AN EVALUATION OF THE RIPARIAN VEGETATION INDEX (RVI) IN KWAZULU-NATAL

By

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Submitted in partial fulfillment of the academic requirements
for the degree of
Master of Environment and Development
in the
Centre for Environment and Development,
School of Applied Environmental Sciences,
University of Natal

Pietermaritzburg
2003

PREFACE

The research described in this mini-dissertation was carried out at the Centre for Environment and Development, University of Natal, Pietermaritzburg, under the supervision of Dr Nevil Quinn.

This mini-dissertation represents the original work of the author and has not otherwise been submitted in any form for any degree or diploma at any university. Where use has been made of the work of others it is duly acknowledged in the text.

Simon Clarke

Dr Nevil Quinn

ACKNOWLEDGEMENTS

I would like to thank Dr Nevil Quinn for his tireless supervision, moral support, encouragement and friendship, without which this degree would not have happened.

I would like to thank the River Health Programme, especially Chris Dickens and Mark Graham from Umgeni Water, for the financial support and tiring RVI assessments.

I would also like to thank the other RVI assessors for taking off time from work to help me in my fieldwork, namely Donovan Kotze, Angus Burns, Roddy Ward and David Johnson.

Lastly I would like to thank my parents for their love and support.

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CHAPTER 1
INTRODUCTION

Rivers provide almost all of the surface water that can be exploited in South Africa, and are not only aesthetically and recreationally important parts of the landscape, but sustain an exceptionally high quality of biodiversity in their ecosystems (Day *et al.* 1986). Riparian vegetation serves to link the instream aquatic ecosystem to the adjacent terrestrial ecosystem, which in turn influences river process and pattern. Montgomery and MacDonald (2002) note that riparian vegetation is a key indicator of channel condition.

Riparian vegetation plays an important role in the functioning of riparian zones (Wissmar & Beschta 1998). These functions are not only important from an instream, aquatic perspective, but are vital for the surrounding terrestrial habitat. This is especially important in arid and semi-arid areas (Patten 1998), which dominate large parts of South Africa. The functions that riparian vegetation perform in an ecosystem also provide a number of important goods and services to society. For example, an undisturbed, functioning riparian zone helps ameliorate water quality. Yet despite these essential roles the rate of its removal is becoming alarming (Henderson & Wells 1986; Rowntree 1991).

In response to the rapid deterioration of our water resources a number of biological monitoring techniques have been developed, globally and locally, in order to improve management of our dwindling aquatic resources. Effective management, however, is dependent on the information provided by appropriate and proper resource monitoring (Roux 2000). Biological monitoring, or biomonitoring is based on the assumption that measurement of the condition of aquatic communities can be used to assess the condition of the associated ecosystem (Roux 1997). In trying to obtain a measure of health, ecologists have focused on identifying sets of indicators which can be used to assess the condition of a river relative to some normative, undegraded or reference condition. A reference condition is that condition which can be expected in the absence of human impacts (Roux *et al.* 1999). The reasons for using reference conditions are that the health of the system can be rated against a comparable, relatively pristine habitat (Roux & Everett 1994). This has elicited a considerable amount of criticism, as there is no historical record of what constitutes a natural, pristine site and as such it is a very subjective decision (Oberdorff & Highes 1992), further exacerbated by the compounding affects of natural and anthropogenic disturbances.

A national monitoring programme that focuses on measuring and assessing the ecological state of riverine ecosystems has been instigated for South Africa. This programme, the River Health Programme (RHP), was developed with the overall goal of expanding the ecological basis of information on aquatic resources, in order to support the rational management of these systems (Roux 1997). The concept of ecological integrity, is used as the basis for measuring and assessing the ecological state of aquatic ecosystems in the River Health Programme (Roux *et al.* 1999). Kleynhans (1996:43) defines ecological integrity as "the ability of an ecosystem to support and maintain a balanced, integrated composition of physicochemical and habitat characteristics, as well as biotic components, on a temporal and spatial scale, that are comparable to the natural characteristics of ecosystems within a specific region". This essentially means that the condition of an ecosystem is assessed relative to how that system would function within its hypothetical natural state (Roux 2001). This suggests that the biomonitoring techniques utilised by the River Health Programme should be functional indices that assess the health of a system comparative to a hypothetical, natural state.

The Riparian Vegetation Index (RVI) is one of the biomonitoring techniques utilised in the River Health Programme. Kemper (2002 *pers. comm.*) notes that the RVI was developed with the following purposes in mind:

- to provide an indicator of riparian vegetation health and ecological status in response to the full range of disturbances typically common in riparian areas;
- to aid decision making by identifying sites of different riparian vegetation status and providing clear indications of the type and extent of disturbances present; and
- the index must be applicable nationwide to a range of systems and which can be rapidly undertaken by staff currently responsible for collecting other monitoring data.

1.1 PROBLEM STATEMENT

The focus of this study will be the verification of the reliability and validity of the RVI. One of the objectives of the River Health Programme is to ensure that all reports provide scientifically and managerially relevant information for national aquatic ecosystem management (Roux 2001). For this to occur the information provided by the biomonitoring techniques must be both reliable and valid. The test of reliability will be whether the results obtained from a number of experts undertaking the RVI assessment can be reproduced or replicated by other experts. The test of validity will be a theoretical assessment of whether the RVI is measuring the attributes that it set out to do, and whether this measure is indeed suitable.

Kemper (2001:3) notes that "development of the RVI must provide a functional and useful index which can be applied or implemented on a wider or even national basis if necessary". This indicates that the RVI should indeed be a measure of the functional attributes of riparian vegetation, and thus the theoretical analysis of the validity of the RVI will be undertaken against functional criteria. Questions will be posed as to whether a functional index of riparian vegetation is suitable, and whether there are any alternatives.

In order for the RVI to provide relevant information it is vital that the index is not only valid, but is reliable too. Therefore the RVI will be tested in a range of different vegetation types to ascertain its reliability.

1.2 AIM

The aim of this study is to determine the reliability and validity of the Riparian Vegetation Index (RVI) in different riparian vegetation types in KwaZulu-Natal and make recommendations for the River Health Progamme for quality assurance standards.

1.3 OBJECTIVES

- To test the current formulation of the RVI in a number of vegetation types in KwaZulu-Natal. A specific purpose of this will be to evaluate whether the RVI is biased toward woody species or not.
- To undertake a sensitivity analysis of sub-indices of the RVI in order to explore the behaviour of the index.
- To assess the reliability of the RVI by testing whether different experts' RVI scores, as well as the sub-indices within the RVI, correlate at the same sites.
- To assess the validity of the RVI by testing whether the RVI is measuring the attributes that it set out to do, and whether this measure is indeed suitable.
- To provide recommendations to achieve quality assurance in the use of the RVI so that operators can be at the same standards countrywide.
- To provide recommendations for the future development of the RVI.

CHAPTER 2

THE IMPORTANCE OF RIPARIAN VEGETATION

2.1 INTRODUCTION

Riparian zones are the interfaces between terrestrial and aquatic ecosystems. Defining riparian zones is important for both ecological and managerial reasons (Naiman & Decamps 1997). The word "riparian" refers to land adjacent to a body of water, as it is derived from the Latin word "ripa" meaning bank or shoreline (Gold & Kellog 1997). The National Water Act (Act No. 36 of 1998) defines a riparian habitat as "the physical structure and associated vegetation of the areas associated with a watercourse, which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent areas."

Riparian environments have been defined in different contexts, usually dependent on the management aim or objective. These contexts can be generically classed into legal, biological, and functional perspectives (Table 2.1).

Table 2.1. Definitions as based on context in which riparian areas are used or managed (Karssies & Prosser 1999; Lovett 2000).

CONTEXT	DEFINITION	DISADVANTAGES
LEGAL	Riparian land constitutes a set width (usually 20m – 40m, according to the act or country in which the area is defined) along the banks of designated rivers and streams. The exception being the National Water Act (Act No. 36 of 1998) primarily due to its recent promulgation.	May not consider stream factors such as channel size, flow characteristics and riparian vegetation.
BIOLOGICAL	**Vegetation:** riparian lands can be distinguished by the vegetation which is obviously (often visually) different to the surrounding terrestrial land.	May be impractical as riparian areas are so varied between sites and within sites.
	Landform: that area between the low-flow level of the watercourse and the highest point of the transition between the channel and its floodplain.	May neglect adjacent features such as wetlands and estuaries which also affect the extent of the riparian area.

		Only applies to riparian defined in the narrow sense of adjacent to the stream channel.
FUNCTIONAL	Riparian lands are part of the landscape adjacent to streams which exert a direct influence on streams and on the water and aquatic systems contained within them. The definition may be accompanied by an indication of: • the type of features directly affected by the riparian area including the channel morphology and bank stability; • the physical and chemical properties of the water; • the aquatic ecosystem and water quality; and • the conservation, recreation, aesthetic, or commercial values of the given riparian area in question.	May not take the importance of the whole landscape into account.

Functional definitions attempt to consider all these factors by defining a riparian area in terms of its functions and benefits, and consequently are usually the most widely adopted choice of definition. Wissmar and Beschta (1998) note that an essential component in the definition of riparian ecosystems is the recognition of the functional roles of these systems across different spatial scales. The fact that riparian vegetation plays such an important role in the functioning of riparian zones makes these definitions more pertinent. The functions that riparian vegetation perform in an ecosystem provide a number of important goods and services to humanity. For example an undisturbed, functioning riparian zone plays an integral role in the lives of many rural people as the vegetation provides important resources in the form of food and medicine.

Understanding the functional aspects of riparian vegetation is essential to grasping why riparian vegetation monitoring is undertaken. In order for these functions to be understood clearly though, the geomorphological and hydrological setting must be described.

2.2 THE GEOMORPHOLOGICAL AND HYDROLOGICAL CONTEXT

2.2.1 Introduction

The functions of riparian vegetation must be analysed in the context of geomorphology and disturbance, specifically hydrology (Bendix & Hupp 1999). The hydrological and geomorphic processes act as primary ecosystem drivers, whereas chemical and biological factors act as secondary response variables (Tabacchi *et al.* 1998). A longitudinal, geomorphic delineation of the stream ecosystem is used in order for all the functions of riparian vegetation to be understood. The reasoning is that riparian vegetation structure, and consequently their functions, can change according to their position in the longitudinal context of a river. This has implications for riparian vegetation monitoring as a site with little riparian vegetation high up in a catchment may be classified in a poor state. However, the lack of riparian vegetation may be as a direct result of intense but natural disturbance, such as regular flooding.

2.2.2 The influence of geomorphology

The myriad of factors governing the health and functioning of stream ecosystems can be classified as internal (endogenous to the riparian system) or external (exogenous to the system) (Tabacchi *et al.* 1998). Thus they can be delimited spatially in order to consider the relationship between the stream and the riparian vegetation. It can be assumed that every type of river system has its own character (e.g. geological and climatic traits), and thus its own geomorphological structure. Therefore the reciprocal control between hydrology and vegetation may be analysed from a geomorphological template.

Stream channel and floodplain morphology are governed by the volume and timing of discharge, the volume, timing and character of sediment delivery and transport, and the large-scale geological history and geomorphology of the drainage basin (Tabacchi *et al.* 1998). The major physical factors of river catchments that influence the development of riparian corridors are the bedrock geology, geomorphic features such as fluvial deposits and landslides, soil character, climate and hydrological regimes (Tabacchi *et al.* 1998). These physical factors operate in three large geomorphic provinces of a river catchment:

- the erosional (E) (headwaters);
- transfer (T); and
- depositional (D) (Schumm 1977 in FISRWG 1998).

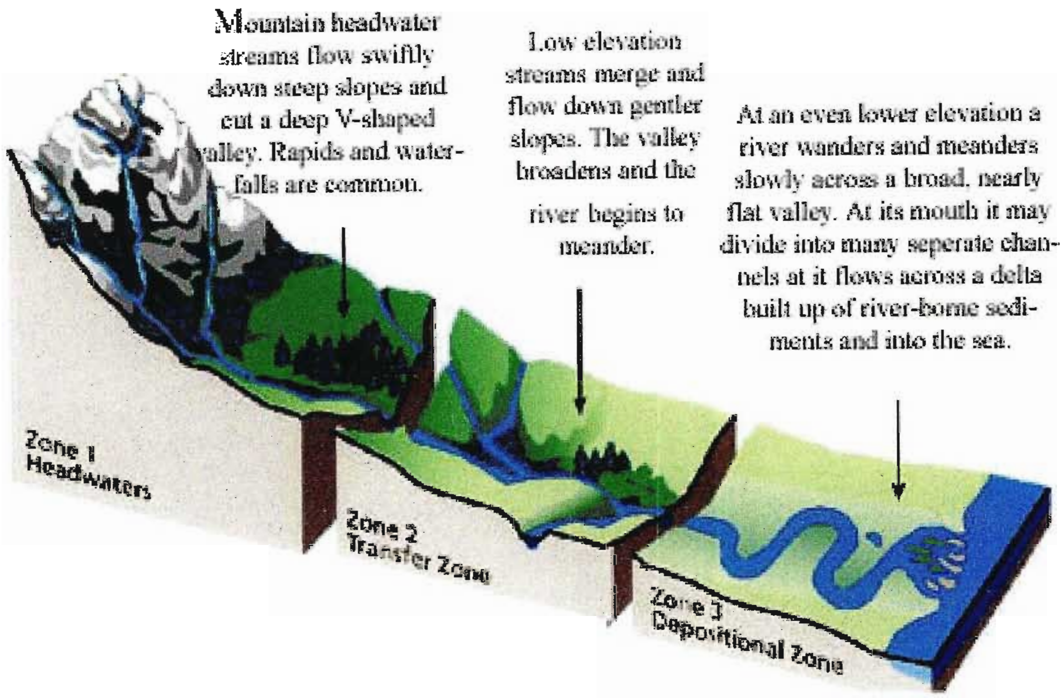

Figure 2.1. Indications of the change in river characteristics in the three geomorphic provinces down the longitudinal profile of a river (FISWRG 1998).

Table 2.2. The geomorphological characteristics of the three longitudinal provinces of a riverine system (after Schumm in FISRWG 1998; Tabacchi *et al.* 1998).

PROVINCE	CHARACTERISTICS
EROSIONAL (E)	Located in the steep headwaters and is characterised by a high gradient channel (>4%) that is structurally controlled by a V-shaped valley. This results in water high in kinetic energy with a greater ability to transport bedload of a variety of particle sizes.
TRANSITIONAL (T)	Located in the river valley and is characterised by a channel gradient ranging from 1 to 4%, with enough kinetic energy for considerable transport of suspended sediments of small size (approximately 0.2 - 250mm diameter). This province is generally located within the middle course of the river, exhibits slow rates of meandering as well as having multiple channels with islands.

DEPOSITIONAL (D)	Characterised by a channel with a shallow, low gradient (<1%). It corresponds to the lower course of a river and contains a braided, unstable channel which exhibits a high rate of deposition of fine sediment (<0.2 mm diameter).

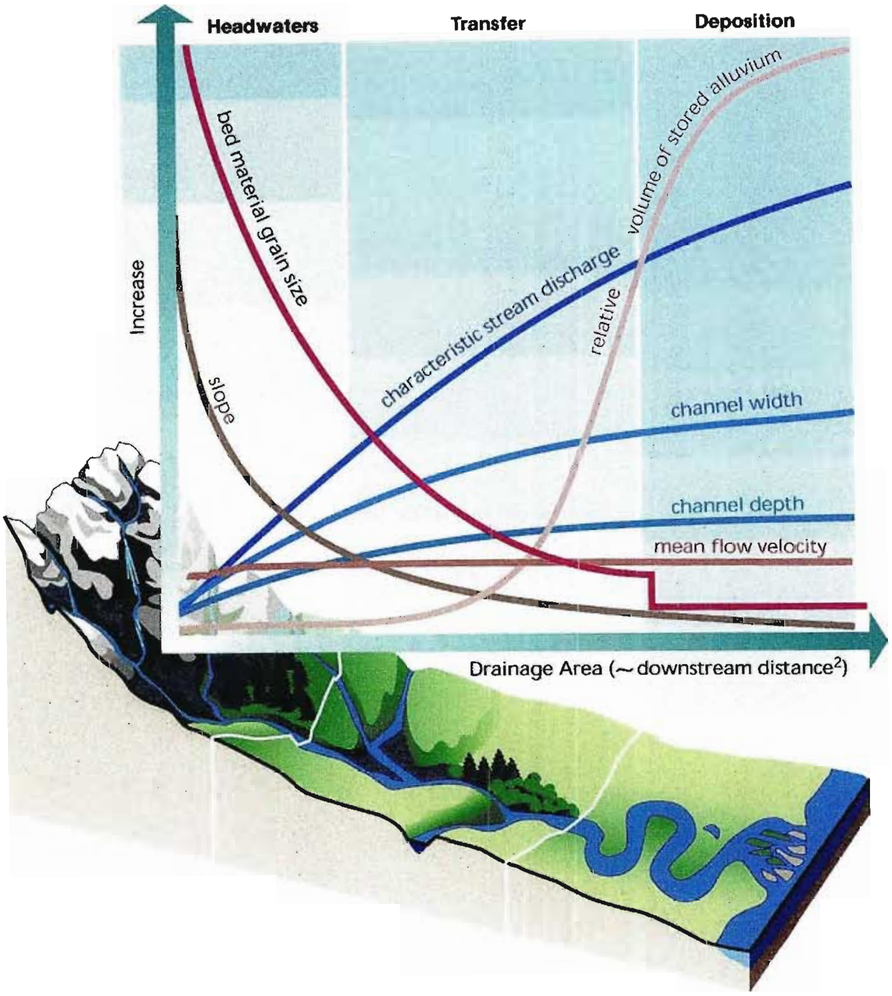

Figure 2.2. An indication of the manner in which flow, channel size and sediment characteristics change throughout the longitudinal profile (FISRWG 1998).

It must be noted that channel type, slope and length throughout the river continuum is also influenced by terrestrial factors, such as bedrock formations and geomorphic changes relating to soil character, hillslope gradient and land use history. For example, an erosion resistant area of bedrock in the transitional province will give rise to a localised section of deposition in that province, which would otherwise not have occurred there. This in turn will affect the composition of riparian vegetation in that localised area. This has implications for a riparian vegetation monitoring technique because if monitoring was undertaken in that specific section the results would not necessarily be representative of that zone, or the whole river.

In order to contextualise how riparian vegetation and their functions may alter down the longitudinal gradient of a river the River Continuum Concept is described.

2.2.2.1 The River Continuum Concept

The River Continuum Concept is an attempt to generalize and explain longitudinal changes in stream ecosystems (Vannote *et al.* 1980). The concept views all rivers as possessing continuous gradients of physical and chemical conditions that are progressively modified downstream from the headwaters to the sea. Each species of riverine organism will be confined to those parts of the river where physical and chemical conditions are suitable for it (Figure 2.3).

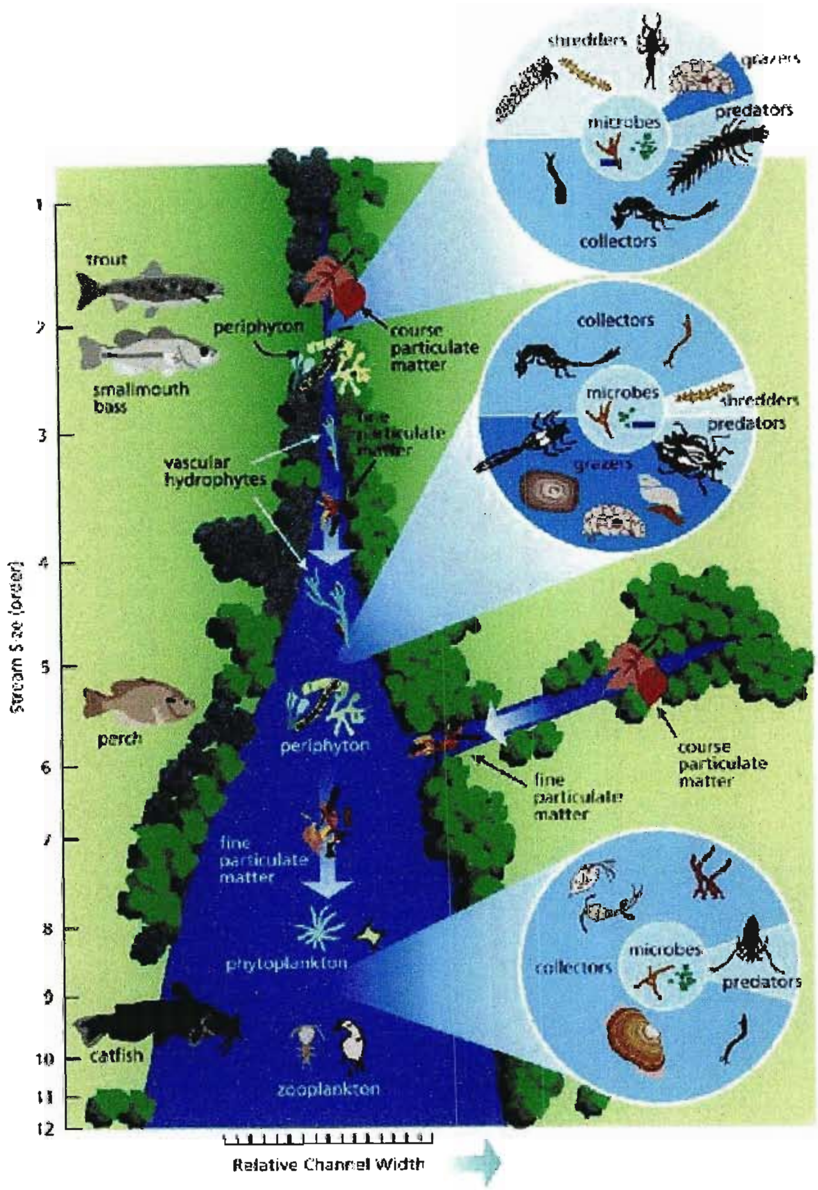

Figure 2.3. The River Continuum Concept which proposes a relationship between stream size and the progressive shift in structural and functional attributes (Vannote *et al.* 1980).

The first to third order streams located in the headwaters, which are generally very narrow, are characterised by shading of riparian vegetation. The stream is therefore reliant on allocthonous inputs to provide the primary productivity as algae and other aquatic plants cannot photosynthesize and provide energy. Thus streams in this zone are considered heterotrophic. These first to third order stream are often located on hard mountain rocks that weather slowly thus reducing the amount of mineral input (Davies & Day 1998). This produces a fairly harsh environment, and along with stable temperature regimes tends to reduce the biodiversity to organisms specifically adapted to those conditions. The quality and quantity of leaves and other plant debris falling into the stream determine not only the number of organisms that can be supported, but also the type and complexity of the food-web (Ferrar *et al.* 1988). This has profound implications for land management, deforestation and river bank clearance in South Africa (Ferrar *et al.* 1988).

As one progresses downstream to the fourth, fifth and sixth order streams, primary production increases and shifts streams to a dependence on autochthonous materials (materials generated from inside the channel), or autotrophic production (Minshall 1978). This is a result of the gentler slope, wider bed, slower currents and increased temperatures due to sunlight penetration therefore allowing the aquatic plants to maintain a hold in the channel, photosynthesize and facilitate primary production. Species richness in this zone tends to increase as a variety of new habitat and food resources appear. Tabacchi *et al.* (1998) note that the diverse plant assemblages characterise the wide riparian corridor in this zone. Davies and Day (1998) point out that patches of vegetation, such as the palmiet reed, *Prionium serratum,* occur in this zone in the Western Cape of South Africa where sufficient sediment has accumulated between rocks.

The larger streams of seventh to twelfth order tend to increase in size but undergo significant changes in structure and biological function. There is an increased reliance on phytoplankton for primary productivity, but there are still heavy inputs of organic particles from upstream. The increased stability increases competition and predation which tends to eliminate less competitive taxa and thus reduce species richness (FISRWG 1998). The slow, wide, depositing system is now an ideal environment for the development of dense stands of emergent plants, such as reeds (*Phragmites australis*) and bulrushes (*Typha capensis*) common in this zone in South Africa (Davies & Day 1998; Ferrar *et al.* 1988).

The fact that the River Continuum Concept only applies to perennial rivers and does not take disturbances into account has elicited criticism (FISRWG 1998). Davies and Day (1998) note that it is difficult, if not impossible, to find a whole river system conforming to this model in South Africa. A widespread feature of South African rivers is that the greater part of their waters are now located in artificial lakes formed by the impoundment of rivers (Davies & Day 1998). The catchments of the headwaters of many Highveld streams, such as the Vaal, are grass-covered with no riparian vegetation (Davies & Day 1998), emphasizing that allocthonous inputs from riparian vegetation in headwaters may not be applicable everywhere. However, it has served as a useful conceptual model to explain the idea of connectivity in riverine ecosystems.

The longitudinal change down a river system then will also have implications for riparian vegetation monitoring and management. Following the River Continuum Concept vegetation cover and composition in the headwaters will be considerably different from vegetation in the lower reaches of a river. A vegetation index that is applicable countrywide should be robust enough to account for the differences down a reach. This means that a relatively 'pristine' site at the top of a catchment must produce a result in line with a relatively 'pristine' site at the bottom of a catchment, despite any differences in structure.

2.2.3 The influence of disturbance events

The role that disturbance events, both natural and anthropogenic, play in the structure and function of riparian zones is significant. Gregory *et al.* (1991) point to the frequency of natural disturbances and biological processes in influencing successional stages of riparian vegetation. Examples of natural disturbances include floods, avalanches, debris flows in channels, fire, wind, glacial activity, tectonic and volcanic events (Tabacchi *et al.* 1998). Examples of anthropogenic disturbances include the construction of impoundments, canalization, agriculture and urban development.

Disturbances act to reshape earth landforms, riparian and channel features and contribute to the formation of new habitats. Generally natural disturbances result in a positive change in the riparian habitats and increase heterogeneity. The exceptions are extremely large events that destroy large parts of the landscape. Flooding and geomorphological impacts are the major disturbances which play the greatest role in riparian vegetation composition (Bendix & Hupp 2000; Gregory *et al.* 1991; Hupp & Osterkamp 1985). The most obvious hydrological impact is the destruction of riparian vegetation by extreme flood events. Geomorphological impacts involve the erosion and creation of substrate. The plant successional process is essentially reset by hydrological and geomorphological disturbances. For this reason riparian vegetation structure has been used as an indicator of hydrological and geomorphological events (Tabacchi *et al.* 1998).

In the South African context the role that disturbances play in determining riparian vegetation composition and structure is significant. Davies *et al.* (1993) note that the major characteristics of South African rivers are their variability and unpredictability. This is due to the general aridity of the country where the potential evaporation rate is typically in excess of annual precipitation, and results in extremely erratic stream flow. Allanson (1995) notes that the summer rainfall areas in the 1980's were characterised by one of the most crippling droughts of this century. The drought was then broken, during the summer of 1987/88, by two major rain-producing synoptic events that caused major flooding in KwaZulu-Natal and the Orange River catchment in the southern Orange Free State and the northern Cape Province.

