CHAPTER 7

Development, Validation and Application of a Sensitivity-weighted Index of Biotic Integrity (SIBI) for the use of fish assemblage characteristics in the assessment of the biotic integrity of the Klip River.

7.1 INTRODUCTION

Human activities have caused severe degradation of many terrestrial and aquatic ecosystems around the world. The deterioration of especially aquatic resources has become a great concern to governments and the general public, due to the importance of water in the daily lives of all earth dwellers. Management towards the sustainable use of water resources has been attempted for many decades. In most cases these processes failed, and the increase in human population was reflected by deteriorating integrity of aquatic ecosystems (Karr and Chu, 1997). Attempts to monitor and restore the integrity of our aquatic resources was however, generally based on non-biological measures of chemical and physical water quality on the assumption that improvement in biological quality would follow (Karr *et al*., 1986). Although this approach provided certain statistical validity and legal defensibility, it did not measure biological or ecological conditions (Herricks and Schaeffer, 1985). From past experience, it has therefore become obvious that biological evaluations and criteria should be included in any aquatic resource-monitoring programme, to improve future management and thus sustainability of our aquatic resources.

Biological communities reflect a combination of current and past watershed conditions, because organisms are sensitive to changes across a wide array of environmental factors (Karr, *et al*., 1986). The assessment of aquatic health by the sampling of biological communities in the field is a promising approach, being applied more often across the world. The inclusion of biological assessments to present and future aquatic health assessments would ensure a more comprehensive and more accurate evaluation than water quality based assessments, and therefore provide for better management of these resources. Furthermore, the use of a range of biological communities increases the validity of assessments and insures that reliable conclusions could be drawn.

Fish communities possess various characteristics that render them important in the assessment of biotic integrity. They occupy positions throughout the aquatic food web and are typically present in all but the most polluted waters. Because fish often range over considerable distances, they have the potential to integrate diverse aspects of relatively large-scale habitats. Fish can therefore provide an integrative view of watershed conditions. Compared to other taxa, fish are also relatively long-lived and are therefore useful to provide a temporal dimension of conditions. They are also relatively easy to identify, and after data is gathered, the fish can be released again. For the general public, fish are also the most well known of aquatic organisms, and they are more likely to understand information about the condition of the fish community than other of taxa such as invertebrates. There are, however, obviously also some difficulties in using fish as biomonitors. Among the problems, is the selective nature of some sampling gear for some biotopes and for certain sizes and species of fish; the mobility of fish on diel and seasonal time scales, and the labour intensity of fish sampling (Karr *et al*., 1986).

The Index of Biotic Integrity (IBI) was developed by Karr (1981), to assess environmental degradation in Midwestern U.S. streams, and has since been adapted for use in many other aquatic ecosystems and even with taxa other than fish (Oberdorff and Hughes, 1992; Hocutt *et al*., 1994; Lyons *et al*, 1996; Schleiger, 2000). For this purpose the Index of Biotic Integrity (IBI) uses variables of species richness and composition, trophic structure, abundance and general health or condition. Even if the water quality is sufficient to allow optimal conditions for a fish assemblage, other aspects may be limiting. An IBI does not only detect the impact of water quality changes, but also other aspects associated with water quantity, flow, habitat alterations and presence of exotic or alien species. Due to biogeographic differences, fish species differ extensively between systems. Headwater streams generally support fewer species than downstream sites, and warm water streams support more species than coldwater streams (Karr, 1981). Thus, it is important to note that the IBI is not a magic index applicable to any aquatic ecosystem, and that any index that uses fish to determine aquatic health or biotic integrity, should be developed specifically for application to a certain system, taking into consideration the characteristics and features native to the system, as well as the resources of the agencies applying the index or doing the monitoring.

Many groups of organisms have been proposed as indicators of environmental quality, but no single group has emerged as the favourite of most biologists. Ideally, a biomonitoring program should be based on a holistic, integrative approach that incorporates representatives of several major taxa (Karr, *et al*., 1986). In South Africa, the most popular and widely used biological index is the macro-invertebrate based South African Scoring System (SASS) (Hohls, 1996; Roux, 1997). Kleynhans (1999) developed the Fish Assemblage Integrity Index (FAII) for application to South African Rivers. This index provided an indication of the overall biological integrity in segments of a river. This initiative by Kleynhans (1999) laid the foundation for the incorporation of fish as a component of biomonitoring assessments in South Africa. Kleynhans (1999) however stated that an aspect of concern regarding this index was that in most cases, it provided an underestimation of the biological integrity of a segment. As with the IBI, the FAII was also not considered suitable for the assessment of streams with a naturally low fish species diversity. The FAII was furthermore developed for the application to fish habitat segments, which should include a few sites, and not for site–specific investigations.

