sampled since they are less able to avoid pollution. "They also represent the effect of short and long term pollution events" (Cook, 1976).

- "Macro-invertebrate communities are differentially sensitive to pollutants of various types and react to them quickly" (Cook, 1976).
- "Sensitivity to stress varies from species to species and the large number of species within a community offers a spectrum of responses to environmental stresses" (Pratt and Coler, 1976).
- "They have longer more complicated lifecycles thus providing good integrators of environmental conditions, allowing them to reflect or integrate water quality over time" (Pratt and Coler, 1976).
- "They may show impacts due to habitat loss not detected by traditional water quality assessment" (McMillan, 1998).
- "They are relatively easy to sample compared to highly motile fishes" (Rosenberg and Resh, 1993).
- "Qualitative sampling and analysis under a rapid assessment protocol can be done using simple inexpensive equipment, requires few people and does not adversely affect the environment" (Hawkes, 1979; Hellawell, 1986; Reynoldson, 1984).
- Finally a biologist experienced in macro invertebrate identification will be able to determine relatively quickly whether the environment has been degraded by identifying changes in the benthic community.

As a result of these factors macro invertebrates act as continuous monitors of the water they inhabit (Hawkes, 1979; Hellawell, 1986) enabling analysis of regular and intermittent discharges and variable concentrations of pollutants.

3.6 WHAT ARE THE DISADVANTAGES OF USING FRESH WATER INVERTEBRATES IN BIOMONTORING STUDIES?

- Freshwater invertebrates apparently do not respond to all impacts. Hawkes (1979) reported "only slight effects of low concentrations of a herbicide on the invertebrate fauna in a river, even though detrimental effects were indicated by angiosperms downstream of the effluent". The responses of taxa to toxic compounds are not as well documented as their responses to organic pollutants.
- "Well defined seasonal variations in abundance and distribution, especially of insects, may create sampling problems during specific periods or in specific habitats or may pose problems in comparing samples taken in different seasons" (Rosenberg and Resh, 1993).
- The potentially confounding effects of seasonal change have to be accommodated in the design of biomonitoring programs. The life history knowledge of the families involved will help in this regard.
- "It is often difficult to decide where an observed change in some aspect of the biota represents a deviation caused by the presence of a pollutant or whether such changes are part of the 'natural' fluctuations inherent in the system" (Miller, 1984).

3.7 CHARACTERISTIC FAUNA OF MAJOR HABITAT CATEGORIES

Invertebrates are affected by the habitat and so their communities can be classified by this habitat (Haslam, 1990). The great majority of stream dwelling insects live in close association with the substratum and so they have been the main focus of organism–substrate studies. Substratum is a complex aspect of the physical environment. Invertebrates occupy both organic and inorganic substrates (Haslam, 1990). When one compares the sand, stones and mud biotopes many taxa appear to show some degree of substrate specialisation. In general, diversity and abundance increase with substrate stability and the presence of organic detritus (Haslam, 1990).

3.7.1 Inorganic Substrate

This includes cobbles, boulders, gravel, sand and silt. "The substratum naturally depends on the parent material available but there is a general tendency for particle size to decrease as one proceeds downstream" (Gerber and Gabriel, 2000b). Stones vary in size, shape, colour, surface complexity and texture thus providing varied amounts of physical structure.

3.7.1.1 Stony Substrates

'Lithophilous' taxa are those found in association with stony substrates (e.g. mayflies, stoneflies and caddisflies). "Streambeds of gravel, cobble and boulders occur in many aquatic water bodies around the world, harbouring a diverse fauna" that Hynes (1970) "remarks is broadly similar everywhere". Attached and encrusting growth forms require a substrate that is not easily overturned by current and large stones provide a more stable substrate. Burrowing taxa can be quite specific in the particle size of the substrate they inhabit. Substrates composed of finer sediments are generally lower in oxygen and some species meet this challenge by beating their gills to create a current. "The mayflies *Ephemera danica* and *E. simulans* burrow effectively in coarse substrate (gravel) since their gills are inefficient at the low O_2 concentrations found in silt deposits" (Wood and Armitage, 1997).

3.7.1.2 Sand

Sand is generally considered to be a poor substrate for macro-invertebrates, due to its instability and because tight packing of sand grains reduces the trapping of detritus and can limit the availability of oxygen. Nevertheless a variety of taxa are specialists of this habitat and are termed 'Psammophilous' (e.g. Chironomidae, and mayflies).

3.7.1.3 Silt

In small amounts, silt benefits at least some taxa. In large amounts silt generally is detrimental to macro-invertebrates. "It causes scour during high flow, fills interstices thus reducing habitat space and the exchange of gases and water, reduces the algal and microbial food supply" (Wood and Armitage, 1997).

3.7.2 Organic Substrate

Very small organic particles (< 1 mm) usually serve as food rather than as substrate, except for the smallest invertebrates and micro-organisms. Larger organic matter from plant stems to submerged logs potentially contributes to habitat structure rather than food. The aggregation of leaves on the stream bottom usually supports the greatest diversity and abundance of invertebrates. The degree of vegetation cover and substrate heterogeneity of a riverine ecosystem will provide varying amounts of microhabitats, which in turn enhances invertebrate diversity and production (Hart and Fuller, 1974).

3.7.2.1 Xylophilous Taxa

Xylophilous or wood-dwelling taxa illustrate that woody debris constitutes yet another substrate category of lotic environments. Wood appears to be utilised as a substrate more often rather than food (example, caddis larvae), although some taxa feed mainly on wood, and many taxa obtain nourishment from a mixture of algae, microbes (the benthic film layer) and decomposing wood fibre found on wood surfaces. Wood is also important in lowland rivers where 70 % or more of the bed is composed of sand and wood provides the only stable substrate.

3.7.2.2 Phytophilous Taxa

Invertebrate taxa that live in association with partly or fully submerged aquatic plants are termed phytophilous taxa (example, some families of dragonflies). A substantial number of invertebrates are found on the surface of submerged macrophytes whilst others utilise marginal vegetation (Gerber and Gabriel, 2000b). Many species also utilise moss and algae.

3.8 MAJOR ORDERS OF RIVER MACRO-INVERTEBRATES

This section depicts a few images and briefly describes some examples of the invertebrates that were encountered during the river exploration. Detailed descriptions of the aquatic invertebrates used in the bioassessment studies of the South African rivers can be obtained using the key produced by Gerber and Gabriel (2000b).

Phylum: Arthropoda

Insect Orders

3.8.1 Order : Ephemeroptera (Mayflies)

"Mayflies are insects that spend most of their lives in streams, emerging briefly as adults ('ephemerally') to mate and lay eggs" (Gerber and Gabriel 2000b). "Adult mayflies are dainty insects with transparent wings and long tails, found in the vicinity of water. All mayfly nymphs are characterised by an elongated body, large head and prominent 'tails'" (Gerber and Gabriel 2000b). They have three pairs of legs, a pair of antennae and generally three long tail filaments (displaying the characteristics of several other insect Orders) (Gerber and Gabriel 2000b). However many have feathery or plate like movable gills located on their abdomen used for oxygen exchange (Gerber and Gabriel 2000b). Mayflies inhabit all types of freshwater bodies (from temporary ponds through all types of streams to large lakes) where oxygen supplies are good (Gerber and Gabriel 2000b). However most species prefer clean water. Mayfly diversity declines as stream and river water quality declines. An example of the Order Ephemeroptera (Family: Baetidae) is illustrated in Figure 2. Inserts depict approximate size of the macro- invertebrates.

3.8.2 Order: Plecoptera (Stoneflies)

"Stonefly nymphs have three pairs of legs and a pair of antennae and generally have two long tail filaments unlike mayfly nymphs that have three tails" (Gerber and Gabriel 2000b). "Many species of stonefly nymphs have fixed gills under their legs" (Gerber and Gabriel 2000b). They live in protected areas of debris, trailing tree leaves or under stones. They prefer clean, cold flowing waters where there is good oxygen supply. "Diversity of these insects declines rapidly at the first signs of human disturbance" (Gerber and Gabriel 2000b). An example of the Order Plecoptera (Family: Perlidae is illustrated in Figure 3).

3.8.3 Order: Odonata (Dragonflies and Damselflies)

3.8.3.1 Sub.Order. Anisoptera (Dragonflies)

Adult dragonflies have a long body, two pairs of large translucent wings and two relatively large eyes (Gerber and Gabriel 2000b). Adult dragonflies have attractive colours ranging from orange, red to blue. The nymphs however are quite dull in colour. They are normally large robust creatures with short antennae and fat bodies with no tails"(Gerber and Gabriel 2000b). An example of the Order Odonata (Family: Gomphidae) is illustrated in Figure 4.

3.8.3.2 Sub.Order Zygopotera (Damselflies)

Adult damselflies have long, but slender bodies. The two pairs of wings are translucent and folded parallel to the body (Gerber and Gabriel 2000b). "The distinguishing feature of the damselflies nymphs are their three feathery gills protruding from the abdomen" (Gerber and Gabriel 2000b). "Nymphs of Odonates are found in a great variety of habitats in slower moving areas of the stream either on plants or submerged vegetation close to the banks or buried in the mud bottom, or on the surface of rocks and wood" (Gerber and Gabriel 2000b).

3.8.4 <u>Order: Trichoptera (Caddisflies)</u>

"All caddisfly larvae have soft bodies, three pairs of legs and sometimes have string-like gills on their abdomen" (Gerber and Gabriel 2000b). The larvae have two hooks on the rear end of the abdomen that are used to anchor them. "The antennae are not usually visible and no wings or wing pads are present in the juvenile stage" (Gerber and Gabriel 2000b). Caddisfly adults resemble moths but do not have scales on their wings as butterfly and moths do. The larvae of caddisflies are soft, delicately coloured insects that live in many different areas of the river. The larvae inhabit fast waters and riffles (on / or under stones), moderate flow (trailing root masses, rocks or twigs, in sandy bottoms) or pond-like conditions (on submerged vegetation or sticks). "Many species of caddisfly larvae build intricate cases made of gravel, sand, sticks, sand and leaves" (Gerber and Gabriel 2000b). "The caseless caddisflies do build protective structures on rocks but these are not portable" (Gerber and Gabriel 2000b).

An example of the Order Trichoptera (Family: Psychomyiidae) is illustrated in Figure 5.

3.8.5 Order : Hemiptera (True Bugs)

Adult bugs are highly variable in size. Wings or pads are present. Their mouthparts are united into a beak or a tube, modified for piercing or sucking. The aquatic Hemiptera are essentially slow water pond forms. In rivers they are found along margins in shallow water (Corixidae) on or among aquatic vegetation along stream margins or in backwaters (Notonectidae, Belostomatidae: Fig. 6 and Nepidae: Fig. 7) and on the surface in fast water (some Veliidae) (Gerber and Gabriel 2000b). Some Naucoridae are found under rocks in fast water (Gerber and Gabriel 2000b).

3.8.6 Order: Coleoptera (Beetles)

This is the largest order of insects and although they are mainly terrestrial, a few are aquatic in the adult or larval stages. Adult beetles need atmospheric oxygen while swimming. "They therefore carry pockets of air attached to "hairs" on various places around the body" (Gerber and Gabriel 2000b). The larvae of this order do not resemble the adults. Beetles differ from bugs by having biting or chewing mouthparts (Gerber and Gabriel 2000b). The adults have hard outer wings often black in colour with well-defined antennae (Gerber and Gabriel 2000b). "They generally live among marginal vegetation, algae and debris and are inhabitants of ponds or pond like situations in rivers and streams" (Gerber and Gabriel 2000b). "They occur in moderate to low levels of pollution" (Gerber and Gabriel 2000b). An example of the Order Coleoptera (Family: Elmidae) is illustrated in Figured 8.

3.8.7 Order: Diptera (Flies, Mosquitoes and Midges)

"Adults from this order are always terrestrial flying insects with one pair of wings" (Gerber and Gabriel 2000b). The most distinguishing feature of the larvae includes an elongated, wormlike body and an absence of true legs. "Midge larvae are very small, often C-shaped and have a "spastic squirming" movement" (Gerber and Gabriel 2000b). They attach themselves to substrates but prefer soft sediment. The aquatic Diptera larvae, commonly Chironomidae (Fig. 9), are found in almost every imaginable habitat (in mud at all levels from the deepest lakes to the shallowest streams, on plants, on all sides of rocks in all degrees of flow, on wood, in algal mats and in sand and in debris between rocks in fast water). "Crane fly larvae (or tipulids) are large and fleshy with very short 'tentacles' at one end" (Gerber and Gabriel 2000b). Colours frequently observed are black, brown, red, yellow, and white. "The Tipulidae larvae occur in moss, leaf packs, mud, and debris along the margins of streams and lakes and on rocks in fast water" (Gerber and Gabriel 2000b). The Simuliidae (Fig. 10) are found on firm substrates, on rocks, wood or leaves in fast flowing water. Ceratopogonidae larvae are most commonly found in bottom mud and debris. Some species of dipterans are found in low levels of pollution whilst others occur in moderate to high levels of pollution.

3.8.8 Phylum: Mollusca

Class: Gastropoda (Snails and Limpets)

Freshwater snails are organisms enclosed within a shell. They inhabit gravel beds or coarse sand in quiet parts of the river. They occur on vegetation or rocks in flowing water. Some families of gastropods survive moderate levels of pollution (Gerber and Gabriel 2000b).

3.8.9 Phylum: Annelida (Segmented Worms)

3.8.9.1 Class: Oligochaetae (Aquatic oligochaets)

Oligochaets have a fragile wormlike body that is segmented and legless. These organisms have no head. In general this group is adapted to a burrowing life in soft sediments. They occur in clear and heavily polluted streams (Gerber and Gabriel 2000b). An example of the Phylum: Annelidae (Class: Oligochaetae) is illustrated in Figure 11.

3.8.9.2 Class: Hirudinea (leeches)

Leeches are included in this grouping and are flat, with suckers on both ends. A solid substrate (stones, rocks or pebbles), is a prerequisite for the proper functioning of the leech sucker. Leeches also inhabit very muddy backwaters provided there is higher aquatic vegetation present. Almost all species prefer standing to running water. They are tolerant of pollution.

Phylum: Arthropoda

3.9 Subphylum: Crustacea

3.9.1 Order: Decapoda (Crabs)

Crabs have a tough outer shell with five pairs of jointed legs. They live amongst rocks on the riverbed. Crabs also burrow in hydrophytes and other biotopes. They are tolerant of high levels of pollution (Gerber and Gabriel 2000b).

3.9.2 Shrimps (Freshwater prawns)

This group of organisms has a cylindrical body with five pairs of legs. There are two black eyes that are carried on stalks. They live amongst vegetation on the edges of ponds or slow streams. They survive low levels of pollution (Gerber and Gabriel 2000b).

3.9.3 Order: Amphipoda (Sideswimmers)

The body of most amphipods is laterally flattened. This group of organisms has seven pairs of legs with two antennae on the head (Gerber and Gabriel 2000b). They occur close to the bottom in cold streams and are only found in unpolluted streams (Gerber and Gabriel 2000b).

This chapter briefly describes the invertebrates encountered during the survey. Further details are available in the separate papers listed in the references. Contamination and toxicity of sediments will therefore affect those organisms that are sensitive. Thus, when environmental changes occur, the species must endure the disturbance, adapt quickly, or die and be replaced by more tolerant species.

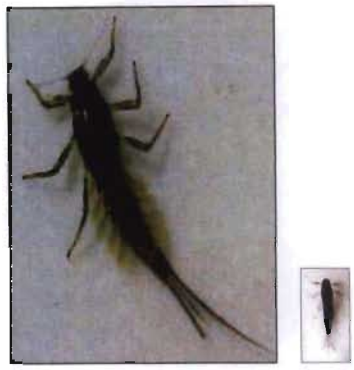


Fig. 2: Baetidae (from Gerber & Gabriel, 2000a)

Fig. 3: Perlidae (from Gerber & Gabriel, 2000a)

Fig. 4: Gomphidae (from Gerber & Gabriel, 2000a)

Fig. 5: Psychomyiidae (from Gerber & Gabriel, 2000a)

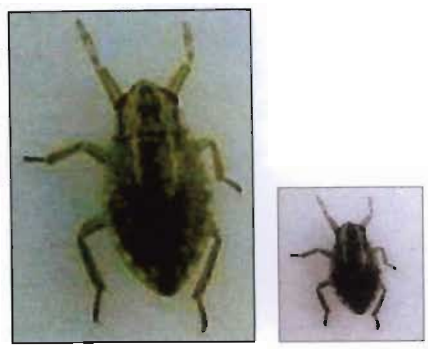
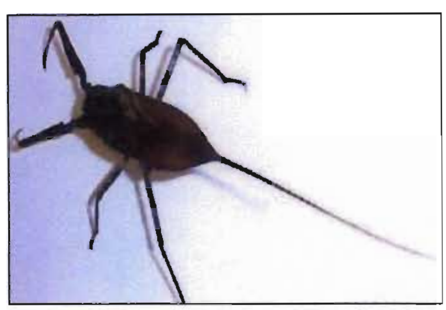


Fig. 6: Belostomatidae (from Gerber & Gabriel, 2000a)



actual size

Fig. 7: Nepidae (from Gerber & Gabriel, 2000a)

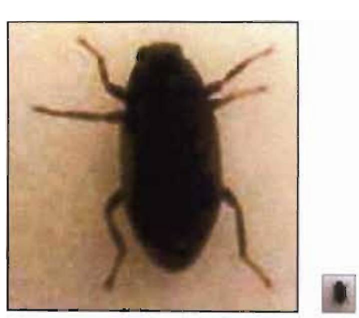


Fig. 8: Elmidae (from Gerber & Gabriel, 2000a)

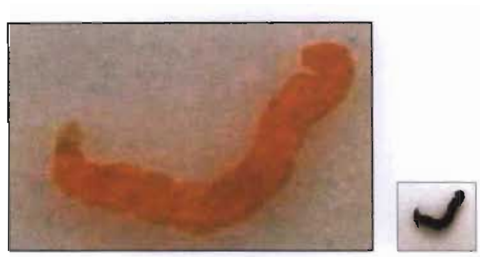


Fig. 9: Chironomidae (from Gerber & Gabriel, 2000a)

Fig. 10: Simuliidae (from Gerber & Gabriel, 2000a)

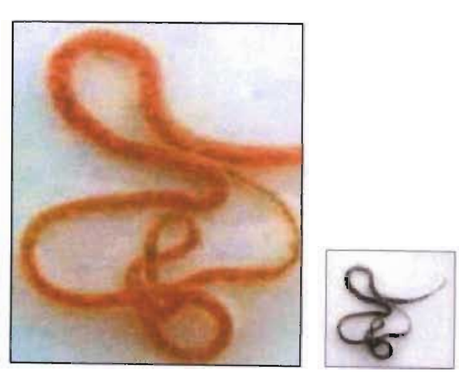


Fig. 11: Oligochaeta (from Gerber & Gabriel, 2000a)

CHAPTER 4

DESCRIPTION OF STUDY AREA AND SITES SELECTED

4.1 STUDY AREA

4.1.1 INTRODUCTION

The aim of this chapter is firstly to describe the study area, which includes the main rivers of the Greater Durban Metropolitan Area (Fig. 1) and secondly to state the reasons for the selection of specific study sites.