The life history strategies of most riparian plants are such that extreme conditions are either endured, resisted or avoided (Naiman & Decamps 1997). Hupp and Osterkamp (1985) note that plant species vary in their susceptibility to flood disturbance, and therefore the varying severity of flooding within the riparian zone serves to influence the spatial pattern of species composition.

It is evident then that disturbance events can significantly alter the composition and cover of the riparian vegetation. Riparian vegetation monitoring must be mindful of the fact that natural disturbances are an integral component of the system and should be taken into account when necessary. This would result in certain sites scoring high on a riparian vegetation index, despite that site being reasonably devoid of vegetation as it has been altered by a natural flood or fire. This emphasizes the importance of understanding the surrounding catchment uses and processes.

2.3 THE FUNCTIONS OF RIPARIAN VEGETATION

2.3.1 Introduction

Now that the geomorphological and hydrological setting has been described it is possible to understand the full effects of the riparian vegetation and how they may change down the length of a river. It must be noted that riparian vegetation's functions are not only important for the instream aquatic ecosystem but also for the surrounding terrestrial habitat. Wissmar and Beschta (1998) note that a landscape perspective of riparian ecosystems reveals how they are dependent on other ecosystems and provide essential information for developing catchment-wide restoration and conservation plans. Figure 2.4 gives an indication of the functions riparian vegetation plays.

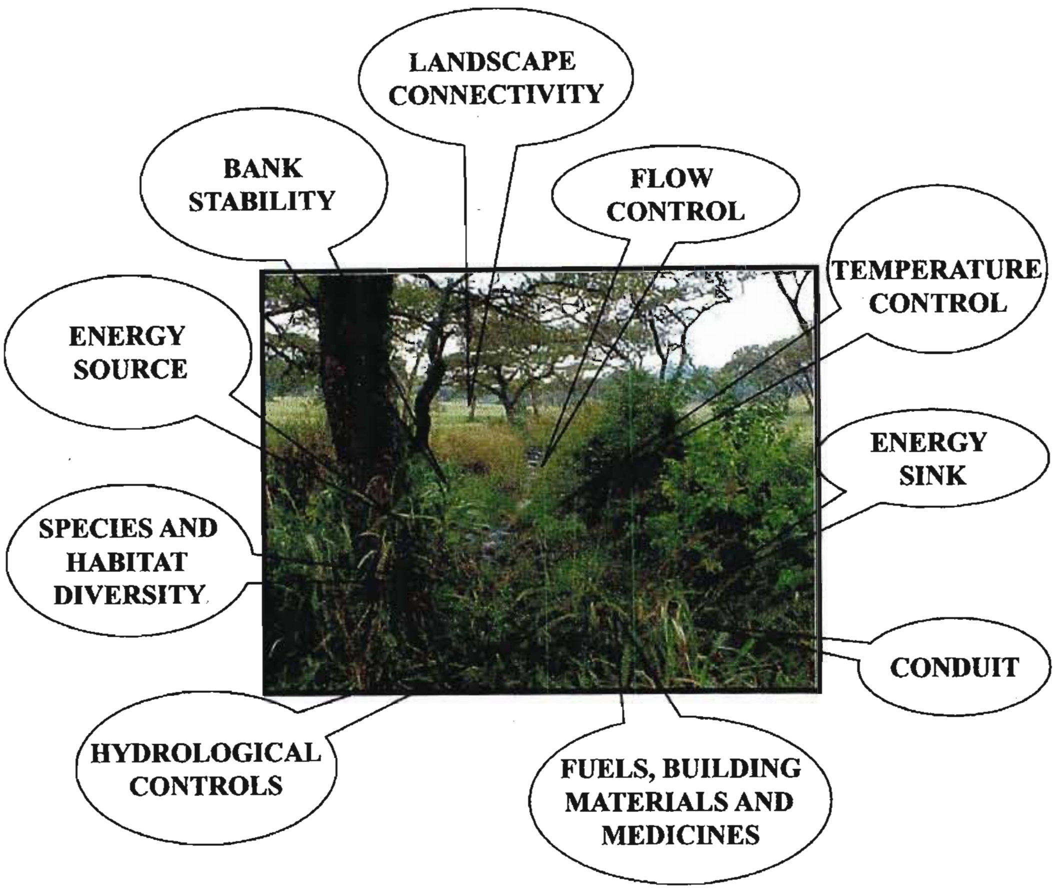

Figure 2.4. An indication of the functions of riparian vegetation in riparian zones.

2.3.2 Riparian corridors and landscape connectivity

The main function of corridors is the provision of pathways along which organisms, energy and matter can move (Forman 1995). The maintenance of genetic variation, dispersal, colonization or recolonization and the provision of habitat are a few of the benefits that corridors provide. A study by Way (1977) illustrated the importance of roadside vegetation corridors in Great Britain. Twenty of the 50 species of mammals, all six species of reptiles, 40 of the 200 bird species, five of the 65 species of amphibians and 25 of the 60 butterflies were all located within the small width of roadside vegetation.

When objects move along a corridor then it is acting as a conduit. The conduit functions of corridors are important for the creation and preservation of stream habitat as the movement of material impacts the hydrology, habitat and structure of the stream as well as the terrestrial habitat and connections in the floodplain and uplands (FISRWG 1998). A wide, contiguous corridor acts as a large conduit, allowing flow laterally and longitudinally. Wider corridors are assumed to be more effective since they have an interior component free of edge effect (Loney & Hobbs 1991). The edge effect refers to the edge (outer band of a patch or corridor), to area ratio of patches or corridors. This ratio can be used to indicate the resistance to external forces of the corridor and can influence the make up of species within a corridor (Forman & Godron 1986), and is exacerbated by disturbance (refer to section 2.4).

The conduit functions of corridors facilitates the colonization of new areas or the recolonization of areas which have suffered losses in species (Nicholls & Margules 1991). The conduit function of riparian vegetation modifies heat and energy from sunlight and regulates extremes in temperatures (refer to section 2.3.6). Although corridors may facilitate the movement of materials and other desirable organisms, their conduit function can also spread weeds, pests and disease both between and across landscapes (Forman & Godron 1986). This has implications for the spread of alien invasive plants longitudinally and laterally into riparian zones in South Africa (refer to section 2.4.3).

A corridor connecting patches acts as a barrier or filter to the movement of materials, organisms, water, wind and other variables (Forman 1995). The stream corridor serves beneficially as a filter or barrier that reduces water pollution, minimises sediment transport, and often provides a natural boundary to land uses, plant communities, and some less mobile species (FISRWG 1998). Riparian vegetation acts as a major filtering agent in riparian corridors as the roots, and associated microfauna, intercept and absorb mineral nutrient runoff and these areas are thus commonly referred to as a sink (refer to section 2.3.4). Furthermore, riparian vegetation may act as a source of energy and matter within the riparian corridor (refer to section 2.3.3). Riparian vegetation may act as a barrier by influencing the movement of water, water runoff and erosion within a corridor (Forman & Godron 1986). A contiguous riparian corridor may act as a barrier to alien invasive plants by out-competing the establishment of alien invasive plant seedlings, an important function in the South African context.

Connectivity has been described as a measure of how spatially continuous a corridor or matrix is (FISRWG 1998). This attribute is affected by breaks in the corridor or between the corridor and adjacent land uses. The high level of connectivity recognised in the riparian corridor mainly results from their location at the interface between the stream and its valley (Tabacchi *et al.* 1998). A stream corridor with a high degree of connectivity promotes valuable functions including the transport of energy and material and the movement of fauna and flora (FISRWG 1998).

It is apparent then that the corridor functions of riparian zones are integral to not only the riparian system but also to the adjoining terrestrial landscape. This function must be expressed in a riparian vegetation monitoring technique in order for it to be considered valid.

2.3.3 Riparian vegetation as a source of energy and matter

Riparian vegetation provides rivers with allocthonous inputs of energy and provides a diversity of habitat. The importance of riparian vegetation as a source is emphasized in the River Continuum Concept where most streams in the erosional province are heterotrophic and rely on inputs of organic matter from the riparian zone (Minshall 1978; Cuffney 1988). Small headwater streams receive as much as 60% to 99% of their organic food base from surrounding riparian forest (Minshall 1978). The vegetation along the stream bank and overhanging the channel provides litter directly into the channel, while vegetation near the bank contributes litter by downslope lateral movement (Correl 1997).

The importance of organic matter inputs in larger, mid-order streams is less so than in the small headwaters (Zah & Uehrlinger 2001). However in a floodplain situation this may differ. The riparian vegetation contributes a considerable amount of primary productivity in the form of leaves, fruit and nuts to the pans in the Pongolo floodplain in northern KwaZulu-Natal, South Africa (Heeg & Breen 1994). The provision of this vegetation to the pans is reliant on the large annual summer flood that overtops the Pongolo River and causes the adjoining pans to fill up, thereby allowing a number of fish species to move into the pans in order to breed.

The provision of woody debris from the riparian zone increases complexity in channel morphology and produces useful habitat for stream biota (Tabacchi *et al.* 1998). Woody debris dissipates energy by decreasing the erosional power of water thereby creating a mosaic of erosional and depositional patches within the river (Naiman & Decamps 1997).

2.3.4 Riparian vegetation as a sink of energy and matter

Stream corridors can act as sinks for the storage of surface water, ground water, nutrients, energy, sediment, water borne soil particles and subsurface mineral nutrients, allowing for materials to be temporarily fixed in the corridor (Forman 1991).

2.3.4.1 Sediment trapping on the surface of riparian vegetation

Sediment loading and deposition constitutes one of the most serious water quality problems throughout the world (Osborne & Kovacic 1993). The semi-arid regions and steep gradients of the rivers; the frequency of flooding; and the history of land mismanagement in many parts of South Africa promotes large sediment loads in South African rivers (Verster *et al.* 1988). Sedimentation can clog fish gills, suffocate fish eggs and aquatic insect larvae and cause fish to modify their feeding and reproductive behaviour (Klapproth 1999). Nitrates and pesticides toxic to aquatic and human life, phosphates which cause algal blooms and faecal bacteria which cause disease all adhere to sediment.

Riparian vegetation facilitates the removal of suspended sediment, along with its nutrient contents from water entering laterally (Lowrance *et al.* 1988; Peterjohn & Correl 1984). The riparian vegetation and the layer of litter it produces is effective at slowing the velocity of water allowing sedimentation to occur on the soil surface (Tabacchi *et al.* 1998). Fine plant roots located at the surface of the soil and microbial communities in the litter assimilate dissolved nutrients at the soil surface attached to the sediment (Peterjohn & Correl 1984). The result is a direct improvement in water quality.

2.3.4.2 Nitrogen and phosphorus trapping by the riparian zone

The consequences of nitrogen and phosphorus pollution are severe. Eutrophication, which is nutrient enrichment by inputs of phosphorus and nitrogen into water resources, is common in South African waters. It causes blooms of aquatic weeds, algae and plankton which cause water quality problems such as unpalatibility of drinking water, foul odours, decreased water transparency, and interference with water treatment processes (Carpenter *et al.* 1998).

It is documented that riparian buffers are one of the most important factors controlling the entry of nitrogen into a stream (Gregory *et al.* 1991; Osborne & Kovacic 1993). Peterjohn and Correl (1984) found that a riparian buffer removed 89% of the nitrogen from field runoff, mostly in the first 19 meters of the buffer. Peterson *et al.* (1992) reported that forested riparian buffer strips reduced nitrogen in the groundwater by 68-100% and in surface runoff by 78-98%. Yet there is still tremendous variation in their effectiveness. Osborne and Kovacic (1993) conducted a review on the effectiveness and variability of riparian buffers on nitrogen and indicated nitrogen reductions of 40-100% due to forested buffer strips and 10-60% for grass buffer strips. Naiman and Decamps (1997) suggest that most of this variability is driven by fine scale differences between rooted and non-rooted soil layers as well as between anoxic and oxic conditions.

There is also tremendous variation in what type of vegetation and what width constitutes the most effective buffer. Blanché (2002) suggested guidelines based on the catchment, organic matter content of the soil, the hydrologic soil group rating and slope in order to establish the most efficient buffer zone for management in South Africa.

It is evident that both the composition and cover of riparian vegetation are essential in acting as both a source and sink within the riparian zone. A functional vegetation monitoring technique would have to include these factors in order to account for these functions. The significance of using cover in a vegetation monitoring technique is dealt with in Chapter 3 and Component B.

2.3.5 Riparian vegetation in arid and semi-arid regions

Watercourses in arid and semiarid regions differ considerably from those in more mesic regions. Their flow is often intermittent or ephemeral and consequently the riparian vegetation is less abundant than in wetter regions, but substantially denser than the vegetation of the surrounding matrix of shrublands or desert scrubs (Salinas *et al.* 2000a). Davies *et al.* (1993) have emphasized that South Africa is characterised by its aridity, which dramatically increases from east to west, and consequently stream flow can be extremely erratic.

Due to the intermittent nature of rivers in arid and semi-arid regions, the riparian vegetation is often dependent on groundwater in aquifers for its survival (Le Maitre *et al.* 1999; Stromberg *et al.* 1996). Riparian vegetation can improve infiltration into alluvial aquifers by improving soil condition and creating surface storage opportunities; and plant roots can increase percolation rates by creating macropores (Le Maitre *et al.* 1999).

This may have implications for a riparian vegetation monitoring technique in South Africa which relies on defining a riparian zone according to the National Water Act (Act No. 36 of 1998) (refer to section 2.1). The riparian zone according to the Act relies on flooding or inundation from the watercourse and does not take alluvial groundwater into account.

2.3.6 Riparian vegetation and stream temperature

Riparian vegetation reduces the temperature of streams by curtailing the amount of solar radiation reaching the channel. The degree of shading is a function of the structure and composition of riparian vegetation (Gregory *et al.* 1991). Light intensity in a shaded stream can be as much as 30% to 60% less than that of an unshaded stream, depending on the season (Klapproth 1999). Continuous stream records showed diurnal fluctuations of up to 5°C in shallow streams with little shading (Sinokrot & Stefan 1993). This can greatly affect the composition of aquatic life so dependent on temperature (Minshall 1978).

Dallas and Day (1993) note that a change in water temperature will affect the dissolved oxygen concentration and change the chemical toxicity of certain elements in the water, such as phosphorus and manganese, to which biota may be exposed. Furthermore, changes in temperature regimes may result in alterations in the timing of life history stages of aquatic organisms by giving false temperature cues and interfering with normal development. There may also be a change in the qualitative and quantitative composition of biota (Dallas & Day 1993). This is because aquatic organisms' body temperatures are regulated by the temperature of the water and if that changes, even by a small increment, movement, behaviour, life stage development, growth and size may all be affected (Dallas & Day 1993).

It is evident then that a vegetation monitoring technique should take aerial cover into account in order for it to be classified as functional.

2.3.7 Species and habitat provision

The riparian habitat is one of the most productive and diverse ecological communities. The flood-pulse concept was developed to summarize how the dynamic interaction between water and land is exploited by the riverine and floodplain biota and contributes to its significant diversity (Figure 2.5). Applicable primarily on larger rivers, the concept demonstrates that the predictable advance and retraction of water on the floodplain in a natural setting enhances biological productivity and maintains diversity (Bayley 1995).

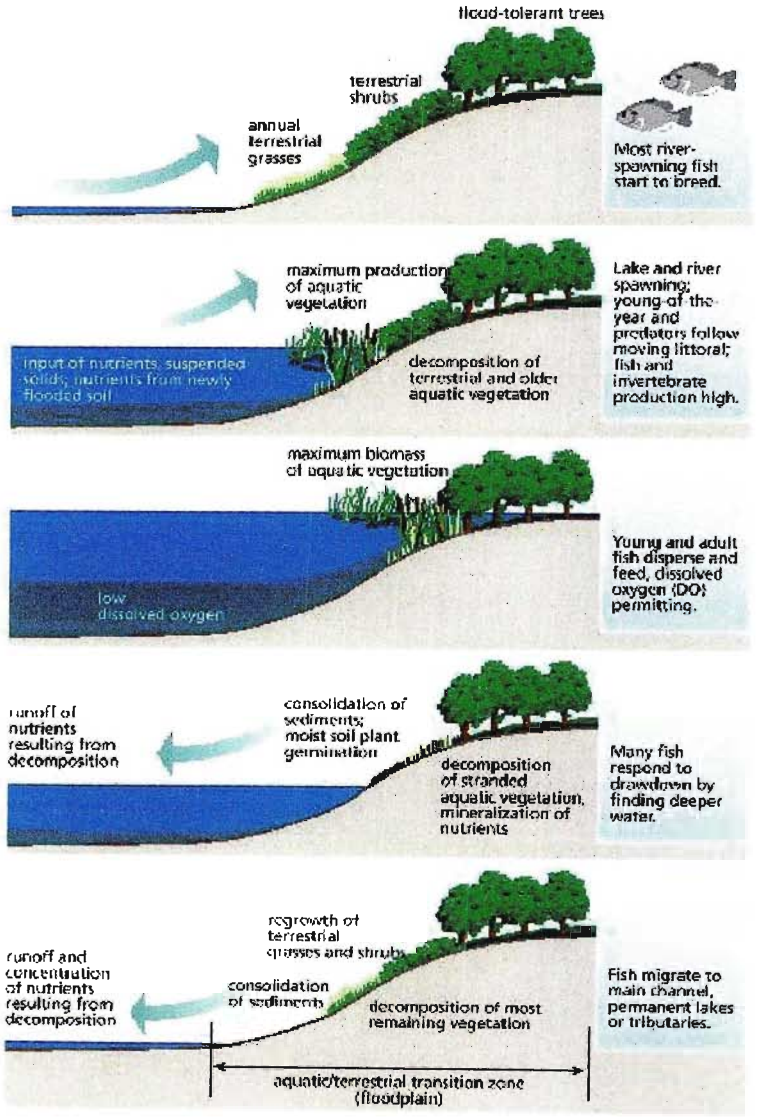

Figure 2.5. An exaggerated section of a floodplain in showing an annual hydrological cycle. The left column describes the movement of nutrients, while the right column describes typical life history traits of fish (Bayley 1995).

Soil properties and topography of valley floors are extremely varied, ranging from perennially-wet to well-drained soils over short distances (Gregory *et al.* 1991). The movement of nutrients, sediment, organic matter and living organisms between the stream, uplands and floodplain and the effect of disturbance and topography contribute to a diverse and productive community.

Due to the abundance of food, water and cover, a considerable number of animals use riparian areas both permanently and temporarily. Within the riparian zone a multi-layered canopy of large trees, an understorey of vines and shrubs and herbaceous vegetation on the forest floor provide an array of habitats. This may emphasize the need to consider all these levels in a riparian vegetation monitoring technique.

2.3.8 Riparian vegetation and stream bank stability

The removal of riparian vegetation has intensified as population growth and economic pressure has increased. During periods of floods, bank erosion problems become more pronounced. This is further exacerbated by a lack of riparian vegetation. The contribution of riparian vegetation to streambank stability is widely recognised (Ikeda & Izumi 1990; Heede 1986; Rutherford *et al.* 2000). Rutherford *et al.* (2000) notes that vegetation reduces erosion in the following ways:

- **Sub-aerial erosion** - vegetation on the bank, or hanging over the bank, protects the bank from erosion due to rain-splash and most sub-aerial processes such as stock trampling.
- **Fluvial scour** - vegetation growing on the bank face dramatically reduces scour (the action of water eroding individual particles). The vegetation also directly strengthens bank material, making it harder to remove from the bank face.
- **Mass failure** – the most important role of vegetation in prevention of mass failure is to reinforce the failure plane (the surface where mass-failure occurs on a stream bank, often identified by a tension crack).

Beeson and Doyle (1995) indicate that bends without riparian vegetation were found to be nearly five times as likely as vegetated bends to have undergone detectable erosion during flood events. Furthermore, the more complex and denser the vegetation the lower the susceptibility of bank erosion.

Rowntree (1991) notes that the roots of vegetation bind the soil, increasing its resistance to erosion by one or two orders. An important distinction can be made between grassy and woody vegetation in terms of their bank stability. Grasses and other herbaceous matter have a low biomass and are shallow rooting, but have a good surface cover. This is most effective against surface scour and enhances stability with respect to shallow slips, but has no effect on mass bank failure (Rowntree 1991). Figure 2.6 is an indication of mass bank failure which may have been prevented by the presence of deep-rooted trees. Trees are less effective against scour, due to their poorer ground cover, but contribute cohesion to the bank material and increase its stability with respect to mass failure (Rowntree 1991). It is vital though that the roots extend to at least the average low water plane. Otherwise, the flow will undercut the root zone (See Figure 2.7). The different contributions of grass and trees to bank stability emphasize the importance of measuring both surface and aerial cover in a vegetation monitoring technique.

Figure 2.6. Mass bank failure.

Figure 2.7. Example of undercutting on the Pongolo River, 2002.

2.3.9 Provision of fuels, building materials and medicines

Riparian vegetation plays an integral role in the lives of many rural people. Mathooko and Kariuki (2000) discovered that approximately 55% of the riparian vegetation species in the Njoro River, Kenya, are used for herbal medicine, treating more than 330 health problems. Sleeping mats, beer strainers, reed screens and traditional mat houses all utilise vegetation located in riparian zones, particularly wetlands (Department of Environmental Affairs & Tourism 2002). Wetland sedges are generally well adapted to regular harvesting and rapidly regrow after they have been cut. Traditional plants located in riparian zones that are used for food include amadumbe (*Colocasia esculenta)* and waterblommetjies (*Aponogeton distachyos)* (Department of Environmental Affairs & Tourism 2002). A riparian vegetation monitoring technique that considers the importance of certain species will ensure that this function provided by riparian vegetation will be accounted for.

2.3.10 Conclusion

It is evident then that there are a number of functions that riparian vegetation contributes to a river ecosystem as well as the adjacent terrestrial system. In order for a riparian vegetation monitoring technique to be considered a functional technique requires careful thought as to whether the aforementioned functions have been included or not.

2.4 ANTHROPOGENIC IMPACTS AND AFFECTS ON THE USE OF RIPARIAN VEGETATION

2.4.1 Introduction

The cumulative effects of anthropogenic disturbances on riparian vegetation can alter the dynamics of the riparian ecosystem resulting in a degradation of water quality and a decrease in aesthetic and economic value. Table 2.3 gives an indication of possible anthropogenic impacts and the effect these play on the riparian vegetation.

Table 2.3. Anthropogenic impacts and the effect these play on the riparian vegetation.

IMPACT	EFFECT ON RIPARIAN VEGETATION
Dam and weir construction, abstraction schemes, hydro-electric schemes and groundwater depletion	Changes in flow regime downstream of the impact, usually result in reduced flows that can cause encroachment of vegetation and a change in species composition in the channel (Bravard & Petts 1996). Surface and groundwater exert a strong influence on abundance and composition of riparian vegetation. Stromberg *et al.* (1996) illustrated that groundwater depletion in semi-arid regions severely threatens riparian ecosystems.
Canalization	Canalization results in the straightening of a river with machinery thus restricting the riparian vegetation to a narrow band and increasing the potential for erosion (Svejcar 1997).
Construction of general infrastructure	Depending on the scale of construction this can result in a change in the physical character of the riparian zone, and may facilitate the introduction of alien species.
Agriculture and forestry	Like the construction of infrastructure these activities will change the physical character of the riparian zone, and may even do so on a larger scale. Forestry is dominated by predominantly exotic species such as black wattle (*Acacia mearnsii*), gum trees (*Eucalyptus spp.*) and pine trees (*Pinus patula*). These are well known alien plants and will change the species composition of the riparian zone (Dye *et al.* 2001). These impacts may also facilitate the invasion of alien plant species.
Grazing and browsing	Excessive grazing and browsing will change the species composition and age structure (Patten 1998). Young, succulent, and preferred species are usually targeted first thus preventing recruitment and changing the age structure and species composition of the vegetation. Overgrazing will result in destabilisation of the river bank which may have disastrous consequences, such as increased sediment loads into the river (Patten 1998).

Utilisation of vegetation for materials and medicinal plants	Unless controlled the effects of overutilisation may result in similar consequences as overgrazing. The targeting of large, mature trees is a specific concern as these trees play an important role in preventing erosion.

2.4.2 Effects at a landscape level

The anthropogenic impacts listed above have resulted in losses to the physical and biological integrity of river catchments. Fragmentation of riparian areas, through human induced disturbance is at the core of habitat loss and decreased biodiversity within riparian zones (Wissmar & Beschta 1998). Fragmentation of the riparian vegetation impedes the movement of energy, material and organisms by reducing the connectivity of the riparian zone. The consequence is formation of patches which have a large edge-to-area ratio. This once again stresses the need for a vegetation monitoring technique that accounts for some measure of connectivity within the riparian zone.

2.4.3 Effect of alien vegetation

A major impact on South African ecosystems over the last 100 years has been their invasion by alien vegetation. Henderson and Wells (1986) have claimed that the most impacted ecosystems in southern Africa are the riparian zones. This is due to their exposure to periodic human and natural disturbance, the perennial availability of moisture, reliable dispersal by water and the role of stream banks as a seed reservoir (Henderson & Wells 1986). The conduit function of riparian corridors has also facilitated the spread of alien invasive plants (Forman & Godron 1986).

Alien vegetation has a significant effect on the abstraction of surface and groundwater, thus reducing streamflows, bank stabilisation and allocthonous inputs into the system. A study of a wattle (*Acacia mearnsii)* plantation north of Pietermaritzburg, KwaZulu-Natal, found that recharge to the groundwater was reduced from the expected 10% of annual rainfall under grassland to zero at five to eight years after planting (Kok 1976 in Le Maitre 1998). A recent study found that the removal of riparian wattle and its replacement by indigenous herbaceous plants may indeed result in significant reductions in annual evapotranspiration, and could very likely lead to streamflow enhancement (Dye *et al.* 2001). Accelerated bank erosion has been associated with *Acacia mearnsii* as well as *A. longifolia, A. saligna., Lantana camara* and *Pinus pinaster*

(Macdonald & Richardson 1986). These species have shallow rooting systems which are unable to maintain stability during floods, are ripped out and cause bank collapse (Rowntree 1991).

The fact that alien vegetation has caused such problems in the rivers in southern Africa, and is directly affecting the functioning of these ecosystems indicates the importance of gauging the level of alien invasion in a vegetation monitoring technique.