This chapter deals with the issues related to the development, validation and application of a fish index for the Klip River System, one of South Africa’s low fish species diversity rivers. The basic principles of the Index of Biotic Integrity (IBI), as developed by Karr (1981) in the USA, were followed to develop an IBI for the Klip River System. This IBI was then used as the foundation for the development of the new Sensitivity-weighted Index of Biotic Integrity (SIBI). The SIBI used differences in sensitivity between fish species as a weighting system, in an attempt to make the index more sensitive to changes in the environment. In the SIBI, different metrics were not scored into classes, but scored on a continuous scale, which meant that even small changes were reflected in the final index score. In this study, the FAII was adapted for site-specific application to allow for comparison with the other indices applied (IBI and SIBI). The FAII was also applied in its original form to determine the general biotic integrity of fish habitat segments of the Klip River.

7.2 METHODOLOGY

7.2.1 THE PURPOSE OF BIOTIC INDICES

The value of using biotic indices is twofold. Firstly, they quantify changes in the biotic composition of an ecosystem and therefore provide tools that can be used to monitor these changes. Secondly, biotic indices can be used to provide an indication of the integrity of an ecosystem. Karr and Dudley (1981) defined *biotic integrity* as “the ability of an ecosystem to support and maintain a balanced, integrated, adaptive community of organisms, having a species composition, diversity and functional organisation comparable to that of the natural habitat of the region”. In terms of *ecological health* (which motivates virtually all environmental legislation), a biological system can be considered healthy when “its inherent potential is realised, its condition is stable, its capacity for self-repair when perturbed is preserved, and minimal external support for management is needed” (Karr et al., 1986). The use of biotic indices for the determination of the biotic integrity would therefore provide an indication of the extent of deviation from the expected biotic condition. It would thus provide information to answer the commonly asked question of whether a system is “polluted’, “pristine” or in-between these categories. The determination of a river’s biotic integrity is of special importance for setting of resource quality objectives, such as Resource Directed Measures (RDM) as determined by the South African Department of Water Affairs and Forestry (DWAF, 1999a).

The biota of a system, and therefore the biotic index score, is a reflection of the conditions reigning in that ecosystem, due to the fact that biota have the ability to indicate the integrated impacts of various stressors. The primary environmental factors that affect, and thus determine the condition of aquatic biota, can be grouped in five major classes, namely energy sources, water quality, habitat quality, flow regime and biotic interactions (Karr *et al*., 1986). A change in a biotic index score is therefore an indication that one or more of these environmental factors have been altered, and a quantification of the extent of change that these alterations has caused on the biota of the system. The final value of any biotic index depends greatly on the interpretation of the index scores. It should be established if a change in the index score was due to natural causes (such as seasonal fluctuation in water temperature) or human-induced stressors (such as a chemical spill). This furthermore stresses the importance of gathering as much information as possible at a site at the time of biological sampling, as this would assist in the interpretation of the index scores.

7.2.2 APPROACH FOLLOWED IN THE DEVELOPMENT OF A FISH INDEX FOR THE KLIP RIVER.

The procedures followed in the development of a fish index for the Klip River are summarised in Figure 8.1. Sampling sites were selected from the source of the Klip River, to its confluence with the Vaal River, and a reference site was selected in the Suikerbosrand River. Sampling of the selected sites was conducted during the winter and summer months, over a period of two years. Historic information and available literature was also gathered for the system under investigation. The basic principles of the Index of Biotic Integrity (IBI), as developed by Karr (1981), were used to develop an IBI for the Klip River, and the data gathered was applied to this index. The Fish Assemblage Integrity Index (FAII) as developed by Kleynhans (1999), was adopted for site-specific use, and the data also applied to it. A new index was then developed, namely the Sensitivity-weighted Index of Biotic Integrity, in an attempt to create a biotic index that would be more sensitive in detecting changes in the biotic integrity of a system (Figure 7.1). The SIBI was then applied to investigate temporal and spatial variation in the biotic integrity of the Klip River System. The FAII in its original form was also used to assess the biotic integrity of four segments of the Klip River.