The study area comprised of fourteen rivers of the Greater Metropolitan Area of Durban, located in the province of KwaZulu Natal, South Africa. Fresh water invertebrates samples were collected from all fourteen rivers traversing the Greater Durban Metropolitan Area. The rivers of the Greater Durban Metropolitan from south to north are the Umgababa, Msimbazi, iLovu, Little Manzimtoti, Manzimtoti, iSiphingo, iziMbokodweni, uMlazi, Mhlathuzana, Umbilo, uMngeni, Ohlanga, uMdloti and Tongati Rivers. The geographical positions of the rivers are shown on Figure 1.

Several of these Metro rivers (uMdloti, Ohlanga, uMngeni, Umbilo, Mhlatuzana, uMlazi, iSiphingo, and Little Manzimtoti) receive sewage effluent after treatment (Archibald, 1998). "In most instances the distance between the waste water works discharge and the estuary is insufficient to allow the river to immobilise the pollutants and perform the so called "ecological service function" (self assimilatory capacity) adequately-hence the estuarine reaches become the primary repository for land derived pollutants" (Archibald, 1998). Most of these rivers are exposed to conditions in which high bacterial contamination originating from untreated sewerage is common and at times render them unsuitable for recreational use (Archibald, 1998). Faecal pollution poses health threats within the community and nutrient pollution contributes to the eutrophication of the rivers. The rapid urbanisation has placed additional stress on existing infrastructure, and has therefore compounded the impact on the rivers of the DMA. Most urban rivers have been highly altered from their natural conditions, with many being diverted from their natural paths to accommodate urban development. In some cases, there is little way of ever knowing what the natural condition was, making restoration activities (returning the disturbed environment back to its original state) impossible but rehabilitation (returning the disturbed environment to a condition similar to that of its original state or to an acceptable alternative) feasible.

Pollution of rivers in the Durban Metropolitan Area is caused by sandwinning, runoff from storm water, flooding due to catchment hardening, soil erosion, and runoff from informal housing and from the occasional accidental or illegal discharge from industrial activities (Archibald, 1998). It appears in a few poorly serviced areas that some residents still rely directly on rivers for their daily water supply, ablution and washing of clothes. Because of these activities, each river has become a recipient and a storage basin for pollutants. These activities intrude on the natural functioning and integrity of the aquatic environment (Archibald, 1998). There are some large valley marshlands in the coastal reaches of the Durban Metropolitan Area and these aquatic systems perform valuable purification and ecological functions within the river system by improving the water quality downstream, for example Ohlanga flood plain (Archibald, 1998). They also provide a variety of habitats and generate resources such as reeds and other commercially useful plants for home industry applications. Most of the rivers in the Durban Metropolitan Areas enter the Indian Ocean via estuarine or coastal lagoons.

4.2 A BRIEF DESCRIPTION OF THE CHARACTERISTICS OF THE RIVERS SURVEYED IN THE GREATER DMA AS THEY ENTER AND LEAVE THE DURBAN BOUNDARY.

4 2.1 THE TONGATI RIVER

The Tongati River rises in the Umvoti foothills of the Groot Noodsberg at an altitude of about 762 m (Brand *et al.*, 1967). The Tongati River was named after the Zulu word for the '*Strychnos mackenii*' trees, which flourish on its banks. Its chief tributary, the Mona, rises on the slopes of Zwatini at about 610 m and flows past Umvoti for about 30.4 km and roughly parallel to the Tongati River joining it at Sibutu a few kilometres inland from the town Tongaat (Brand *et al.*, 1967). Below this confluence the river passes the northern side of the town of Tongaat and is joined by the Wewe River. Just below the town, the Tongati River is joined by a tributary the Amanzimnyana, which flows through the town itself and channel about 22.4 km^2 of the coastal plain to the south. The whole of the Tongati River catchment is almost entirely devoted to the cultivation of sugar cane. The Tongaat Sugar Company extracts water from the Tongati River (Brand *et al.*, 1967). This river is continuously exposed to runoff from agricultural activities associated with sugar cane cultivation.

4.2.2 THE UMDLOTI RIVER

The uMdloti River, after having traversed a course of 72 km, passes the town of Verulam where it crosses the coastal plain and drains an area of 297.6 km^2 before finally entering the Indian Ocean (Brand *et al.*, 1967). The uMdloti River takes its name from a species of wild tobacco, which grows on its banks. Considerable use is made of the river for the irrigation of sugar cane. Like the Tongati River system this river system is exposed to runoff from agricultural activities associated mainly with sugar cane cultivation.

4.2.3 The Ohlanga River

The Ohlanga River rises at an altitude of 305 m at Inanda about 22.4 km inland and flows for 25.6 km over a meandering course to enter the Indian Ocean about half a kilometre north of Umhlanga Rocks (Brand *et al.*, 1967). The water of the Ohlanga River is used for irrigating agricultural lands in the vicinity of the village of Blackburn, but otherwise the river serves as a drainage canal for irrigation water from the canefields. Consequently the lower reaches are often unexpectedly wider compared to those higher up. This system receives return flow from wastewater works located in developed industrial and urbanised catchments within a few kilometres of the estuary. This river system receives poor quality storm water runoff from a large high density/low cost housing scheme.

4.2.4 The uMngeni River

The uMngeni River, in its last 40-48 km, traverses a deeply dissected terrain, the Valley of a Thousand Hills (Brand *et al.*, 1967). It then enters the Durban boundary and finally the river crosses a short flood plain and enters the Indian Ocean just north of Durban after flowing a total length of 230 km. In the Greater Durban Metropolitan Area, Metro Water is responsible for the supply of water for municipal purposes within the City. The capacity of the uMngeni River has been almost fully utilised for industrial, residential and recreational use while not denying the needs of rural people. This coastal system is continuously exposed to development pressures from return flows from wastewater works sited in heavily developed industrial and urbanised catchments within a few kilometres of the estuary. This is the most heavily utilised system, which provides for the potable and industrial needs of the urban centres but also that of a large rural population. Poor quality stormwater runoff from high density/low cost housing schemes is a problem.

4.2.5 THE UMBILO RIVER

The Umbilo River rises at the foot of Field's Hill and winds through Kloof, flows past an industrial area west of Pinetown and then drains the residential area of the southern side of Pinetown and numerous small industrial parks (Brand *et al.*, 1967). Domestic and industrial wastewater from these areas is discharged to Pinetown wastewater works for treatment and disposal. Flowing adjacent to the boundary of Queensburg and Westville, the river receives runoff from heavy and light industrial areas. Within the Durban Municipal area, the river flows through open lands to its point of canalisation near Bellair Road. It flows through residential and a light industrialised zoned and alongside Portnet's container terminal, before joining the canalised section of the Mhlathuzana River and draining into the harbour. It should also be noted that the uMbilo River passes through the popular Paradise River Valley Nature Reserve, which is a popular recreation centre, and that plans are to develop it further as a holiday resort and tourist attraction.

4.2.6 THE MHLATHUZANA RIVER

The Mhlathuzana River rises in Assagai within the boundary of the Town Board. Land use within this area comprises of small holdings, with some agriculture, and no industry. The small holdings are served individually by French drain systems. Further downstream, the river drains the areas of Mariannhill, Shallcross, Queensburgh and Chatsworth, which includes semi-formal and informal settlements, and light industry. The river enters the Durban Municipal Area in the area of the Stainbank Nature Reserve. The lower reaches of the river drain residential areas and the Rossburgh industrial area before entering the canalised section of the river where the Umbilo River joins it before draining into the harbour.

4.2.7 THE UMLAZI RIVER

At Reunion, the uMlazi River crosses the Durban boundary and enters the Reunion Canal through which its course is diverted so that it now enters the Indian Ocean about 4 km north of its old mouth (Brand *et al.*, 1967). The townships of Lamontville, Umlazi and Chatsworth are situated in this area. The effluent and seepage from the sewage ponds of these towns also drains into the uMlazi River. This river receives return flow from the KwaDengezi, Dassenhok, Hammersdale and Mpumalanga Works (Table 2). This system receives return flows from wastewater works sited in the heavily developed industrial and urbanised catchments within a few kilometres of the estuary. This river system also receives poor quality stormwater runoff from large high density / low cost housing schemes.

4.2.8 THE ISIPHINGO RIVER

The iSiphingo River rises near Inwabi at an altitude of just over 305 m, flows south eastwards 19 km before entering the Indian Ocean at Isipingo Beach (Brand *et al.*, 1967). The township of Isipingo Beach occurs at the mouth of the river. Just inland of Isipingo Beach is the industrial area of Isipingo Rail. A kilometer or so inland from Isipingo Rail the river passes through the residential and informal settlements of Umlazi Township. This system also receives return flow from Umlazi wastewater treatment works sited in heavily developed industrial and urbanised catchments within a few kilometres of the estuary.

4.2.9 THE IZIMBOKODWENI RIVER

The iziMbokodweni River rises at an altitude of about 691 m about 4.8 km east of Eston (Brand *et al.*, 1967). After flowing about 19.2 km, it enters the Umlazi Township through which it flows for 22.4 km. About 4.8 km from the coast it leaves the Umlazi area and finally enters the Indian Ocean 3.2 km north of Umbogintweni. About 3.2 km inland from the mouth of the river is the African Explosives and Chemical Industries (AECI) Factory, which extracts water from the river. There is a large sewage treatment plant in the factory, which discharges digested and chlorinated effluent into the river. It appears that besides sewage the effluent contains other discharges from other sources in the factory. Land use in the catchment is mainly commercial and industrial.

4.2.10 THE MANZIMTOTI RIVER

The Manzimtoti River rises at an altitude of about 153 m about 3.2 km of Adams Mission (Brand *et al.*, 1967). This river receives sewage effluent from the sewage treatment plant, which is situated 2.4 km from the mouth.

4.2.11 LITTLE MANZIMTOTI RIVER

This river rises about 3.2 km south of Adams Mission (Brand *et al.*, 1967). Its catchment includes portions of the Umlazi and Amanzimtoti as well as an urbanised strip at the coast. In addition, it drains the sugar cane estates on either side of the Adams Mission to Illovo road (Brand *et al.*, 1967). This river system is exposed to development pressures from return flows from wastewater works sited in heavily developed industrial and urbanised catchments within a few kilometres of the estuary. This river system receives poor quality runoff from large high density/low cost housing schemes.

4.2.12 THE ILOVU RIVER

This river enters the Durban boundary at Umlazi. The river then crosses a narrow belt (± 1 km) of sugar cane fields and passes the Illovo Sugar Mill before entering the urbanised coastal area in its lowest mile of flow. The Illovo Sugar Estate abstracts water from the river for use in the mill and refinery and most is returned to the river for the irrigation of sugarcane. This river system receives runoff from agricultural activities associated mainly with sugar cane cultivation.

4.2.13 THE MSIMBAZI RIVER

The last 4.8 km of its course the river forms the boundary between the Umwini on the south and the sugar estates and Hibberdene on the north. The Msimbazi River located in the southern regions of the city drains primarily undeveloped or agricultural areas.

4.2.14 THE UMGABABA RIVER

The Umgababa River is also located in the southern regions of the city limits, drains primarily undeveloped or agricultural area.

The rivers of the Greater Durban Metropolitan Area were chosen as suitable sampling stations because of several features. These features are described in Chapter 1. The rivers can be seen on the map of the Greater Durban Metropolitan Area, Fig. 1. The associated hydrological and morphometric characteristics of the rivers of the Greater Durban Metropolitan Area are listed in Table 1 and the main uses of the Metro Rivers are given in Table 2.

Table 1: Morphometric and hydrological characteristics of rivers passing through the DMA.

River System (South to North)	Catchment Area	River Length	Lagoon Area
	Km^2	Km	Ha
Umgababa	35-39	13-16	17,6
Msimbazi	33-41	14-18	13,2
iLovu	893-1036	135	10,5
Little Manzimtoti	10-15	15	1,5
Manzimtoti	28-33	10-14	6,7
iziMbokodweni	235-256	47-71	7,2
iSiphingo	29-46	27	6,8
uMlazi	417	no info	0
Mhlathuzana	113	50	1060
Umbilo	67	35	1060
uMngeni	4385-5850	230-235	48
Ohlanga	85-196	28	11,4
uMdloti	481-704	74-88	13,6
Tongati	370-468	40-60	7.6

Table 2: Main uses of Durban Rivers

River system (South to North)	Main uses	Return Flow	River Regulation
Umgababa	no info	None	no info
Msimbazi	no info	None	no info
iLovu	Recreation	Sugar Mill	None
Little Manzimtoti	Recreation	Kingsburgh Sewage Works	None
Manzimtoti	Recreation	None	None
iziMbokodweni	Recreation	AECI / KwaMakuta / Toti	None
iSiphingo	Recreation	iSiphingo Works	Diversion weirs
uMlazi	None	KwaDengezi / Dassenhok Hammersdale & Mpumalanga Works	Shongweni Dam
Mhlathuzana	None	Hillcrest / Mhlathuzana Findlay Court / Blundell Rd Works	None
Umbilo	None	Pinetown Sewage Works	None
uMngeni	Recreation	New Germany / Northern and KwaMashu Works	Inanda Dam
Ohlanga	Recreation	Phoenix/Umhlanga Works	None
uMdloti	Recreation	Verulam / Mdloti Works	Hazelmere Dam, Midmar Dam, Albert Falls Dam and Nagle Dam
Tongati	Recreation	Tongaat South and Tongaat Central Works / Whitehead Textiles	No info

Data obtained for Table 1 and Table 2 from Durban Waste Water Management Division.

Notes: Return Flow is defined as the water returned to a river from a wastewater treatment works.

4.3 SELECTION OF THE SAMPLING SITES.

The main criteria for study site selection were impacts on water quality. The ability of biological assessment methods to demonstrate differences in water quality was one of the core objectives of this study. In order to facilitate comparisons between sampling sites all available biotopes were sampled. Two sampling sites were chosen at each of the rivers surveyed, except at the iziMbokodweni River where three sampling sites were selected. Three sampling sites were selected for iziMbokodweni River because of the variety of biotopes that were present. Due to large spatial and temporal variability associated with the rivers surveyed and the high degree of anthropogenic disturbances the selection of reference sites (i.e.pristine rivers with a diverse assemblage of invertebrates) was particularly difficult and beyond the scope of this study. No reference sites were chosen as controls since no previous work had been conducted on all of the rivers in the DMA using SASS4 and IHAS analysis.

The SASS4 and IHAS data collected as each river entered the Durban boundary allowed for the establishment of site 01. As each river flows through the city many users utilises this available water for various activities that could have an impact on the quality of water. To determine the accumulative impact on the invertebrate fauna, the second sampling site was selected immediately above the estuary and was referred to as site 02. In order to obtain a selection of sampling sites the following factors were also taken into consideration during the survey.

4.3.1 Sites monitored by Durban Metro Water and Umgeni Water

Sampling sites were selected in relation to the effluent outlet, near areas of known natural and human induced disturbance. Study sites that were chosen for biological research by Durban Metro Water and Umgeni Water were also included as study sites for this project. In this way, pertinent data from Umgeni Water and Durban Metro Water could be used in this study, and the data collected during this study would in turn be useful to these local authorities. These data could also be available to identifiable groups or agencies that would continue to monitor these rivers.

4.3.2 The presence of riffles

The sites were selected carefully so as to minimise differences between them, apart from water quality. The sites chosen had suitable riffles (shallow, fast- flowing reaches of a river with turbulent flow and broken water, Chutter, 1994) where the water was not deeper than 500 mm.

4.3.3 Accessibility of the sites

Sampling sites on all rivers were selected as close to the roadside as possible given the constraints of accessibility and suitability. The sites selected were at times not close to the road and required bush clearance in order to get to the water. Sampling of the biotopes took place during periods of low flow since the protocol required the maximum depth of 0.5m.

4.4 Description of Study Sites

It was an important criterion to document the exact location of the selected sites chosen for biological analysis, for future assessments. This was achieved by using the Garmin GPS 11 PLUS Personal Navigator. Sampling points from which the samples were collected are listed in Table 3. Site 01 was classified as upstream and site 02 as downstream.