2.4.4 Other anthropogenic effects

Rowntree (1991) notes that grassy banks are associated with wider, shallower channels and tree-lined banks with narrower, deeper channels in higher order streams. An anthropogenic impact such as an impoundment or abstraction scheme can result in a change in riparian vegetation type and a change in channel morphology. Eschner *et al.* (1983) in Rowntree (1991) describe vegetation encroachment following upstream impoundment of the North Platte River which resulted in wide, shallow channels being transformed to narrow deep channels. This was confirmed by Rowntree (1991) in a study on the effect of *Acacia mearnsii* on the Mooi River in the north-eastern Cape and was attributed to the sediment trapping of the vegetation. Furthermore, the encroachment of vegetation may be terrestrial vegetation (terrestrialisation) not usually associated with riverine conditions because the flow level has been altered and the conditions now suit terrestrial species. This will alter the functioning of the system as terrestrial species may not be adapted to the specific functions, such as nutrient trapping, that riparian species are (Rowntree 1991). This highlights the importance of understanding other catchment processes, such as the effect of impoundments, in a vegetation monitoring program.

2.5 SYNTHESIS

The objective of this chapter was to establish the primary functions of riparian vegetation, not only from an aquatic instream and landscape level, but also from a societal perspective. It is quite clear that riparian vegetation plays a significant and essential role in the overall functioning of an aquatic ecosystem. Anthropogenic fragmentation of the riparian vegetation is consequently destroying this functioning. The functions of riparian vegetation must be seen from a use perspective. If a resource is to be maintained for the purpose of human use it must be done sustainably, and the use value of the resource should not decline (Walmsley 2002). Use value can also be related to the concept of goods and services. In the field of ecological economics, the concept of ecosystem goods and services has been developed to facilitate dialogue between economists and ecologists (Brismar 2002). An ecosystem good or service is defined as any natural phenomenon that has a perceived societal function or value (Brismar 2002). The river system can be viewed as a potential provider of so-called river goods and services, which are of importance for human life and the functioning of society. The provision of river goods and services fundamentally depends on the natural characteristics of the river ecosystem. Walmsley (2002) notes that the use value of a system is directly related to ecosystem integrity, and if the ecosystem is not functioning properly, this will have a direct effect on use value. In other words the goods and services that are provided by riparian vegetation are dependent on the functions that they perform. The biological monitoring of riparian vegetation then should be a measure of the functions that riparian vegetation perform, as these control the goods and services that society is concerned with.

This chapter, however, has also introduced a number of issues that must be taken into consideration in a riparian vegetation monitoring technique. The geomorphological and hydrological context has illustrated that longitudinally river systems change considerably. The issue of representativeness of a certain section then comes into play in a vegetation monitoring technique, as a site within the depositional province may not reflect the condition of the vegetation in the erosional province. A vegetation monitoring technique must be cognizant of this and theoretically must be robust enough to be used down a river system without being biased to certain sections.

Another issue worth mentioning is the role played by disturbance. Disturbances such as floods and fire are naturally occurring phenomena that can result in a positive change in the riparian vegetation. These disturbances must be accounted for and should not necessarily negatively skew the results of a vegetation monitoring technique. The major problem, however, is when natural disturbances are exacerbated by anthropogenic impacts which negatively impact on the condition of the vegetation. This is a contentious issue that may emphasize the need for experienced, qualified assessors to undertake riparian vegetation monitoring. The preceding chapter has also emphasized that the different functions of riparian vegetation need to be represented by different indicators within a riparian vegetation monitoring technique. For example the width of the riparian zone may be an indicator of the connectivity of the riparian zone and the cover of alien vegetation may be an indicator of the extent of invasion by alien vegetation.

The following chapters then will analyse the context in which the Riparian Vegetation Index (RVI) is found in terms of monitoring, assessment and management and the extent to which the RVI does indeed measure the essential functions mentioned.

CHAPTER 3

KEY CONCEPTS IN RIPARIAN VEGETATION MONITORING

3.1 INTRODUCTION

Rivers are not only aesthetically and recreationally important parts of the landscape, but they act as drains for the land, sustain an exceptionally high biodiversity in their ecosystems and provide almost all of the surface water that can be exploited by man in South Africa (Day *et al.* 1986). Furthermore water is the primary resource upon which social and economic developments are based and sustained. It is vital then that aquatic ecosystems are managed effectively and sustainably for present and future generations. Effective management, however, is dependent on the information provided by appropriate and proper resource monitoring (Roux 2000). One of the critical success factors for effective water resource management is the appropriate assessment of the diverse, interacting components of catchment processes, and the resource management actions that have an impact on the water resources in a catchment (Walmsley 2002). This has led to the development of a number of resource monitoring techniques, globally and in South Africa, to provide a measure of river health, so that effective management can be coordinated. One of these techniques is the Riparian Vegetation Index (RVI) developed to assess river health in terms of riparian vegetation.

This chapter explores how the RVI contextually relates to biomonitoring globally, within the framework of South Africa's legislation. The concepts of river health and biological integrity are assessed in relation to the River Health Programme in South Africa. Indicators, indices and their reference conditions and classification systems are analysed in the international and South African context. The concept of quality control is assessed. Specific reference to riparian vegetation and the RVI is made, where pertinent.

3.2 RIVER HEALTH

The restoration and maintenance of 'healthy' river ecosystems have only recently become important objectives of river management (Karr 1991). Wissmar and Beschta (1998) point out that ecologically two conservation policies have persisted in the United States over the past 50 years: i) the wise use of natural resources by federal agencies; and ii) wilderness preservation by conservation organisations. Today these principles are being replaced by concepts that focus on the preservation of biodiversity and ecosystem function or 'health' (Wissmar & Beschta 1998).

Often ecosystem or river health is seen as being analogous to human health giving a sense of understanding, yet the meaning of river health remains obscure (Norris & Thoms 1999; Hart & Campbell 1994). Norris and Thoms (1999) suggest that it may not be necessary to define the term river health to gain scientific and management value from it. The symptoms and indicators of poor health may be more easily defined and should include physical, chemical, biological, social and economic variables. At a group discussion at a joint South African/Australian workshop held in 1994 participants defined an ideally healthy river as "one which is in or very close to its natural (undisturbed) state" (Hart & Campell 1994:369). Thus the natural state of the river becomes the baseline against which to measure the deterioration of its health. Hart and Campbell (1994) note that the idea of the health of a river originated as a way of describing its condition from the viewpoint of its ecological functioning. This definition and way of thinking is analogous to what an effective riparian vegetation monitoring technique should measure, in other words its functions. However, there are probably no completely natural rivers anywhere and thus a river with few modifications may be termed healthy. One of the better definitions of river health is schematically shown in Figure 3.1.

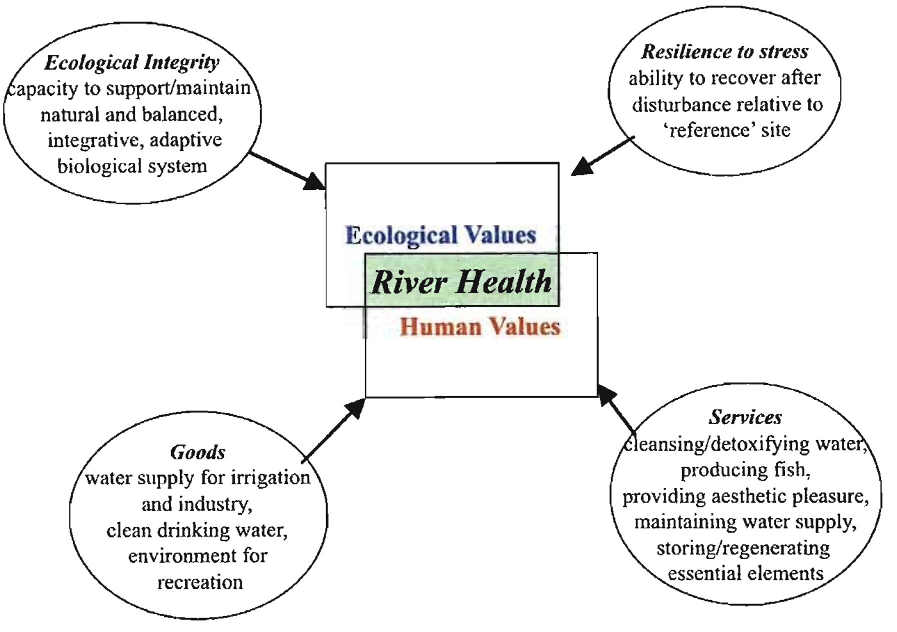

Figure 3.1. Schematic representation of the concept of river health (after Boulton 1999).

The judgment of river health must include human values, uses and amenities derived from the system (Fairweather 1999; Karr 1999; Rogers & Biggs 1999). The values, uses and amenities are represented by goods and services in Figure 3.1. Clean water, providing aesthetic pleasure and storing/regenerating essential elements are all examples of the goods and services provided by riparian vegetation. The inclusion of the human dimension gives the concept of river health part of its novelty and may provide impetus for advances in river ecology (Boulton 1999). Karr (1999) believes that the use of the word health in ecology is useful because it is a concept all people are familiar with. Words such as health and integrity are inspiring to citizens as they are a reminder to those who enforce the law to maintain a focus on the importance of living systems for the well-being of society (Karr 1999).

Despite the apparent value of the health metaphor, it has its critics. Many argue that the term encourages a simplistic value of ecosystems (Callicott 1995; Jamieson 1995) and that attempts to define ecosystem health operationally have resulted in indices with variables that have no ecological meaning. Karr (1999), argues, however, that this may indicate poor choice of metrics rather than being the fault of the metaphor.

3.3 BIOMONITORING

There has been an increase in the use of rapid biological assessments worldwide in order to gauge river health (Norris 1994; Norris & Thoms 1999; Karr 1999). Traditionally, information gathered to assist the management of water resources was non-ecological in nature (Roux 1997). Monitoring was largely focused on chemical and physical water quality variables, with the presumption being that improvements in water quality would result in an improvement in ecosystem condition. However, the measurement of only physical and chemical water quality variables cannot provide an accurate account of the overall condition of an aquatic ecosystem (Roux 1997). For example, physical and chemical water quality variables cannot measure the influence of factors such as the introduction of exotic species or the creation of a barrier that alters stream flow.

Karr (1999) suggests that the rise of biological assessment is attributed to an increase in knowledge and a change in societal values concomitant with an increase in frequency and complexity of human induced stresses. However, the reductionist viewpoint of some of these biological assessment measures (Karr 1991) and the omission of others, such as the social and economic variables, is seen as a criticism (Rogers & Biggs 1999; Fairweather 1999). It is believed that the limited use of biological indicators and techniques in monitoring has contributed to a decline in the health of natural systems (Roux & Everett 1994), and has resulted in the integration of the concept of human values into the definitions of river health as indicated by Figure 3.1 above.

Despite these problems, the trend in increasing use of rapid biological monitoring, or biomonitoring techniques is gaining credibility and popularity as recent advances have made them more user friendly and reliable. Biomonitoring is based on the assumption that measurement of the condition of aquatic communities can be used to assess the condition of the associated ecosystem (Roux 1997). Aquatic biomonitoring can be defined as "the gathering of biological data in both the laboratory and the field for the purposes of making some sort of assessment, or in determining whether regulatory standards and criteria are being met in aquatic ecosystems" (Hohls 1996:12). The use of biomonitoring provides an integrated and sensitive measurement of environmental problems and represents progress in the assessment of ecological impacts and thus the management of water resources (Roux 1997). Furthermore the rapid biomonitoring techniques, which are generally qualitative in nature, are far less costly than quantitative approaches which were seen as a major preventative factor (Norris 1994).

Norris and Thoms (1999) point out that the Australian and New Zealand Environment and Conservation Council water quality guidelines now call for biological assessment. The United States Environmental Protection Agency (EPA) has included biological criteria in its water quality standards programme and a range of other requirements that need biological assessment (Karr 1991). The River Health Programme (RHP), a sub-programme of the proposed National Aquatic Ecosystem Biomonitoring Programme in South Africa, utilises biological assessment in order to monitor its water resources.

In short, the purpose of biomonitoring is:

- to assess the status of a river in order to contribute to management decisions;
- to assist in defining the range of potential uses of the river;
- to ensure that management objectives are met; and
- to detect and estimate the extent of impacts on the river system (Hart & Campbell 1994).

The assessment of river health then relies heavily on the use of biomonitoring techniques. Fairweather (1999) notes that the assessment of health necessarily entails subjective judgements, making comparisons between observations or measurements and non-scientific expectations. The inclusion of human values into the concept of river health ensures that there will be some subjectivity involved.

3.4 INDICATORS USED FOR BIOMONITORING

The choice of biomonitoring technique depends on the choice of indicator. Walmsley (2002) points out that indicators provide a means of communicating information about progress towards a goal in a significant and simplified manner. Fairweather (1999) notes that an indicator is a measure of part, or all of an environment, and which designates its condition along a continuum from degradation to excellent quality. Fairweather (1999) considers that to be useful for management, indicators should also be aligned explicitly against a system of values that aid their interpretation in society's terms. Boulton (1999) notes that perhaps one of the most important roles for river ecologists in this field is to identify and measure indicators of river health. Yet obtaining consensus on this has proved to be elusive.

However, there is some consensus on the attributes of indicators. A good indicator should be cost effective, quick to measure, amenable to sampling, contain clarity of outputs, be repeatable and robust (Cairns *et al.* 1993). Fairweather (1999) notes, however, that many of these features may be in mutual conflict. Sensitivity and robustness must be at loggerheads and so there must be a direct trade-off between these two characteristics. For example, an indicator may be robust enough to sample all river types within a country, but due to the enormous temporal and spatial variability inherent in aquatic ecosystems it may not have the sensitivity to assess these. Finally, the indicator should be one that can be validated: the reliability of the data and what they indicate should be clear (Cairns *et al.* 1993).

A number of authors have recognised that riparian vegetation is a key indicator of channel condition (Kleynhans 1996; Montgomery & MacDonald 2002; Petersen 1992). This is a direct consequence of the functional attributes that riparian vegetation contributes to the channel (Montgomery & MacDonald 2002) and to the habitat and the landscape (Kleynhans 1996; Peterson 1992). Patten (1998) notes that the type, age and spatial patterns of the riparian vegetation can indicate the nature and intensity of past disturbances.

In trying to obtain a measure of health, ecologists have focused on identifying sets of indicators which can be used to assess the condition of a river relative to some normative, undegraded or reference condition.

3.5 REFERENCE CONDITIONS

At the cornerstone of a number of biomonitoring programmes is the use of reference conditions or benchmarks as controls. A reference condition is that condition which can be expected in the absence of human impacts (Roux *et al.* 1999). The reference condition, however, does not imply a stable state and should reflect natural variation over time (Roux *et al.* 1999). Ecosystems are naturally dynamic, often exhibiting hydrological extremes that can still be classified as the normal range of conditions. Since pristine sites are almost non-existent the least impacted sites may be used to define the 'best attainable reference condition' (Oberdorff & Hughes 1992).

Therefore the challenge lies in distinguishing between natural and unnatural ranges of change. Establishing a 'natural' benchmark or reference condition can allow a manager to determine unnatural change and take the necessary remedial steps to prevent the change becoming permanent (Roux 1997). The problem, however, noted by Boulton (1999) is that most river ecologists seem to have adopted the idea that a healthy river and its ecological integrity are as 'natural' and intact as possible. The dilemma arises when we seek departures from this natural state that exceed usual background variability (Boulton 1999). This is especially acute when no unmodified reference state exists.

The reasons for using reference conditions are that the health of the system can be rated against a comparable, relatively pristine habitat (Roux & Everett 1994). Norris and Thoms (1999) suggest that classification of stream types is essential for establishing characteristics of reference sites. The large range of ecosystem types found in South Africa makes assessment of river health difficult. Roux and Everett (1994) point out that the variability among natural surface waters, resulting from climatic, landform, vegetation, soil type and other geographic features favours the use of regional reference conditions, emphasizing the importance of classification. Rogers and Biggs (1999) illustrate that clear definitions of desired conditions, given differing surrounding land uses such as agriculture, forestry or conservation, are required for effective management and assessment. The emphasis on suggesting that reference conditions should be based on the surrounding land use or geographic factors further strengthens the argument in favour of classification.

There has been some criticism leveled at reference conditions, especially at the fact that too much subjectivity may be introduced in their establishment. Bunn *et al.* (1999) suggest that direct measures such as gross primary productivity and the fate of organic carbon should be an integral component in the assessment of stream health. They suggest that these two approaches, both rapid and inexpensive, can be used to establish baseline values for undisturbed systems in order to establish credible reference conditions.

3.6 CLASSIFICATION SYSTEMS FOR ESTABLISHING RELIABLE REFERENCE CONDITIONS FOR BIOMONITORING

A classification system helps us to organise and thus understand complex and variable objects, systems or ideas. The classification of rivers is complicated by both longitudinal and lateral linkages, by changes that occur in the physical features over time and by boundaries between apparent patches that are often indistinct (Eekhout *et al.* 1997). Another problem noted by O'Keeffe *et al.* (1994) is that conditions in the channels, especially in the lower reaches, are often a reflection of conditions upstream, rather than those of the immediate catchment. As a result river classification regions may not coincide with catchment boundaries. This emphasizes the importance of the careful selection of criteria according to the utility of the classification, but may even lead to disappointment of those who believe that one classification system can satisfy all potential users (O'Keeffe *et al.* 1994). This is an indication of the considerable complexity within the field of classification. The following figure best expresses the essential elements of an ideal river classification system (Naiman *et al.* 1992). If utilised, it will lead to the establishment of reliable and valid reference conditions thereby enhancing biomonitoring techniques and ensuring good management practice.

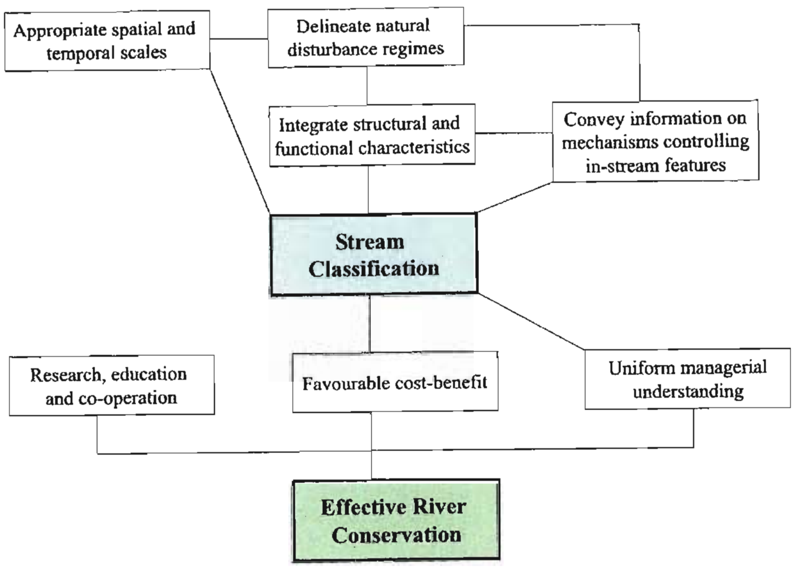

Figure 3.2. Relations between essential elements of an ideal stream classification system (after Naiman *et al.* 1992).

Eekhout *et al.* (1997) note that in the classification of South African rivers, data on structural attributes (species lists) was utilized in place of functional attributes. They recognized that incorporating functional attributes, such as nutrient cycling and sediment transport, which Naiman *et al.* (1992) recognise as an essential element to a classification system, was necessary, but not feasible. This was due to the fact that data on structural attributes were far more accessible and easier to analyse than functional attributes (Eekhout *et al.* 1997).

Various classification systems based on riparian vegetation patterns have also been developed (Eekhout *et al.* 1997; Swanson *et al.* 1988). This has potential in assessing the conservation value of rivers because riparian zones may be indicators of environmental change as they are active boundaries between upland and aquatic systems (Naiman *et al.* 1992). Furthermore they play an important role in shaping the physical and biotic characteristics of rivers due to their functional capabilities (Gregory *et al.* 1991). The fundamental classification unit of riparian zones is the community type, defined by present vegetative composition or by potential climax vegetation (Swanson *et al.* 1988). Stratification of community type can be based on overstorey, an indicator of longer temporal variation or understorey, an indicator of current soil and hydrologic conditions (Naiman *et al.* 1992). The most valuable riparian classification schemes are based on relationships of riparian vegetation characteristics, for example growth forms, to physical factors in the landscape (Naiman *et al.* 1992).

One of the objectives listed by scientists and consultants in the classification of South African rivers was for baseline data in order to determine natural 'pristine' conditions and to determine the limits for extrapolation and interpolation of research results (Eekhout *et al.* 1997). Thus a regional, biotic classification of the rivers was undertaken according to the distribution records of species of riparian vegetation, fish, molluscs, mayflies, caddisflies and blackflies. The riparian vegetation proved to be the most problematic as the cluster analysis results obtained indicated a level of 60% similarity across differing geographical areas, compared with 20% and 30% in the case of fish and invertebrates respectively. This was attributed to the fact that riparian vegetation exhibits extended distribution as they occupy linear "oases" in what would otherwise be inhospitable environments (Eekhout *et al.* 1997). The implications of this for the Riparian Vegetation Index are significant. Setting characteristic reference conditions of natural riparian vegetation in a particular zone is particularly complex due to the wide distribution of these species. This makes a comparative analysis between an ideal natural state and the state of the vegetation at a site a particularly difficult task.

3.7 THE LEGISLATIVE CONTEXT OF BIOMONITORING IN SOUTH AFRICA

The National Water Act (Act No. 36 of 1998) and the National Environmental Management Act (Act No. 107 of 1998) have both contributed to the monitoring and management of aquatic resources in South Africa. The National Water Act (Act No. 36 of 1998) has been regarded internationally as one of the most progressive pieces of legislation regarding the control and management of water. The Act redefines appropriate water rights and uses, with implications for people throughout the country. The Act sets out specific guidelines regarding the control, management, utilisation and conservation of South Africa's water resources. Sustainability and equity are identified as central guiding principles.

The Act specifies only one right to water in law, that of the so-called Reserve. It consists of two parts:

- **the basic human needs reserve** – includes water for drinking, food preparation and personal hygiene; and
- **the ecological needs reserve** – includes the water required to protect the aquatic ecosystems and must be determined for all or part of any significant water resource.

As part of the Act a national water resource strategy is implemented. The national water resource strategy is the framework where all the different strategies that are needed to manage water resources sustainably can be amalgamated. This strategy includes a classification system for all water resources. The classification system establishes guidelines and procedures to determine the different classes of water resources. Additionally, with each class there must be a procedure to determine the Reserve. The main objective of the classification system is to provide a nationally consistent basis to assess impacts on water resources, and whether these impacts are acceptable.

Once the classification system is in place, the Act specifies that it must be used to determine the class and resource quality objectives of all or part of each significant water resource. Each class will represent a certain level of protection. Thus if a river has a high level of protection, i.e., a high-level class, there will be less risk acceptable on that river and there will be stricter rules governing its protection.

As a consequence, resource quality objectives can be determined based on the class of the water resource. Resource quality objectives represent the desired level of utilisation and protection of a water-resource. They include the following:

- the quantity, pattern, timing, water level and assurance of instream flow;
- the water quality, including the physical, chemical and biological characteristics of the water;
- the characteristics, condition and distribution of the aquatic biota; and
- the character and condition of the instream and riparian habitat.

It is evident then that an effective, valid and reliable riparian vegetation index is essential in setting the correct resource quality objectives in order to ensure good management according to the National Water Act (Act No. 36 of 1998).

The National Environmental Management Act (Act No. 107 of 1998) or NEMA states that everyone has the right to an environment that is not harmful to his or her health or well being, and that everyone has the right to have the environment protected. An effective riparian vegetation index will promote the correct resource quality objectives so that the environment is both protected and will help in ensuring an environment that is not harmful.

3.8 THE RIVER HEALTH PROGRAMME

A national monitoring programme that focuses on measuring and assessing the ecological state of riverine ecosystems has been designed for South Africa. This programme, the River Health Programme (RHP), was developed with the overall goal of expanding the ecological basis of information on aquatic resources, in order to support the rational management of these systems (Roux 1997). The RHP was based on the design and implementation of other aquatic biomonitoring programmes from around the world. Uys *et al* (1996) point out that the most noteworthy of these programmes are:

- the British River Invertebrate Prediction and Classification (RIVPACS) methodology;
- the Australian National River Health Programme; and
- the Rapid Bioassessment Protocols For Use in Streams and Rivers of the United States.

The design of the RHP was initiated in 1994 by the Department of Water Affairs and Forestry (DWAF). Part of the institutional arrangements are that the Department of Environmental Affairs and Tourism (DEAT) and the Water Research Commission (WRC) have, together with the DWAF, become joint custodians of the programme at a national level. Implementation at a provincial level is carried out by Provincial Champions and Provincial Implementation Teams.

The primary objectives of the RHP are to (Roux 2001):

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

- ensure that all reports provide scientifically and managerially relevant information for national aquatic ecosystem management.

The design of the RHP is such that it is implemented in a manner that it is modified through ongoing learning, to match the evolving information needs of resource managers. The result is that the RHP was developed in the context of adaptive environmental assessment management (AEAM) (see Figure 3.3).

In applying AEAM, resource management is essentially treated as an adaptive learning process where management activities are viewed as the primary tools for experimentation (Roux *et al.* 1999). AEAM was developed by Holling (1978) as the need for flexibility in terms of ongoing learning and adaptation in natural resource management was perceived. Walters and Holling (1990:2037) point out that in "no place can we claim to predict with certainty either the ecological effects of the activities, or the efficacy of most measures aimed at regulating or enhancing them". Haney and Power (1996) illustrate that resource managers must make decisions in the face of incomplete information and uncertainty of how ecosystems work. For this reason AEAM is an iterative process that includes collecting data, setting goals, modelling the effects of management options on ecological and social attributes, monitoring outcomes and revising the management plan.