7.2.3 OPTIMISING OF SAMPLING TEQHNIQUES & RESULTS

A very important aspect in the use of any biotic indices using fish, is the assumption that a fish sample is representative of the entire fish community. Variation in stream sizes and habitats requires differences in sampling techniques, and should thus be adopted accordingly. It must be ensured that all of the habitat types at a site are sampled effectively, to ensure that all possible species present will be included in sample. Larger rivers may need longer sampling reaches (± 1km) than small streams (±100m). Biotic indices are monitoring tools, used to monitor changes over a long period, and it is therefore important to keep the sampling as uniform as possible over time. Sampling techniques might, however, change between seasons, due to variation in water levels and flow velocity. Gill nets were used in this study to survey the deep pools of the Suikerbosrand site, due to the importance of sampling this reference site comprehensively and effectively.

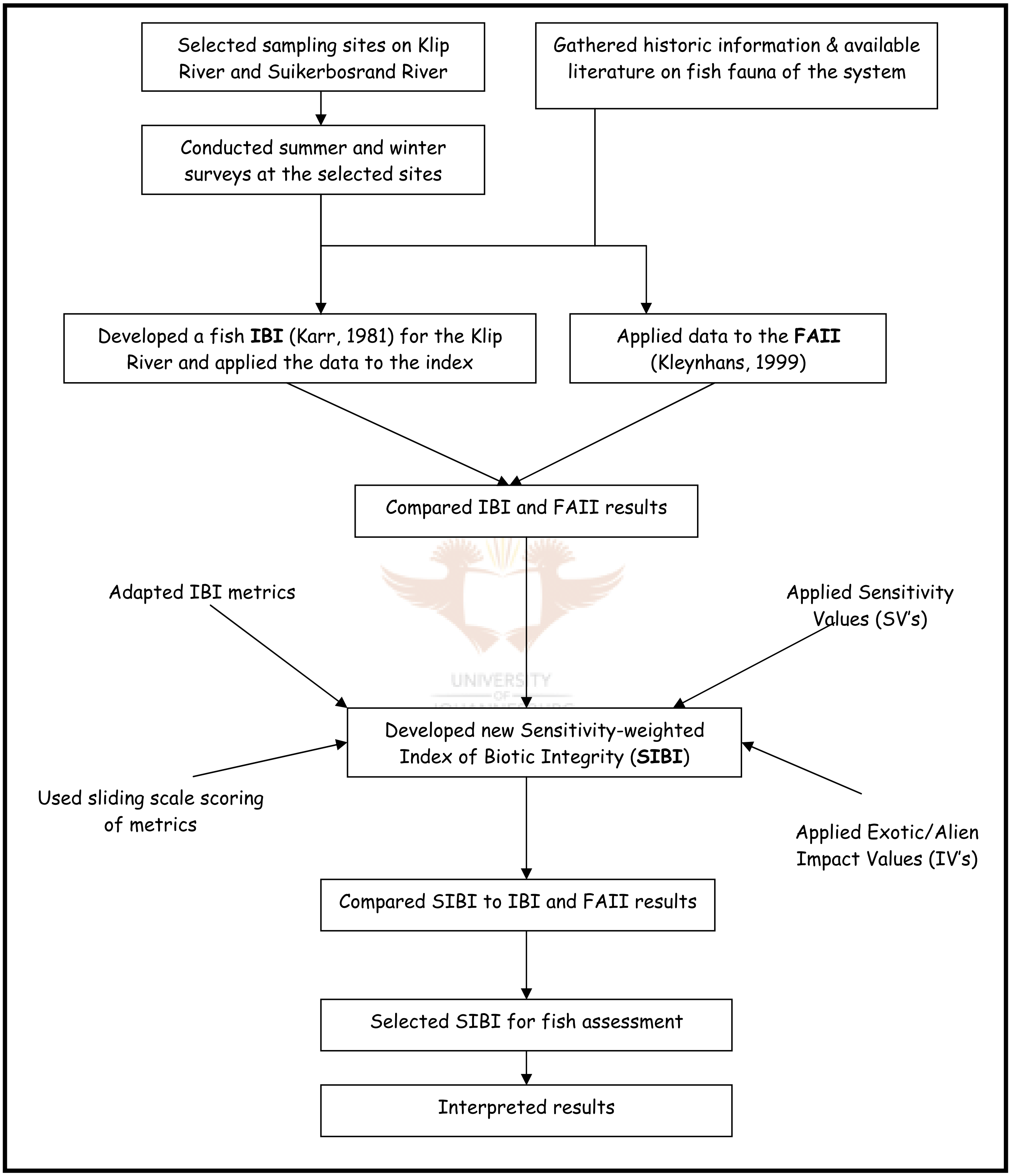

Figure 7.1: Procedures followed in the development of a fish index for the Klip River System.