Table 3: Sampling Points in the Durban Metropolitan Area

Site Number	River	Locality	Longitude	Latitude
R-BABA-01	Umgababa	Below dam wall at Mnini	30 48 37	30 08 52
R-BABA-02	Umgababa	At Sportsfield, Mnini	30 49 01	30 09 14
R-MBAZI –01	Msimbazi	Close to Alpha	30 49 15	30 07 37
R-MBAZI-02	Msimbazi	At Karridene	30 50 30	30 07 37
R-LOVU-01	iLovu	Above Sugar Mill	30 49 20	30 04 37
R-LOVU-02	iLovu	Below Sugar Mill	30 49 20	30 05 52
R-LTOTI-01	Little Manzimtoti	At Kingsway	30 51 08	30 04 24
R-LTOTI-02	Little Manzimtoti	At Sports Club	30 52 20	30 04 30
R-TOTI-01	Manzimtoti	At N2 Highway	30 52 06	30 03 07
R-TOTI-02	Manzimtoti	At Riverside Road	30 52 40	30 03 23
R-MBOKO-01	iziMbokodweni	Below Sewage Works1	30 53 07	30 00 43
R-MBOKO-02	iziMbokodweni	At AECI Purification Plant	30 54 22	30 00 30
R-MBOKO-03	iziMbokodweni	At Amanzimtoti Country Club	30 55 24	30 00 40
R-SPING-01	iSiphingo	At Road 2123	30 53 59	29 59 10
R-SPING-02	iSiphingo	At Flambouyant Rd Sportsfield	30 54 57	29 59 36
R-MLASS-01	uMlazi	At Sportsfield	30 55 52	29 57 07
R-MLASS-02	uMlazi	Below informal settlement	30 55 33	29 56 57
R-ZANA-01	Mhlathuzana	Clairwood Quarry Compound Rd	30 57 25	29 54 31
R-ZANA-02	Mhlathuzana	South Coast Road SWD	30 58 27	29 54 34
R-MGENI-01	uMngeni	At Sirripat Road	30 57 13	29 47 51
R-MGENI-02	uMngeni	North end of Connaught Bridge	30 58 49	29 48 12
R-UBILO-01	Umbilo	At Paradise Valley Nature Reserve- below waterfall	30 53 29	29 50 01
R-UBILO-02	Umbilo	At Edenweg Rd, Sarnia	30 52 29	29 49 44
R-HLOTI-01	uMdloti	Above Verulam SW	31 07 06	29 38 50
R-HLOTI-02	uMdloti	Above Sewage Works	31 06 24	29 38 53

R-OHL-01	Ohlanga	Below PWWTW Ponds	31 02 12	29 40 34
R-OHL-02	Ohlanga	Above Umhlanga Sewage Works	31 11 07	29 34 15
R-TONG-01	Tongati	At Sugar Mill	31 07 42	29 33 18
R-TONG-02	Tongati	Below Central Sewage Works	31 08 40	29 34 19

Latitude and Longitude are recorded in degrees, minutes and seconds.

This chapter described the 14 rivers of the Durban Metropolitan Area with regard to the geographical features of the catchments and the nature of the pollutants that could be found in the river systems. The cause of each impact on the biological status of the river could be predicted because the characteristics of the river and sources of pollution entering the river are known. Unfortunately historical biological data using the SASS4 and IHAS methods in the study area was at times not available because of limited existing data. Collection of the biological data was therefore necessary and procedures selected are described in the following chapter.

CHAPTER 5

MATERIAL AND METHODS OF ANALYSIS

5.1 INTRODUCTION

In this chapter methods and procedures for measuring environmental quality by examining the condition of the biological community *in situ* are described firstly by the general issues applicable and secondly by the sampling technique implemented in this study. It took a period of four months (extending from September to December 2000) to conduct a once off survey of all 14 rivers of the Greater Durban Metropolitan Area. Only a single sample from each site (site 01 and site 02) of each of the rivers of the Durban Metropolitan Area was taken. The sampling area extended 10 metres each way (or 20 metres one way) from an operator's position and the assessment is based on the 20 metre sampling area.

Two methods were used to obtain the reported data. The first was used to determine the diversity of macro-invertebrates as an indicator of river health at the sampling site using SASS4 (Chutter, 1998). The second method dealt with the assessment of the physical characteristics of the habitat using the site based habitat quality index (Integrated Habitat Assessment System), IHAS 2c method. A comprehensive documentation of the SASS4 Rapid Biological Assessment (RBA) technique, standard equipment and methods are described in Chutter (1998). An extensive documentation of the IHAS 2c technique is given in the report by McMillan (1998). Section 5.2 provides a brief overview of these two approaches.

5.2 River Monitoring Programme

5.2.1 The SASS Method (South African Scoring System)

The SASS method, based on rapid biological assessment, has been developed for use in South African streams and rivers and has become the national standard (Chutter, 1998). It is based on the sensitivity tolerance of numerous families of macro-invertebrates and is specifically aimed at assessing the impairment of water quality. This method relies on the assignment of tolerance values to various macro-invertebrate taxa. Initially adapted from a British System by Dr. Mark Chutter in 1990, (Chutter, 1998), and a national forum in 1992, it is now locally known as SASS4, (South African Scoring System, version 4).

The Rapid Biological Assessment (RBA) using SASS4 involves collecting invertebrates from different habitats at representative sites on river stretches and streams using a standardised net following defined methods and identified to the required taxonomic level. A RBA using SASS4 is designed to use family level data (Thorne and Williams, 1997). "SASS4 utility in other countries other than for those for which they were originally designed may be limited, as family tolerances may not be reliably transferred between continents and different climatic regions because different families may be encountered in different areas" (Thorne and Williams, 1997). A RBA using SASS4 relies on the arthropod fauna (also includes many non-arthropod taxa) but takes into account abundance in contrast to the British Monitoring Working Party (BMWP) (Chutter, 1998). The presence or absence of each taxon has been included in a yes / no manner in the score sheet and when present the abundance (in broad classses) of the taxon is estimated.

This scoring system is derived from the BMWP system although scores have been modified for local taxa and the range of scores expanded so that a tolerant taxon is allocated a score of one whereas a sensitive taxon is allocated a score of fifteen (Appendix 1). These scores are based on expert opinion, in particular the opinions of researchers within the RBA Forum who have and are utilising the SASS method. The total score per site is calculated for each family represented in the sample, which is then summed to give the SASS4 score. The number of different taxa present in the sample is also considered as another measure of river condition. The Average Score Per Taxon (ASPT) computation is obtained by dividing the SASS4 total by the number of taxa in the sample. This score has been applied to SASS4 because it is independent of the number of taxa counted. Both scores are considered when determining water quality impairment. The SASS score is an indication of community health based on species diversity and is designed to assist in the detection and monitoring of the condition of the water in riverine and stream ecosystems.

5.2.3 Habitat Assessment

5.2.3.1 "Integrated Habitat Assessment System (IHAS version 2c) for the Rapid Biological Assessment of Rivers and Streams"(McMillan, 1998)

Generally different families or species of invertebrates prefer different habitats and all types of habitats in a stream or river should be sampled if they are present. Areas with one ubiquitous habitat, a few habitats and a mixture of habitats will respectively have increasing levels of diversity. They can adapt to other habitats, but where more habitat types are missing the greater is the overall chance that an invertebrate family will be absent (McMillan, 1998).

Invertebrates tend to congregate in areas that provide the best shelter, the most food and the most dissolved oxygen. It has been observed from previous studies that the absence of a major type of habitat, such as the stones-in-a-stream current, can cause a particular family to be absent. At all sites where RBA assessment is made, a habitat evaluation should also be taken for the above reasons. This is simply a numerical evaluation of the habitat conditions that influence the stream at the sampling point. According to McMillan (1998) habitat assessment forms an important aspect of the field work component of ecological methods because any change (natural or unnatural) in the habitat will lead to a change in the ecological balance (species, abundance and diversity of organisms present). Consequently a field record sheet (Appendix 2), which describes the habitat condition and indicates any signs of contamination, was completed for each sampling site.

5.2.3.2 IHAS Scoring System

This habitat scoring system is based on 100 points (or percentage) and is split into two sections: the sampling habitat (55) points and the stream characteristic (45) points. The sampling habitat section is further broken down into three sub sections: stones-in-current (20) points, vegetation (15) and other habitat / general (20) points. Although these sub-sections have a maximum score of 20/15/20, it is possible to score higher than these values if there is a particularly good habitat available. In such a case, the scores would be reduced to the maximum, 20/15/20: (i.e. an 'ideal" habitat, not a pristine one). A further calculation in each of these sub-sections is needed: an adjustment value to equal the maximum 20/15/20. To summarise, each subsection needs three scores: the actual value of the marked boxes; and a final 'useable' total which is the lower of the actual total or the maximum 20/15/20. The stream characteristic section records the physical aspects of the stream and man–made or natural impacts and contributes to the overall habitat score. "This score has a maximum of 45 points and needs no adjustment. The absence of a major habitat requirement may substantially reduce the SASS4 score. A low SASS4 score in conjunction with a low habitat score would show that the stream is not as "bad" as a low SASS4 score alone would suggest" (McMillan, 1998). A comprehensive documentation of the Integrated Habitat Assessment System (IHAS version 2c) is described in the user manual (Moore and McMillan, 1993).

5.2.4 Metrics

A simple integrated estimate of the pollution status of each site was calculated so those sites could be readily compared. Water quality classes were awarded to each site using biological condition class as referred to in Table 4 so those sites with similar water quality can be referred to with ease. This was achieved by ranking the sites for each of the scores obtained. These scores were adapted from Chutter (1998).

A SASS4 score greater than 80 is considered to reflect unmodified water quality (good water quality), and an ASPT of greater than 6. This is a very rough guide to the to the score: for instance an ASPT of 5.8 should not be thought of as bad simply because it is below 6, similarly a score of 70-80 is still good. Concern should be shown when SASS4 scores start showing values of 50 or less, although circumstances, regions and habitats should be taken into account.

At all sites where an RBA assessment is made, a habitat evaluation was also taken for reasons previously described. This is simply a numerical evaluation of the habitat conditions that influence the stream at the sampling point. A total habitat score of >10 represents good habitat conditions, a score of =10 indicates adequate habitat conditions and < 10 indicates reduced habitat diversity.

Table 4: Biological Condition Class and Integrated Habitat Class

Score	ASPT	IHAS	Condition
>80	>6	>10	Water quality unmodified, habitat diversity high
< 80	>6	>10	Water quality unmodified, habitat diversity high
>80	<6	>10	Border line between some deterioration in water quality, interpretation is based the extent by which SASS4 exceeds 80 and ASPT is < 6, habitat diversity high
50 – 80	4 – 6	<10	Some deterioration in water quality, habitat diversity reduced
<50	Variable	>10	Major deterioration in water quality, habitat diversity high.

5.3 SAMPLING TECHNIQUE

5.3.1 Biological Field Procedures

Macro-invertebrate sampling was conducted on all fourteen rivers of the Durban Metropolitan Area. Two sampling sites were chosen for thirteen rivers (upstream as the river enters the Durban boundary and downstream as the river enters the estuary) except for iziMbokodweni River were three sampling sites were selected (the middle reach was selected as an additional sampling site). This third site was selected for the iziMbokodweni River in view of the variety of biotopes available for sampling. This site could have been used as a reference site, this was however considered to be beyond the scope of this study. At each river two replicate samples were collected (one upstream as the river enters the Durban boundary and the second sample was taken before the river enters the estuary). Standardised samples were collected concurrently from up to six habitats depending on the number present at each site to provide good biotope diversity, which included stones-in-current, stones-out-of-current, bedrock, mud, sand, gravel, aquatic vegetation, marginal vegetation, and any other available data. Whenever a macro-invertebrate sample was taken at a sampling site, physical data were also recorded. The main objective of the invertebrate sampling programme was to assess the "health " of the river in terms of SASS and IHAS scores, and to obtain the most comprehensive family list for each site within the limits imposed by the time available.

SASS4 protocol involves a "kick and sweep" technique (Chutter, 1998). The standard kick net (1000 µm mesh, 300 X 300 mm square aluminium frame, 275 mm bag depth) on a 1 m handle attached at the middle of one side of the frame, was recommended for obtaining a qualitative sample of the fauna. This technique is carried out in depths up to a maximum of 1 m using hard-soled wet boots for a measured duration over all major biotopes present within the sampling area which as far as possible was typical of the survey area as a whole. The "kick and sweep" sampling technique is the method that is used in the protocol to sample the stones on the bottom of the stream. This method involves kicking and moving the stones with the feet while the net is held downstream of the collector for a period of two minutes, flat side of the net resting on the substrate of the river.

The stones are sometimes firmly wedged against each other, making the kicking method less effective, often to the point, where they have to be first loosened by hand. For larger boulders the net in the sample area is held down stream while the boulder is brushed by hand. Stones out of current are kicked over an area ±1 m ^{2}. The kick and sweep sampling technique is highly versatile and can be used on rock, sand, mud and gravel bottoms. The investigator walks back and forth over a chosen area kicking up the substrate, and sweeping above the disturbed area, to capture dislodged or escaping invertebrates, but leaving behind much of the debris. The net should be kept moving forward or lifted out of the water between sweeps to prevent specimens from escaping. Where possible the feet are dug well into the sediments to dislodge burrowing organisms. Sand, mud and gravel are stirred with feet for a period of 30 seconds.

Areas with overhanging banks and trailing terrestrial vegetation hanging into the water, and just under it, are swept for a length of about two metres. Beds of aquatic macrophytes are sampled in a similar manner. There is however no official protocol to sample aquatic vegetation that grows completely underwater and includes filamentous algae but a suggested protocol is a sampling area of ½ - 1 square metre. Several sweeps were made upstream from where one is standing to collect animals that may be swimming or living in water just above the bottom. Hand picking and visual observation is conducted for 1 minute. Standard time collections of invertebrates allow comparison amongst sites.

All samples were collected from riffle zones of the rivers in the area where there was the best canopy coverage and side bank vegetation to portray the best overall results. Depending on the abundance of fauna and the diversity of habitats available at a sampling point, the various habitats may be sampled one after another into one collection. As previously mentioned the selected sampling area would probably not exceed more than 10 metres each way, or 20 metres one way, from an operator's position.

Sorting of live samples was done on shore, adjacent to the sampling site. The net contents was quickly emptied into a white sorting tray, with about 20 mm of clear water to prevent escape of active taxa such as freshwater crabs and swimming Ephemeroptera. The netting was swished in the water to release any invertebrates that may have adhered to the mesh.

Material remaining in the net can be washed into the pan by spraying the outside of the mesh with water from a wash bottle to ensure minimum loss of organisms during retrieval. The net was checked for remaining invertebrates. The sample was then spread out in a small amount of water to allow macro-invertebrate specimens to be picked out with fine forceps and pipettes. Small portions of the sample were moved towards the empty part of the pan and invertebrates were removed by using a pair of forceps. As the goal of the study was a qualitative characterisation of biodiversity, it was sufficient to sort for a 15-minute period or until roughly 5 minutes had passed since an additional family was found. The aim was to collect as wide a range of macro-invertebrates as possible within these constraints. The selection of only conspicuous or colourful specimens was deliberately avoided and efforts were made to obtain small cryptic invertebrates as well as larger ones.

The specimens were sorted alive. Small and encased invertebrates were easily detected by their movements. The sample was carefully examined to remove common and rare families alike. When similar looking families were present only microscopic examination of preserved specimens could avoid confusion.

It was easiest to do a two-stage sort:

(1) A coarse sort, in which large invertebrates or pieces of debris were removed from portions of the sample in a shallow, white pan, followed by

(2) A fine sort in which portions of the sample were examined closely and debris teased apart. All invertebrates that were removed from the sample were examined under a magnifying glass.

Organisms were identified and enumerated live, but any species or families that could not be positively identified in the field were removed and placed into 10 ml glass vials containing 70 % alcohol and were taken to the laboratory for later identification. This was accomplished under a binocular microscope. Identification was achieved at family level because this is the resolution to which rapid assessment SASS4 is taken (Dallas *et al.*, 1994). Identification of the invertebrates was carried out by the author on site by making reference to taxonomic literature and freshwater keys followed by two substantial checking procedures to ensure both accuracy of identification and consistency in the level of identification. Drawings and notes were made to further aid in identifications. Specimens that could not be identified were sent to a qualified contracted person where organisms were identified to family level. A label accurately describing the sample location (river name, site number, geographical location, date and collector's name) was added to the jar.

The rest of the sample returned to the stream. Each of the taxa at each site on the river was recorded on a SASS sheet specially designed for this purpose (see Appendix 1). Two different measures were obtained from each sample, viz., the total SASS score and the Average Score Per Taxon (ASPT). These scores are complementary. The SASS score is most useful in polluted sites and ASPT most useful in cleaner waters (Dickens and Graham, 1998). A measure of abundance of species was assigned an alphabetic code (A-D): A 1-10, B 10-100, C 100-1000, D >1000. This code was used in order to provide an indication of the number of individuals per family present, for example, if there was 20 Chironomidae in the sample, the field data sheet indicated with reference to the above-mentioned family, an abundance value of B.

5.3.2 Physical and Chemical Data Collection

Physical data to complement the species lists for each site were obtained. Appendix 2 lists all environmental variables used in this analysis, together with brief notes on procedures for data collection. The variables obtained for a sampling site at the time of sampling included measures of sampling habitat and stream characteristics. Comprehensive temperature records could not be obtained for all sites and hence water temperature is not included in the analyses. Data relating to water chemistry variables (oxygen, nitrogen, phosphorous, pH and heavy metals) were obtained from Durban Metro Waste Water Management Branch.

This chapter describes the methods and procedures for SASS and IHAS monitoring techniques. Physical parameters of water quality were recorded in order to aid in the interpretation of the health of the rivers whilst the biological studies reflected changes in the macro-invertebrate diversity and abundance in relation to water quality.

CHAPTER 6

RESULTS

The collected data concern SASS4, ASPT and IHAS scores as well as the number of families present and the number of biotopes present at each of the selected river sites in the Durban Metropolitan Area. Deterioration of the environment through large-scale land use such as agriculture, road building, clear cutting and urbanisation is difficult to document on a case by case basis because there are seldom point sources of discharge into the river. Therefore, deterioration from non-point discharges is usually documented as cumulative impact rather than individual effects.