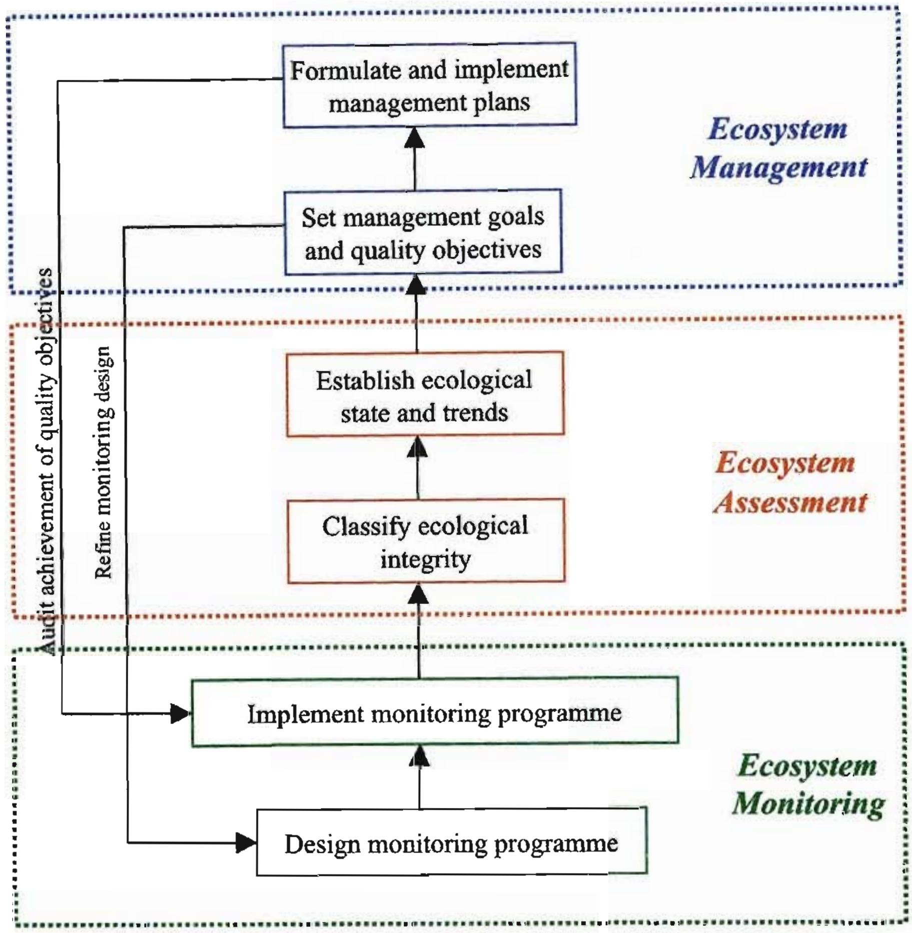

Figure 3.3. The AEAM procedure, as developed for application in the RHP context (Roux *et al.* 1999).

The overall goal of the procedure seen in Figure 3.3 is to facilitate environmentally sustainable development of riverine ecosystems at the highest levels of governance in line with the National Water Act (Act No. 36 of 1998).

The RHP makes use of instream biological response monitoring in order to characterise the response of the environment to disturbance (Roux *et al.* 1999). The concept of ecological integrity is used as the basis for measuring and assessing the ecological state of aquatic ecosystems (Roux *et al.* 1999).

According to Webers Third International Dictionary integrity refers to a condition of being unimpaired, or corresponding to an original condition. Kleynhans (1996:43) defines ecological integrity as "the ability of an ecosystem to support and maintain a balanced, integrated composition of physicochemical and habitat characteristics, as well as biotic components, on a temporal and spatial scale, that are comparable to the natural characteristics of ecosystems within a specific region". This essentially means that the condition of an ecosystem is assessed relative to how that system would function within its hypothetical natural state (Roux 2001). Any reduction in the natural ability of an ecosystem to function then is viewed as a reduction in integrity.

The ecological integrity of an ecosystem may be affected by five major classes of environmental factors, namely chemical variables, flow regime, habitat structure, including riparian vegetation, biotic interactions and energy sources (Roux 1997). In order to assess integrity then, a range of indicators that will identify perturbations in an integrated manner, and which are available in terms of time, money and human resources must be utilised. Communities of fish, aquatic invertebrates and riparian vegetation are the primary indicators used in the RHP.

3.9 INDICES USED IN BIOMONITORING

The information obtained from measuring these indicators needs to be integrated so that managers, conservationists and the public can use it. This can be done with a biological index which integrates and summarises ecological data within a particular indicator group (Roux 1997). Neuman (2000:176) defines an index as "a measure in which a researcher adds or combines several distinct indicators of a construct into a single score." The score is often a single sum of the multiple indicators. Durrheim (1999) points out that an index is formed in such a way that irrelevant factors are controlled or eliminated in developing a numerical estimate of an object. Biological indices quantify the condition of aquatic ecosystems, and the output format of the resulting information is usually numeric. Non-biological indices are used to measure river health and are often supportive in the interpretation of biological results.

Biomonitoring programmes incorporate biological and non-biological indices to form an assessment procedure to evaluate aquatic ecosystem quality. The biological indicators most commonly used are fish and invertebrates (Norris 1994; Uys *et al.* 1996; Roux 1997). The biological indices primarily associated with biomonitoring are the South African Scoring System

Version 5 (SASS5) (Chutter 1998; Dickens & Graham 2002); the Index of Biotic Integrity (IBI) (Karr 1981); the Fish Community Index (FCI) (Roux 1997) and the Riparian Vegetation Index (RVI) (Kemper 2001). The non-biological indices that have been used include the Index of Habitat Integrity (IHI) (Roux 1997); the Habitat Integrity Assessment (HIA) (Kleynhans 1996); the Habitat Assessment Matrix (HAM) (Roux *et al.* 1999); the Hydrological Index (HI) (Roux 1997); the Hydraulic Biotope Diversity Index (HBDI) (Roux 1997); the Water Quality Index (WQI) (Moore 1990) and the Geomorphological Indices (GI) (Rowntree & Ziervogel 1999).

The RHP eventually settled on the biological indices of SASS5, the Fish Assemblage Integrity Index (FAII), the Index of Habitat Integrity (IHI) and the Riparian Vegetation Index (RVI) for biomonitoring in South Africa.

With integrity being the basis of the RHP, it is important to assess whether these suites of indices do indeed measure a functional state of the river. Fairweather (1999) notes that many of the ecological indicator programmes under development around the world focus upon static or structural aspects of ecosystems. These may be rapid snapshots of population or community structure, often presumed to be the endpoints of important ecological processes.

Both SASS5 and the IBI have been developed to measure specific structural assemblages of invertebrates and fish respectively. From the results obtained inferences are made with regard to functioning of that specific section of river. This indicates that these indices do not measure functional attributes directly. The Habitat Integrity Assessment developed by Kleynhans (1996) places less emphasis on the hypothetical natural state of the river as a baseline against which to measure modification. More importance is placed on the functionality of the river to provide suitable living conditions for biota within the context of the temporal and spatial scale of the habitat. This is compared with what is considered likely to have been the case in the absence of artificially created disturbance regimes. Despite its importance, Kleynhans (2002 *pers. comm.*) notes that this method only provides a wide, general perspective on the changes that take place in the river and that there is a lack of quantification of the criteria used for impact assessment.

3.10 QUALITY ASSURANCE/CONTROL

An issue that relates to obtaining reliability and validity in biomonitoring techniques, and one which the River Health Programme is striving for, is quality control and quality assurance. This is in line with the fourth objective of the RHP, which is to ensure that all reports provide scientifically and managerially relevant information for national aquatic ecosystem management. Quality control is defined as the routine application of procedures for obtaining prescribed standards of performance in the monitoring and measurement process (Plafkin *et al.* 1989 in Palmer 1998). Quality assurance is the incorporation of the quality control functions in a totally integrated programme designed to ensure the reliability of monitoring and measurement data (Plafkin *et al.* 1989 in Palmer 1998). This can be achieved through training, documentation and management of field data and verification of data reproducibility.

The USEPA (2002) notes that quality control and quality assurance cannot be achieved without representativeness. The sample site must be chosen to represent that section of the river. This is particularly relevant to the sampling of riparian vegetation as localised disturbances in one site may not be representative of the whole river.

Graham (2002) notes that the results of a biomonitoring technique are a function of analyst variability, methodological variability and site variability. Verification or certification of skills can control analyst variability. Ensuring that the technique has been exhaustively tested so that it is reliable and valid may control method variability. Ensuring site representativeness will help in controlling site variability.

3.11 SYNTHESIS

As the concept of river health emerged so too did a number of biomonitoring techniques to assess the health of aquatic ecosystems. The term river health is conceptually anthropocentric, and relies on rivers, and riparian vegetation, in providing a number of goods and services to the value of society. Concomitant to the emergence of river health is the concept of integrity. Fundamentally the functioning of a system, in relation to a 'natural' site, lies at the basis of integrity. This has elicited criticism as what is defined as a natural site is subjective and presupposes that man knows how a system behaves and functions before anthropogenic impacts occurred.

Despite this, the River Health Programme in South Africa has adopted the concept of integrity in its biomonitoring of aquatic water resources. This is in line with other biomonitoring programmes globally. In the United States of America federal agencies responsible for aquatic ecosystem monitoring have adopted the definition where the goal is preserving, restoring or stimulating ecosystem integrity as defined by the composition, function and structure that also maintains the possibility of sustainable societies and economies (Hohls 1996). In the United Kingdom the RIVPACS system allows for the assessment of actual data gathered from sites, against a baseline established at reference sites (Hohls 1996). The biomonitoring techniques must be a measure of the functional attributes of ecosystems in order for them to be in line with the concept of integrity, so that a true measure of river health can be gauged.

A question that must be posed is that; is the adoption and use of the concepts of health and integrity, and with them the subjective use of hypothetical desired reference states, the correct way of measuring, and ultimately managing aquatic resources? Rogers and Biggs (1999) identify that to some the desired state may be represented by scientifically identified endpoints, while to others it may be represented by human values. Without an operational definition of the desired endpoint, and societal consensus on that definition, effective management is unlikely. Rogers and Bestbier (1997) developed a hierarchy of objectives which could provide operational goals and that were acceptable and achievable by management. These conservation goals must be achievable, testable and auditable, as well as being scientifically rigorous without compromising the value systems. The objective hierarchy is structured to integrate value systems and scientific principles (Rogers & Biggs 1999). Too often river health assessment and monitoring remains largely focused on a narrow range of taxa (fish or invertebrates) and is seldom linked to a specific management programme (Rogers & Biggs 1999). By adopting the principles espoused by Rogers and Biggs (1999) the objective of river health can still be attained, but the subjectivity inherent in the perceived reference state may well be made more explicit by sound scientific values.

With this in mind the RVI will firstly be assessed in the context of its stated objectives. In other words, are the specific measures that the RVI hopes to address clearly stated, and if so, are these measures adequately addressed? If these measures are addressed questions will be posed as to whether this is the correct way of addressing riparian vegetation monitoring, and if not, are there any alternatives?

CHAPTER 4
THE RIPARIAN VEGETATION INDEX

4.1 INTRODUCTION

Riparian vegetation serves to link the instream aquatic ecosystem to the surrounding terrestrial ecosystem, which in turn influences river process and pattern. Montgomery and MacDonald (2002) note that riparian vegetation is a key indicator of channel condition. The type, age and spatial patterns of the riparian vegetation can indicate the nature and intensity of past disturbances (Patten 1998). Deterioration of the riparian vegetation has direct effects on channel structure, water quality and biotic integrity of the aquatic ecosystem (Uys *et al.* 1996).

Despite this importance the use of riparian vegetation as an indicator of river health has been widely neglected in the past (Hart & Campbell 1994; Roux 1997; Uys *et al.* 1996). The potential use of riparian vegetation as an index of river health was only recently proposed at a joint South African/Australian workshop on the classification of rivers and environmental health indicators (Hart & Campbell 1994). Yet a riparian vegetation index was only recently put to use in South Africa in 2001 (Kemper 2001).

Kemper (2001) notes that there are a considerable number of challenges inherent in the monitoring of vegetation:

- the slow growth rate of trees;
- the diversity of tree species and growth forms;
- the responses of vegetation to different influences; and
- problems associated with cause and effect relationships.

These influences significantly affect and shape the structural, compositional and functional characteristics of the vegetation (Kemper 2001).

Chapters two and three have indicated that there are further issues worth considering in vegetation monitoring:

- the simultaneous impact of numerous natural and anthropogenic influences;
- the intention of the vegetation monitoring technique, i.e. what it is trying to achieve; and
- the expertise required for both sound vegetation identification and quality assurance.

This chapter involves assessing the development of the RVI, in the context of the stream-side zone index (SZI) (Ladson & White 1999), from which it developed. The various sub-indices of the RVI will be assessed and the various issues relating to the practical application of the RVI will be considered. The chapter will conclude with an assessment of the reliability and validity of the RVI.

4.2 THE STREAMSIDE ZONE INDEX (SZI)

One index, the Streamside Zone Index (SZI), a sub-index of the Index of Stream Condition (ISC) (Ladson & White 1999) was selected as the basis of the RVI. This index was chosen as it was found to be the most applicable as it is a rapid assessment of the quantity and quality of riparian vegetation, and also forms part of an integrated programme to monitor river health in Australia much like the RHP in South Africa (Kemper 2001).

The ISC was designed to assess rural streams and provides a summary of the extent of changes to:

- hydrology (flow volume and seasonality);
- physical form (stream and bed condition, presence and access to physical habitat),
- streamside zone (quantity and quality of streamside vegetation);
- water quality (nutrient concentration, turbidity, salinity and acidity); and
- aquatic life (diversity of macroinvertebrates).

A score is provided for each of these sub-indices, which is a measure of change from natural or ideal conditions.

The SZI was developed to measure the functions that riparian vegetation provide in both the instream aquatic ecosystem as well as the surrounding terrestrial landscape. The indicators considered for the streamside zone needed to represent both the quantity and quality of this zone (Ladson & White 1999). Table 4.1 gives an indication of these indicators

Table 4.1. Indicators considered for the Streamside Zone Sub-index.

CHARACTERISTICS OF THE STREAMSIDE ZONE	POSSIBLE INDICATOR
FILTER OF INPUTS TO STREAM (INCLUDING LIGHT, SEDIMENT AND NUTRIENTS)	• Width of streamside zone • Longitudinal continuity • Structural intactness • Cover of exotic vegetation • Cover • Land uses in catchment
SOURCE OF INPUTS TO STREAM (INCLUDING LARGE WOODY DEBRIS, LEAVES, INSECT FALL)	• Ratio of streamside zone width to stream width • Longitudinal continuity • Structural intactness • Cover of exotic vegetation • Diversity of flora • Billabong condition
HABITAT FOR TERRESTRIAL FAUNA	• Width of streamside zone • Longitudinal continuity • Structural intactness • Cover of exotic vegetation • Diversity of flora • Regeneration of indigenous vegetation
SCENERY AND LANDSCAPE VALUES	• Ratio of streamside zone width to stream width • Amount of trash • Landscape value indicators • Regeneration of indigenous vegetation

The following six indicators were chosen for the SZI: width of streamside zone; longitudinal continuity; structural intactness; cover of exotic vegetation; regeneration of indigenous woody vegetation; and billabong condition (Ladson & White 1999). Diversity of flora and scenery and landscape values were excluded as primary indicators. It was felt that these involved identification of taxa, which is too detailed; and that the ISC is a measure of condition rather than use values, respectively. The SZI equation is presented in section 4.4.

(i) Width of streamside zone. The width of the streamside zone is important in its ability to filter light, nutrients and sediment; provide a source of inputs to a stream; provide terrestrial habitat; and provide scenery and landscape values. The importance of these roles depends on the stream size, and as such ratings are provided for two size classes: small streams (<15m wide) and large streams (>15m wide).

(ii) Longitudinal continuity. This measure contains two components: 1.) the proportion of bank length with vegetation greater than five metres wide; and 2.) the number of significant discontinuities per kilometer. The number of significant discontinuities is defined as a gap in the streamside vegetation of ten metres or more. This measure is a function of the connectivity of a riparian zone.

(iii) Structural intactness. This is a measure of whether the natural vertical size distribution of streamside vegetation has been disturbed. Cover is measured for the tree, shrub and grass layers and is rated against a natural or pristine site. These are then summed to obtained a single rating.

(iv) Cover of exotic vegetation. The reasons for estimating cover of exotic vegetation are: 1.) exotic plants may reduce food, habitat and nesting sites and may form barriers to movement for terrestrial fauna; 2.) exotic plants may provide allocthonous inputs into the river that the system has not evolved to cope with; and 3.) exotic plants can out compete and prevent regeneration of indigenous plants. The rating is applied for each structural layer, namely trees, shrubs and grasses.

(v) Regeneration of indigenous woody vegetation. Detection of indigenous regeneration of the ground layer is difficult and as such this sub-index concentrates on indigenous regeneration of woody species.

(vi) Billabong condition. This is done in order to assess the quality and quantity of fringing vegetation and evidence of pollution in billabongs adjoining rivers in lowland areas.

4.3 THE RIPARIAN VEGETATION INDEX (RVI)

4.3.1 The aerial-based RVI

The aerial-based RVI was developed to reflect the condition of five-kilometer segments of river as part of the Kruger Park Rivers Research Programme, where no site-specific data had been collected. The assessment of habitat integrity developed by Kleynhans (1996) was used as the basis for the aerial-based method. The method was designed to operate with data taken from an aerial or video survey and as such criteria were developed that were applicable to this method. The method utilised a scoring and weighting system according to riparian vegetation criteria in order to assess the status of five-kilometer segments.

However, there was a need to develop a methodology to determine the condition of the riparian vegetation that fell in line with the other biomonitoring techniques in the RHP, and consequently a site-based RVI was developed.

4.3.2 The site based RVI

4.3.2.1 Development of the RVI: the five stages

The site based RVI was developed over a two-year period during the Mpumalanga pilot study on the Sabie and Olifants River systems. Development of the RVI took place in five stages (Kemper 2001):

i. *Formulation of an understanding of riparian zones.*

This stage involved gaining an understanding of riparian zones. This involved determining what their roles are, what comprises them, what the essential components are, how they function, how they are impacted by disturbance and how they differ between systems as defined by the National Water Act (Act No 36 of 1998) (Kemper 2001).

ii. *Collection of pertinent riparian zone data.*

This stage involved determining data that would be required, how the data would be recorded and problems with the process.

iii. Selection and development of a suitable index.

The SZI was selected as the basis for the RVI as explained in 4.2.

iv. Testing and refinement of the RVI

Once the RVI was developed it was tested over a number of sites with varying characteristics during the pilot study. This was done to ascertain whether it was capable of handling the variety and diversity of data and still provide meaningful scores that reflect the condition of the sites. It must be remembered that the RVI was developed and tested on the Sabie and Olifants Rivers in Mpumalanga. These sites are effectively in the transitional province, according to the River Continuum Concept, and accordingly are characterised by well-developed, woody riparian vegetation. This has the potential to introduce bias into the RVI, as grassland sites were not included in the pilot study.

Kemper (2001) points out that some of the major challenges faced in this process were to provide a diverse range of RVI scores that reflect the characteristics of the site, but which also conform to the six assessment classes from A to F utilised in the Ecological Reserve process of the National Water Act (Act No. 36 of 1998). Table 4.2 gives an indication of the six classes and their corresponding RVI scores.

A 'gut condition score', or reference site, was employed in the RVI in order to calibrate the RVI score and to assign each site to a specific vegetation assessment class (Kemper 2001). This is a subjective score out of five. These scores were continually compared against those in the RVI in order to indicate whether adjustments were required to the weightings of sub-indices (refer to section 4.5.4 for a full explanation).

v. Determination of specific riparian vegetation assessment classes

The RVI scores were placed into perspective in terms of the broad assessment classes currently employed in the Ecological Reserve process. This was done when the assessors felt that the RVI scores reasonably reflected the condition of the site and the sub-index scores reflected the diversity of the site characteristics (Kemper 2001).

Table 4.2. The Ecological Reserve classes and their corresponding RVI scores and descriptions.

RVI SCORE	ASSESS-MENT CLASS	DESCRIPTION
19 - 20	A	Unmodified, natural.
17 - 18	B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
13 - 16	C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.
9 - 12	D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
5 - 8	E	The loss of natural habitat, biota and basic ecosystem functions are extensive.
0 - 4	F	Modifications have reached a critical level and the system has been completely modified with almost complete loss of natural habitat and biota. In the worst case the basic ecosystem functions have been changed.

4.4 RVI FIELDSHEET AND DATA COLLECTION

The RVI fieldsheet is provided in the Appendix. The RVI field assessment is undertaken over a period of 30 to 45 minutes in line with the other RHP biomonitoring techniques. The assessment is split into two components. The site walkabout form is filled in first and should take 15 minutes to complete. The average site is approximately 200 metres in length with a riparian zone of approximately 30 metres in width (Kemper 2001). Species within the riparian zone are recorded and placed into height classes, with an estimate of their numbers. It is important that the assessor carefully defines the riparian zone and ensures that the site chosen is representative of that section of river. Species not identified should be noted and a specimen taken for later identification.

Once the walkabout form has been completed the information is used to complete various other parts of the remaining field assessment form. It is required that every section of the fieldsheet is filled in, even though not all of the sheet is used in the calculation of the index. The information from the fieldsheet is entered into the Rivers Health Database and a score between one and 20 is obtained that is comparable with the six Ecological Reserve assessment classes shown in Table 4.2.

4.5 RVI DERIVATION AND ITS COMPONENTS

4.5.1 Introduction

The RVI is based on the SZI which comprises two areas of vegetation quality at a site, the extent of coverage of the riparian zone by vegetation and the structural and compositional integrity of the present vegetation.

The SZI formula is as follows:

$$\mathbf{SZI = [(W + LC) + ((SI \times PCI) + R) / 2]}$$

Where:

W = width (m)
LC = longitudinal continuity
SI = structural intactness
PCI = percentage cover of indigenous species
R = regeneration of indigenous species

This was then modified to South African conditions and the result is the RVI formula which is as follows:

$$\mathbf{RVI = [(EVC) + ((SI \times PCIRS) + (RIRS))]}$$

Where:

EVC = extent of vegetation cover
SI = structural intactness
PCIRS = percentage cover of indigenous riparian species
RIRS = recruitment of indigenous species

4.5.2 Extent of vegetation coverage of the riparian zone (EVC)

In the RVI, EVC replaces width (W) and longitudinal continuity (LC) used in the SZI. It is determined by calculating the mean score of EVC1 and EVC2 using two methods:

- EVC1 is a direct assessment of the percentage vegetation coverage of all vegetation, natural or unnatural, by the assessor on a six point scale.

Table 4.3. Calculation of EVC1.

PERCENTAGE SCORE	0%	1 – 5%	6 – 25%	26 – 50%	51 – 75%	76 – 100%
EVC1 SCORE	0	2	4	6	8	10

- EVC2 is a subtraction of the extent of anthropogenic and other disturbances from the perceived reference state (PRS) which is 100% in most cases, or a lesser percentage depending whether the site is located on bedrock or not.

$$\mathbf{EVC2 = [10 - Disturbance\ Score]}$$

Table 4.4. Calculation of disturbance score for EVC2.

DISTURBANCE RATING	0	VL	L	M	H	VH
DISTURBANCE SCORE	0	1	2	4	6	10

Where : 0 = No disturbance
VL = Very low disturbance
L = Low disturbance
M = Medium disturbance
H = High disturbance
VH = Very high disturbance

Therefore the total EVC score out of 10 is as follows:

$$\mathbf{EVC = [(EVC1 + EVC2) / 2]}$$

4.5.3 Structural Intactness (SI)

Structural intactness in the SZI makes use of three scales of density/distribution rated against a reference condition for the overstorey, understorey and ground layers. The RVI employs a four scale density/distribution rank utilising a comparison matrix between the Perceived Reference State (PRS) and the Present State (P/S). SI is scored for the tree (SI1), shrub (SI2), reed (SI3), sedge (SI4) and grass (SI5) layers and the maximum possible score is 1. Both the SZI and the RVI rely on the PRS to calculate the structural intactness. The major difference is that the calculation of the SI in the SZI is a measure of cover for the tree, shrub and grass layers whereas the calculation of the SI in the RVI is a measure of the connectivity for the five layers mentioned above.

Table 4.5. Calculation of structural intactness (SI).

	PRESENT STATE (P/S)			
PERCEIVED REFERENCE STATE (PRS)	**Continuous**	**Clumped**	**Scattered**	**Sparse**
Continuous	3	2	1	0
Clumped	2	3	2	1
Scattered	1	2	3	2
Sparse	0	1	2	3

$$\mathbf{SI = [((SI1 + SI2 + SI3 + SI4 + SI5)/5) * 0.33]}$$

4.5.4 Percentage cover of indigenous riparian species (PCIRS)

The SZI does not rate the percentage cover of indigenous species, but rather uses a calculation of the cover of exotic vegetation according to the percentages on four transect lines systematically placed in the site, and is not calculated within a time limit. These are assessed for the tree, shrub and ground cover layers.

The RVI considers the extent of exotic species, terrestrial species and reed beds. The reasoning is that terrestrialisation and reed bed invasion is a frequent problem in rivers where flow has been impacted and which are exposed to high nutrient loads.

The sum of the weighted cover scores for all the invading species (exotic, terrestrial and reed species) are subtracted from the adjusted EVC score. The maximum attainable score for a site rich in desirable indigenous species is 5.

Table 4.6. Calculation of percentage cover of indigenous riparian species (PCIRS).

COVER SCORE	**0**	**VL**	**L**	**M**	**H**	**VH**
PCIRS SCORE	0	1	2	3	4	5

PCIRS = [(EVC/2) – (EXOTICS x 0.7) + (TERRESTRIALS x 0.1) + (REEDS x 0.2))]

4.5.5 Regeneration of indigenous species (RIRS)

The RIRS score in the SZI is based on observation on the four transect lines in much the same fashion as the PCIRS.

This sub-index in the RVI is a measure of the extent to which recruitment of indigenous riparian species is present at the site relative to the recruitment of exotic species. It does also include coppice recruitment as well as the spread of grass into disturbed zones in a grassland dominated biome. The maximum attainable score is 5.

Table 4.7. Calculation of regeneration of indigenous species.

EXTENT OF RECRUITMENT	**0**	**VL**	**L**	**M**	**H**	**VH**
RIRS SCORE	0	1	2	3	4	5

Table 4.8. Recruitment of the regeneration of indigenous species (RIRS) (Kemper 2001).

SCORE	INDIGENOUS SPECIES	EXOTIC SPECIES (if present)
0	No evidence of recruitment.	Only exotic recruitment evident.
VL	Evidence of recruitment of any species is rare.	Large quantities evident.
L	Recruitment of mainly abundance dominant species.	Moderate quantities evident.
M	Recruitment of moderate numbers of both abundance and biomass dominant species.	Recruitment common.
H	Recruitment of large quantities of biomass dominant species.	Limited recruitment is evident.
VH	Extensive recruitment of the majority of species being biomass dominant species.	No recruitment evident.

4.6 FURTHER ISSUES WITH THE RVI

As mentioned, one of the objectives of the RVI is the determination of the reliability and validity of the index. Reliability means dependability or consistency (Neuman 2000). In this context the test of reliability will be whether the results obtained from a number of experts undertaking the RVI assessment can be reproduced or replicated by other experts. Validity means 'truthful' and refers to the bridge between a construct and the data (Neuman 2000). In this context the measure of validity should be how well the sub-indices, as well as the final index score in the RVI, actually reflect the condition of the vegetation at that moment.

The concept of validity is essential in the RVI but is difficult to test. This is because one cannot be totally sure that an index really reflects the condition of the vegetation when the index is subjective. Furthermore, the true test of validity would require comparing the RVI against an external, objective criterion that is known will reflect the condition of the vegetation. Finding such a test is exceptionally difficult, and thus the measure of validity in this context will be a theoretical assessment of whether the RVI is a functional index.