Gill nets are, however, a destructive sampling method and should, as far as possible, be excluded from sampling techniques when biomonitoring is conducted. A non-destructive approach should always be followed and an attempt made to impact as little as possible on the fish community at a site. Another aspect of concern is the fact that small fish are sometimes difficult so sample and impossible to identify on site, therefore Karr *et al.* (1986) proposes to exclude fish smaller than 20 mm in size. During this study, fish in this size range that could not be identified positively on site, were excluded from the sample.

Due to variation in habitat types and habitat diversity, not all sites were subjected to the same sampling effort or the same diversity of sampling methods. However, sampling effort for the various sampling methods were standardised according to the following:

One sampling unit comprised of:

- Twenty minutes electro-fishing by wading OR
- Twenty minutes electro-fishing by boat OR
- Sixty minutes of gill netting (110 m stretch with mesh sizes ranging between 70 and 110mm).

Relative abundances were determined by using the catch-per-unit-efforts (CPUE's) of each species at a site, based on the above-mentioned sampling unit classification. This gives more accurate results than when working with the number of individuals observed. The relative abundances were determined as follows:

The total number of sampling units applied at a site was determined as follows:

Sampling units$_{(\text{site A})}$ (SU's) = (minutes of electro-fishing (boat) / 20)+(minutes of electro-fishing (wading)/20) + (minutes of gill netting/60)

(e.g. 10 minutes electro-fishing at a site, and 3 hours gill netting would mean that a total of 3.5 units of sampling were conducted).

The number of individuals of each species sampled at a site (all methods included) was then divided by the sampling units applied at the site, to determine the CPUE for each species at the site.

$CPUE_{(species\ 1)}$ = Number of individuals of species 1 / total number of SU's applied at site. (e.g. If 30 *Lb. aeneus* individuals were sampled during 3.5 SU's at a site, the CPUE for *Lb. aeneus* at a site would be 8.57).

The relative abundance of a species/group of species were then calculated by dividing the CPUE of the species OR sum of CPUE's of a group of species by the sum of all CPUE's of all species sampled at the site, and multiplying it by 100.

Relative $abundance_{(species\ 1)} = [CPUE_{(species\ 1)} / (CPUE_{(species\ 1)} + CPUE_{(species\ 2)} \ldots CPUE_{(species\ X)})] \times 100$.

7.2.4 DEFINING AND ESTIMATING THE EXPECTED SCENARIOS/REFERENCE CONDITION FOR MEASURING BIOLOGICAL (BIOTIC) INTEGRITY

An essential component of biological assessments and criteria is how to determine whether a water body is healthy or unhealthy (Hughes, 1995). In an attempt to answer this commonly asked question, namely the current ecological status of a river, it must be compared to an expected or best attainable scenario, generally based on a reference condition. An ecological reference condition is defined as the condition that is representative of a group of "least-impacted" or minimally disturbed sites, organised by selected physical, chemical and biological characteristics (Dallas, 2000) and, in general, equates with biological integrity (Karr & Chu, 1997). Reference conditions enable the degree of degradation or deviation from natural conditions to be ascertained, and thereby serve as a foundation for developing biological criteria for the protection of aquatic ecosystems. When using biotic communities to detect the impact of one or more environmental stresses on a site, it is thus necessary to know the fauna that could be expected at the site in the absence of environmental stress (Dallas 2000). In the determination of the ecological integrity of the Klip River, it was therefore essential to determine reference conditions against which the current status of the Klip River could be compared.

The approach with the greatest potential for success in setting reference conditions combines an assessment of reference sites and historical data, interpreted through the use of linear models and professional judgement (Hughes, 1995). For the Klip River, reference conditions were therefore based on historic data, a reference site and professional judgement (Discussed in detail in Chapter 6, also see Appendix 6.2). Based on this approach, it is believed that the estimated reference/expected conditions are the best attainable in the system, based on the current information and expertise available. It is therefore the most realistic depiction of the fish assemblage expected at a site, and depicts the scenario that should prevail if the catchment is managed effectively and human activities are minimal. The expected fish species diversity was first estimated, based on the expected habitat diversity attainable at each site, considering if human impacts were minimal. Based on the expected amount of habitat available at a site, an estimation of the number of individuals that should be sampled during one unit of sampling (20 minutes electro-fishing) was then made (Table 7.1, also see Appendix 6.2). These estimations were used in setting the expected values for the different criteria used in the fish indices applied during this study.