6.1 SELECTION OF SASS4, ASPT AND IHAS SCORES

The results are illustrated in the form of Graphs (Figs 12-14) and Tables (5, 6 &7). Figure 12 depicts the IHAS score for the different river sites surveyed. Figure 13 shows the results obtained by applying SASS4 technique to different samples collected at different river sites. Figure 14 illustrates the ASPT results at each site. Table 5 lists the biotopes sampled at the different river sites. Table 6 represents the invertebrate families found at the different river sites and also records the abundance class of the families found at each river site. Table 7 provides a summary of the health of the rivers of the DMA. In summary the graphs are used to interpret the main variables of interest, which are the SASS4, ASPT and IHAS scores. The tables represent the number of taxa present at each site and their relative abundance and the biotopes present in addition to a summary of the health of the rivers of the DMA. The abbreviation of the monitoring stations as depicted in the Graphs and Tables in this section are classified in List of Abbreviations.

6.2. RESULTS OBTAINED WITH RESPECT TO THE BIOTOPES SURVEYED

Eight biotopes (stones-in-current, stones-out-of current, marginal vegetation, aquatic vegetation, mud, sand, gravel and bedrock) or the best overall habitat area were collectively sampled in the different reaches of river. Table 5 presents data on the biotopes found at each site. In this study it was found that some measures of biotope diversity (Table 5) related to the diversity and composition of the river fauna (Table 6). It was observed that greater numbers of families were recovered from stones-in-current and marginal vegetation, all of which provided an increased habitat structure. As a general point of observation the number of aquatic invertebrates were much higher on organic than on mineral substrate and least on sand. Similar responses are consistent with experimental studies that have showed effects of habitat complexity on fauna within the streams of the DMA (Chutter, 1972; 1998). Palmer and O'Keeffe (1990) suggested that "biotopes in the Buffalo River (Eastern Cape) were characterised by particular macro invertebrate assemblages".

The lowest habitat values (Fig. 12) were recorded at some sites when macro invertebrate data from few biotopes were used in the calculation (Table 5). On the other hand, the high structural diversity and large numbers of microhabitats or biotopes combined (Table 5) resulted in an enhanced population of macro-invertebrates, which was reflected in higher habitat values (Fig. 12). This finding however was not consistent for all rivers with higher biotope diversity. These results suggested that species diversity and composition of fauna living in rivers was related to some attributes of habitat structure, such as habitat heterogeneity which itself may have been related to disturbances rates. In the present study it was concluded with little doubt at least for most rivers surveyed that the diversity of invertebrates increased as one proceeded from sand to gravel substrates. Substrate stability was thought to be part of the answer and presumably this was the one disadvantage of sand, at least to the large invertebrates. Numbers of individuals and families appeared to be greatest on some substrate types and varied with the number of available of biotopes. Determination of the role of the substrate was further complicated by its tendency to interact with other environmental variables.

6.3. EVALUATION OF HABITAT SCORES

Virtually all statements concerning ecological processes in running waters have to be qualified by some reference to the physical location and specific circumstances of the site. Whether it is a headwater stream or a lowland river, shaded by forest canopy or exposed to full sunlight, modified by human activity or pristine, our interpretation of particular findings is incomplete without such information.

For this study the habitat sampled in the different reaches of the river was carefully selected in order to the best represent the overall habitat condition. The IHAS scores used in the analysis related to both biotopes present and stream condition and are graphically represented in Figure 12.

At certain sampling sites for example in the Manzimtoti and the Umbilo Rivers, *all biotopes were present* (Table 5), and resulting *IHAS scores were high* (Fig. 12). Figure 12 shows that at other sampling sites the *IHAS scores were high* even though some *biotopes were absent* (Table 5) for example the uMngeni River at site 02.

At certain localities *IHAS score was low* (Fig. 12) and this low score was attributed to the *absence or loss of some or most biotopes* (Table 5) for example the iziMbokodweni at site 01. On the other hand, at other sampling sites for example the Mhlathuzana River and the uMngeni River at site 01 (Fig. 12) even though *most the biotopes were present* (Table 5) the *IHAS score remained low* (Fig. 12). Some sites had good riparian buffers and canopy but lacked adequate substrate types and bank stability that influenced the IHAS scores. In addition, at other sites riparian zones were not maintained and bank vegetation was scarce and at some sites even absent. These factors alone or in combination could have contributed to the low IHAS score.

Certain sites were characterised by good water quality due to the presence of number of macro-invertebrates. At these sites there was a tendency for *SASS4 scores to increase with IHAS scores* for example the iziMbokodweni at site 02. At certain sites for example the Umgababa River site 02, *a low IHAS score* in conjunction with *a low SASS4 score* showed that the river is not as 'bad' as a low SASS4 score alone would suggest. The results also showed that at the intermediate and poor water quality sites there was no tendency for SASS4 to increase with IHAS scores for example the iSiphingo River site 01. This would leave water quality as the main source of difference at this sampling site. This result therefore confirms that where water quality was impaired, habitat diversity had little impact on SASS4 scores.

From the results obtained it would seem that ASPT scores (Fig 14) were largely independent of habitat diversity. This finding would appear to be rational in that each habitat would be expected to support some taxa which would be classified as pollution sensitive (high scoring taxa) and some that would be classified as pollution tolerant (low scoring taxa).

6.4. BIOLOGICAL DATA

Table 6 represents data related to the number and abundance of taxa observed at each sampling site. Rivers with widely diverse invertebrate fauna that included appreciable proportions of Plecoptera, (stonefly nymphs) and/or Ephemeroptera (mayfly nymphs), Trichoptera (caddisfly larva), (animals that are adapted in characteristic ways, having sharp claws to cling to stone surfaces) were the Manzimtoti, iLovu and iziMbokodweni Rivers (Table 6). The presence of the plecopterans (stoneflies) at the iLovu River, *site 01* and the Little Manzimtoti River, *site 02* and iziMbokodweni at *site 02* (Table 6) suggested that the water quality at these sites was unmodified and that the available habitats were hospitable to their survival (Table 6). As mentioned previously the plecopterans (stoneflies) have a restricted occurrence in South Africa (Chutter, 1972) and are found only in well-oxygenated water, and were rare in most of the rivers surveyed in the Durban Metropolitan Area.

The Chironomids were present at most sampling sites reaching their highest numbers at the iSiphingo and uMlazi Rivers (Table 6). During the present survey the Odonata had a higher percentage occurrence in the iziMbokodweni and the Manzimtoti Rivers than any of the other rivers surveyed. Some of the invertebrates that were abundant at iLovu and Umgababa Rivers were rare or absent within the city (Table 6). Oligochaetes and leeches were approximately as abundant within the city as further south in the Umgababa and the Msimbazi River (Table 6).

Taxa usually associated with large amounts of organic materials were numerically dominant in the iSiphingo and uMlazi Rivers (Table 6). The ubiquitous Chironomidae (Diptera), were relatively more abundant than any other invertebrate group followed by the Oligochaetes (Table 6).

In areas were there was a measurement of low dissolved oxygen (chemical data obtained from Durban Waste Water Management Branch), resulting from return flow from wastewater treatment plants the families present were characterised by an increased ratio of aquatic worms and midges compared to other aquatic insects. These results were present in the samples obtained from the Little Manzimtoti, iSiphingo, uMlazi, uMdloti and Tongati Rivers (Table 6).

At certain localities were heavy metals were known to occur (chemical analysis obtained from Durban Waste Water Management Branch), there was a direct increase of aquatic worms and midges compared to other aquatic insects, for example the Umbilo River (Table 6). At certain sites where there was most likely an increase of fine sediment (due to construction activities) these sites favoured some invertebrate fauna at the expense of others. There was an increase in the chironomids and oligochaetes and a decrease in mayflies and midges as observed in uMngeni River (Table 6). Quinn and Hickey (1993) also noted "low densities of benthic flora and macro-invertebrate in their case studies and attributed this finding to the high level of suspended solids". In areas where the water was likely to be eutrophic (this information obtained from Durban Metro Waste Water Management Branch) there was an increased ratio of Oligochaetes to Chironomids for example the Ohlanga and Tongati Rivers (Table 6). Saether (1979) noted that "an increasing ratio of oligochaetes to chironomids was a good indicator of eutrophication". Stoneflies, caddisflies and mayflies are generally intolerant of pollution. Large number of these insect types collected in the sample indicated that the water in the river was likely to be unmodified for example the iLovu River (Table 6).

The absence of intolerant macro-invertebrate groups and the dominance of pollution-tolerant groups were indicative of pollution (Table 6). Diversity of macro-invertebrates generally decreased moving downstream through the river systems (Table 6). The number of families recorded tended to decrease at sites where the water quality was poor (low SASS scores) however the numbers of individuals present increased (Table 6). A larger number of different families and a larger number of species within each family for example, at both sampling sites of the iLovu River, indicated greater taxa richness and evenness, which generally pointed towards better water quality.

6.5. EVALUATION OF METRICES

The present ecological status of the respective river sites was defined by applying the results for the biological indices obtained during the survey of the DMA rivers, to the ecological health classification scheme (see methods, chapter 5).

The results obtained using SASS4 and ASPT scores (Fig. 13 and Fig. 14) in this study indicated that most of the rivers were of modified (poor) water quality. However the water quality in the Umgababa, iLovu and Manzimtoti Rivers were rated as moderately modified to unmodified water quality (fair to good quality) (Fig. 13 and Fig. 14).

A sharp decline in SASS4 and ASPT scores between *sites* 01 and 02 on the iziMbokodweni and uMngeni Rivers (Fig. 13 and Fig. 14) was also noted. At some sampling points unsuspected sporadic pollution (no clear point sources of pollution noted) reduced the number of macro-invertebrate families present, for example the Umbilo River (Table 6). In other rivers, gradual recovery downstream was observed in relation to the diversity and abundance of macro-invertebrate composition, for example at *site 02* the Mhlathuzana River (Table 6). At some sampling points, SASS4 scores and ASPT scores were remarkably constant from *site 01* through to *site 02*, for example the uMlazi River. Sampling sites that displayed poor water quality (for example the uMlazi River) were located below point sources of pollution, where there was good reason to conclude that water quality was impaired. Most of the intermediate water quality sampling sites (Umbilo River) was in recovery zones of polluted rivers. Table 7 provides a summary of the health of the rivers of the DMA. A discussion of the SASS4 and ASPT and IHAS scores at each river site and their implications is presented in the Chapter 7.

Table 5

Record of the biotopes sampled at river sites upstream and downstream DMA.

Value 1 indicates presence of the biotope whereas 0 indicates absence.

Biotopes	R-Baba 01	R-Baba 02	R-Mbazi 01	R-Mbazi 02	R-Lovu 01	R-Lovu 02
SIC	1	0	0	1	1	1
Marginal Vegetation	1	1	1	0	1	1
Aquatic Vegetation	1	1	1	0	1	1
SOOC	1	0	0	1	0	1
Mud	1	1	1	1	1	1
Bedrock	1	0	0	0	0	0
Sand	1	1	1	1	1	1
Gravel	1	1	1	1	1	1

Table 5 (*continued*)

Biotopes	R-Ltoti 01	R-Ltoti 02	R-Toti 01	R-Toti 02	R-Mlass 01	R-Mlass 02
SIC	1	1	1	1	1	1
Marginal Vegetation	1	1	1	1	1	1
Aquatic Vegetation	1	1	1	1	1	1
SOOC	1	1	1	1	1	0
Mud	1	1	1	1	1	1
Bedrock	1	1	1	0	0	1
Sand	1	1	1	1	1	1
Gravel	1	1	1	1	1	0

Table 5 (*continued*)

Biotopes	R-Mboko 01	R-Mboko 02	R-Mboko 03	R-Sping 01	R-Sping 02
SIC	0	1	1	1	0
Marginal Vegetation	0	1	0	1	0
Aquatic Vegetation	0	1	0	0	0
SOOC	0	1	1	1	0
Mud	0	1	1	1	1
Bedrock	0	1	0	1	1
Sand	1	1	1	1	1
Gravel	0	1	0	1	0

Table 5 (*continued*)

Biotopes	R-Zana 01	R-Zana 02	R-Ubilo 01	R-Ubilo 02	R-Mgeni 01	R-Mgeni 0 2
SIC	1	1	1	1	1	1
Marginal Vegetation	1	1	1	1	1	1
Aquatic Vegetation	1	1	1	1	1	0
SOOC	1	0	1	1	1	1
Mud	0	1	1	1	1	1
Bedrock	1	0	1	1	1	0
Sand	1	1	1	1	1	1
Gravel	1	1	1	1	1	1

Table 5 (*continued*)

Biotopes	R-Ohl 01	R-Ohl 02	R-Hloti 01	R-Hloti 02	R-Tong 01	R-Tong 02
SIC	0	0	0	1	0	0
Marginal Vegetation	1	0	1	0	1	0
Aquatic Vegetation	0	0	1	1	0	0
SOOC	0	0	0	1	0	0
Mud	1	1	1	1	1	1
Bedrock	0	0	0	0	0	0
Sand	1	1	1	1	1	1
Gravel	1	1	0	1	1	0

Table 6
Record of invertebrate families found at river sites upstream and downstream Durban Metropolitan Area.
Values indicate midpoint of abundance classes, i.e. 5 (1-10), 50 (10-100), 500 (100-1000) and 1000 (>1000).

Site	R-Baba 01	R-Baba 02	R-Mbazi 01	R-Mbazi 02	R-Lovu 01	R-Lovu 02	R-Ltoti 01	R-Ltoti 02
Oligochaeta	5	—	—	50	—	—	—	5
Leeches	5	5	—	50	—	—	—	5
Amphipoda	—	50	—	500	—	500	—	5
Crab	5	5	5	5	5	50	5	5
Shrimp	50	50	5	50	5	50	5	5
Hydrachnellae	5	—	5	—	—	—	—	—
Perlidae	—	—	—	—	5	50	—	—
Baetidae (1spp)	—	—	—	—	—	—	—	—
Baetidae (2 spp)	—	—	—	—	—	—	—	50
Baetidae (>2 spp)	—	—	—	—	50	50	50	—
Leptophlebiidae	50	—	—	—	—	—	—	—
Caenidae	—	—	—	—	—	—	5	5
Chlorolestidae	—	—	—	—	—	—	5	—
Lestidae	—	—	—	—	—	—	—	—
Protoneuridae	—	—	—	—	—	—	—	—
Platycnemidae	—	—	—	—	—	—	—	—
Coenagriidae	—	—	50	—	5	—	5	—
Gomphidae	—	—	5	—	5	5	5	—
Aeshnidae	—	—	—	—	5	—	5	—
Corduliidae	—	—	—	—	—	—	—	—
Libellulidae	5	—	—	—	—	—	—	—
Notonectidae	5	—	—	—	5	—	—	5
Naucoridae	50	—	—	—	—	5	5	—
Nepidae	—	—	—	—	—	5	5	—
Belastomatidae	50	5	5	5	—	5	5	—
Corixidae	—	—	5	—	—	—	—	—
Gerridae	—	—	—	—	—	—	—	—
Veliidae	5	—	—	—	—	—	—	—
Corydalidae	—	—	—	—	5	5	—	—
Hydropsychidae 1 spp	—	—	—	—	—	—	—	—
Hydropsychidae 2 spp	—	—	—	—	—	—	—	—
Hydropsychidae >2 spp	—	—	—	—	5	5	—	—
Psychomyiidae	—	50	—	—	—	—	—	—
Movable case 1 spp	—	—	—	—	5	—	—	—
Nymphulidae	500	50	—	—	50	—	—	—
Dytiscidae	—	—	—	—	—	5	—	—
Elmidae	—	—	—	—	—	—	—	—
Gyrinidae	—	—	—	—	—	—	—	—
Tipulidae	—	—	—	—	—	—	—	—
Psychodidae	—	—	—	—	—	—	—	—
Culicidae	—	—	—	—	—	—	—	—
Simuliidae	50	—	—	—	—	5	50	50
Chironomidae	50	—	—	—	—	5	—	50
Ceratopogonidae	50	—	—	—	—	—	—	50
Syrphidae	—	50	—	—	—	—	—	—
Athericidae	—	—	—	—	—	—	5	—
Muscidae	5	—	—	—	—	—	5	—
Lymnaeidae	5	—	—	—	—	—	—	—
Melaniidae	—	—	—	—	—	—	—	—
Planorbidae	5	—	—	—	—	—	—	—
Physidae	—	—	—	—	—	—	—	—
Ancylidae	—	—	—	—	—	—	—	—
Sphaeriidae	5	—	—	—	—	—	—	—
Number of families	**19**	**8**	**7**	**6**	**12**	**14**	**14**	**11**
SASS4	**95**	**56**	**38**	**33**	**99**	**101**	**91**	**57**
ASPT	**5**	**7**	**5.4**	**5.5**	**8.25**	**7.2**	**6.5**	**5.2**

Table 6 (*continued*)