Neuman (2000) points out that reliability is necessary in order to have a valid measure of a concept. It does not guarantee that a measure will be valid. In other words a measure can produce the same result over and over (i.e., it has reliability), but what it measures may not match the definition of the construct (i.e., validity). This emphasizes the importance of attaining both reliability and validity in the RVI as it would be useless if the index did not fully reflect the condition of the vegetation as well as being able to be replicated by different experts.

The assessment of the reliability and validity must, however, be done within the context of what the RVI is attempting to measure. In other words, does this index meet the objectives that were put forward, and if so, does it do so adequately? To analyse this the relevant objectives of the RVI must be listed. Thereafter, the pertinent questions of, should we be measuring what the stated intention of the RVI is, and if not, what are the alternatives, need to be answered. The following objectives listed in the RVI are relevant to this discussion (Kemper 2001:14):

- "The RVI must be usable by technical personnel of provincial and other responsible organisations. It must therefore:
    - not require a high level of vegetation knowledge and experience, and
    - be as qualitative as possible and avoid technical and quantitative considerations.
- The RVI be developed within a hierarchical framework. In the initial stages of the index development, the emphasis should be on an index that provides a synoptic assessment of riparian vegetation condition. Later development must provide a functional and useful index which can be applied or implemented on a wider or even national basis if necessary."

The fact that the index is being implemented on a national basis must lead us to believe that the index is indeed one that is developed to a functional level. The validity of the RVI will thus be analysed in the context of the functions of riparian vegetation, and criteria have been listed in Table 4.9 in order to assess this.

4.6.1 Validity issues

A number of issues regarding the functionality of the RVI have already been raised. As mentioned, a valid RVI in this context is one that is a measure of the functions that riparian vegetation performs. In order to assess the validity of the RVI comprehensively the index will be rated against criteria, in this case functions of riparian vegetation. Certain functions cannot be measured directly but can be inferred from certain indicators. For example, the ability of the riparian vegetation to control stream temperature is dependent on the aerial cover of trees. Table

4.9 lists the functions of riparian vegetation and their respective indicators. A validity assessment matrix is then used in Table 4.10 in order to measure the sub-indices in terms of functions.

Table 4.9. Functions of riparian vegetation, their possible indicators and their codes used in the validity assessment matrix.

FUNCTIONS OF RIPARIAN VEGETATION	POSSIBLE INDICATORS AND THEIR CODES
CONDUIT – PROVISION OF PATHWAYS FOR ENERGY, MATTER AND ORGANISMS	• Width of riparian vegetation (W) • Longitudinal continuity (LC) • Structural intactness (SI) • Cover (COV)
SINK OF ENERGY AND MATTER	• Width of riparian vegetation (W) • Cover of exotic vegetation (C-EV) • Cover of indigenous vegetation (C-IV)
SOURCE OF ENERGY AND MATTER	• Ratio of riparian vegetation width to stream width (RATIO) • Longitudinal continuity (LC) • Structural intactness (SI) • Cover of exotic vegetation (C-EV) • Diversity of flora (DIV)
STREAM TEMPERATURE CONTROL	• Aerial cover (AC)
SPECIES AND HABITAT DIVERSITY	• Width of riparian vegetation (W) • Longitudinal continuity (LC) • Structural intactness (SI) • Cover of exotic vegetation (C-EV) • Diversity of flora (DIV) • Regeneration of indigenous vegetation (RIV)
STREAM BANK STABILITY	• Aerial cover (AC) • Basal cover (BC)
PROVISION OF FUELS, BUILDING MATERIALS AND MEDICINES	• Regeneration of indigenous vegetation (RIV) • Cover of exotic vegetation (C-EV) • Diversity of flora (DIV)

A matrix table is used in order to assess each sub-index in relation to the functional indicators (Table 4.10). Refer to Table 4.9 for the respective codes for each indicator. It must be noted that this is a coarse assessment in order to give a general idea of the ability of the RVI to represent the functional attributes of riparian vegetation, and to indicate where the major problems are, and how they may be addressed.

Table 4.10. Validity assessment matrix.

FUNCTIONS	INDICATORS	RVI SUB-INDICES			
		EVC	SI	PCIRS	RIRS
CONDUIT	***W***				
	LC				
	SI		X		
	COV	X			
SINK	***W***				
	C-EV				
	C-IV			X	
SOURCE	***RATIO***				
	LC				
	SI		X		
	C-EV				
	DIV				
TEMPER-ATURE	***AC***				
DIVERSITY	***W***				
	LC				
	SI		X		
	C-EV				
	DIV				
	RIV				X
STABILITY	***AC***				
	BC				
USES	***RIV***				X
	C-EV				
	DIV				

The assessment matrix indicates that two functions, bank stability and stream temperature are not represented by the RVI. This is attributed to the fact that cover is not separated into a basal cover score and an aerial cover score. A site may be scored as 100% cover, but this is aerial cover, and below the trees the ground is bare. Dickens (2002 *pers. comm.*) notes that this is an issue in the RVI that needs to be addressed.

Although all the remaining functions of the RVI are represented to some extent by a sub-index it is evident that the RVI does not adequately depict the range of functions considered. For example, the RVI does take exotic vegetation into account but this is used in the calculation of the percentage cover of indigenous species, when it could be a separate sub-index itself. An important issue such as estimating the degree of exotic vegetation infestation should carry more weight in a vegetation index in this country. A further example is that the species richness is estimated in the RVI, which would represent the functions of source of energy and matter and species and habitat diversity, but it is not utilised in the calculation of the index and is consequently not included. A problem that is noted is that the width of the riparian vegetation is not measured. Kemper (2001) notes that the objective of the RVI was to produce an index that was more qualitative, so that untrained personnel could use it. However, measuring the average width of the riparian vegetation is a quick, easy task that can contribute greatly to improving the functional capacity of the RVI. Longitudinal continuity is replaced in the RVI with a measure of cover. Cover, however, does not directly measure longitudinal continuity and consequently cannot be used as a proxy for continuity. Estimating a measure of longitudinal continuity would certainly enhance the RVI at a functional level.

4.6 ALTERNATIVE VEGETATION MONITORING TECHNIQUES

The literature has indicated that there are few applicable alternative vegetation monitoring options. A complex, time consuming method is that outlined by Dudley *et al.* (1998) to measure woody riparian density. The assessment involves using the point-frame method where estimates of vegetated area are obtained by pushing pins, supported by a frame on legs, which extend to a height of 1.8 meters, through the vegetation and recording the number of pins that intersect vegetation.

An example of an aggregative method developed for the public is the Stream Visual Assessment Protocol (SVAP) (Bjorkland *et al.* 2001). This method involves rating the riparian vegetation on a ten-point scale based only on the width of the riparian zone. Kotze *et al.* (1998) developed the RIPARI-MAN in KwaZulu-Natal, South Africa, but like SVAP is an aggregative technique that measures the biophysical status of the channel and only takes plant cover and alien vegetation invasion into account.

The Floristic Quality Assessment (FQA) (Taft *et al.* 1997) is a method developed to assess floristic integrity and is based on the tenets that plant species differ in their tolerance to disturbance, and that plant species display varying degrees of fidelity to habitat integrity. Plant species are assigned values according to these tenets. Furthermore, guild diversity, wetness characteristics, relative importance of native species, physiognomic characteristics and rare species are taken into account. This method has potential for application in this country provided there are good species lists, as well as data relating to degrees of fidelity and habitat integrity for each species, in the area one is looking to perform this method. Furthermore, it requires considerable knowledge and experience in plant distribution and identification.

A method that is very similar to the RVI was developed in Spain by Salinas *et al.* (2000b). The degradation state of the riparian vegetation in each reach was quantified into one index by integrating five vegetation indices, namely percentage cover, species richness, degree of connectivity between patches, number of exotic species and evidence of natural regeneration. The major difference is that this method is essentially quantitative as plots of 120 m^2 (30 m X 4 m), one on each bank, were assessed using the line-intercept method. This method consisted of extending a tape measure and noting the length in centimeters along which each species was intercepted by the tape. The intercept measurements were taken at heights of 5 m, 1.5 m and 0.5 m. This method, too has application in this country and may well address the issue of subjectivity inherent in the RVI.

4.7 SYNTHESIS

Chapter four has analysed the history and development of the RVI, specifically in relation to the SZI, on which the RVI was predominantly based. The derivation of the RVI was then explored and alternative vegetation monitoring techniques were assessed. The theoretical analysis of the RVI indicates that there are issues that may well be reducing the validity of the index. The validity assessment matrix presented in Table 4.10 is a coarse assessment that indicates that although the RVI does measure certain functional attributes, it requires refinement. It is felt that the RVI is a measure of structural attributes, rather than functional ones. In order for the RVI to become a functional index at a theoretical level, requires the consensus of experienced and knowledgeable people. The theoretical basis must then be tested at a field level for the RVI to become a truly functional and useful index and to ensure that the index is both practical and relevant.

The question of whether a functional index of riparian vegetation is the right one must be considered. Harris (1994) notes that patterns of species richness and abundance are undoubtedly important elements of river health but often contribute little to an understanding of how a system works. Bunn *et al.* (1999) point out that patterns of species richness and abundance are often used as surrogate measures of the fundamental processes in aquatic systems. Although altered function may affect patterns, pattern and processes are not necessarily linked (Bunn *et al.* 1999). Bunn *et al.* (1999) continue and state that ecosystem-level processes or functions are ideal measures of stream health because they provide an integrated response to a broad range of catchment disturbances. This is especially pertinent in South Africa with the development of catchment management agencies (CMAs) who are responsible for the management of the country's water resources. Indices that can provide information to the CMAs that is relevant at a catchment level, rather than a site-specific level, will contribute greatly to improved management of our water resources. This is an indication that a structural index of riparian vegetation may not be as potentially useful compared to a functional index in enhancing catchment management in South Africa.

The preceding chapters have clearly indicated that there are fundamental problems with the RVI that must be addressed. Consequently these issues have provided the basis for the RVI to be tested in a number of vegetation types using a number of expert vegetation assessors.

CHAPTER 5
METHODOLOGY

1. Preliminary evaluation

The first step of the methodology involved dialogue with a number of RVI experts and a review of the national and international vegetation monitoring literature. A workshop held by the River Health Programme in August 2002 provided the basis for the dialogue. The objective of the workshop was for the key players in the development and implementation of riparian vegetation monitoring to collectively scrutinize the RVI, determine reasons for the methods not being more widely used and to put in place steps towards revising or changing the methods where necessary.

2. Sensitivity analysis

A sensitivity analysis was conducted in order to ascertain which sub-indices within the index have the most potential to alter the final RVI scores, and where uncertainty or field estimation error could have an impact on the final score or management class. This facilitated the interpretation of the field data.

Each sub-index was subjected to 20% changes above and below a value assumed to be the actual value or correct field estimate for the variable (Figure 1). The remaining sub-indices were kept constant. A 20% change was chosen as each sub-index is ranked on a 5-point scale. The effects of over or underscoring a particular sub-index by one category becomes significant when a component such as cover is approximately 50% (Figure 1). This value is on the border between two categories and the sensitivity analysis would illustrate the effect on the final RVI score of placing cover in the 26-50% category or in the 51-75% category. This holds true for other values such as 5%, 25% and 75% which are also on the border.

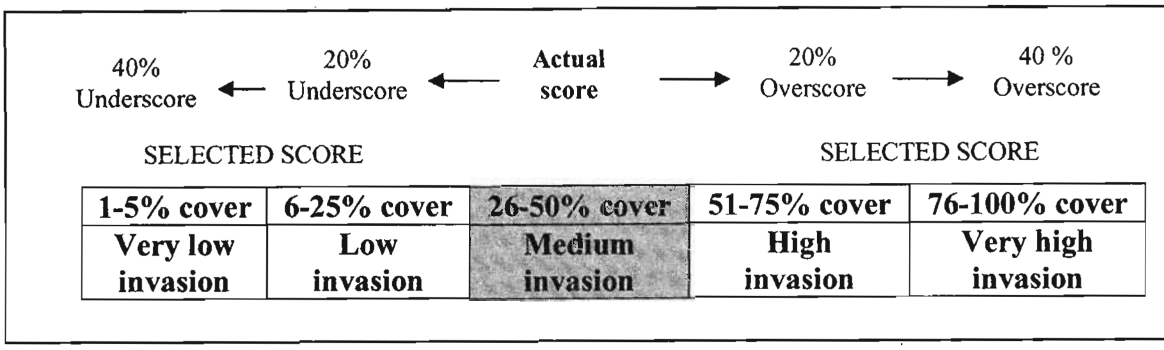

Figure 1. An illustration of the methodology utilised in the sensitivity analysis where each block represents a 20% underscore or overscore of a particular sub-index.

3. Data collection

Eight sites in three vegetation types were chosen for the purpose of evaluating the reliability of the RVI method. Table 2 provides a summary of the sample sites, indicating the vegetation type, disturbance level, surrounding landuse and additional comments. Six assessors were chosen on account of previous experience in using the RVI, or with the necessary botanical and aquatic ecosystem knowledge. Utilising assessors, however, did prove to be a limitation as the assessors were professional, working people with limited time. Consequently the number of assessors per sample site varied between five and seven.

3.1 Study area

Table 2. Description of data collection sites

SITE NO.	RIVER	DESCRIPTION			
		Vegetation type	**Disturbance level**	**Surrounding landuse**	**Comment**
1.	Umgeni	Savanna	Medium/ low	Conservancy	Large, unvegetated boulders with minor alien vegetation infestation.
2.	Gwenspruit Tributary	Grassland	Low	Conservancy	Small stream in excellent condition.
3.	Mlazi Tributary	Mistbelt forest	Low	Forestry	Well-vegetated mistbelt forest in excellent condition.

4.	Mlazi Tributary	Mistbelt forest	Medium	Conservancy	Well-vegetated mistbelt forest but with alien invasion on one bank.
5.	Mlazi Tributary	Grassland	High	Conservancy	Site disturbed by recent alien vegetation removal.
6.	Mlazi	Savanna	High	Piggery	One bank completely covered in alien vegetation.
7.	Mlazi Tributary	Grassland	Medium	Stock farming	Riparian zone disturbed by stock grazing and site characterised by *Phragmites* build up.
8.	Mlazi	Grassland	High	Stock and sugarcane	Highly disturbed site with considerable alien vegetation infestation.

3.2 RVI procedure

The RVI field assessment was undertaken over a period of 30 to 45 minutes according to the guidelines provided by Kemper (2001). This was adhered to but proved to be a limitation as assessors found that identifying plant species was time-consuming and that the whole method could take up to an hour to complete. The assessment was split into two components. The site walkabout form was filled in first and took 15 minutes to complete. According to the guidelines the average site was approximately 200 metres in length with a riparian zone of roughly 30 metres in width (Kemper 2001). Species within the riparian zone were recorded and placed into height classes, with an estimate of their numbers.

The walkabout form information is subsequently utilised in calculating the sub-indices and final RVI score defined in equations 1 to 4. It is required that every section of the fieldsheet is filled in. However, only certain sections contribute to the final RVI score (Table 3).

Table 3. Indication of which components in the RVI fieldsheet contribute to the final RVI score and which components do not.

COMPONENTS USED IN THE RVI CALCULATION	COMPONENTS NOT USED IN THE RVI CALCULATION
Percentage vegetation cover (all vegetation)	Channel type
Reason(s) why less than 100% vegetation cover	Active channel width
Distribution of vegetation cover rated against a perceived reference state	Width of the potential riparian zone
Invasion of riparian zone – exotic, terrestrial and reed species	Estimate of the riparian zone substrate
Recruitment of indigenous riparian species	Site disturbances
	Surrounding land use
	Estimate of cover rated against a perceived reference state
	Dominance by biomass
	Dominance by recruitment
	Species richness
	*Assessor gut score

* Assessor gut score does not contribute to the actual calculation but is used in this study by means of comparison.

4. Data analysis

For each site the range in individual assessments for each factor of a sub-index, the sub-index and the final RVI score was compared. The final RVI score and the assessors' gut condition score was also compared. In the latter case a two-tailed paired two-sample for means t-test was applied to the data, where

H_0 = There is no significant difference between the final RVI score and the gut condition score.

H_1 = There is a significant difference between the final RVI score and the gut condition score.

An assumption is made whereby the middle value of the gut condition score is chosen as the gut scores are represented by classes as indicated in Table 1. For example a value of 17.5 is used for a gut condition B class (17-18)

CHAPTER 6

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APPENDIX

BLANK RVI ASSESSMENT FORM

APPENDIX 1

FIELD RESULTS OF ALL THE RVI SITES

TE 1

RVI	RVI ASSESSORS					Mean	sd
Subindex	DJ	MG	CD	DK	SC		
EVC	8.00	5.00	5.00	5.00	7.00	6.00	1.41
SI	0.80	0.93	0.73	1.00	1.00	0.89	0.12
PCIRS	1.50	0.60	0.00	0.00	2.30	0.88	1.00
RIRS	3.00	3.00	3.00	3.00	3.00	3.00	0.00
RVI	**12**	**9**	**8**	**8**	**12**	9.81	2.24
CLASS	**D**	**D**	**E**	**E**	**D**		
GUT	**C**	**C**	**C**	**C**	**B**		

[TE 2

RVI	RVI ASSESSORS					Mean	sd
Subindex	DJ	MG	CD	DK	SC		
EVC	8.50	9.00	8.50	6.00	9.00	8.20	1.25
SI	0.60	0.60	0.60	0.60	0.60	0.60	0.00
PCIRS	4.15	4.50	4.05	2.20	4.40	3.86	0.95
RIRS	2.00	0.00	1.00	4.00	3.00	2.00	1.58
RVI	**13**	**12**	**12**	**11**	**15**	12.51	1.34
CLASS	**C**	**D**	**D**	**D**	**C**		
GUT	**A**	**B**	**B**	**B**	**B**		

ITE 3

RVI	RVI ASSESSORS								Mean	sd
Subindex	AB	RW	CD	DK	SC	SC	DJ	MG		
EVC	6.00	10.00	9.00	10.00	9.00	9.00	10.00	10.00	9.13	1.36
SI	0.87	0.80	1.00	0.87	0.93	1.00	1.00	1.00	0.93	0.08
PCIRS	1.60	4.20	3.80	3.60	3.70	3.80	4.30	4.20	3.65	0.87
RIRS	4.00	4.00	2.00	3.00	4.00	4.00	3.00	4.00	3.50	0.76
RVI	**11**	**17**	**15**	**16**	**16**	**17**	**17**	**18**	16.05	2.14
CLASS	**D**	**B**	**C**	**C**	**C**	**B**	**B**	**B**		
GUT	**C**	**B**	**B**	**B**	**B**	**B**	**B**	**B**		

SITE 4

RVI Subindex	RVI ASSESSORS					Mean	sd
	SC	DJ	MG	CD	AB		
EVC	8.00	6.50	10.00	8.00	8.00	8.10	1.24
SI	0.80	0.87	0.999	0.87	0.87	0.88	0.07
PCIRS	1.80	1.85	3.30	2.60	2.60	2.43	0.62
RIRS	2.00	3.00	2.00	3.00	2.00	2.40	0.55
RVI	**11**	**11**	**15**	**13**	**12**	12.67	1.69
CLASS	**D**	**D**	**C**	**C**	**D**		
GUT	**C**	**C**	**C**	**C**	**C**		

SITE 5

RVI Subindex	RVI ASSESSORS								Mean	sd
	AB	RW	CD	DK	SC	SC	DJ	MG		
EVC	5.00	9.00	8.00	8.00	7.00	7.00	10.00	8.00	7.75	1.49
SI	0.80	0.80	0.93	0.87	0.67	0.67	0.87	0.73	0.79	0.10
PCIRS	1.00	3.80	2.40	3.10	1.80	2.30	3.60	3.00	2.63	0.94
RIRS	4.00	0.00	2.00	3.00	2.00	2.00	2.00	2.00	2.13	1.13
RVI	**10**	**12**	**12**	**14**	**10**	**11**	**15**	**12**	11.98	1.81
CLASS	**D**	**D**	**D**	**C**	**D**	**D**	**B**	**D**		
GUT	**C**	**D**	**D**	**C**	**D**	**D**	**D**	**C**		

SITE 6

RVI Subindex	RVI ASSESSORS								Mean	sd
	AB	RW	CD	DK	SC	SC	DJ	MG		
EVC	10.00	10.00	9.00	9.00	10.00	10.00	9.00	7.50	9.31	0.88
SI	0.93	0.80	0.73	0.87	0.87	0.87	0.80	1.00	0.86	0.08
PCIRS	2.70	3.50	1.00	1.70	1.90	1.70	1.30	1.15	1.87	0.85
RIRS	3.00	2.00	3.00	4.00	2.00	2.00	2.00	2.00	2.50	0.76
RVI	**16**	**15**	**13**	**14**	**14**	**13**	**12**	**11**	13.42	1.58
CLASS	**C**	**C**	**C**	**C**	**C**	**D**	**D**	**D**		
GUT	**C**	**C**	**E**	**D**	**D**	**D**	**E**	**D**		

SITE 7

RVI Subindex	RVI ASSESSORS					Mean	sd
	DJ	MG	CD	AB	SC		
EVC	10.00	10.00	8.00	6.00	6.00	8.00	2.00
SI	0.80	0.87	0.73	0.73	0.80	0.79	0.06
PCIRS	2.30	1.60	0.80	0.30	0.30	1.06	0.87
RIRS	2.00	2.00	2.00	3.00	3.00	2.40	0.55
RVI	**14**	**13**	**11**	**9**	**9**	11.25	2.23
CLASS	**C**	**C**	**D**	**D**	**D**		
GUT	**D**	**D**	**E**	**D**	**D**		

SITE 8

RVI Subindex	RVI ASSESSORS					Mean	sd
	DJ	MG	CD	AB	SC		
EVC	10.00	9.00	6.00	6.00	6.00	7.40	1.95
SI	0.87	0.73	0.73	0.73	0.73	0.76	0.06
PCIRS	1.80	1.40	0.40	0.60	0.10	0.86	0.71
RIRS	2.00	2.00	3.00	3.00	3.00	2.60	0.55
RVI	**14**	**12**	**9**	**9**	**9**	10.68	2.01
CLASS	**C**	**D**	**D**	**D**	**D**		
GUT	**E**	**C**	**D**	**C**	**D**		

APPENDIX 2

BLANK RVI ASSESSMENT FORM

RIPARIAN VEGETATION - RVI (1)

Ver: 05/02/00

BIOMONITORING SITE ASSESSMENT FORM

RIVER: ______________________ Date: _____/_____/___

Site/Segt No:_______ Site Name:_______________________ LatLong: S:_____°______'_____

Assessor names (print): ____ E: _____°______'_____

CHANNEL DESCRIPTION

Channel type (tick):

CHANNEL TYPE:	Single		Multiple	Braided		Anabranching		Mixed	

Active channel width:

Width (m)	

RIPARIAN ZONE DESCRIPTION

Width of potential riparian zone:

Width (m)	LHB		RHB		Islands	

Substrate (tick):

Bedrock	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Rock/cobble	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Soil	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Gravel/sand	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Sediment	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	

Percentage vegetation cover (all vegetation) (tick):

LHB	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
RHB	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Islands	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	

SITE CONDITION

Reason(s) why less than 100% vegetation cover: (refer to user manual)

REASON	EXTENT (tick)									
Natural	VL		L		M		H		VH	
Disturbed	VL		L		M		H		VH	

Site disturbances:

DISTURBANCE		IMPACT ORDER	EXTENT OF IMPACT (tick)									
Floods, elevated flows			VL		L		M		H		VH	
Flow regulation (dam upstream)			VL		L		M		H		VH	
Weir / dam (local inundation)			VL		L		M		H		VH	
Bush clearing / ploughing			VL		L		M		H		VH	
Vegetation removal (fuel, materials, feed)			VL		L		M		H		VH	
Crop farming			VL		L		M		H		VH	
Forestry			VL		L		M		H		VH	
Grazing / browsing / trampling (stock)			VL		L		M		H		VH	
Sand winning, quarrying, mining			VL		L		M		H		VH	
Picknicking, golf course, trails and paths			VL		L		M		H		VH	
Roads, bridges, other infrastructures			VL		L		M		H		VH	
Vegetation invasion (exotic, terr, reeds)			VL		L		M		H		VH	
Erosion / sedimentation			VL		L		M		H		VH	
Other: specify			VL		L		M		H		VH	

Surrounding land-use (tick):

Nature reserve, game farming		Stock farming (various stock)		
Subsistence (rural) farming		Irrigation farming (formal), crops		
Forestry		Picknick site / recreational		
Residential (urban)		Residential (rural)		
Mining / quarrying		Dumping		
Sewerage treatment		Other: Specify		

DISTRIBUTION AND EXTENT OF VEGETATION COVER

NB. canopy cover for trees and shrubs; ground cover for grass, sedges and reeds

Cover:

	Cover component											
	Trees		Shrubs		Reeds		Sedges		Grasses		Bare ground	
Cover score	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS
0%												
1 - 5%												
6 - 25%												
26 - 50%												
51 - 75%												
76 - 100%												

Distribution:

	Component											
	Trees		Shrubs		Reeds		Sedges		Grasses		Bare ground	
Score	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS
Continuous												
Clumped												
Scattered												
Sparse												

INVASION OF RIPARIAN ZONE

Exotic species: (refer to user manual)

Species (list in order of problem)	Invasive/Recruit				Extent of invasion (tick)									
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
Total extent of invasion					VL		L		M		H		VH	

Terrestrial species: (refer to user manual)

Species (list in order of problem)	Extent of invasion (tick)									
	VL		L		M		H		VH	
	VL		L		M		H		VH	
	VL		L		M		H		VH	
	VL		L		M		H		VH	
	VL		L		M		H		VH	
	VL		L		M		H		VH	
Total extent of invasion	VL		L		M		H		VH	

Reeds: (refer to user manual)

Species		Extent of Problem (tick)									
Phragmites sp.		VL		L		M		H		VH	
Typha latifolia		VL		L		M		H		VH	
Arundo donax (Spanish reed)		VL		L		M		H		VH	
Other: specify		VL		L		M		H		VH	
Total extent of invasion		VL		L		M		H		VH	

SPECIES COMPOSITION:

NB: Includes only woody species (trees and shrubs) including exotics species.
Order - refers to order of species in descending order of abundance within site.

Dominance by biomass

		Height class (enter number of individuals per class)				
Order	Species	2-4m	4-8m	8-12m	12m+	Total

Dominance by recruitment

		Height class (enter number of individuals per class)		
Order	Species	< 1 m	1- 2m	Total

Recruitment of indigenous riparian species: (refer to user manual)

Extent of Recruitment	None		VL		L		M		H		VH	

Species richness:

Number of indigenous tree and shrub species	
Number of exotic tree and shrub species	
Total species	

<u>ASSESSOR GUT SCORE:</u>

Insert appropriate site score based on gut feeling only.