7.2.5 MULTI-METRIC FISH INDICES

7.2.5.1 THE INDEX OF BIOTIC INTEGRITY (IBI)

The conventional Index of Biotic Integrity (IBI), as developed by Karr (1981), is a composite multimetric index based on an array of ecological attributes of fish communities, namely species richness, indicator taxa, trophic guilds, fish abundance and the incidence of hybridisation, disease and anomalies. This fish community based index is considered to provide an indication of the biotic integrity of a river when it is compared to reference or baseline conditions (Karr, 1981; Miller *et al*., 1988; Karr, 1991; Kleynhans, 1997). It is a robust tool for assessing the quality of the entire water body because of its ability to integrate biological, physical and chemical effects of surface water perturbations (Oberdorff & Hughes, 1992).

Successful biomonitoring depends on demonstrating that an attribute – a measurable component of a biological system – changes consistently and quantitatively across a gradient of human influence. The goal is to identify metrics, which are attributes that show an empirical and predictable change in value along a gradient of human disturbance.

Combining the selected metrics, and assigning scores to them, according to how they respond to human disturbances, then forms the IBI (Karr & Chu, 1997).

Table 7.1: Expected relative composition of each species (%), proportion tolerant individuals (%), proportion omnivore individuals (%), and catch per unit effort (individuals per effort) estimated for each site (From Chapter 6).

SPECIES	**LOCALITY**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Labeobarbus aeneus O-RRR	0	17.9	8.8	16.7	10.3	18.2	22.3	6.9	13	13.9
Labeobarbus kimberleyensis RRR	0	0	0	0	5.2	9.1	4.5	6.9	6.5	6.9
Barbus anoplus T-O-VH-PS	26.3	17.9	14.7	8.3	15.5	9.1	13.4	13.9	6.5	6.9
Barbus pallidus VH-PS	15.8	10.7	14.7	8.3	10.3	9.1	8.9	6.9	6.5	6.9
Barbus paludinosis T-VH-PS	15.8	10.7	0	8.3	10.3	9.1	8.9	6.9	6.5	6.9
Labeo capensis RRR	0	0	5.9	16.7	10.3	9.1	13.4	27.8	26	27.8
Labeo umbratus T-PS	0	0	0	8.3	10.3	9.1	4.5	6.9	13	6.9
Clarias gariepinus T-O-PS	10.5	7.1	8.8	8.3	5.2	5.5	4.5	6.9	6.5	6.9
Austroglanis sclateri RRR	0	0	0	0	2.1	3.6	1.8	2.8	2.6	2.8
Tilapia sparrmanii T-O-VH-PS	15.8	17.9	8.8	8.3	10.3	9.1	8.9	6.9	6.5	6.9
Pseudocrenilabrus philander T-VH-PS	15.8	17.9	8.8	16.7	10.3	9.1	8.9	6.9	6.5	6.9
Total CPUE (individuals/effort)	**19**	**28**	**34**	**60**	**97**	**55**	**112**	**72**	**77**	**72**
% of individuals of tolerant species	**84**	**64**	**71**	**58**	**62**	**51**	**49**	**49**	**45**	**42**
% of individuals of omnivorous species	**53**	**54**	**56**	**42**	**41**	**42**	**49**	**35**	**32**	**35**

T - Tolerant species. O – Omnivorous species

RRR - Sensitive to degradation/loss of riffle/rapid/run habitats

VH - Sensitive to degradation/loss of vegetated habitats

PS - Sensitive to degradation/loss of pool/slow flowing habitats

7.2.5.2 Description and justification of the metrics included in the Index of Biotic Integrity (IBI) for the Klip River Systems.