Site	R-Toti 01	R-Toti 02	R-Mlass 01	R-Mlass 02	R-Sping 01	R-Sping 02	R-Zana 01	R-Zana 02
Oligochaeta	—	—	50	50	50	50	—	—
Leeches	—	—	50	50	50	5	50	—
Amphipoda	—	—	—	—	—	—	—	—
Crab	5	5	—	—	5	—	—	5
Shrimp	5	5	—	—	—	—	5	5
Hydrachnellae	—	—	—	—	—	—	—	—
Perlidae	—	—	—	—	—	—	—	5
Baetidae (1 spp)	—	—	—	—	5	—	—	—
Baetidae (2 spp)	50	50	—	—	—	—	—	—
Baetidae (>2 spp)	—	—	50	50	—	50	50	50
Leptophlebiidae	—	—	—	—	—	—	—	—
Caenidae	5	—	—	—	—	—	—	5
Chlorolestidae	5	—	—	—	—	—	—	—
Lestidae	5	—	—	—	—	—	—	—
Protoneuridae	5	—	—	—	—	—	—	—
Platycnemidae	—	—	—	—	—	—	—	—
Coenagriidae	—	5	—	—	—	—	—	—
Gomphidae	5	5	5	—	5	—	—	5
Aeshnidae	5	—	—	—	—	—	—	50
Corduliidae	—	—	—	—	5	—	—	—
Libellulidae	—	—	—	—	—	—	—	5
Notonectidae	5	—	—	—	—	—	—	5
Naucoridae	—	5	—	—	5	—	—	5
Nepidae	5	5	5	5	5	—	—	—
Belastomatidae	5	—	5	5	—	—	—	—
Corixidae	5	5	—	—	—	—	—	5
Gerridae	—	—	—	—	—	—	—	—
Veliidae	—	—	—	—	—	—	—	—
Corydalidae	—	—	—	—	—	—	—	—
Hydropsychidae 1 spp	—	—	—	—	—	—	—	—
Hydropsychidae 2 spp	—	—	—	—	—	—	—	—
Hydropsychidae >2 spp	—	—	—	—	—	—	5	—
Psychomyiidae	—	—	—	—	—	—	—	—
Movable case 1 spp	—	—	—	—	—	—	—	5
Nymphulidae	—	—	—	—	—	—	—	—
Dytiscidae	—	—	—	—	—	—	—	—
Elmidae	5	5	—	—	—	—	—	—
Gyrinidae	—	—	—	—	—	—	—	—
Tipulidae	5	—	—	—	—	—	—	5
Psychodidae	—	—	—	—	—	50	5	5
Culicidae	—	—	—	—	—	—	—	—
Simuliidae	—	—	500	500	—	50	50	50
Chironomidae	50	—	500	500	500	500	50	50
Ceratopogonidae	5	—	—	—	—	500	50	—
Syrphidae	—	—	—	—	—	—	—	—
Athericidae	5	—	—	—	—	—	—	5
Muscidae	—	—	—	5	—	—	5	50
Lymnaeidae	5	5	5	50	50	—	5	5
Melaniidae	5	—	—	—	—	—	5	—
Planorbidae	—	—	—	—	—	—	—	—
Physidae	—	—	—	—	—	—	—	—
Ancylidae	—	—	—	—	—	—	—	—
Sphaeriidae	—	—	—	—	—	—	—	—
Number of families	**20**	**10**	**9**	**9**	**10**	**7**	**11**	**19**
SASS4	**112**	**51**	**38**	**33**	**40**	**29**	**55**	**110**
ASPT	**5.6**	**5.1**	**4.2**	**3.7**	**4**	**4.1**	**5**	**5.8**

Table 6 (*continued*)

Site	R-Mboko 01	R-Mboko 02	R-Mboko 03	R-Ubilo 01	R-Ubilo 02	R-Mgeni 01	R-Mgeni 02
Oligochaeta	—	5	—	5	5	5	—
Leeches	—	5	—	5	5	5	—
Amphipoda	—	—	—	—	—	—	—
Crab	—	5	5	—	—	—	50
Shrimp	—	50	—	—	—	5	50
Hydrachnellae	—	—	—	—	—	—	—
Perlidae	—	5	—	—	—	—	—
Baetidae (1 spp)	—	—	—	50	—	—	—
Baetidae (2 spp)	—	—	—	—	—	—	—
Baetidae (> 2 spp)	50	50	—	—	50	5	—
Leptophlebiidae	—	5	—	—	—	—	—
Caenidae	—	5	—	—	—	—	—
Chlorolestidae	—	5	—	—	—	—	—
Lestidae	—	5	—	—	—	—	—
Protoneuridae	—	5	—	—	—	—	—
Platycnemidae	—	5	—	—	—	—	—
Coenagriidae	—	—	—	—	50	—	—
Gomphidae	—	5	—	5	—	—	—
Aeshnidae	—	—	—	—	—	5	—
Corduliidae	—	5	—	—	—	—	—
Libellulidae	—	5	—	5	—	—	—
Notonectidae	—	—	—	5	—	50	—
Naucoridae	—	5	—	—	—	—	—
Nepidae	—	—	—	—	—	—	—
Belastomatidae	—	—	—	—	—	—	—
Corixidae	—	5	5	5	—	50	—
Gerridae	—	—	—	—	—	—	—
Veliidae	—	—	—	—	—	—	5
Corydalidae	—	5	—	—	—	—	—
Hydropsychidae 1 spp	—	—	—	—	—	—	—
Hydropsychidae 2 spp	—	—	—	—	—	—	—
Hydropsychidae > 2 spp	—	—	—	—	—	—	—
Psychomyiidae	—	5	—	—	50	—	—
Movable case 1spp	—	5	—	—	—	—	—
Nymphulidae	—	—	—	—	—	—	—
Dytiscidae	—	—	—	—	—	—	—
Elmidae	—	—	—	5	—	—	—
Gyrinidae	—	5	—	—	—	—	—
Tipulidae	—	5	—	—	—	—	—
Psychodidae	—	—	—	50	—	50	—
Culicidae	—	—	—	50	50	—	—
Simulidae	50	—	—	50	50	—	—
Chironomidae	50	—	—	50	—	—	—
Ceratopogonidae	50	—	—	—	50	—	—
Syrphidae	—	—	—	—	—	—	—
Athericidae	—	—	—	—	5	—	—
Muscidae	—	—	5	—	—	—	—
Lymnaeidae	—	—	—	5	—	5	—
Melaniidae	—	—	—	—	—	—	—
Planorbidae	—	—	—	—	—	—	—
Physidae	—	—	—	—	—	—	—
Ancylidae	—	—	—	—	5	—	—
Sphaeriidae	—	—	—	—	—	—	—
Number of families	4	22	3	13	10	9	3
SASS4	24	154	7	44	58	42	16
ASPT	6	7	2.3	3.4	5.8	4.7	5.3

Table 6 (*continued*)

Site	R-Ohl 01	R-Ohl 02	R-Hloti 01	R-Hloti 02	R-Tong 01	R-Tong 02
Oligochaeta	—	—	5	—	—	5
Leeches	—	—	5	—	—	5
Amphipoda	—	—	—	—	—	—
Crab	—	—	—	5	5	—
Shrimp	5	50	5	5	50	50
Hydrachnellae	—	—	—	—	—	—
Perlidae	—	—	—	—	—	—
Baetidae (1 spp)	—	50	—	—	—	—
Baetidae (2 spp)	—	—	—	—	—	—
Baetidae (>2 spp)	50	—	—	50	—	—
Leptophlebiidae	—	—	—	—	—	—
Caenidae	—	—	—	—	—	—
Chlorolestidae	—	—	—	—	—	—
Lestidae	—	—	—	—	—	—
Protoneuridae	—	—	—	—	—	—
Platycnemidae	—	—	—	—	—	—
Coenagriidae	5	—	—	—	—	—
Gomphidae	—	—	—	—	—	—
Aeshnidae	—	—	—	—	—	—
Corduliidae	—	—	—	—	—	—
Libellulidae	—	—	—	5	—	—
Notonectidae	5	—	—	50	—	—
Naucoridae	—	5	5	50	5	—
Nepidae	—	5	—	—	—	—
Belastomatidae	5	—	—	—	—	5
Corixidae	—	—	—	5	—	5
Gerridae	—	—	—	—	—	—
Veliidae	—	—	—	—	—	—
Corydalidae	—	—	—	—	—	—
Hydropsychidae 1 spp	—	—	—	—	—	—
Hydropsychidae 2 spp	—	—	—	—	—	—
Hydropsychidae >2 spp	—	—	—	—	—	—
Psychomyiidae	—	—	—	—	—	—
Movable case 1spp	—	—	—	—	—	—
Nymphulidae	5	—	—	—	—	—
Dytiscidae	—	—	5	5	—	—
Elmidae	—	—	—	—	—	—
Gyrinidae	5	—	—	—	—	—
Tipulidae	5	—	—	—	—	—
Psychodidae	—	50	—	50	—	—
Culicidae	—	50	50	—	—	5
Simuliidae	50	—	50	—	—	50
Chironomidae	50	—	50	50	50	50
Ceratopogonidae	50	5	—	—	50	50
Syrphidae	—	—	—	—	—	—
Athericidae	—	—	—	—	—	—
Muscidae	—	—	—	—	—	—
Lymnaeidae	—	—	50	50	5	—
Melaniidae	5	—	—	—	—	—
Planorbidae	5	5	—	—	50	—
Physidae	—	—	—	—	—	—
Ancylidae	—	—	—	—	—	—
Sphaeriidae	—	—	—	—	—	—
Number of families	**13**	**8**	**9**	**11**	**7**	**9**
SASS4	**66**	**32**	**35**	**51**	**31**	**31**
ASPT	**5.1**	**4**	**3.9**	**4.6**	**4.4**	**3.4**

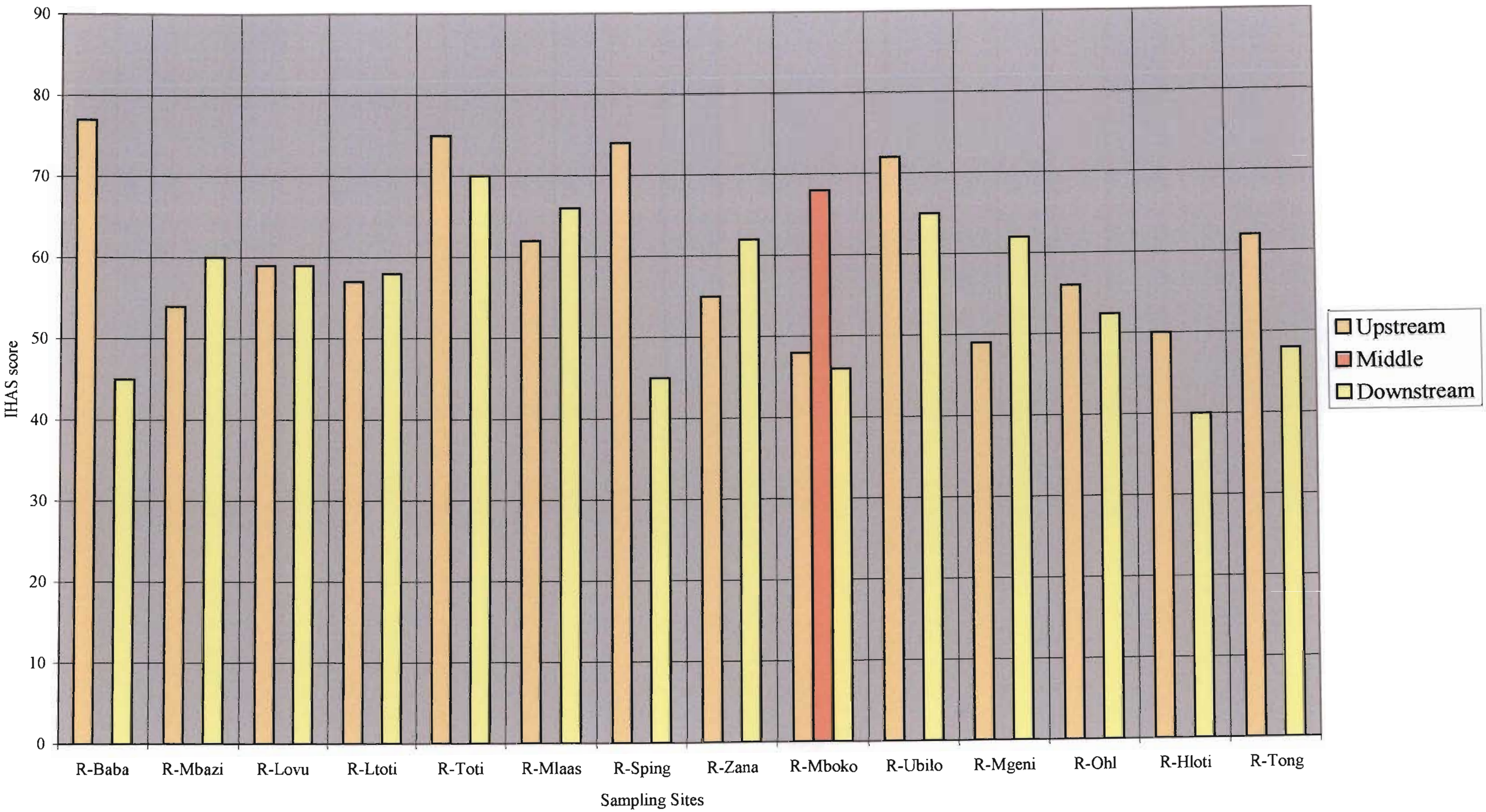


Fig. 12. IHAS scores for river sites upstream, middle and downstream DMA.

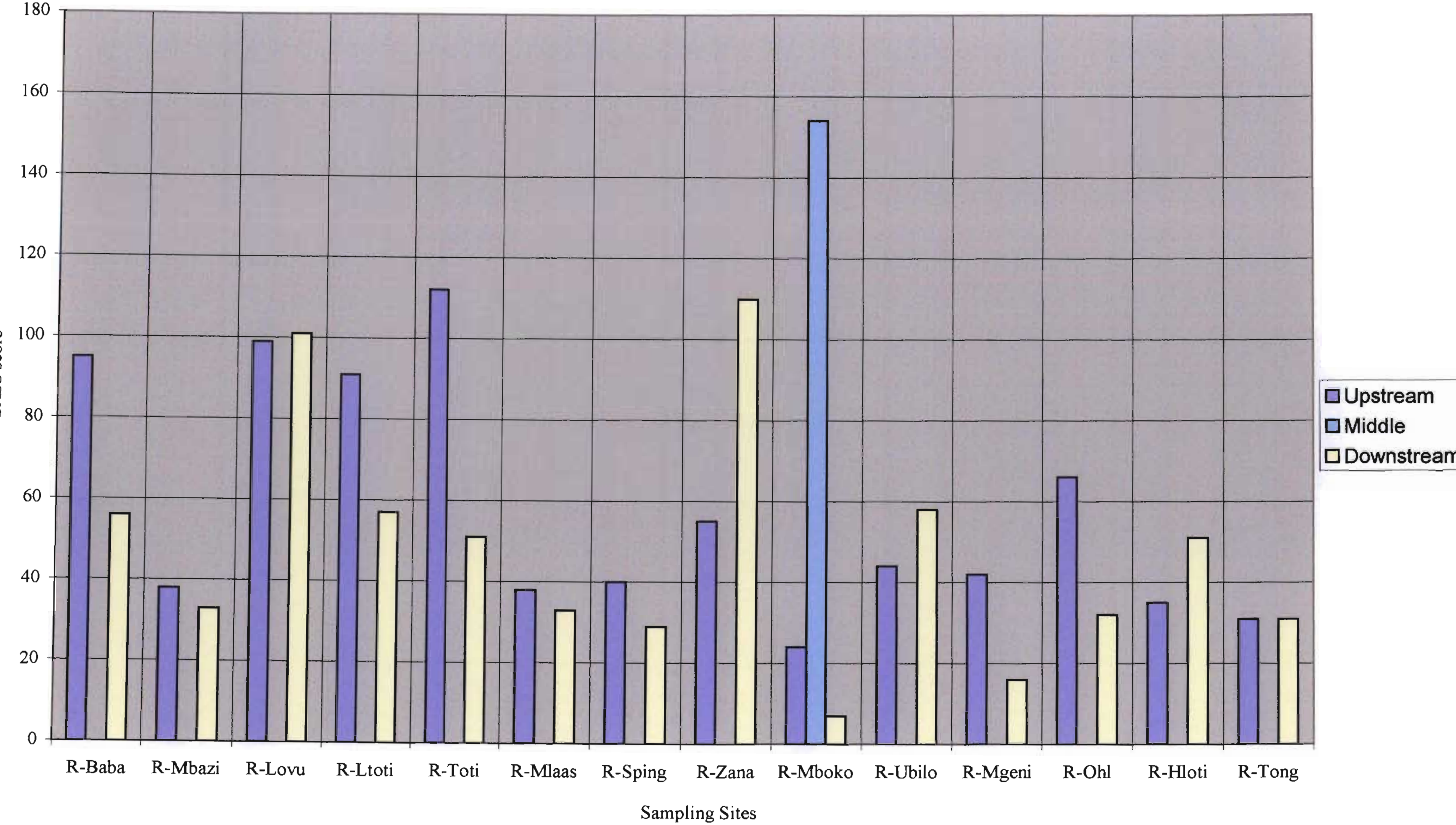


Fig. 13. Biotic Index (SASS) scores for river sites upstream, middle and downstream DMA.