Score	1 - 4		5 - 8		9 - 12		13 - 16		17 - 18		19 - 20	
Class	F		E		D		C		B		A	

<u>SITE MAP</u>:

Hand drawn map including pertinent details such as: river course; direction of river flow; riparian zones; banks; distinctive vegetation communities / clumps; north arrow; point of access to site; area where SASS and fish surveys were undertaken; infrastructure such: as bridges, roads and fences.

RIPARIAN VEGETATION - WALK ABOUT FORM

During the initial site investigation, record the number of individuals of each prominent components with small ticks in the appropriate size class blocks.
Use a "c" to describe clumps applicable to reeds and prominent forbs, sedges and grasses in average size class blocks.
Type is either (t) tree, (s) shrub, (f) forb, (r) reed or (g) for sedges and grasses. Add (e) if exotic.

SPECIES	Type	<1	1-2	Sub-Total (1)	Order	2-4	4-8	8-12	>12	Sub-Total (2)	Order

RIPARIAN VEGETATION - RVI (1)

Ver: 05/02/00

BIOMONITORING SITE ASSESSMENT FORM

RIVER: ______________________ Date: _____/_____/__

Site/Segt No:______ Site Name:______________________ LatLong: S:____°______'_____

Assessor names (print): ____________________________________ E: ____°______'_____

CHANNEL DESCRIPTION

Channel type (tick):

CHANNEL TYPE:	Single		Multiple	Braided		Anabranching		Mixed	

Active channel width:

Width (m)	

RIPARIAN ZONE DESCRIPTION

Width of potential riparian zone:

Width (m)	LHB		RHB		Islands	

Substrate (tick):

Bedrock	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Rock/cobble	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Soil	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Gravel/sand	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Sediment	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	

Percentage vegetation cover (all vegetation) (tick):

LHB	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
RHB	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	
Islands	0%		1 - 5%		6 - 25%		26 - 50%		51 - 75%		76-100%	

SITE CONDITION

Reason(s) why less than 100% vegetation cover: (refer to user manual)

REASON	EXTENT (tick)									
Natural	VL		L		M		H		VH	
Disturbed	VL		L		M		H		VH	

Site disturbances:

DISTURBANCE		IMPACT ORDER	EXTENT OF IMPACT (tick)									
Floods, elevated flows			VL		L		M		H		VH	
Flow regulation (dam upstream)			VL		L		M		H		VH	
Weir / dam (local inundation)			VL		L		M		H		VH	
Bush clearing / ploughing			VL		L		M		H		VH	
Vegetation removal (fuel, materials, feed)			VL		L		M		H		VH	
Crop farming			VL		L		M		H		VH	
Forestry			VL		L		M		H		VH	
Grazing / browsing / trampling (stock)			VL		L		M		H		VH	
Sand winning, quarrying, mining			VL		L		M		H		VH	
Picknicking, golf course, trails and paths			VL		L		M		H		VH	
Roads, bridges, other infrastructures			VL		L		M		H		VH	
Vegetation invasion (exotic, terr, reeds)			VL		L		M		H		VH	
Erosion / sedimentation			VL		L		M		H		VH	
Other: specify			VL		L		M		H		VH	

Surrounding land-use (tick):

Nature reserve, game farming		Stock farming (various stock)		
Subsistence (rural) farming		Irrigation farming (formal), crops		
Forestry		Picknick site / recreational		
Residential (urban)		Residential (rural)		
Mining / quarrying		Dumping		
Sewerage treatment		Other: Specify		

DISTRIBUTION AND EXTENT OF VEGETATION COVER

NB. canopy cover for trees and shrubs; ground cover for grass, sedges and reeds

Cover:

	Cover component											
	Trees		Shrubs		Reeds		Sedges		Grasses		Bare ground	
Cover score	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS
0%												
1 - 5%												
6 - 25%												
26 - 50%												
51 - 75%												
76 - 100%												

Distribution:

	Component											
	Trees		Shrubs		Reeds		Sedges		Grasses		Bare ground	
Score	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS	P/S	PRS
Continuous												
Clumped												
Scattered												
Sparse												

INVASION OF RIPARIAN ZONE

Exotic species: (refer to user manual)

Species (list in order of problem)	Invasive/Recruit				Extent of invasion (tick)									
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
	I		R		VL		L		M		H		VH	
Total extent of invasion					VL		L		M		H		VH	

Terrestrial species: (refer to user manual)

Species (list in order of problem)	Extent of invasion (tick)									
	VL		L		M		H		VH	
	VL		L		M		H		VH	
	VL		L		M		H		VH	
	VL		L		M		H		VH	
	VL		L		M		H		VH	
	VL		L		M		H		VH	
Total extent of invasion	VL		L		M		H		VH	

Reeds: (refer to user manual)

Species	Extent of Problem (tick)									
Phragmites sp.	VL		L		M		H		VH	
Typha latifolia	VL		L		M		H		VH	
Arundo donax (Spanish reed)	VL		L		M		H		VH	
Other: specify	VL		L		M		H		VH	
Total extent of invasion	VL		L		M		H		VH	

SPECIES COMPOSITION:

NB: Includes only woody species (trees and shrubs) including exotics species.
Order - refers to order of species in descending order of abundance within site.

Dominance by biomass

		Height class (enter number of individuals per class)				
Order	Species	2-4m	4-8m	8-12m	12m+	Total

Dominance by recruitment

Order	Species	Height class (enter number of individuals per class) < 1 m	1- 2m	Total

Recruitment of indigenous riparian species: (refer to user manual)

Extent of Recruitment	None		VL		L		M		H		VH	

Species richness:

Number of indigenous tree and shrub species	
Number of exotic tree and shrub species	
Total species	

<u>ASSESSOR GUT SCORE:</u>

Insert appropriate site score based on gut feeling only.

Score	1 - 4		5 - 8		9 - 12		13 - 16		17 - 18		19 - 20	
Class	F		E		D		C		B		A	

<u>SITE MAP</u>:

Hand drawn map including pertinent details such as: river course; direction of river flow; riparian zones; banks; distinctive vegetation communities / clumps; north arrow; point of access to site; area where SASS and fish surveys were undertaken; infrastructure such: as bridges, roads and fences.

RIPARIAN VEGETATION - WALK ABOUT FORM

During the initial site investigation, record the number of individuals of each prominent components with small ticks in the appropriate size class blocks.
Use a "c" to describe clumps applicable to reeds and prominent forbs, sedges and grasses in average size class blocks.
Type is either (t) tree, (s) shrub, (f) forb, (r) reed or (g) for sedges and grasses. Add (e) if exotic.

SPECIES	Type	<1	1-2	Sub-Total (1)	Order	2-4	4-8	8-12	>12	Sub-Total (2)	Order

INTRODUCTION

Rivers provide almost all of the surface water that can be exploited in South Africa, and are not only aesthetically and recreationally important parts of the landscape, but sustain an exceptionally high biodiversity in their ecosystems (Day *et al.* 1986). Riparian vegetation serves to link the instream aquatic ecosystem to the adjacent terrestrial ecosystem, which in turn influences river process and pattern. Montgomery and MacDonald (2002) note that riparian vegetation is a key indicator of channel condition.

Riparian vegetation plays an important role in the functioning of riparian zones (Wissmar & Beschta 1998). These functions are not only important from an instream, aquatic perspective, but are vital for the surrounding terrestrial habitat. This is especially important in arid and semi-arid areas (Patten 1998), which dominate large parts of South Africa. The functions that riparian vegetation perform in an ecosystem also provide a number of important goods and services to society. For example, an undisturbed, functioning riparian zone helps ameliorate water quality. Yet despite these essential roles the rate of its removal is becoming alarming (Henderson & Wells 1986; Rowntree 1991).

South Africa's national monitoring programme, the River Health Programme (RHP), focuses on measuring and assessing the ecological state of riverine ecosystems, in order to support their rational management (Roux 1997). The concept of ecological integrity is central to the core of the River Health Programme (Roux *et al.* 1999). Kleynhans (1996:43) defines ecological integrity as "the ability of an ecosystem to support and maintain a balanced, integrated composition of physicochemical and habitat characteristics, as well as biotic components, on a temporal and spatial scale, that are comparable to the natural characteristics of ecosystems within a specific region". Thus the condition of an ecosystem is assessed relative to how that system would function within its hypothetical natural state (Roux 2001). Biomonitoring techniques utilised by the River Health Programme should therefore be functional indices that assess the health of a system relative to a hypothetical, natural state.

The Riparian Vegetation Index (RVI) is one of the biomonitoring techniques utilised in the River Health Programme, developed with the following purposes in mind (Kemper 2001):

- to provide an indicator of riparian vegetation health and ecological status in response to the full range of disturbances typically common in riparian areas;
- to aid decision making by identifying sites of different riparian vegetation status and providing clear indications of the type and extent of disturbances present; and
- the index must be applicable nationwide to a range of systems and which can be rapidly undertaken by staff currently responsible for collecting other monitoring data.

The RVI is a vegetation monitoring technique that produces a score out of 20, in accordance with the broad assessment classes employed in the Ecological Reserve process (Table 1).

Table 1. The Ecological Reserve classes and their corresponding RVI scores and descriptions.

RVI SCORE	ASSESS-MENT CLASS	DESCRIPTION
19 - 20	A	Unmodified, natural.
17 - 18	B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
13 - 16	C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.
9 - 12	D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
5 - 8	E	The loss of natural habitat, biota and basic ecosystem functions are extensive.
0 - 4	F	Modifications have reached a critical level and the system has been completely modified with almost complete loss of natural habitat and biota. In the worst case the basic ecosystem functions have been changed.

Four sub-indices form the basis of the RVI, namely extent of vegetation cover (EVC); structural intactness (SI), percentage cover of indigenous riparian species (PCIRS) and recruitment of indigenous riparian species (RIRS) (Kemper 2001).

The calculation of EVC is based on an estimation of the percentage vegetation cover (EVC1) and an estimation of a measure of the level of disturbance in that site (EVC2). EVC comprises a maximum score of 10 out of the final RVI score of 20, and is calculated using the formula:

$$EVC = [(EVC1 + EVC2)/2] \ldots\ldots (1)$$

Structural intactness (SI) is calculated according to the formula:

$$SI = [((SI1) + (SI2) + (SI3) + (SI4) + (SI5))/5)^{*} 0.33] \ldots\ldots (2)$$

Where SI1, SI2, SI3, SI4 and SI5 represent a structural intactness score rated against a perceived reference state for the tree, shrub, reed, sedge and grass components respectively. Structural intactness comprises a maximum score of 1.

A measure of the invasion of the riparian zone is used to calculate the sub-index percentage cover of indigenous riparian species (PCIRS). PCIRS is calculated according to the formula:

$$PCIRS = [(EVC/2) - ((EXOTICS \times 0.7) + (TERRESTRIALS \times 0.1) + (REEDS \times 0.2))] \ldots\ldots (3)$$

Where exotics, terrestrials and reeds represent the level of invasion of these three components, rated on a 6-point scale from zero to very high. PCIRS comprises a maximum score of 5.

The last sub-index, recruitment of indigenous riparian species (RIRS), is a 6-point scale rating of the recruitment of indigenous species from zero to very high. RIRS comprises a maximum score of 5.

The RVI is thus calculated according to the formula:

$$\mathbf{RVI = [(EVC) + (SI \times PCIRS) + (RIRS)] \ldots\ldots (4)}$$

This study focuses on the evaluation of the reliability and validity of the RVI. One of the objectives of the River Health Programme is ensuring that all reports provide scientifically and managerially relevant information for national aquatic ecosystem management (Roux 2001). Information provided by the biomonitoring techniques must therefore be both reliable and valid. In this context reliability is whether the results obtained from an expert undertaking the RVI assessment in a vegetation type can be reproduced or replicated by other experts, while the evaluation of validity will constitute a discussion of whether the structure of the RVI meets the stated objectives.

METHODOLOGY

1. Preliminary evaluation

The first step of the methodology involved dialogue with a number of RVI experts and a review of the national and international vegetation monitoring literature. A workshop held by the River Health Programme in August 2002 provided the basis for the dialogue. The objective of the workshop was for the key players in the development and implementation of riparian vegetation monitoring to collectively scrutinize the RVI, determine reasons for the method not being more widely used and to put in place steps towards revising or changing the methods where necessary.

2. Sensitivity analysis

A sensitivity analysis was conducted in order to ascertain which sub-indices within the index have the most potential to alter the final RVI scores, and where uncertainty or field estimation error could have an impact on the final score or management class. This facilitated the interpretation of the field data.

Each sub-index was subjected to 20% changes above and below a value assumed to be the actual value or correct field estimate for the variable (Figure 1). The remaining sub-indices were kept constant. A 20% change was chosen as each sub-index is ranked on a 6-point scale. The effects of over or underscoring a particular sub-index by one category becomes significant when a component such as cover is approximately 50% (Figure 1). This value is on the border between two categories and the sensitivity analysis would illustrate the effect on the final RVI score of placing cover in the 26-50% category or in the 51-75% category. This holds true for other values such as 5%, 25% and 75% which are also on the border.

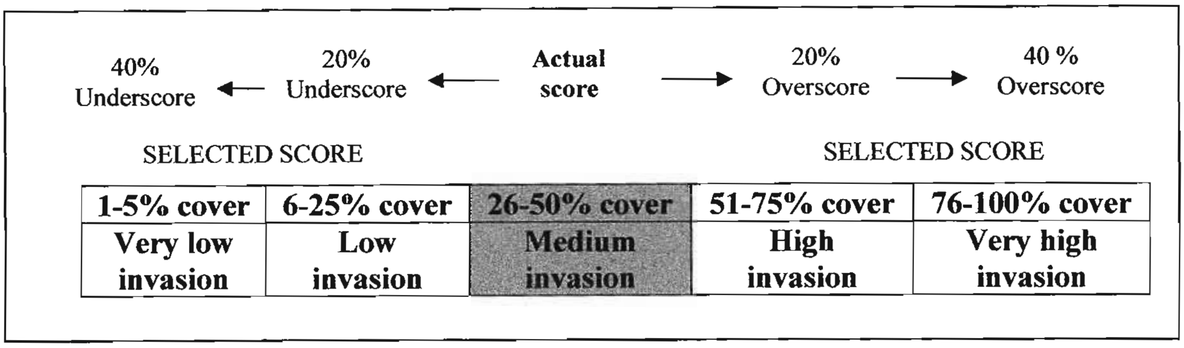

Figure 1. An illustration of the methodology utilised in the sensitivity analysis where each block represents a 20% underscore or overscore of a particular sub-index.

3. Data collection

Eight sites in three vegetation types were chosen for the purpose of evaluating the reliability of the RVI method. Table 2 provides a summary of the sample sites, indicating the vegetation type, disturbance level, surrounding landuse and additional comments. Six assessors were chosen on account of previous experience in using the RVI, or with the necessary botanical and aquatic ecosystem knowledge. Utilising assessors, however, did prove to be a limitation as the assessors were professional, working people with limited time. Consequently the number of assessors per sample site varied between five and seven.

3.1 Study area

Table 2. Description of data collection sites.

SITE NO.	**RIVER**	**DESCRIPTION**			
		Vegetation type	**Disturbance level**	**Surrounding landuse**	**Comment**
1.	Umgeni	Savanna	Medium/ low	Conservancy	Large, unvegetated boulders with minor alien vegetation infestation.
2.	Gwenspruit Tributary	Grassland	Low	Conservancy	Small stream in excellent condition.
3.	Mlazi Tributary	Mistbelt forest	Low	Forestry	Well-vegetated mistbelt forest in excellent condition.

4.	Mlazi Tributary	Mistbelt forest	Medium	Conservancy	Well-vegetated mistbelt forest but with alien invasion on one bank.
5.	Mlazi Tributary	Grassland	High	Conservancy	Site disturbed by recent alien vegetation removal.
6.	Mlazi	Savanna	High	Piggery	One bank completely covered in alien vegetation.
7.	Mlazi Tributary	Grassland	Medium	Stock farming	Riparian zone disturbed by stock grazing and site characterised by *Phragmites* build up.
8.	Mlazi	Grassland	High	Stock and sugarcane	Highly disturbed site with considerable alien vegetation infestation.

3.2 RVI procedure

The RVI field assessment was undertaken over a period of 30 to 45 minutes according to the guidelines provided by Kemper (2001). This was adhered to but proved to be a limitation as assessors found that identifying plant species was time-consuming and that the whole method could take up to an hour to complete. The assessment was split into two components. The site walkabout form was filled in first and took 15 minutes to complete. Consistent with the guidelines each site was approximately 200 metres in length with a riparian zone of roughly 30 metres in width (Kemper 2001). Species within the riparian zone were recorded and placed into height classes, with an estimate of their numbers.

The walkabout form information is subsequently utilised in calculating the sub-indices and final RVI score defined in equations 1 to 4. It is required that every section of the fieldsheet is filled in. However, only certain sections contribute to the final RVI score (Table 3).

Table 3. Indication of which components in the RVI fieldsheet contribute to the final RVI score and which components do not.

COMPONENTS USED IN THE RVI CALCULATION	COMPONENTS NOT USED IN THE RVI CALCULATION
Percentage vegetation cover (all vegetation)	Channel type
Reason(s) why less than 100% vegetation cover	Active channel width
Distribution of vegetation cover rated against a perceived reference state	Width of the potential riparian zone
Invasion of riparian zone – exotic, terrestrial and reed species	Estimate of the riparian zone substrate
Recruitment of indigenous riparian species	Site disturbances
	Surrounding land use
	Estimate of cover rated against a perceived reference state
	Dominance by biomass
	Dominance by recruitment
	Species richness
	*Assessor gut score

* Assessor gut score does not contribute to the actual calculation but is used in this study by means of comparison.

4. Data analysis

For each site the range in individual assessments for each factor of a sub-index, the sub-index and the final RVI score was compared. The final RVI score and the assessors' gut condition score was also compared. In the latter case a two-tailed paired two-sample for means t-test was applied to the data, where

H_0 = There is no significant difference between the final RVI score and the gut condition score.

H_1 = There is a significant difference between the final RVI score and the gut condition score.

An assumption is made whereby the middle value of the gut condition score was chosen as the gut scores are represented by classes as indicated in Table 1. For example a value of 17.5 is used for a gut condition B class (17-18).

RESULTS

1. Sensitivity analysis

1.1 Extent of vegetation cover (EVC)

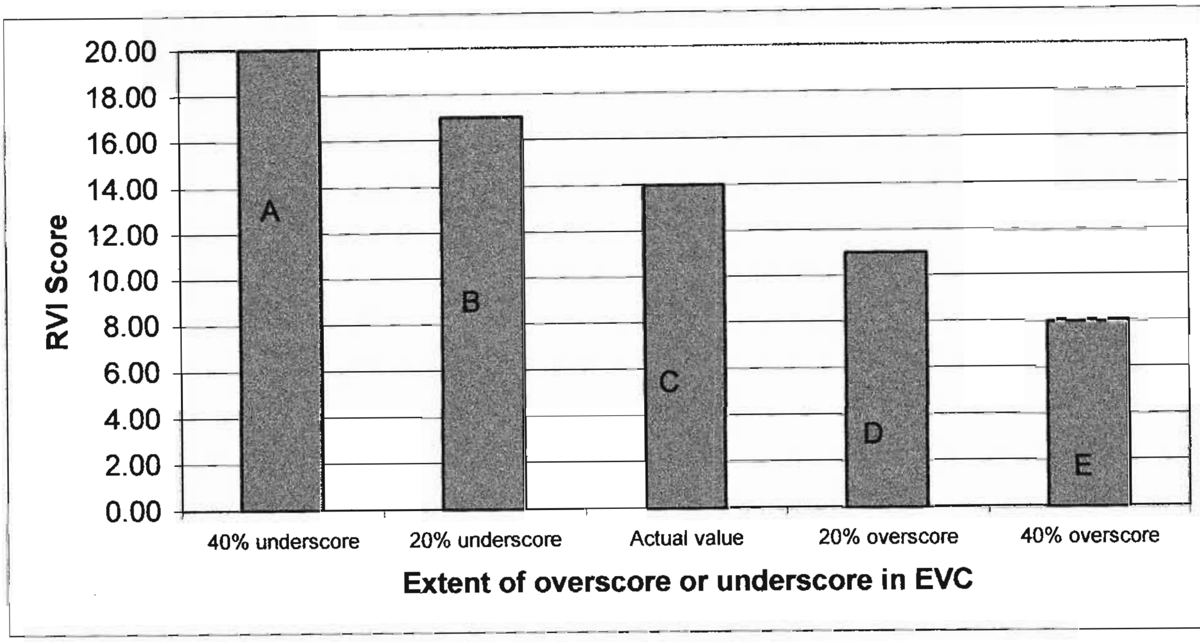

Figure 2. The effect of 20% and 40% underscores or overscores in factors determining the extent of vegetation cover (EVC) on the calculation of the final RVI score and associated management class.

As indicated in equation 1, the calculation of EVC is an average of both EVC1 and EVC2. Consequently for there to be a 20% overscore or underscore in EVC would require both EVC1 and EVC2 to be overscored or underscored by one category, or would require either EVC1 or EVC2 to be overscored or underscored by two categories. Figure 2 indicates that for every 20% overscore or underscore in EVC there is a change in the RVI score that results in a change in management class. This is a result of EVC contributing a maximum score of 10, of the maximum RVI score of 20, in other words a 50% weighting. This would indicate that if the two components of EVC were to fall on the boundary of two categories and were scored differently by two assessors, the final RVI score and associated management class would be different.

1.2 Structural intactness (SI)

Figure 3 indicates that a 20% overscore or underscore in the SI score results in a minor change in the overall RVI score. A 40% overscore would indicate that the assessor believes that the present state for the tree, shrub, reed, sedge and grass layers is completely different from the perceived reference state, i.e. there has been a complete vegetation change. This should have a larger bearing on the overall score, yet it only drops the RVI score from a B class (middle value of 17.5) to a C class (middle value of 14.5). This is attributed to the fact that the SI component of the RVI comprises a maximum score of 1, or a 5% weighting. This would indicate that errors in the estimation of the factors comprising the SI sub-index will not significantly alter the final RVI scores of the assessors.

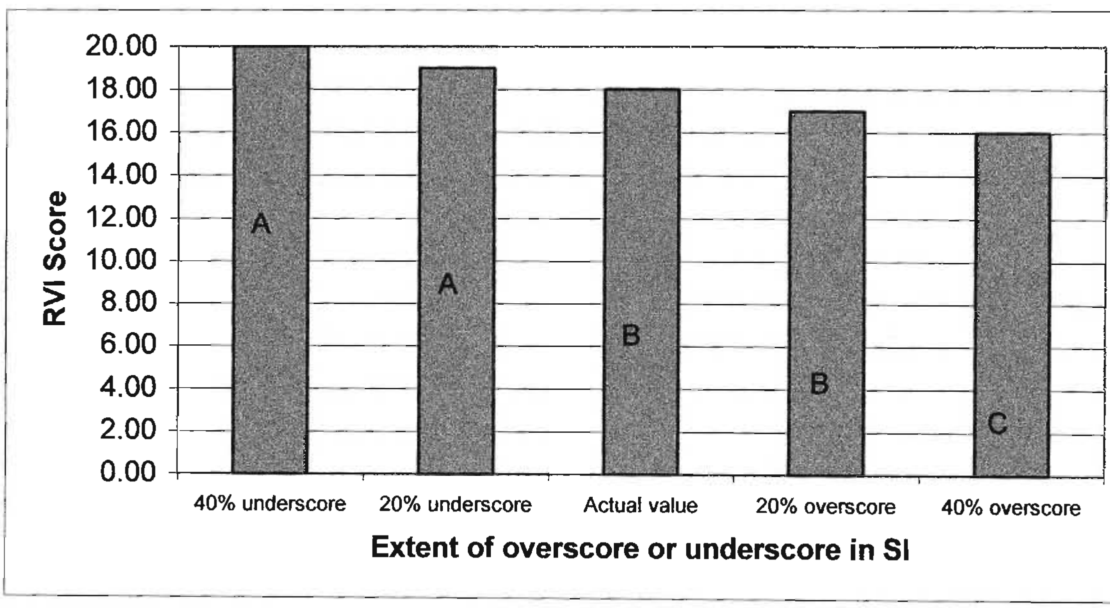

Figure 3. The effect of 20% and 40% underscores or overscores in factors determining the extent of structural intactness (SI) on the calculation of the final RVI score and associated management class.

1.3 Percentage cover of indigenous riparian species (PCIRS)

Equation 3 indicates that PCIRS is comprised of an estimation of the invasion of exotics, terrestrials and reeds subtracted from EVC. Consequently a 20% overscore or underscore would require all of these components to be underscored or overscored by one category. Figure 4 illustrates that this sub-index has a large effect on the overall score as a 20% underscore in PCIRS results in a change in class from D to C, and a 40% underscore changes the class from D to A. The reason that overscoring does not alter the RVI scores in the same proportion as underscoring does is that negative values are obtained which are assigned zero, as negative levels of cover cannot be obtained (Kemper 2002 *pers. comm.)*. Negative values are obtained as the calculation of PCIRS relies on subtracting the extent of invasion from EVC. If the value of EVC is low and the level of invasion is high then negative values are obtained. The fact that this sub-index relies on EVC, which itself is a variable sub-index illustrated in Figure 2, may explain the variability found in PCIRS.

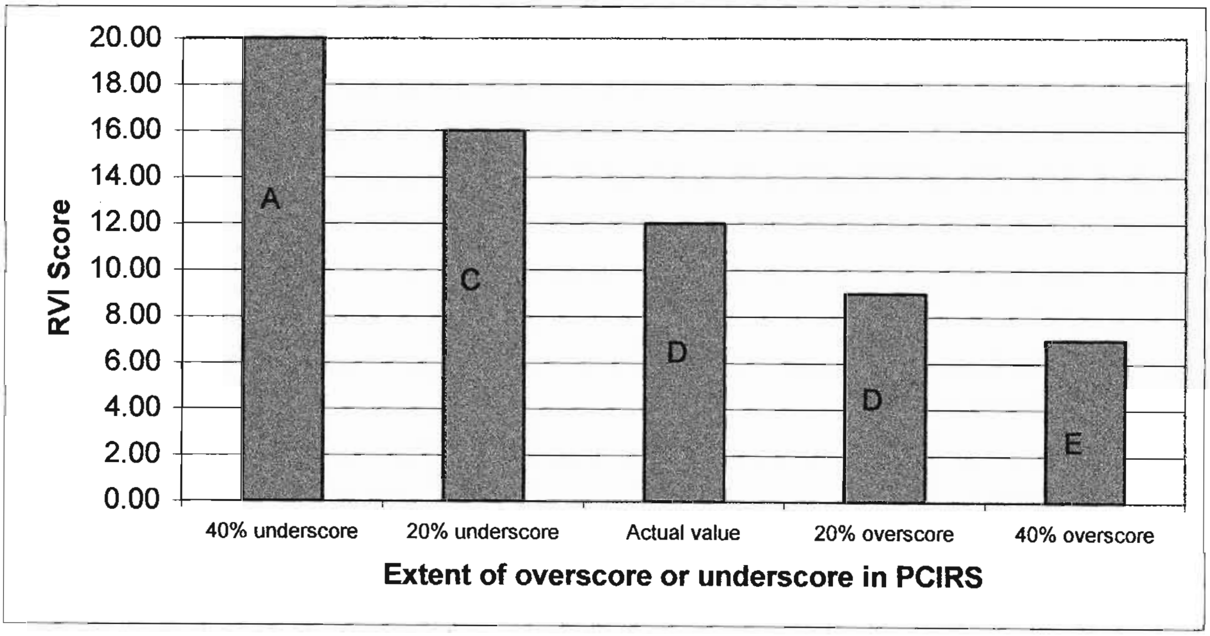

Figure 4. The effect of 20% and 40% underscores or overscores in factors determining the extent of percentage cover of indigenous riparian species (PCIRS) on the calculation of the final RVI score and associated management class.