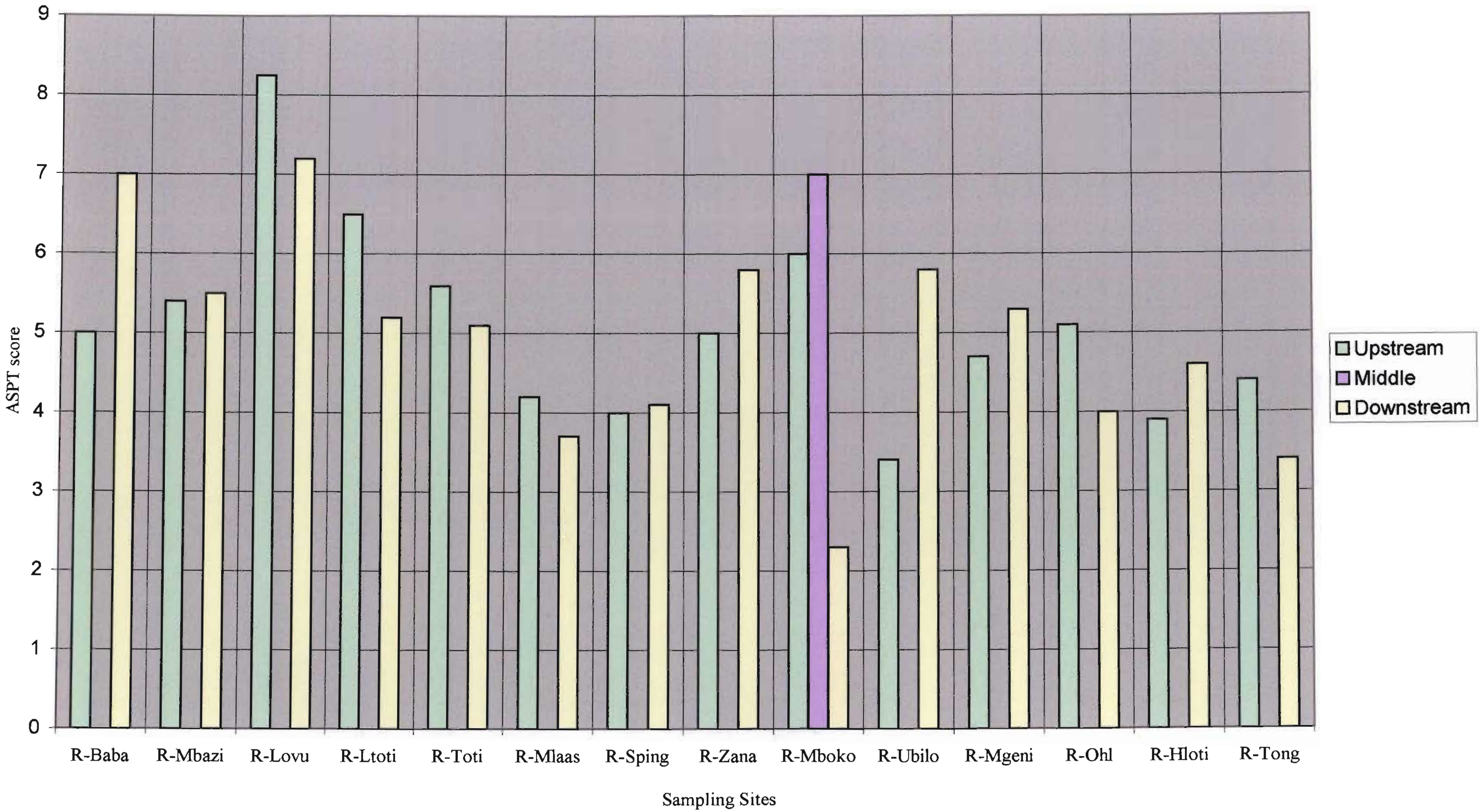


Fig . 14. Biotic Index (ASPT) scores for river sites upstream, middle and downstream DMA.

Table 7: A summary of the "Health" of the Rivers of the DMA

Site Number	River	Modified Water Quality (Polluted)	Moderately Modified	Unmodified Water Quality (Unpolluted)
R-BABA-01	Umgababa	✔		
R-BABA-02	Umgababa			✔
R-MBAZI –01	Msimbazi	✔		
R-MBAZI-02	Msimbazi	✔		
R-LOVU-01	iLovu			✔
R-LOVU-02	iLovu			✔
R-LTOTI-01	Little Manzimtoti		✔	
R-LTOTI-02	Little Manzimtoti		✔	
R-TOTI-01	Manzimtoti			✔
R-TOTI-02	Manzimtoti		✔	
R-MBOKO-01	iziMbokodweni	✔		
R-MBOKO-02	iziMbokodweni			✔
R-MBOKO-03	iziMbokodweni	✔		
R-SPING-01	iSiphingo	✔		
R-SPING-02	iSiphingo	✔		
R-MLASS-01	uMlazi	✔		
R-MLASS-02	uMlazi	✔		
R-ZANA-01	Mhlathuzana	✔		
R-ZANA-02	Mhlathuzana			✔
R-MGENI-01	uMngeni	✔		

R-MGENI-02	uMngeni	✔		
R-UBILO-01	Umbilo	✔		
R-UBILO-02	Umbilo		✔	
R-HLOTI-01	uMdloti	✔		
R-HLOTI-02	uMdloti	✔		
R-OHL-01	Ohlanga	✔		
R-OHL-02	Ohlanga	✔		
R-TONG-01	Tongati	✔		
R-TONG-02	Tongati	✔		

CHAPTER 7

DISCUSSION

The distribution in time and space of benthic macro-invertebrate in a section of a river is the result of a series of responses (which varies according to the species involved) to a set of complex interactions between the invertebrates and the aquatic environment. The change in the species assemblages depends more or less on the changes in the water quality and physical attributes of each river during the survey. Due to the differences between each site the discussion below deals with each river separately.

7.1. THE ILOVU RIVER

The iLovu River receives return flow from iLovo Sugar Mill. *Site 01* was chosen below the iLovo Sugar Mill. This site was selected as the appropriate sampling point because it was here that the river entered the Durban boundary.

Of particular interest was the diverse assemblage of invertebrates present at *site 01* which included an appreciable proportion of Plecoptera (stonefly nymphs), Ephemeroptera (mayfly nymphs) and Trichoptera (caddisfly larvae) (Table 5). The sample showed a normal community with no species present in large numbers. It can be concluded from the SASS4 (99) and ASPT (8,25) scores obtained that water quality deterioration at this river site was minimal.

This section of the river (*site 01*) was highly stable in terms of sediment dynamics and quality of water surrounding the site. The stream characteristics were well balanced for RBA sampling and very little impact was noticed.

Most of the biotopes at this river site (*site 01)* were sampled except bedrock and stones-out-of-current (Table 5). Although a sub optimum IHAS score (59) was obtained there was adequate habitat available for maintaining a healthy invertebrate population as evidenced by the presence of pollution sensitive families.

Diversity increased from *site 01* to *site 02* with the addition of a few more families at *site 02* (Table 6). The invertebrate community as a whole was quite varied. Examination of the score sheet of *site 02* revealed that four relatively high scoring families were found (Table 6). These were the Perlidae, Nymphulidae, Hydropsychidae (> 2 spp) and Baetidae (> 2 spp). This difference in the above-mentioned invertebrate distribution might be due to the nature of the sediment deposited in the habitats sampled. The SASS4 (101) and the ASPT (7,2) scores obtained at *site 02* suggested that the water quality at this site was unlikely to be impaired. The recent construction activity and surrounding farmland appeared to have little impact on the SASS4 score.

Site 02 had a wide variety of biotopes available for invertebrates (Table 5). The IHAS score obtained at *site 02* was similar to that of *site 01* (59). The analysis of the stream characteristic showed that at *site 02* the river was fast-flowing, wide and moderately deep. The above conditions, coupled with excellent habitat structure were no doubt extremely important in explaining the high biological diversity of *site 02*. The conclusion reached by Brand *et al.*, in 1967 who surveyed the whole of the iLovu River stated that "the river is in a good condition" and according to the SASS results obtained in this study the iLovu River still remains in a good condition. The iLovu River at *site 01* and *site 02* supported a high diversity of invertebrate life and neither the SASS4 score (99, 101) nor the ASPT values (8,25 & 7,2) revealed any associated change along the two sites sampled. Water quality at this sampling site was unmodified, a result derived from the high SASS4 and ASPT scores obtained and habitat diversity was high. High scores were obtained at both sampling sites and the scores would have been higher had the full range of habitats in addition to the stones-in-current been sampled at *site 01*. An interesting result was obtained with regard to the condition of the river at *site 02*. This is explained as follows: in the upper reaches (*site 01*) of the iLovu River, SASS4 scores were high but rose to higher values downstream (*site 02*). In reviewing the results from the iLovu River (*site 01* and *site 02*) attention has to be drawn to the fact that in the iLovu River there was no evidence of impact due to the return effluent from the sugar mill at Karridene and the surrounding farmland.

7.2. THE UMGABABA RIVER

This river receives no industrial or sewage effluent. As the local people do their laundry in the river, soap and detergents enter the river.

At *site 01,* the presence of the emergent semi-aquatic vegetation and aquatic macrophytes contributed to nutrient and energy cycling and provided additional habitat and food for the biota. Many river invertebrates, particularly filter feeders and scraper feeders rely on microphyte growth and were observed in the sample. The faunal analyses indicated moderate pollution, with a few intolerant species present, whilst the medium tolerant species predominated in both the marginal and aquatic vegetation and tolerant species in large numbers predominated the bottom sediments (Table 6). The abundance of tolerant species probably reflected their response to the enriched food supply (as evidenced by cattle droppings alongside the riverbed). A diverse group of Hemiptera, a good assemblage of Gastropoda and large numbers of

Diptera (Table 6), fish and amphibians were present at this sampling site. Of particular interest were the large numbers of *Nymphulidae* and *Leptophlebiidae* collected at this site (Table 6). The good SASS4 scores (95) and a moderate ASPT score (5) suggested that the water quality at *site 01* was slightly impaired at the time of sampling but previous studies (Brand *et al.*, 1967) suggested that "this river was seriously polluted by the various uses made of it". The relatively medium flow regime combined with the excellent condition of the river, the low turbidity with a good diversity of biotopes available (Table 5) resulted in an optimum IHAS score (77) as displayed in Figure 12.

At *site 02* the surrounding land-use was confined to farmland with little riparian vegetation and side bank cover. The SASS4 score (56) and the number of taxa (Table 6) declined downstream (*site 02*) whilst the ASPT score increased. An ASPT score of (7,1) was recorded and was attributed to the presence of Amphipoda, Nymphulidae and Hydropsychidae (Table 6). Large numbers of isopods, fish and a few Syrphidae (rat tailed maggots) were also present at this sampling site.

The low habitat score (45) obtained was attributed to the poor biotope diversity (Table 5). This result also confirmed findings made in other studies (Chutter 1994)– missing biotopes such as stones-in-current (Table 5) resulted in a low SASS4 score (56) but ASPT (7,1) was unaffected. The results obtained therefore indicated unmodified water quality with restricted habitat availability. It can therefore be concluded that an overall reduction of habitat heterogeneity accounted for a reduction in species diversity and a greater abundance of those species favoured by the altered conditions.

7.3 THE MSIMBAZI RIVER

Water quality in the Msimbazi River is not subjected to point source modification. Utilisation of the river for personal ablution and washing of clothes, utilisation of dirty containers to collect river water, failing sanitation and ineffective waste disposal has altered the water quality and the environment as a whole. The study was conducted when the first light rains of the summer had fallen and the general lack of cleanliness of the area had serious polluting effects on the quality of surface runoff on the receiving river. Subsistence farming and fishing activities are undertaken in this area with a close linkage between the river and the people.

Poor farming practices and the removal of riverine vegetation was one of the likely contributors of soil erosion at this site and the high sediment levels in the water. This may have increased nutrient levels due to the presence of fertilisers, animal wastes and discharges of untreated organic waste into the river. These factors probably contributed to the low flow and high turbidity. Water quality at *site 01* was considered poor from the very appearance of the river. Algal blooms, the absence of pollution intolerant macro-invertebrates and a coloured sheen on the water may indicate the dumping of automobile oil, poor fertilizing practices and defective septic tanks systems.

Medium tolerant species consisting of shrimps and Hydrachnellae predominated in the stones-in-current habitat and tolerant species in the bottom sediments (Table 6). A low SASS4 score (38) combined with a moderate ASPT score (5,4) and the presence of many tolerant taxa suggested impaired water quality at this sampling site. Marginal and aquatic vegetation biotopes were missing from the sampling points further inhibiting the productivity of the invertebrates (Table 5). The IHAS score was subsequently low (54). Above *site 01* extensive riparian vegetation was present alongside the river, which was an additional source of particulate organic matter, however at *site 01* there was no riparian vegetation present except for occasional blades of grass.

Site 02 demonstrated a similar pattern to *site 01*. The invertebrate fauna present at these sampling sites may have been influenced by sediment mobility. The dominant species in terms of both abundance and biomass were the amphipods (which was considered rather unusual) (Table 6) and they remained the pivotal group in terms of the ecology of this section of the river. Large numbers of freshwater shrimps were present whilst pollution intolerant species, Trichoptera and Ephemeroptera and Plecoptera were absent (Table 6). The tolerant taxa comprised of oligochaetes and leeches (Table 6). The SASS4 score was low (33), and ASPT score (5,5) was moderately high due to the presence of a small number of high scoring taxa. The IHAS score (60) recorded was low. According to Chutter (1994) "at low SASS scores the ASPT score becomes an unreliable indicator of water quality". In this case of restricted habitat diversity, the SASS4 score was low in relation to the ASPT. This finding was supported by Chutter (1998).

The riverbed was sandy, though there were stones to sample. This site suffered from impaired substrate with the absence of two major biotopes (stones-in-current and stones-out-of current). Habitat related environmental degradation and poor water quality a possible result of severe organic pollution reduced the variety of invertebrates present in this river. The SASS4 scores recorded was low but ASPT was moderately high and a poor IHAS score (Fig. 12) in combination suggested that this site suffered from impaired water quality.

7.4. THE MANZIMTOTI RIVER

Site 01 was located at Riverside Road, below a nature conservation area. Zones of natural vegetation alongside the river stabilised side banks from the effects of erosion. Aggregation of leaves on the river bottom could have also contributed to aquatic food source through allochthonous input for aquatic micro-organisms and plant eating invertebrates. It was observed that the vegetation hanging into flowing water supported some families of invertebrates in the absence of suitable stones (high densities of midge larvae recorded) (Table 6). These factors favoured growth and development of a diverse invertebrate community including Ephemeroptera, Plecoptera and Trichoptera (Table 6).

The absence of industrial pollution was the most likely explanation of the apparent richness of the Trichoptera and Plecoptera communities (Table 6). The Plecoptera, was abundant at this sampling site (Table 6). This family is adapted to live in cool running water with plenty of oxygen and a substratum comprising of stones and gravel. Their presence in this section of the river confirms that their habitat requirements were being met. The resulting macro-invertebrate community in this section of the river was one of the best sites surveyed in the whole study.

The great diversity of biotopes present at this site together with the presence of many different families suggested that this segment of the river was highly stable in terms of the sediment dynamics and the quality of water surrounding the site. The mud was well compacted and stable, which appeared to be reflected in the nature of the invertebrate community (a number of chironomids, ceratopogonids and tipuilids were present). The sandy substrate was firmly packed and comparatively stable and supported a rich diversity of intolerant species. The stable substratum within the zone appeared to be able to support diverse productive (the number of individuals per family recorded were high) communities.

SASS4 scores obtained were high (112) and the ASPT score (5,6) good whilst the IHAS score obtained (75) was considered excellent. These results in combination suggested that water quality at this site was unmodified. A significant deterioration was observed in the macro-invertebrate communities as one proceeded downstream, *site 02*, when measured using SASS4 (51). Although the ASPT score (5,1) did not reveal significant change, the SASS4 score (51) reflected a large change in water quality. The most notable difference was the loss of the Plecoptera and Trichoptera families and general diversity with half the number of families found at *site 02* compared to *site 01* (Table 6).

It can be seen from the high IHAS score at *site 02* (70) obtained and the widely diverse biotopes available (Table 5) for invertebrate assemblages that the diversity of biotope was not contributing to the low SASS4 (51) and ASPT (5,1) scores. The low SASS4 (51) and ASPT (5,1) scores in this section of the river indicated some deterioration in water quality. This was as a result of the relatively high-suspended solids due to erosion and poor bank cover. According to Williams and Feltmate (1992) high levels of sedimentation can affect aquatic insects by altering biochemical conditions, food resources, respiratory diffusion gradients, and habitat space. The recorded scores revealed that water quality at this site could be classified as impaired (Table 7).

7.5. THE LITTLE MANZIMTOTI RIVER

Chosen for its position, directly after Kingsburg Sewage works, *site 01* received urban runoff and treated effluent. Where sewage comes into the treatment plant with industrial effluent, as is often the case, attention has to be paid to the possibility of toxic materials being discharged into the river. Discharge of sewage effluent into the river could have resulted in the deterioration of the water quality and proceeded to the point of obvious signs of pollution.

Large numbers of Odonata and Chironomidae were found at *site 01* (Table 6). This site was located downstream of the sewage treatment works. The families present at this sampling site support previous studies for example Hellawell (1986), who also noted that "discharges of organic material and sedimentation generally eliminates some taxa altogether and reduced the numbers of other taxa present whilst increasing the number of tolerant species". The SASS4 and ASPT results (91 and 6,5) reflected moderately impaired water quality.

The flow regime was low and turbidity was high, a possible consequence of the increased sediment load from land–use changes which may have contributed to an increase in anthropogenically induced fine sediment deposition. A wide diversity of biotopes was available and sampled (Table 5) for invertebrates and the IHAS score (57) obtained was considered fair.

Site 02 was located at Kingsway Road. At this site intolerant clean water forms were rare (Table 6). The fauna consisted chiefly of Diptera, Oligochaeta (aquatic earthworms) and Hirudinea (leeches) (Table 6). The decline of intolerant, clean water families and the increase of tolerant families reflected the degradation of the water quality (Table 6). The low diversity and the reduced number of the macro-invertebrates were a result of nutrient enrichment and siltation from urban runoff. The full range of biotopes (Table 5) was sampled and the IHAS score (58) obtained was considered fair. At *site 02*, a SASS4 score (57) and an ASPT score of (5,2) was recorded. This finding suggested that the low SASS4 and ASPT scores were a result of impaired water quality rather than that of habitat degradation. The SASS4 (Fig. 13) and ASPT (Fig. 14) scores differed between the two sampling sites (*site 01* and *site 02* samples). Both sampling sites could be classified as moderately impacted. Diversity was higher at *site 01* than at *site 02.*

7.6. THE ISIPIHINGO RIVER

This river receives return flow from the Isipingo waste waterworks that is of domestic and industrial origin.

During the survey *site 01* and *site 02* showed evidence of faecal pollution and litter. When sampling began the first light rains of the season had fallen and as always after rain, there was much paper and street litter in evidence, which was a possible source of contamination. *Site 01* had excellent bank cover and riparian vegetation. A great diversity of biotopes was available for the sampling of macro-invertebrates (Table 5) and contributed to the excellent physical condition of the river, which resulted in a good, IHAS score (74).