1.4 Recruitment of indigenous riparian species (RIRS)

Figure 5 indicates that the RVI is not particularly sensitive to changes in RIRS. Forty percent changes in RIRS scores alter the RVI score either down or up one management class. This would indicate that errors in the estimation of the factors which generate the RIRS sub-index have less potential to sign alter the final RVI scores of the assessors.

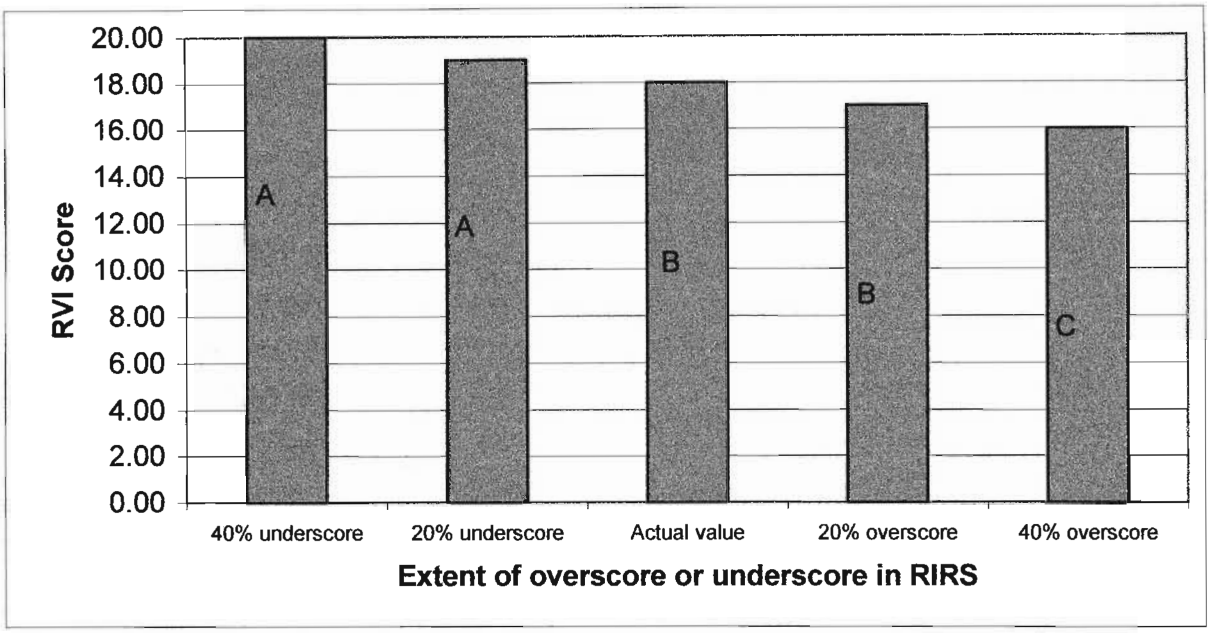

Figure 5. The effect of 20% and 40% underscores or overscores in factors determining the extent of recruitment of indigenous riparian species (RIRS) on the calculation of the final RVI score and associated management class.

The results of the sensitivity analysis indicate that the two sub-indices, EVC and PCIRS, have the most potential to alter the final RVI score.

2. Field results

2.1 Individual site analyses

The t-test results are presented in Table 4. The results indicate that three out of the eight sites showed a significant difference between the means of the calculated RVI scores and the gut condition scores. These results are further discussed in the individual site analysis.

Table 4. Results of the t-test conducted on the RVI sample sites in order to compare final RVI scores against gut condition scores, indicating p values, degrees of freedom (DF), vegetation type, disturbance levels and significance at the 5% significance level.

SITE NO	VEGETATION TYPE	DISTURBANCE LEVEL	P VALUE	DF	SIGNIFICANCE $\alpha = 0.05$
1	Savanna	Medium/ low	0.002	4	Significant
2	Grassland	Low	0.001	4	Significant
3	Mistbelt forest	Low	0.050	7	Not significant
4	Mistbelt forest	Medium	0.070	4	Not significant
5	Grassland	High	0.980	7	Not significant
6	Savanna	High	0.010	7	Significant
7	Grassland	Medium	0.780	4	Not significant
8	Grassland	High	0.260	4	Not significant

2.1.1 Site 1

Figure 6 compares the RVI score calculated for site 1 by each of the five assessors, and their estimation of the gut condition score. The stacked bar chart represents the upper and lower limits of the gut condition score. The upper and lower limits are given as the gut condition score is rated according to the management class, which are represented by upper and lower limit values as indicated in table 1. The numbers on the x-axis represent individual assessors, and are ranked in no particular order. In all cases assessors indicated a higher management class (gut condition score) than that which was subsequently calculated. The P value of 0.002 confirms that there is a significant difference between the means of the RVI scores and the means of the gut condition scores. Furthermore, there was a reasonably large spread of results indicated by the standard deviation of 2.24 for site 1 (See Appendix 1). An assessment of the sub-indices indicates that EVC and PCIRS were responsible for this variation, with EVC ranging between 5 and 8, and PCIRS between 0 and 2.3 for site 1 (See Appendix 1).

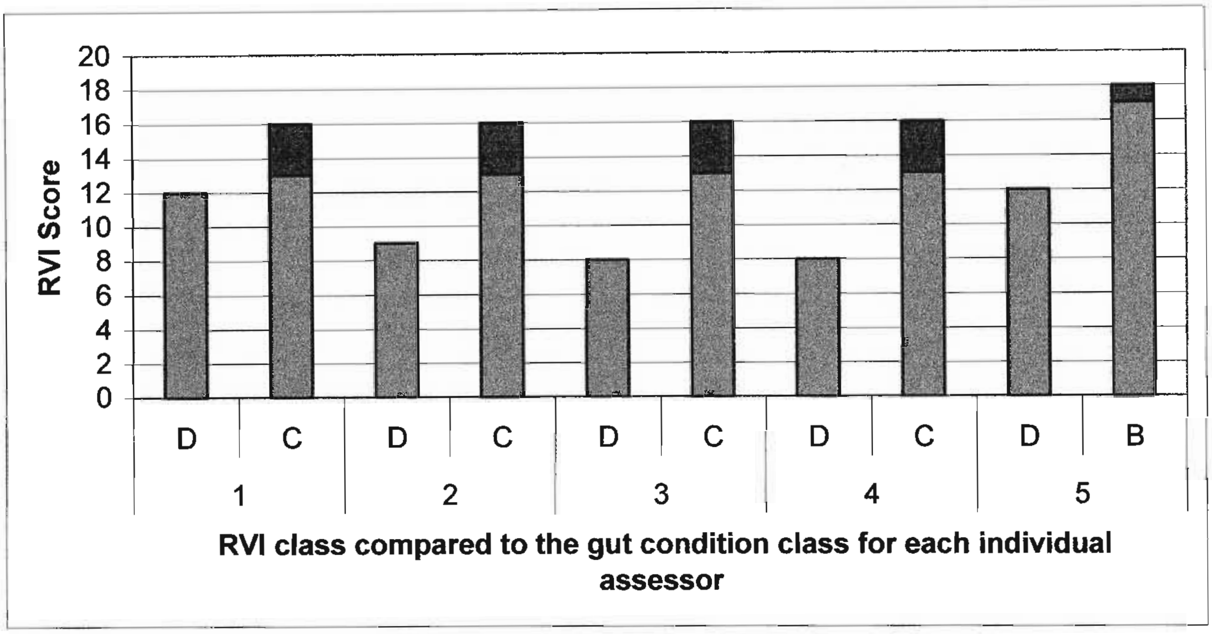

Figure 6. Illustration of the final RVI score and class (left) compared to the gut condition class (right) for each individual assessor at site 1.

<u>2.1.2 Site 2</u>

Figure 7 indicates that in all cases assessors indicated a higher gut condition score than that which was subsequently calculated. This was confirmed by the P value of 0.001 indicating a significant difference between the RVI scores and the gut condition scores. The variation in EVC, with the scores ranging between 6 and 9 and RIRS, with scores ranging between 0 and 4 for site 2, were the contributing factors to the variation in the final scores (See Appendix 1).

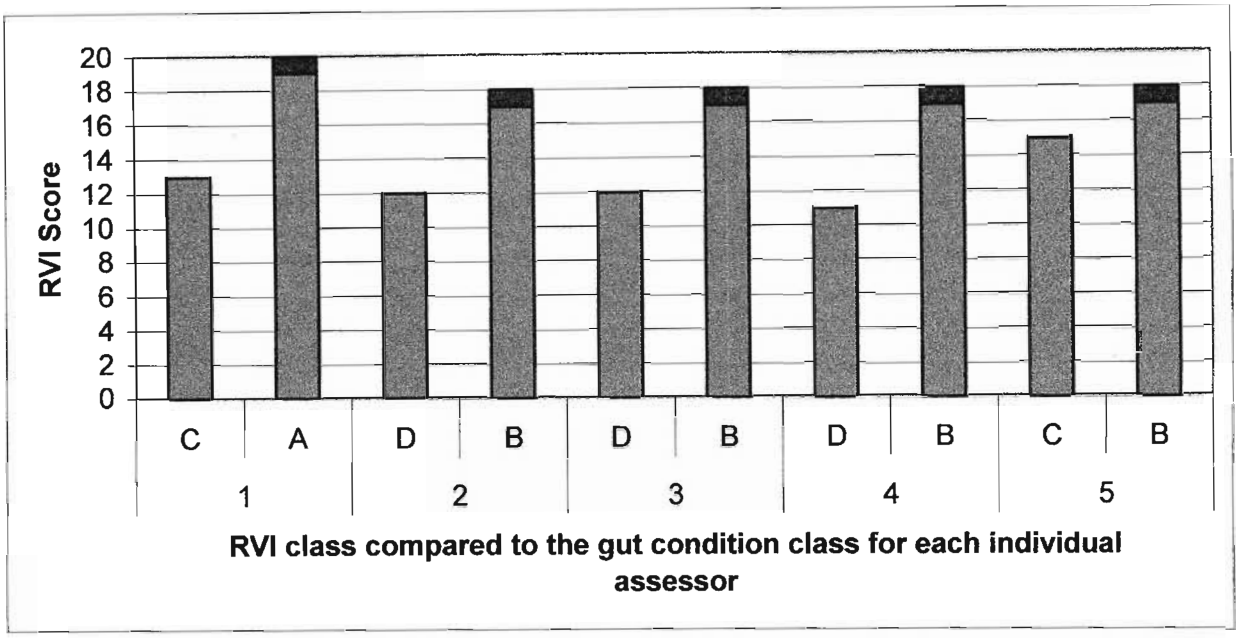

Figure 7. Illustration of the final RVI score and class (left) compared to the gut condition class (right) for each individual assessor at site 2.

2.1.3 Site 3

Figure 8 illustrates that four out of the eight assessors obtained calculated RVI scores equivalent to the gut condition scores while the other four assessors indicated higher management classes compared to the calculated RVI score. Assessor 5 was repeated as this assessor undertook the RVI twice on different occasions. The P value of 0.05 indicates that there may be no significant difference between RVI scores and gut scores. EVC scores ranged between 5 and 10 for site 3 (See Appendix 1).

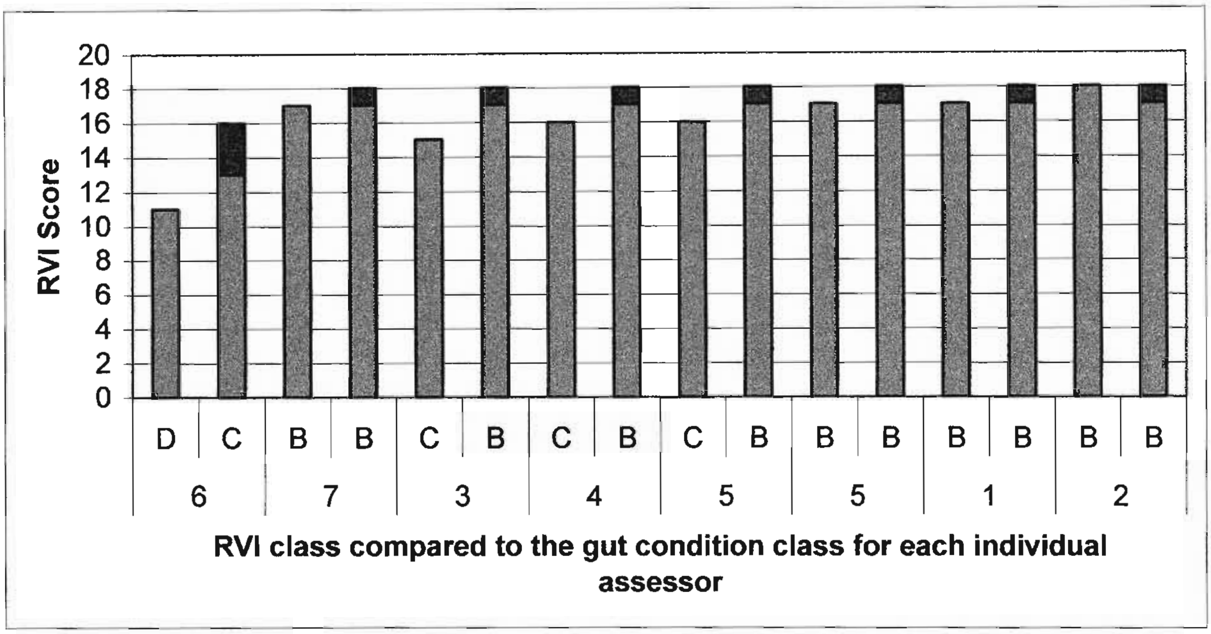

Figure 8. Illustration of the final RVI score and class (left) compared to the gut condition class (right) for each individual assessor at site 3.

2.1.4 Site 4

Figure 9 illustrates that four out of the five assessors consistently indicated higher management classes compared to the calculated RVI score, while one assessor obtained an RVI score equivalent to the management class. The P value of 0.07 indicates that there may be no significant difference between RVI scores and gut scores. EVC showed variation of between 6.5 and 10 for site 4 (See Appendix 1).

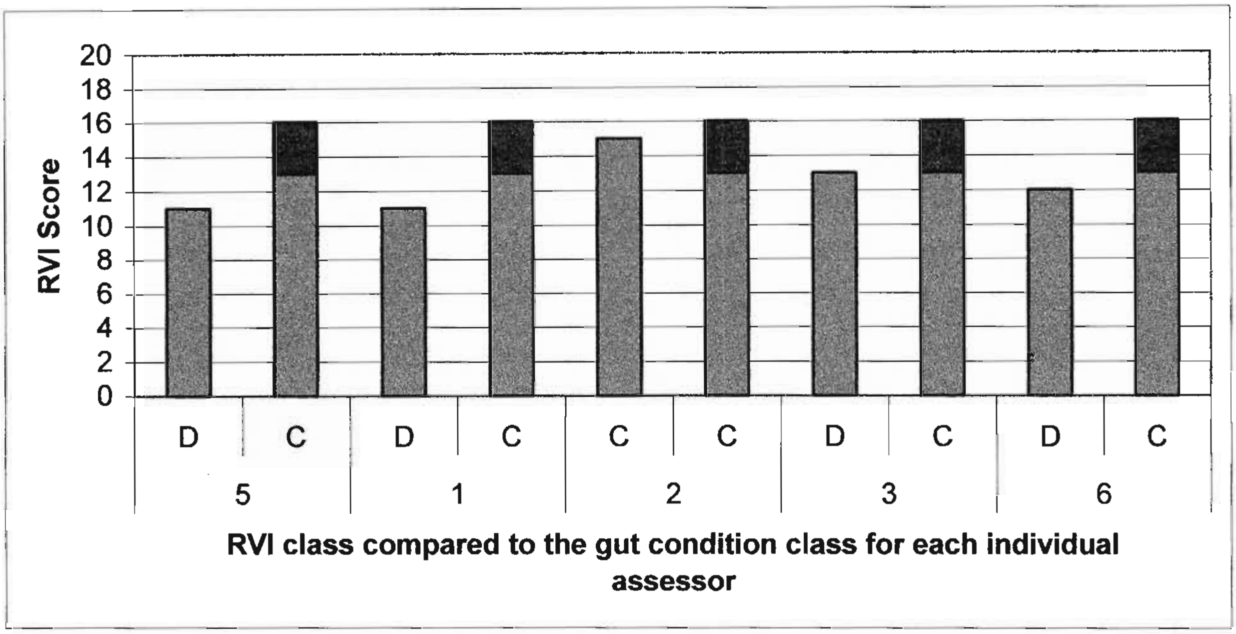

Figure 9. Illustration of the final RVI score and class (left) compared to the gut condition class (right) for each individual assessor at site 4.

2.1.5 Site 5

Figure 10 illustrates that the assessors were fairly consistent in scoring site five in relation to the gut condition scores as six of the eight assessors final RVI scores matched the gut condition class scores. This was confirmed by the P value of 0.98, which indicates that there may be no significant difference between RVI scores and gut scores. EVC scores ranged between 5 and 10, while RIRS scores ranged between 0 and 4, contributing to the variation in final RVI scores for site 5 (See Appendix 1).

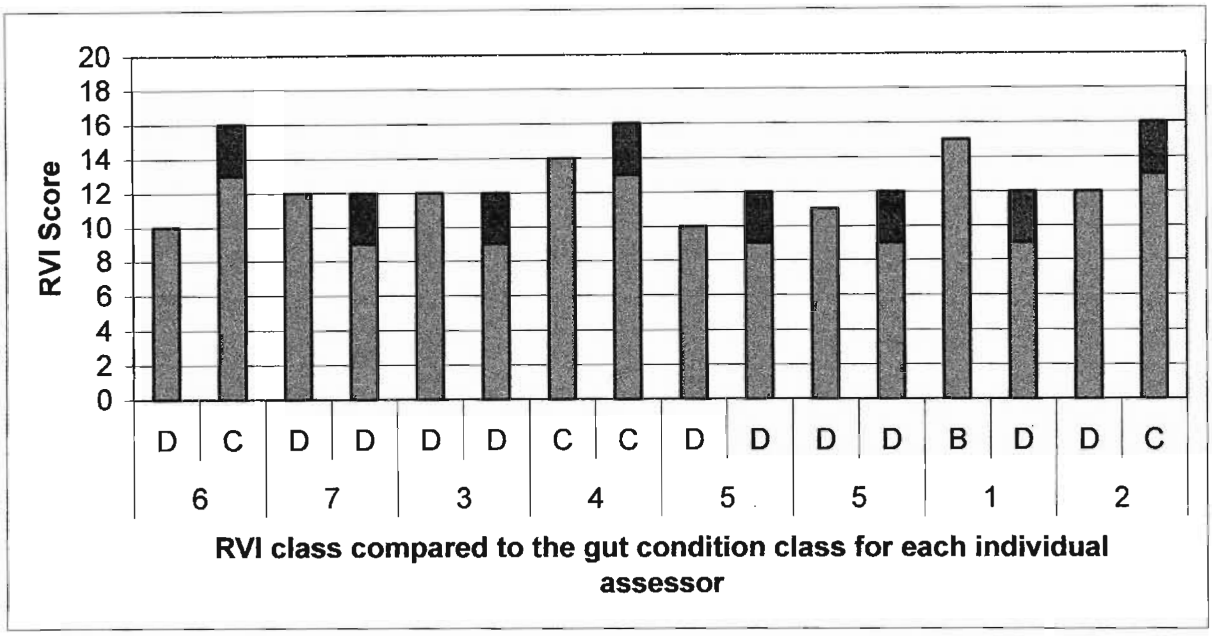

Figure 10. Illustration of the final RVI score and class (left) compared to the gut condition class (right) for each individual assessor at site 5.

2.1.6 Site 6

Figure 11 illustrates that assessors indicated a lower management class compared to the calculated RVI score. This was confirmed by the P value of 0.01 indicating a significant difference between the RVI scores and the gut condition scores. There was also considerable variation in the range in gut condition scores from an E class to a C class between expert assessors.

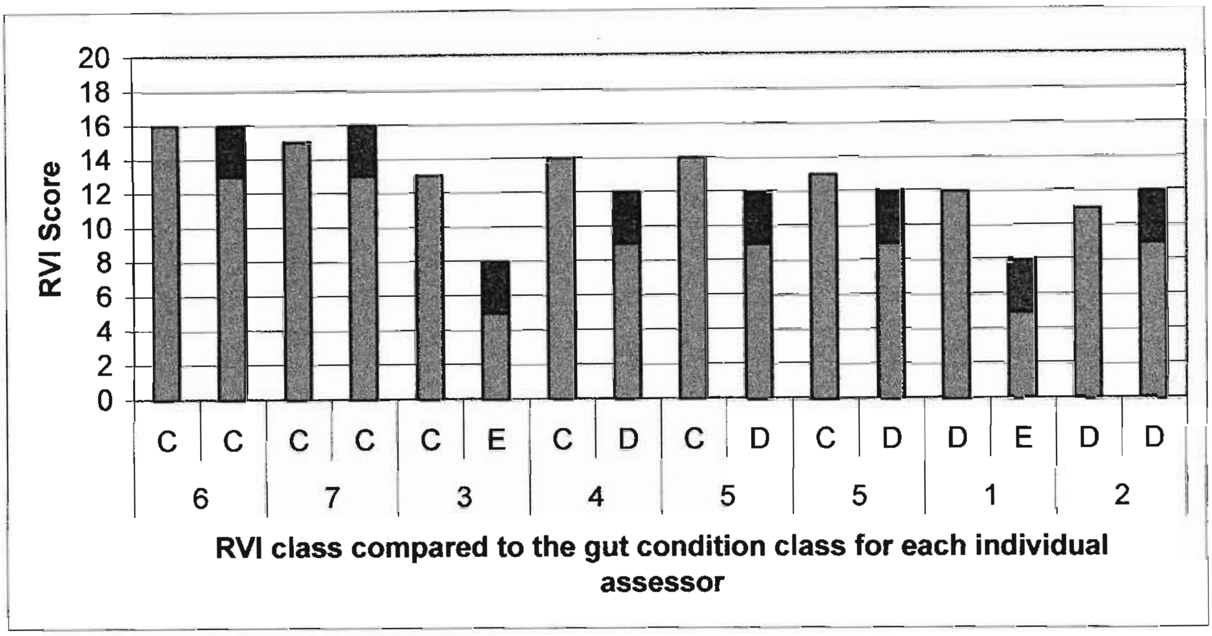

Figure 11. Illustration of the final RVI score and class (left) compared to the gut condition class (right) for each individual assessor at site 6.

2.1.7 Site 7

Figure 12 illustrates that the final RVI scores exhibited large variation, with a standard deviation of 2.01 (See Appendix 1). Three out of the five assessors indicated lower management classes compared to the calculated RVI scores, while two assessors were consistent in their scoring. The P value of 0.78 indicates that there may be no significant difference between RVI scores and gut scores. EVC ranged between 6 and 10 for this site (See Appendix 1). Gut condition scores ranged between an E class and a C class.

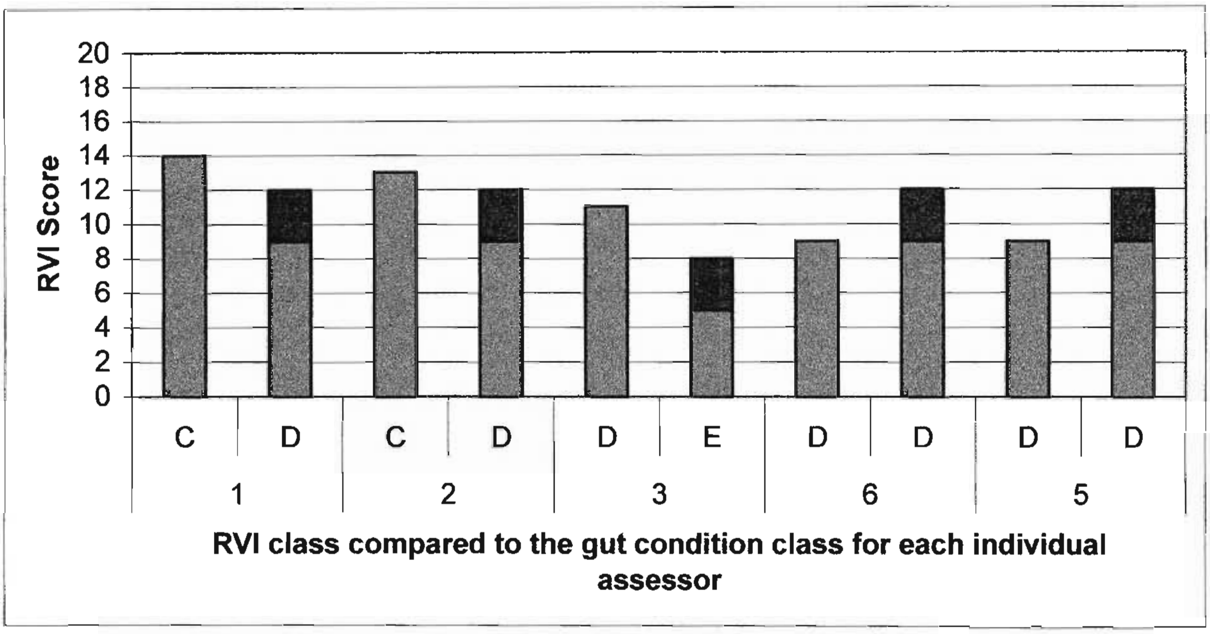

Figure 12. Illustration of the final RVI score and class (left) compared to the gut condition class (right) for each individual assessor at site 7.