The macroscopic invertebrate fauna occurred in lower numbers although Chironomids (Table 6) remained one of the most common family. The most noticeable differences in the biota was the greater diversity of annelids present at *site 01* but absent at *site 02* (Table 6) and the IHAS score recorded at *site 02* was low (45). The low SASS4 (40) and ASPT (4) scores at *site 01* suggested that some other factor (most possibly the affects of faecal pollution) other than habitat availability had contributed to the decline in the biodiversity of the invertebrates at this section of the river.

The low scores obtained could have been attributed to the fact that this river receives sewage effluent (organic pollution) the associated nutrient enrichment, which may have contributed to the poor water quality at this site.

At *site 02* more than one species of Ephemeroptera were present. This was considered rather unusual. However a likely explanation for their presence could be they have an ability to tolerate the silt conditions and therefore survived the deposition of materials from organic effluents. Examples of exploiters of severe organic enrichment at this site were the larvae of flies and their abundance could have been associated with organically enriched waters. *Psychoda* is essentially an inhabitant of mud flats and more commonly associated with heavy organic loading. The decline of intolerant species and the increase of tolerant species reflected degradation of the water quality.

At this site the removal of bank-side vegetation resulted in the subsequent loss of shading and loss of detrital input during leaf fall and so increased light entering the water, which could have encouraged algal growth and soil erosion. The large quantity of silt that was present in the water was detrimental to macro-invertebrate growth and development. It filled interstices thus reducing habitat space and the exchange of gases and water and most certainty resulted in the absence of oxygen-sensitive species. According to Wood and Armitage (1997) and once again confirmed in this study, silt altered habitat structure and leads to a decline in habitat quality. Most of the biotopes were absent (Table 5). The IHAS score (45) obtained at *site 02* was low.

The SASS4 score and the ASPT score recorded at *site 02* were as follows (29, 4,1). Low SASS4 (Fig. 13) and ASPT (Fig. 14) scores at both sites indicated that the water quality was severely impacted (Table 7).

7.7. THE IZIMBOKODWENI RIVER

This river receives return flow from the KwaMakuta / Toti wastewater treatment works. The point sources of pollution are factory and sewage effluent and one of the diffuse sources of pollution was probably due to the sporadic storm sewer runoff from the surrounding area which "drain" into the river.

At *site 01*, most of the major biotopes were absent (Table 5). The available biotope was restricted to only a sandy riverbed. At this location the river was reduced to a small stream. The water was discoloured, muddy and highly turbid which reflected the effect of sedimentation from sand mining. Since large quantities of fine particles were washed from the sand back into the river using river water, the impact on the biota was similar to the impact of increased silt load due to erosion. This led to the reduction of habitat diversity and habitat modification through siltation and an altered food source. Increased sediments found in the area were thought to have originated as a result of human influenced erosion rather than material brought down the river from the upper zone. The combined action of sedimentation and water level must have contributed towards the steady disappearance and modification of a whole series of microhabitats at this sampling site. The scant number of families present (Table 6) indicated that the water quality at this site was severely impacted and the low SASS4 and ASPT scores recorded confirmed this finding (24 and 6). A slightly different distribution of invertebrates were observed at *site 01* with a community restricted in terms of both family composition and abundance influenced by the highly mobile nature of the sediment preventing any degree of settlement. The IHAS score (48) rated low at *site 01* compared to excellent IHAS score obtained at *site 02* (68).

The AECI water purification plant was located in close proximity to *site 02*. Points of particular interest included the considerable biological improvement at the *site 02* compared to *site 01* with noticeable differences in biota that were present. Plecoptera, Trichoptera, Ephemeroptera and a greater diversity of Odonata dominated the macro-invertebrate communities at this sampling site (Table 6). An appreciable abundance of fish (including eels) frogs and spiders were also present. This site had a higher number and diversity of families present in the sample (Table 6) which remained remarkably high.

The change in water quality between *site 01* and *site 02* coincided with an increase in the SASS4 (154) and ASPT (7) scores. The SASS4 score (Fig. 13), ASPT score (Fig. 14) and the number of families present were high, confirming that the water quality was not impacted at this site.

At *site 02* there appeared to be a strong relationship between invertebrate pattern and the amount of vegetation available for sampling and the associated invertebrates increased with the increase of vegetation and benthic ones increased with increased open bed. The gravel was probably well oxygenated and stable due to the high flow and low turbidity. Sand mining at *site 01* played a role in the decline of the SASS4 scores as the impacts of sand mining which include erosion and sedimentation did not allow invertebrate communities to establish themselves. The sand biotope had the fewest taxa associated with it. All biotopes available were sampled (Table 5) and an IHAS score of (68) was obtained at *site 02*.

Site 03, selected below the pipe system embedded into the river from the AECI chemical factory where treated effluent was discharged into the river. This represented an additional point source of pollution to the river.

Slime, silt and sludge covered up and destroyed bottom dwelling organisms. Therefore only a few highly tolerant families were represented at *site 03* (Table 6) due to the unfavourable environment. Whereas the water at *site 02* was clear, at *site 03* the water was foamy and discoloured. It was assumed that the discharge of chemical material into the water might have produced the persistent foams, which significantly reduced the rate of oxygen exchange at the water surface. The railway bridge located overhead may have also added other dirty and poisonous runoff into the river. This most probably reduced the diversity of invertebrates present and contributed towards the altered water quality. The river was impacted upon by a recent disturbance (road construction), which resulted in an increased sediment deposition. These factors in combination resulted in the poor water quality recorded at this site.

The water was turbid and flow of the river was minimal. Most biotopes were present apart from stones-in-current and bedrock (Table 5). It can be concluded from the results obtained that the absence of a major type of habitat such as the stones-in-current, can be the cause of a particular family not being present. The IHAS score (46) at this site was reduced. The macroscopic fauna was severely restricted to pollution tolerant organisms (Table 6). At *site 03* SASS4 and ASPT scores (7 and 2,3) were low and showed degraded/ modified conditions.

7.8. THE uMLAZI RIVER

The uMlazi wastewater plant is the only continuous point source discharge into this river and included the effluent flow and seepage from the Lamontville, Umlazi and Chatsworth wastewater works that drain into the uMlazi River. This river is disturbed before it reaches the Durban boundary but is further degraded within the city.

Site 01 was located in close proximity to an informal settlement, which occurred along side the river and the population density remained high all along the river valley to the second sampling point. Informal settlements impact on water quality when the waste that is generated as part of the normal day to day activities in the settlement reaches the river. Sanitary conditions were rather primitive and pollution must have occurred during all seasons. Within the context of developing communities, diffuse pollution generally results from a variety of sources which include a lack of adequate infrastructure, sewage waste from failing or non–existent sanitation system, household refuse and litter (solid waste), land-use practices and storm water which washes pollutants into the rivers. The condition of the uMlazi River reflected the impacts of dense informal settlements without formal sanitation facilities. As a result, much of the river was devoid of life and notorious for the smell. The combination of the physio-chemical factors made this sampling site probably the most stressful environment for macro-invertebrate.

This is a moderately sized river with a widely fluctuating flow, upstream being medium and downstream almost still. Even though stones and gravel were present at *site 01* (Table 5) dense algal growth on these surfaces tended to clog interstices. Interstices were filled with sediment (a result of erosion and sediment containing waste) that had accumulated because of the reduced flow. In such an environment, burrowers tended to increase in numbers for example, worms which live under the sediment surface, build tubes and feed on detritus. Marginal vegetation was coated with green slime that produced surfaces unfavourable for dragonflies, leeches and worms but favoured midges and small mayflies. The result was a limited fauna comprising freshwater species that could tolerate the increased organic matter and capable of withstanding wide variation in oxygen levels. Leeches were present but were restricted in terms of their numbers. A likely explanation for this was that without a clean, hard substrate to adhere to, clingers like the leeches also disappeared. This was reflected in a decline in invertebrate taxa, with a progressive disappearance of mayflies, stoneflies and caddisfly larvae. Most outstanding were the large numbers of simuliids and chironomids present.

There was a reduction in the diversity of the macro-invertebrate community (this is a condition typical of many stresses) represented by relatively few individuals characteristic of clean water families. These families are those, which are able to take advantage of the changes, which the pollutant induces, and exploit the increased organic particulate matter in the riverine ecosystem. The second change noted was the absence of indicator species characteristic of clean water such as the stoneflies and the replacement of species previously not abundantly present. The SASS4 score and ASPT score recorded at this site were as follows: (40 and 4). The IHAS score obtained was high (74).

Site 02 consisted of a number of planorbids and physid snails as well as Chironomids, Ceratopogonidae and Psychodidea (Table 6) reflecting the poor quality of the receiving river. The SASS4 (29) and ASPT (4,1) scores were recorded.

The area sampled had a number of biotopes present except for bedrock (Table 5). The most significant feature providing the necessary evidence of a highly polluted reach was the formation of a black layer of ferrous sulphide in the mud and sand biotopes. This was associated with decaying matter with a diminished circulation of air and water through the substrate. The IHAS score obtained was high at both sampling sites (Fig. 12).

Diversity was reduced at both sampling sites however a few highly tolerant taxa were present in fairly large numbers. The faunal analysis at *site 01* and *site 02* of the river indicated conditions of organic enrichment. The number and diversity of intolerant macro-invertebrates recorded were low (Table 6). The presence of high numbers of the genus *Baetis* was attributed to the presence of suitable substratum. It was concluded that the water quality upstream and downstream in the uMlazi River was heavily polluted (Table 7) as displayed by SASS4 (Fig. 13) and ASPT (Fig. 14) scores.

7.9. THE MHLATHUZANA RIVER

This river receives return flow from Hillcrest, Umhlatazana, Findlay Court and Blundell Road Sewage Waste Water Treatment Works.

At *site 01* certain invertebrates were present in fairly large numbers mostly comprising of the highly tolerant Diptera (Simuliids and Chironomids) as well as Oligochaetes and leeches (Table 6). The presence of three species of Hydropsychidae however cannot be accounted for. The most likely explanation of the presence of this species could be attributed to the high-low regime and medium turbidity. The water quality at this point was classified as impaired as indicated by the taxa present as well as the low SASS4 (55) and the moderate ASPT scores (5). The variable substratum and a wide range of habitats available, provided a surface for macro-invertebrates to cling to or burrow in, shelter from the current, material for construction of cases and tubes and refuge from predators. The IHAS score (55) obtained at this point was low despite most biotopes being present (Table 5).

Site 02 comprised of a diverse invertebrate fauna including a large number of Plecoptera, and Ephemeroptera and Trichoptera (Table 6). Even though *site 02* was located close to the road and below the railway line these surrounding land use did not seem to have any significant impact on the SASS4 score (110) and the ASPT score (5,8). This could be due to excellent condition of the river at this site and the fact that all major biotopes were available for sampling (Table 5). The water was clear and of good quality as indicated by the presence of pollution intolerant macro-invertebrates. The IHAS score (62) was rated as good. Clearly a combination of factors including high flow as well as low turbidity, a good mixture of bank and riparian vegetation and good bank cover contributed to the invertebrate diversity at this site.

The Mhlathuzana River was highly polluted at *site 01* but recovered significantly in a downstream direction. The water quality recovery was reflected in the SASS4, ASPT scores and the number of taxa present, at *site 02*. The most probable explanation for the recovery of the macro-invertebrate communities was related to sediment stability and higher oxygen levels at *site 02*. These factors were probably responsible for the large number and diversity of aquatic insects found at *site 02*.

7.10 THE UMBILO RIVER

This river receives return flow from Pinetown Sewage Works. The Umbilo River at Paradise Valley Nature Reserve is a well-known recreational spot. Recreation therefore contributed to increased disturbances and possibly resulted in the loss of structure (bank cover). Activities in the catchment are reflected in changes in the associated riverine ecosystems and disturbances even in the upper reaches may have an effect down the entire length of the river.

The N3 Bridge located above *site 01* may have also contributed to the storm water runoff. Motor vehicles imposed an additional urban-related stress on aquatic insects due to hydrocarbons leaked from automobiles (i.e. oil and petrol) as well as rubber and heavy metals. Urban runoff also contains significant quantities of lead that contributes to the heavy metal concentrations in the riverine ecosystem.

Site 01 was located below the waterfall at Paradise Valley Nature Reserve. At this site the river had already passed through approximately 5 km of heavily industrialised and commercialised area. The invertebrate fauna composed exclusively of a diverse family of Diptera in fairly large numbers; also quite surprising were the large numbers of mayflies present (Table 6). It can therefore be concluded from the nature of invertebrates present (Table 6) and the dense algal growth at this sampling site that this section of the river suffered from organic enrichment and eutrophic conditions. The low SASS4 (44) score combined with a low ASPT score (3,4) indicated impaired (modified) water quality.

The river at this sampling point had excellent bank cover and riparian vegetation. The full complement of biotopes was available and sampled at this site (Table 5).

The IHAS score (72) obtained at *site 01* was high. From the scores obtained it can be concluded that habitat availability was not responsible for the poor diversity of invertebrates found at this site and that water quality at this site was impaired as a result of the various uses made of this river as it travels through the city.

Site 02 was located below Caversham Road in the centre of Pinetown. This river drains the industrial heartland of Pinetown and is subjected to insults of intensive exploitation particularly from the textile and pharmaceutical factories upstream, urbanisation and new construction before reaching the sea.

A number of planorbid and physid snails, oligochaetes, chironomids and leeches (Table 6) were present at this site. This sampling site was characterised by a diverse group of Baetidae (close to four species). The mayfly *Baetis* is an active freshwater genus, which tolerates low values of oxygen except in slow current (Allan, 1995). The current was moderately fast flowing at this river site which was a possible explanation of the largely diverse population of mayflies that develop at this site.

Site 02 demonstrated a similar pattern to *site 01* with the invertebrate fauna influenced by sediment mobility. However, stable patches of substratum within the zone appeared to support a divergent mayfly population. It was of interest that SASS4 scores showed that although considerably degraded conditions occurred at *site 01* whilst conditions at *site 02* were better. The IHAS score was good (65) despite the absence of the marginal vegetation and bedrock biotopes (Table 5). At this point the river had a mixture of vegetation and excellent bank cover. The SASS4 (58) and ASPT (5,8) scores were low and reflected the modified water quality.

According to Chutter (1998) the Umbilo River according to SASS4 and ASPT scores was not considered polluted however this study shows that the two sampling sites selected for rapid biological assessment were indeed impacted/ modified (Table 7).

7.11. THE UMNGENI RIVER

This river system receives return flow from New Germany, Northern and KwaMashu Works and is subjected to various forms of pollution as it passes through urbanised and the highly industrial areas.

The uMngeni River at *site 01* was situated a few hundred metres away from a textile factory. The riparian vegetation comprised of grass. All biotopes were present and sampled at this site (Table 5). Large amounts of silt altered the substrate resulting in distinct changes in the invertebrate assemblage. The large unstable superficial layer of silt and sand together with the reduced amount of light reaching the substrate because of the rise in water level (taking into account the considerable turbidity), created conditions which were unsuitable for the benthic algae and macro-invertebrates, which depend on such flora. The water was discoloured and turbid.

According to Chutter (1994) it was concluded that when "SASS4 is less than 50, ASPT is of little use in interpreting the results in relation to water quality". "In this SASS4 range ASPT values less than 6 indicate water deterioration, the lower the SASS4 score and the ASPT value the greater the deterioration" (Chutter, 1994). The conclusion to be drawn from the SASS4 (42) and ASPT (4,7) data collected at *site 01* was that water quality was impaired for invertebrates at this sampling site (Table 6). This site indicated an altered water quality in a manner consistent with changes in other rivers of DMA where urban runoff and organic enrichment occurred.

Two events that had an impact on the SASS scores at *site 02* were urban runoff from Connaught Bridge and storm discharges from surface runoff. During the wet season, the storm water drains into the river and carries much organic matter and street refuse into the river as evidenced from litter found at this site during the study. The large amounts of debris alongside the river were suspected as another possible entry point for additional pollution. A few hundred metres upstream of the sampling point, mining of the river sand is a major activity.

Macro-invertebrate fauna was severely restricted to a few tolerant organisms comprising of only oligochaetes and chironomids (Table 6) being more pronounced in the sandy bottom. The SASS4 (16) and the number of taxa (Table 6) decreased in a downstream direction following the broad trend of deterioration in water quality. The ASPT score of (5,3) was recorded at *site 02* and the IHAS score was 62. The overall picture derived from a broad comparison of the fauna in the uMngeni River suggested that this river was severely impacted at both sampling points a result of different types of effluents and runoff entering the river.

The IHAS score (Fig. 12) was high and all biotopes were sampled (Table 5). The flow rate was constant. The bed of the river below the discharge of the motorway construction runoff acquired a covering of sand and sandbanks began to build up.

The results obtained from this study suggested an impaired water quality for the selected sampling sites, for scores were not nearly as high as recorded in unpolluted sections of the uMngeni River by Chutter (1994).

7.12. THE UMDLOTI RIVER

This river receives both point and diffuse source of pollution. Point source of pollution includes return flow from wastewater works. Diffuse source of pollution includes runoff from agricultural land. Agriculture in the river valley is extensively developed and comprises mainly of extensive sugar farming and it is assumed that biocides may have occasionally drifted into the aquatic ecosystem. As previously mentioned farming practices tend to speed runoff and remove the protective cover on the land and excessive sedimentation may have choked, smothered and created instability as well as altered the chemistry of the riverbed and altered the invertebrate community.

At *site 01* the most outstanding result was the presence of the large numbers of snails, simuliids, chironomids and Ceratopogonidae (Table 6). The changes in the substratum through increased sedimentation of organic matter resulted in the predominance of tolerant and the absence of intolerant freshwater invertebrates.

The conditions were more enriched as displayed by the low SASS4 (35) and ASPT (3,9) scores. From the nature of the pollution of rivers by agricultural land, increased organic load and nutrient load usually accompanies low dissolved oxygen content (chemical analysis obtained from Durban Metro Waste Water Management Branch), the results obtained are not at all unexpected.