2.1.8 Site 8

Figure 13 illustrates that the final RVI scores again showed large variation, with a standard deviation of 2.28 (See Appendix 1). Two out of the five assessors indicated lower management classes compared to the calculated RVI scores, while two assessors were consistent in their scoring, one assessor indicated a higher management class and two assessors were consistent in their scoring. The P value of 0.28 indicates that there may be no significant difference between RVI scores and gut scores. EVC ranged between 6 and 10 for this site (See Appendix 1). Gut condition scores ranged between an E class and a C class.

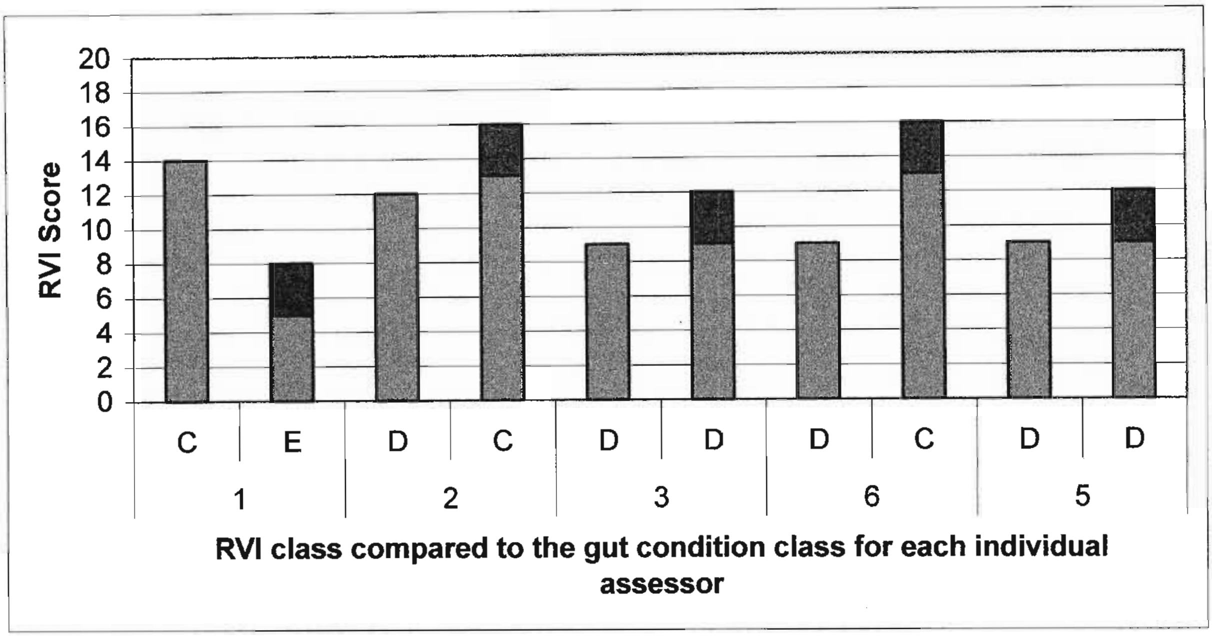

Figure 13. Illustration of the final RVI score and class (left) compared to the gut condition class (right) for each individual assessor at site 8.

2.2 Sub-index analysis

Figure 14 indicates that EVC exhibited the greatest variation of the sub-indices across sample sites, while SI exhibited the smallest variation. In contrast EVC carries the highest weight in the final RVI score while SI carries the lowest weight. It is evident that variation may not necessarily occur according to vegetation type, as it appears fairly uniform acoss all sites. This is further illustrated by the box-and-whisker plot in Figure 15 which indicates the large spread in EVC scores across the three vegetation types. Figure 15 further emphasizes the variation produced by EVC across vegetation types.

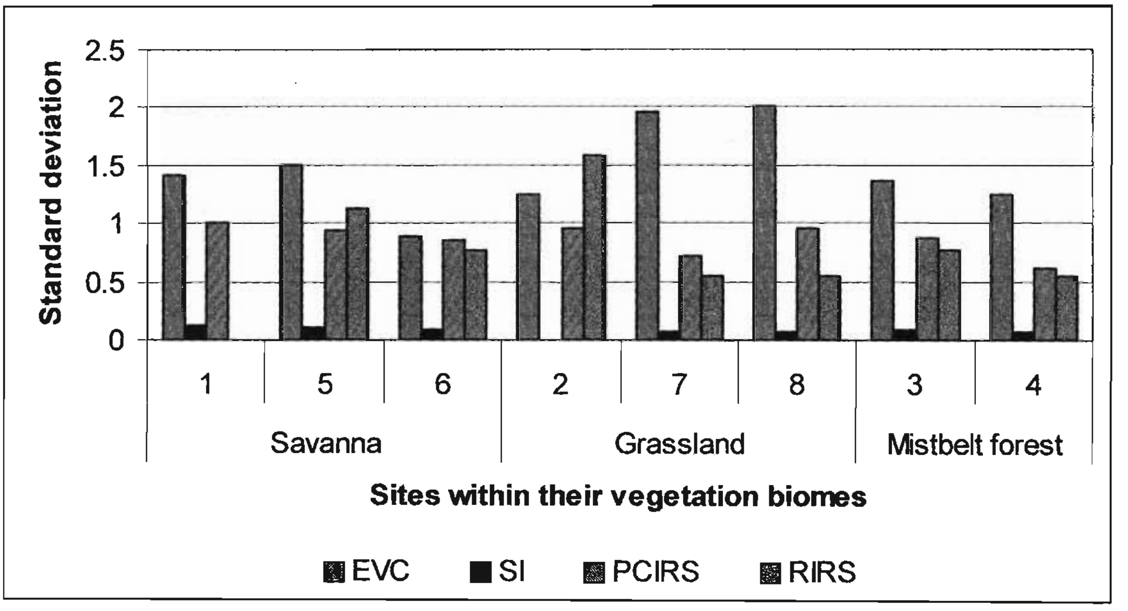

Figure 14. Standard deviations of the four sub-indices across all sample sites.

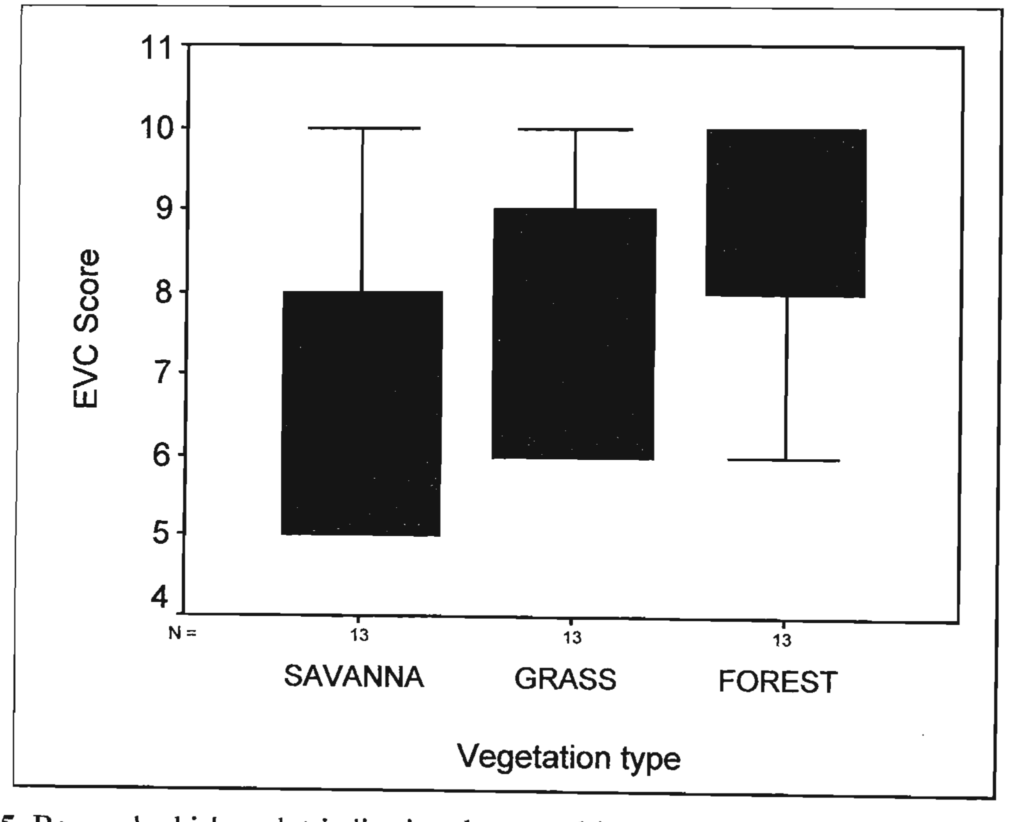

Figure 15. Box-and-whisker plot indicating the spread in combined EVC scores across the three vegetation types.

The analysis of the individual components of the sub-indices in Figure 16 indicated that EVC2, the measure of the level of disturbance, exhibited considerable variation. It is mostly responsible for the variation in EVC shown in Figure 15 as EVC1 exhibited variation of less than 1.5 standard deviations from the mean. The components making up SI, namely tree, shrub, reed, sedge and grass are fairly evenly distributed with the majority below one standard deviation from the mean. The components making up PCIRS, namely exotic, terrestrial and reed are fairly evenly distributed with the majority below one standard deviation from the mean.

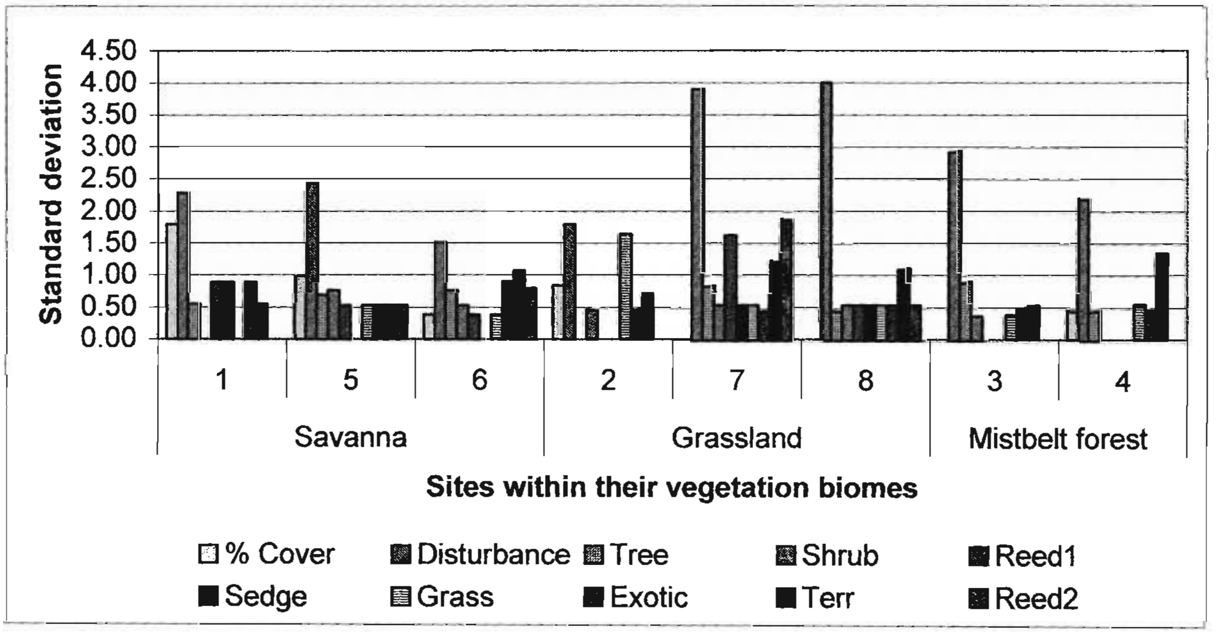

Figure 16. Standard deviations of the the individual componenets of the four sub-indices across all sample sites.

DISCUSSION

The results of the RVI assessment will now be discussed in order to establish the reliability and validity of the index. Recommendations will then be made to improve both the reliability and the validity of the index so that the River Health Programme can be assured of some form of quality control for this index. Issues relating to the four sub-indices, integral to the index calculation will now be dealt with separately.

1. Extent of vegetation cover (EVC)

1.1 EVC1

The calculation of the percentage vegetation cover requires scoring of both banks, and the islands if necessary (Table 5).

Table 5. The percentage vegetation cover scale used in the RVI fieldsheet.

LHB	**0%**		**1-5%**		**6-25%**		**26-50%**		**51-75%**		**76-100%**	
RHB	**0%**		**1-5%**		**6-25%**		**26-50%**		**51-75%**		**76-100%**	
Islands	**0%**		**1-5%**		**6-25%**		**26-50%**		**51-75%**		**76-100%**	

Situations exist where the riparian zone is completely degraded, yet there is a small island with 100% cover. Furthermore, one bank may be completely denuded of riparian vegetation and the other complete. The RVI scores are averaged in the final calculation, placing the same weighting on the cover of the island as on the cover for each bank (Ewart-Smith 2002 *pers. comm.*).

Another factor that may introduce bias into the scoring is that aerial and basal cover are not scored independently. Situations exist where there is a complete canopy cover of trees, yet the basal cover of grasses is bare.

1.2 EVC2

Page two of the fieldsheet included in Appendix 2 implies that if there is 100% vegetation cover then measuring the level of disturbance, or EVC2, should not be filled in. A site completely covered in exotic vegetation, i.e. there is 100% cover, is disturbed. By labeling this field "reason why there is less than 100% vegetation cover" suggests that a site with 100% cover, regardless of the vegetation type, is not disturbed.

The difference between a natural disturbance and any other type of disturbance is not made explicit. If a site has been termed naturally disturbed EVC2 is allocated a maximum score of five. The major difficulty is that it is exceptionally difficult to rate whether a disturbance is natural or not after a 45-minute site visit.

2. Structural intactness (SI)

The calculation of SI relies on the assessor deciding what the perceived reference state of that site is. The perceived reference state (PRS) refers to the 'natural' condition or characteristics of the site (Kemper 2001). There are no historical botanical records of this on any rivers, and consequently one has to imagine what this condition is like (Kemper 2001). This is a potential source of subjectivity, and is one which RVI assessors expressed dissatisfaction at, both at the workshop and during the RVI assessments conducted for this study.

3. Percentage cover of indigenous riparian species (PCIRS)

It is evident from equation 3 that EVC is used in determining PCIRS and if the assessor incorrectly scored the components making up EVC, then that error will also be carried through to the sub-index PCIRS.

The weightings of the sub-indices of 0.7, 0.1 and 0.2 for the exotic, terrestrial and reed components respectively were calibrated according to a subjective 'gut condition score' (Kemper 2002 *pers. comm.*). In other words these weightings were altered until the gut condition score equaled the RVI score for that particular sub-index. These weightings are not assigned according to the level of influence on the functioning of the river and the manual does not indicate the exact location of the sites where this calibration occurred. This is a potential source of bias as these weightings could easily change according to the vegetation type in which one undertook this calibration exercise.

The calculation of the extent of terrestrialisation is subjectively dependent on the assessor deciding whether a species in the riparian zone is a riparian species or a terrestrial species. Eekhout *et al.* (1997) mention that there are no checklists of riparian plant species occurring in South Africa. Boucher (2002 *pers. comm.*) also notes that there is considerable debate as to what should be considered a riparian species. The consequence is that a species located in a riparian zone in one vegetation type may not be found in a different vegetation type. Therefore one assessor may decide that there may be terrestrialisation in a site while another assessor may disagree.

4. Recruitment of indigenous riparian species (RIRS)

Determining the extent of recruitment in a grassland-dominated site is exceptionally difficult as determining recruitment of grasses is considerably more difficult than for woody species, as the growth nature of grasses prevents one from visually noting recruitment easily.

It is evident that there are issues with all four sub-indices that may be reducing the reliability and validity of the RVI. Furthermore, other considerations have been identified with the RVI as a whole that must be discussed.

5. Other considerations

5.1 Emphasis on woody terrestrial species

The RVI was developed on the Sabie and Olifants Rivers in Mpumalanga. These study sites are characterised by well-developed riparian zones, usually dominated by large trees. The determination of structural intactness relies on determining distribution for trees, shrubs, reeds, sedges and grasses. A purely grassland site will not contain trees and shrubs, yet one needs to estimate the structural intactness of the trees and shrubs for any site, which can have a negative effect on the final score.

5.2 Training

The RVI assessment requires adequately trained and experienced staff, who essentially require a minimum botanical knowledge to undertake the assessment (Kemper 2001). However, the calculation of the index itself is almost completely independent of species. The assessor does need to be able to rate the exotic vegetation invasion, but this comprises a very minor proportion to the score. This may lead to situations where unqualified people could use the index without the requisite botanical knowledge.

5.3 Seasonal vegetation changes

The fact that vegetation changes according to season, and due to disturbance such as fire, is another perceived cause of concern, as one will obtain different results on the same site of a river as the season changes. This is especially pertinent with the RVI which places emphasis on cover, which changes dramatically with a disturbance such as fire.

5.4 Database

Dialogue from the workshop indicated that the entering of the fieldsheet scores into the rivers database is seen to be a 'black box' as one is unable to visualize the calculations. The database should be more transparent so that assessors are able to visualize each calculation.

5.5 Site representativeness

The choice of a site is often subjective and may not be wholly representative of the river. Furthermore, biomonitoring sites are often chosen to provide best habitat diversity for fish and invertebrates and may not be as good for riparian vegetation as they are often located on rapids and riffles, which are usually in rocky areas. Sites are also chosen according to ease of access and this may result in anthropogenic disturbances at the site such as a clearing for a path, bridges or weirs which will adversely affect the RVI score.

5.6 Defining the riparian zone

Defining the riparian zone is essential as it can greatly affect the outcome of the RVI result. Kemper (2001) notes that usually the riparian vegetation comprises distinct riparian species. However, in a site that has been highly impacted, or in a very small stream this can be a difficult task. Assessors noted that this is one of the more difficult tasks in the RVI and emphasizes the importance of having trained or experienced RVI assessors.

5.7 Fieldsheet components

Table 3 indicates that there are time-consuming components of the fieldsheet that require entering by the assessor but do not contribute to the final RVI score.

It is evident that there are reliability and validity issues, with both the RVI as a whole, as well as with the various sub-indices making up the index. The results of the field results will now be discussed.

The results of the t-test indicate that in three of the eight sites there is a significant difference between the calculated RVI score and the gut condition score. The other five sites still exhibit variation between the calculated scores and the gut scores, but are not significant. The majority of this variation was due to the calculated RVI scores being lower than the gut condition scores, i.e. underscoring the site in comparison with the gut condition scores. Site 6 is an example of the RVI overscoring a site. The left-hand bank is primarily responsible for this variation as it is 100% alien vegetation cover. As mentioned, the fieldsheet implies that if one obtains 100% cover, then the disturbance value must not be scored. A highly impacted site such as site 6 should produce lower final RVI scores than those which were produced by the expert assessors, as indicated by the low gut condition scores, yet the final scores are elevated due to the high EVC scores.

There is often considerable difference in scores between assessors at the same site. Sites seven and eight are clear examples of this as RVI scores ranged between 14 and 9, and gut condition scores between a C class and an E class between assessors.

Although the individual site analysis does not indicate that the RVI is inconsistent in different vegetation types, there is some evidence to suggest that this may occur. For example, site two is a 'pristine' grassland that produced low RVI scores relative to the gut condition scores, whereas site three is a 'pristine' mistbelt forest that produced RVI scores consistent with the gut condition scores. SI and RIRS are difficult to determine in grassland sites and the individual sub-index results from site 2 indicate that this may well be the case (see Appendix 1). The SI and RIRS values in site 3 in the mistbelt forest were higher and more consistent between assessors (see Appendix 1). There was no apparent difference between the scores in the different vegetation types in the other sites, and this can possibly be attributed to the fact that they are disturbed. The sensitivity analysis emphasizes that EVC and PCIRS have the most potential to alter the final RVI scores. Figure 16 indicates that EVC2 exhibits considerable variation, while EVC1 showed very little variation. The variation caused by EVC2 can possibly be attributed to a poor explanation in the field manual, subjective ideas on levels of disturbance by different assessors and subjective definitions of the riparian zone by different assessors.

At a functional level Ladson and White (1999) note that structural intactness is important to the ecological functioning of a riparian zone. However, SI only contributes a score of 1 out of 20. Furthermore, the measure of SI depends on the perceived reference state, which assessors expressed dissatisfaction at attempting to define. A reference state is that condition which can be expected in the absence of human impacts (Roux *et al.* 1999). Rogers and Biggs (1999), however, have pointed out that recognition and description of the reference state has proved elusive, particularly in highly variable semi-arid conditions such as in South Africa.

CONCLUSION

It is evident that there has been considerable variation between calculated RVI scores for a site, and between calculated RVI scores and their respective gut condition scores for a site. The measure of the level of disturbance, EVC2, is principally the cause of this significant variation. The fact that considerable weight has been placed on EVC is cited as the main cause of the variation found in the calculated RVI scores. The following recommendations would significantly contribute to increasing the reliability and validity of the RVI:

- Explain clearly and define each step, and important terms, of the fieldsheet so that assessors understand exactly what is required of the index. This would contribute to eliminating some of the variability of EVC2.
- Measure and calculate EVC1 and EVC2 separately. Thus EVC1 would be a separate sub-index and would be an assessment of the cover of vegetation. EVC2 would be a separate sub-index and would be an assessment of the level of disturbance in that site, and consequently should be named accordingly. Furthermore, these sub-indices should not be carried through into the calculation of any other sub-indices, as any error in one would then be carried through to another.
- Consider a method of assessing structural intactness, and then weight that measure accordingly in the final calculation. This will enhance the index at a functional level, increasing its validity. One possibility is the use of photographs as a reference state against which to measure the present state. Photographs of varying levels of disturbance, in different vegetation types, would help in reducing the subjectivity that is inherent in the perceived reference state.
- Re-evaluate the weightings of the sub-indices so that they explicitly reflect the level of functioning that they measure, and avoid weighting one sub-index considerably greater that the others. Deciding on relevant weightings, as well as the contribution of each sub-index to the final RVI score, could be done via a workshop of experts. Consensus could then be

obtained on how a sub-index could be weighted according to its functional contribution. These could then be tested in the field and reported back to the workshop of experts in order to assess whether these weightings are producing scores that are reliable and valid.

- Include a measure of the overall width of the riparian zone. Ladson and White (1999) note that the width of the riparian zone is important in its ability to filter light, nutrients and sediment; provide a source of inputs to the river; provide terrestrial habitat; and provide scenery and landscape values. This will enhance the index at a functional level, increasing its validity. Physically measuring the width of the riparian vegetation down the length of the measured section is an option. Alternatively using a formula based on the ratio between the active channel width and the potential riparian vegetation width is another possibility.
- Change the perceived reference state so that the condition of the vegetation at the time of measurement is the reference state and subsequent visits would measure the change against that condition. This would eliminate the subjectivity of the perceived reference state.
- Remove EVC from the PCIRS calculation so that error involved in EVC would not be carried through to PCIRS. Therefore PCIRS would become a sub-index that only measures the level of invasion of the riparian zone, a far more valid concept in the South African context. PCIRS could then be changed to a measure of the level of exotic vegetation invasion, calculated in the same manner as is used in the RVI at present. Alternatively, photographs of various disturbance levels, agreed upon by a number of expert vegetation assessors, could supplement this methodology in order to help in deciding in which category of disturbance a site may fall into.
- Include a measure of recruitment in grassland situations. Ladson and White (1999) note that detection of indigenous regeneration of the ground layer is difficult. Determining a qualitative, yet reliable, method of assessing grassland riparian vegetation cover remains one of the most difficult issues to resolve in the RVI.
- Assess the sections of the fieldsheet that are required to be filled in but do not contribute to the calculation of the index, and include only those that make a significant contribution. Alternatively, indicate which sections are vital to generating a score so that if assessors need to do a quick assessment this option is available.

- Consistently test the same RVI sites, in a variety of vegetation types, during different seasons of the year. This will provide an indication of the necessity of introducing standards that will ensure that the RVI is undertaken only during certain seasons.
- Introduce standards that may ensure that sites chosen are representative of that section of river. This can be done by the training workshops to prevent assessors choosing sites that are not representative of certain reaches.
- Introduce training workshops that could be used to certify assessors so that they are all at the same standards country-wide.
- Consider situations where the riparian vegetation is completely different on either bank and account for these differences. Averaging out the scores in the percentage of vegetation cover estimate is not a viable method of scoring the riparian vegetation. Furthermore weighting the islands the same as either bank must be addressed, as it is a potential source of bias. Accounting for both aerial cover and basal cover will substantially enhance the RVI at a functional level. Where a situation is encountered where there is a considerable difference in riparian vegetation on the two opposite banks the RVI should be flexible enough to allow for separate RVI assessments to be undertaken.
- Alter the Rivers Database so that the RVI calculation becomes visible and can be manually checked. Furthermore, providing a spreadsheet with the RVI calculations will allow assessors to calculate the RVI scores manually.

In terms of the stated objectives the RVI was tested in three different vegetation types in KwaZulu-Natal. One of the major obstacles was acquiring the services of a number of expert assessors on the same day. Consequently, the sample size was smaller than anticipated and has made commenting on the variability of the RVI between vegetation types difficult. Furthermore commenting on whether the RVI is biased toward woody species or not, has also been made difficult. However, enough data was collected to assess the reliability of the RVI, as stated in objective three. The variability in final RVI scores, gut condition scores and sub-index scores produced between assessors at the same sites indicated that there were specific issues within the construction of the index that warranted closer investigation. The sensitivity analysis conducted on the RVI, and the theoretical validity assessment of the RVI confirmed this. The sub-indices do not reflect a functional index, as indicated in table 4.10. The RVI is biased toward cover, indicating a structural index. Indicators of functions, such as riparian vegetation width and longitudinal continuity need to be included in the RVI for it to be a truly functional and useful index. Decisions on their specific contributions to the final RVI score need to be decided on, and tested. However, this will require a collective effort of knowledgeable, expert assessors. This should be done in the form of regular workshops to decide on exactly which sub-indices should be used in the RVI, their relevant weightings according to their functional contribution and ways in which these can then be tested in the field, in different vegetation types and at different times of the year. Furthermore the use of photographs in addressing the perceived reference state needs to be seriously considered.

The recommendations made in the bulleted list above should provide the basis for the initial workshop, and if these recommendations are implemented a large amount of variability that was encountered in this study will be eliminated. This will then provide a second version of the RVI that a number of expert people are satisfied with that can be tested thoroughly, in different vegetation types across the country.

One of the stated objectives was to provide recommendations to achieve quality assurance in the RVI. The major recommendation is to implement regular RVI training days, once consensus has been achieved on a methodology provided by the workshop. Training days should culminate in an RVI test. Those trainees that achieve above a certain score will be registered and allowed to enter their RVI scores into the Rivers Database.

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