Increased sediment found at this site was thought to have originated as a result of human influenced erosion, rather than material brought down from the upper zone. The increase of nitrogen and phosphorous content in the water (chemical analysis obtained from Durban Metro Waste Water Management Branch) have been perhaps one of the major man induced water quality changes influencing the productivity of river ecosystems.

Inorganic and organic enrichment in the river resulted in slime infestations and deoxygenation of water, which could have decreased the primary productivity. This was evidenced by the dense algal growth. Biotope diversity was greatly restricted with the absence of stones-in-current, stones-out-of current, bedrock and gravel. The IHAS score at this point was relatively moderate (50).

Site 02 showed impacts of intensive agricultural farming displayed by the resulting low SASS4 score (51) and the intermediate number of families that were present (Table 6) and a consequently low ASPT score (4,6). The riparian vegetation and bank cover were well developed in this section of the river. There were pieces of dead vegetation floating in the water and the surrounding area was under intensive sugar cane cultivation, which also may have contributed to runoff into the river. The water at this site was slow flowing and highly turbid. A low IHAS score (40) was obtained (Table 6). Nutrient enrichment tends to mirror changes in rivers subjected to organic pollution. There was a decline in oxygen–sensitive families as the water deoxygenated (a result obtained from Durban Metro Waste Water Management Branch).

7.13 THE OHLANGA RIVER

This river system receives return flow from Phoenix and Umhlanga works.

Site 01 was upstream of a small dust road used daily by vehicles associated with the sugar industry. The surrounding land was all under sugar cane. Sugar cane cultivation is a major driving force in this region and has impacted on the natural environment as large tracts of land have been cleared for plantations. At *site 01* the flow rate was medium and turbidity low. There were dense clumps of algae and water lettuce floating in the river. There was also a highly offensive odour in the atmosphere and clear signs of organic pollution. Loss of streamside vegetation in this section of the river was attributed to cultivation and other human activities. Runoff from agricultural land and discharge from the sewage treatment works contain high concentration of nitrogen and phosphorous (chemical analysis obtained from Durban Metro Waste Water Management Branch). The increase in the temperature (a result obtained from Durban Metro Waste Water Management Branch) of this segment of the river resulted from deforestation which could have contributed to the deterioration in the faunal composition at this site (Table 6).

The recorded SASS4 (66) and ASPT (5,1) scores *at site 01* indicated impaired water quality. The SASS4 scores (Fig. 13) were not in conflict with the suggestion that organic pollution was contributing to the decline in the invertebrate composition at this sampling site.

Biotopes required for sampling of invertebrates were limited at this *site 01* (Table 5). The changes in the structure of the assemblages of invertebrate appeared to correspond to the elimination of many taxa caused by the progressive modification of the biotope. A moderate IHAS score (Fig. 12) was obtained at this site.

At *site 02* of particular interest was the number of planorbid and physid snails that were present (Table 6). Certain groups such as stoneflies and cased caddisflies were absent and the loss of these species were attributed to the discharge of sewage effluent further upstream and conditions not being appropriate for growth and development of these relatively clean-water species. The leeches also became less abundant, a changed attributed to the loss of a suitable substratum. The recorded SASS4 (32) and ASPT (4) scores indicated major deterioration in water quality.

Both flow regime and sedimentation governs physical structure, therefore affecting the biotope availability. Sediment will erode from land by natural processes and incoming sediment from the land contains chemicals. It is assumed that the removal of trees might have increased silting downstream. Agricultural activities in this area may have enhanced soil erosion and has likely resulted in large areas of soil and subsoil disturbance. This may have also lead to increased loads of silt and soil particles entering the river resulting in the observed high turbidity. Thus the combined action of sedimentation and water level must have contributed to the steady disappearance of a whole series of microhabitats and hence the development of varied fauna. The biotopes available for sampling were restricted to sand, mud and gravel (Table 5). A moderate habitat score was obtained (52).

7.14 THE TONGATI RIVER

This river system receives discharging effluent from a mixed residential and heavily industrialised area. The industrial component included a proportion of textile waste from Whitehead textiles and return flow from Tongaat Sugar Mill.

Sources of possible contaminants entering this river might have included runoff from the sugarcane field, which usually contains organic matter, and residues from chemical sprays. Deforestation and construction are two other possible sources of impacts at this sampling site and may have also altered macro-invertebrate population. Where the substratum were absent, it was evident that the invertebrate population was altered i.e. they can adapt to other habitats, but where more than one habitat types are missing, the greater is the overall chance that an invertebrate family will be missing. Consequently altered erosion/silting regimes does not allow invertebrate populations to develop properly. These changes in the structure of the substratum modify the retention and development capacities of the food resources used by the macro-invertebrate (Allan, 1995). Many invertebrates need to crawl out of water to become adults. Increased sedimentation can limit their movement. Even though the effluent is treated to a high standard, because the flows are large, the polluting load causes a drop in the dissolved oxygen. Sampling was conducted in spring with a high midday temperature.

This river is also a recipient of textile waste that contains both organic and inorganic ingredients. These wastes tend to produce high turbidity and consequently result in the discoloration of the water.

The aquatic insect community was reduced (Table 6) through substrate instability, variable discharge, periodic oxygen depletion and occasional introduction of toxic substances. At *site 01* Chironomids, Ceratopogonidae, and Simuliids occurred in fairly large numbers and some Baetidae also were present (Table 6). The SASS4 (31) and ASPT (4,4) scores recorded was low.

Site 02 was situated in close proximity to the construction site. This site receives urban runoff. Most biotopes were absent at both sampling sites (Table 5). The SASS4 and ASPT scores recorded were as follows (31 and 3,4). The IHAS score was higher at *site 01* (62) than at *site 02* (48). The fauna at both sites was severely restricted both in numbers as well as in diversity. Conditions at *site 02* were similar to that found at *site 01*. The biota found below the effluent discharge was consequently made up of the most tolerant taxa with only few families present (Table 6). The recorded SASS4 and ASPT scores (Fig. 13 and Fig. 14) at both sampling sites were low and indicated major deterioration in the water quality (Table 7).

****

Data concerning the rivers of the Durban Metropolitan Area has been collected and analysed. The three-metrics, SASS4, ASPT and IHAS scores have been examined. Invertebrate abundance within the rivers of the DMA appeared to vary uniformly with variation in the habitat. Invertebrate families often experience the effects of more than one environmental variable simultaneously.

CHAPTER 8

8.1 CONCLUSION

In conclusion, this study has shown that most of the rivers in the DMA are under pressure from a range of human activities: some suffer from eutrophication, for example the Ohlanga River. There are those rivers contaminated with bacteria originating from untreated sewage arising from poorly serviced settlements or broken down blocked sewerage pipes, for example the uMlazi River. Furthermore most of the rivers in the DMA are negatively affected by catchment malpractices such as sandwinning, flooding due to catchment hardening, soil erosion, siltation, runoff from informal housing and from accidental or illegal discharges from industrial activities, for example the Tongati, Umbilo, iSipihingo Rivers. Drawing more than the sustainable yield, the increasing water demands and pollution of the existing resources will only further weaken the DMA future freshwater resource capacity.

The primary objective of the thesis was to assess the health of the rivers in DMA using freshwater aquatic invertebrates. In doing so, this document incorporated two data processing methods used in biomonitoring, the South African Scoring System SASS4, RBA and the Integrated Habitat Assessment System (IHAS version 2c). These data processing techniques were applied to macro-invertebrate data collected from fourteen rivers of different water quality status in the DMA.

SASS has proved to be an extremely useful tool for assessing water quality and the general river health of the DMA. Detection of impairment of water quality or river health was based on the interpretation of SASS scores calculated for a monitoring site and the general guidelines for the interpretation of SASS scores have been formulated (Chutter, 1998) was adapted in this study. The results of this study demonstrated that biological methods could integrate responses to combinations of all contaminants and to other sources of environmental stress, thereby indicating overall affects in a water body. In the aquatic environment, the quality and quantity of water is reflected in the biotic communities and a reduction in either or both of these components may lead to changes in the biota. The resultant mismatch between biological data and environmental conditions has been used in this study, to an advantage, to show how far faunal communities have changed as a result of impacts (they cover the whole range from sensitive stoneflies to mayflies to very tolerant aquatic worms). The relatively undisturbed river ecosystems with acceptable water quality and substrate conditions were characterised by high family diversity or richness (several different types or taxa e.g. stoneflies, mayflies and caddisflies) and an even distribution of individuals amongst aquatic invertebrate families. A healthy population of these organisms indicated nonpolluted waters for example the iLovu River. In disturbed river ecosystem subjected to point or nonpoint sources of contaminants, altered community structure (usually a decrease in family diversity) for example the iSipihingo River and the uMlazi River. If a river contains a large number of pollution tolerant organisms, like sludge worms and leeches, along with few or no pollution sensitive species, then the river water may well be polluted.

This study demonstrated how simple and rapid (but controlled and standardised) sampling analysis of aquatic invertebrate communities using SASS4 Rapid Biological Assessment technique provided valuable information about river health. In drawing conclusions about the likely quality of water at low SASS4 scores (below 50) the SASS4 score would be the reliable indicator rather than the ASPT score. It is suspected that this is the result of a relatively high scoring family in a community otherwise made up of a few low scoring families would have a disproportionate impact on the ASPT. At ASPT scores above six, ASPT scores were considered the indicator of water quality rather than SASS4 scores. Thus an ASPT score above six combined with SASS4 score (between 50 and 80) represented a better water quality than indicated by the SASS4 score alone. Both scores were considered when determining water quality impairment. SASS "appears" to be sensitive to most forms of pollution (for example disturbance as defined by proximity to sewage treatment plants, catchment land-use and cover, industrial and residential effluent, agricultural and storm water run off, soil erosion and run off from informal settlements and other forms of pollution), which were recognised as having an impact on aquatic invertebrates. This study also shows that even infrequent RBA analyses can report reduced scores and provide at least an indicator that such events have indeed taken place.

The interpretation of results also required the careful recording of the habitat types from which the invertebrate collection was made. Generally, different families or species of invertebrates prefer different habitats, and all types of habitats in the river were sampled if they were present. It was reaffirmed that the habitat integrity of the rivers in the DMA provided the template for a certain level of biological integrity to be realised. Although sedimentation is a naturally occurring phenomenon in rivers, poorly managed agricultural practices and construction have resulted in an increase in anthropogenically induced fine sediment deposition leading to a decline in habitat quality. In particular it would appear that anthropogenic modifications (sand mining, dredging, channelisation and impaired riparian buffer zones) had a detrimental impact on the habitat integrity of the rivers surveyed in the DMA.

The results thus far obtained showed that ASPT was largely independent of habitat diversity. Indeed this finding would appear to be rational, in that each habitat would be expected to support some taxa, which would be classified as pollution intolerant (high scoring taxa) and some would be classified as pollution tolerant (low scoring taxa). Thus there is a logical argument that habitat diversity should have little impact on ASPT, since the absence of a habitat(s) should result in the loss of both tolerant and sensitive taxa (Chutter, 1998). At intermediate and poor water quality sites ASPT scores did not follow habitat quality, and in good water quality sites both SASS4 and ASPT tended to be greatest where habitat quality was the best. The inclusion of the Integrated Habitat Assessment System (IHAS 2c) allowed for a more comprehensive assessment of ecosystem health and more confidence could be linked to the outcome of the results. The concept of SASS4 is speed, with as much reliability and consistency as possible. The IHAS system was similarly designed. The preceding chapter has provided sufficient biological and physical information (based on the SASS4, ASPT and IHAS scores) on the state of the rivers in DMA, (see Section 6.7).

Although this was only a pilot study, all fourteen rivers in the Durban Metropolitan Area, were surveyed. This thesis provided valuable insights on the health of rivers of DMA and identified the need for biological monitoring using SASS4 and IHAS assessment techniques. It should be noted that the SASS4 and IHAS techniques was not designed to enable the exact nature of the disturbance to be determined, and it was intended that once an impairment of water quality was established it would require further analysis via intensive chemical and other studies. In this study no attempt was made to relate SASS4 results to water quality by means of statistical analysis due to the small data set produced, a consequence of a single sampling of the rivers surveyed. Further studies need to take several factors into consideration, which should include seasonal variability, classification of reference sites and environmental variables.

It must be emphasised that SASS provided a rapid and understandable method of determining river health. This method is relatively simply in its demands on taxonomic skills and in the interpretation of results. SASS4 is an efficient and cost effective method for the detection of water pollution that generates a reliable index of water quality and river health. Savings can be made in reduced sampling and more efficient data analysis. This method also allows one to survey a large number of sites using limited resources and provides timely feedback to water resource and wastewater managers. The information obtained using SASS methods of water quality analysis as well as IHAS analysis could be used by water resource managers, prospective developers and controlling bodies to formulate an environmentally acceptable plan for the conservation and protection of the rivers of the DMA. It may also be used to explore patterns in structure and functioning of river communities. This thesis confirmed that SASS (RBA) provides a reliable source of information, which reflects water quality over prolonged periods and integrates all water quality impacts. It should be the first component to be adopted in any biomonitoring programme.

It is recommended that the City of Durban make use of biological indicators to monitor river health (SASS) and recognise the values of river systems at the macro planning level and at the level of decision-making affecting individual river systems. Given the importance that catchment management is receiving at a national level (via the Water Act) it is timeous that this study shows in practical terms the applicability and potential benefits of using SASS4 as a preferred method of monitoring river health.

The City of Durban needs to place additional focus on protecting its extensive freshwater environment through the implementation of SASS (RBA) technique and Intergrated Habitat Assessment System so as to rebuild collapsed freshwater ecosystems, protect their biodiversity and create a greater sense of responsibility and awareness amongst those who utilize this resource and indicate where conservation resources should urgently be concentrated. This study can be usefully transferred to future projects, which, it is hoped, will benefit from this information.

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Appendix 1

The SASS Field Record Sheet

SASS 4 Score Sheet

UMGENI WATER•AMANZI

Date: / /200__

Grid References:
S: ° ' "
E: ° ' "

:..
Sample point no:............ Sampler..................
ple point description:..
her Condition:..
ument used: Probe ID
.............:................) Temp:.............°C
.............:................) pH:...................
.............:................) DO:...............mg/l
.............:................) Cond:...............mS/m

ple type: Routine/Non-Routine/Customer

opes sampled:
.... Time................minutes
inal veg'n......... Dom. sp......................................
tic veg'n......... Dom. sp......................................
C................ Sand................
.... Gravel.............
ock.............. Hand picking/Visual observation

regime: Low/Medium/High/Flood

dity: Low/Medium/High

ian land use: eg. industrial, cattle farming, etc.

bance in the river: eg. sandwinning,
lrinking point, floods etc.

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

observations:

√	Taxon	Score	Abun
	Porifera	5	
	COELENTERATA		
	Hydra sp.	1	
	Planarians	5	
	ANNELIDA		
	Oligochaeta	1	
	Leeches	3	
	CRUSTACEA		
	Amphipoda	15	
	Crabs*	3	
	Shrimps	8	
	HYDRACARINA		
	Hydrachnellae	8	
	PLECOPTERA		
	Notonemouridae	12	
	Perlidae	12	
	EPHEMEROPTERA		
	Polymitarcyidae	10	
	Ephemeridae	15	
	Baetidae 1sp	4	
	Baetidae 2 sp	6	
	Baetidae > 2 sp	12	
	Oligoneuridae	15	
	Heptageniidae	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	

√	Taxon	Score	Abun
	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	
	Hydropsychidae 2 sp	6	
	Hydropsychidae > 2 sp	12	
	Philopotamidae	10	
	Polycentropodidae	12	
	Psychomyiidae	8	
	Ecnomidae	8	
	Hydroptilidae	6	
	Other moveable case larvae:		
	case types		
	1	8	
	2	15	
	3	20	
	4	30	
	5	40	
	> 5	50	
	LEPIDOPTERA		
	Nymphulidae	15	
	COLEOPTERA		
	Dytiscidae*	5	
	Elmidae/Dryopidae	8	
	Gyrinidae*	5	
	Haliplidae	5	
	Helodidae	12	
	Hydraenidae	8	
	Hydrophilidae	5	
	Limnichidae	8	
	Psephenidae	10	

√	Taxon	Score	Abun
	DIPTERA		
	Blepharoceridae	15	
	Tipulidae	5	
	Psychodidae	1	
	Culicidae*	1	
	Dixidae	13	
	Simulidae	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	
	Sphaeriidae	3	
	Unionidae	6	
	Sample score		
	No. of families		
	Score/taxon		
	IHAS		

Other families present:

cedure: Kick stones in current (SIC) for 2mins. Sweep marg/aq. veg'n for 2m. SOOC kick +/- 1m2, sand/mud stir with feet for 30 secs. Sample gravel and any other biotopes for 30 secs. Hand picking & visual observation for 1 min. 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

APPENDIX 2

THE IHAS FIELD RECORD SHEET

INTEGRATED HABITAT ASSESSMENT SYSTEM (IHAS)

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

SAMPLING HABITAT

	0	1	2	3	4	5
Stones In Current (SIC)						
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 SICs (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

	0	1	2	3	4	5
Vegetation						
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		mi…
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

	0	1	2	3	4	5
Other Habitat / General						
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	>…
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.	no…
Tray identification: (PROTOCOL - using time: *corr*=correct times)		under		corr		ov…

(** *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

	0	1	2	3	4	5
Physical						
River make-up: (*pool*=pool/still/dam only: run only: rapid only: *2 mix*=2 types etc.) ..	pool		run	rapid	2 mix	3 …
Average width of stream: (metres)		>10	>5-10	<1	1-2	>2-…
Average depth of stream: (metres)	>2	>1-2	1	>½-1	½	<…
Approximate velocity of stream: (slow=<½m/s, fast=>1m/s)	still	slow	fast	med.		m…
Water colour: (disc.=discoloured with visible colour but still clearish)	silty	opaque		discol		cle…
Recent disturbances due to: (constr.=construction)	flood	fire	constr	other		no…
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		op…
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: % T