Although some metrics may sometimes seem redundant because they are sensitive to the same impact, in the aggregate they appear to be responsive to changes of relatively small magnitude, as well as to broad ranges of environmental degradation (Karr et al., 1986). Because the metrics are differentially sensitive to various perturbations, as well as to various portions of the range of integrity, conditions at a site can be determined with considerable accuracy. Various metrics used in the application of the IBI to freshwater systems around the world, were tested with the data gathered during this study. Metrics not indicating changes, or those considered to be of little value were rejected, and eight metrics were selected for inclusion into the Klip River IBI (Table 7.2). In this study, a metric score of 1 indicates poor conditions, deviating largely from the expected scenario. A metric score of 3 indicates moderate conditions, deviating slightly from the naturally expected conditions, and a metric score of 5 would indicate the minimally impacted scenario.

Table 7.2: Metrics used in the IBI for the Klip River System

CATERORY A: SPECIES RICHNESS AND COMPOSITION
Measure of general species diversity
Metric 1: Number of native species
Measure of habitat degradation
Metric 2: Number of species sensitive to loss/degradation of riffle/rapid/run habitats.
***Metric 3*:** Number of species sensitive to loss/degradation of vegetated habitats
Metric 4: Number of species sensitive to loss/degradation of pool/slow flowing habitats
Measure of general tolerance to environmental degradation
***Metric 5*:** Relative abundance of individuals of tolerant species
CATEGORY B: TROPHIC COMPOSITION
***Metric 6*:** Relative abundance of omnivore individuals
CATEGORY C: ABUNDANCE AND CONDITION
***Metric 7*:** CPUE of native individuals
***Metric 8*:** Percentage of individuals with anomalies

The IBI is structured under three categories of fish population characteristics that can be expected to change under perturbed conditions, namely (A) *Species richness and composition*, (B) *Trophic composition* and (C) *Fish Abundance and Condition*.

<u>Category A: Species Richness and Composition</u>

This category deals with species richness and species composition attributes of a site. The expected ranges were based on the probability that a species would occur in that section of the river, and the possibility that, under natural conditions, habitat at the site would be able to sustain a viable population of the species. Changes in the aquatic environment can be expected to cause a decrease in species diversity and a change in the species composition at a site.

Measure of general species diversity

IBI Metric 1: **Number of native species**:

In the past, and even today, the disappearance of a species from a river system is the first impulse to trigger concern (Scott *et al*., 1987). The assumption for the use of this criterion is that degradation in overall integrity (physical and chemical), due to any human disturbance, would result in a loss of species diversity at a site. Due to a lack of historic data on fish distribution of the Klip River system, the expected species richness was based on distribution maps in existing literature (le Roux and Steyn, 1968; Skelton 1993), limited historic information of a previous survey, personal communication with anglers and residents in the area as well as observations made during the current study. If their basic habitat requirements are met (Chapter 6), the following indigenous fish species can be expected to occur naturally in the Klip/Suikerbosrand River system:

- *Labeobarbus aeneus*
- *Labeobarbus kimberleyensis*
- *Barbus anoplus*
- *Barbus pallidus*
- *Barbus paludinosus*
- *Labeo capensis*
- *Labeo umbratus*
- *Clarias gariepinus*
- *Austroglanis sclateri*
- *Tilapia sparrmanii*
- *Pseudocrenilabrus philander*

Only native species that occurred naturally in a system must be considered for inclusion in this metric. Indigenous species introduced into a system should be considered as alien species.

Measure of habitat degradation

In the original IBI, the following fish families were used because of their sensitivity to specific changes (Karr, *et al*., 1986):

1) *Number of darter species* (family: Percidae): These species are sensitive to degradation, particularly as a result of their specificity for reproduction and feeding in benthic **habitats**. These habitats are generally degraded by channelisation, siltation, and reduction in oxygen.
2) *Number of sunfish species* (family: Centrarchidae): These species are particularly responsive to degradation of pool **habitats** and other habitat structures such as instream cover.
3) *Number of sucker species* (family: Catostomidae): All species of this family are intolerant to **habitat** and chemical degradation.

As far back as the early 80's, Skelton (1983) emphasized that the destruction of habitats was clearly the most significant threat to southern African aquatic environments and their respective organisms. It is therefore of cardinal importance to include metrics into the IBI that would react to the deterioration in habitat quality. The family groups of fish as used in the original IBI are not represented in the Klip River System, and therefore the following approach was followed.

Three primary habitat components of the Klip River System that may be influenced by human activities were identified. These were rapid/riffle/run habitats (RRR-habitats), vegetated habitats (overhang, root wads etc.) and pool/slow flowing habitats. Each fish species present in the Klip River is dependant on one or more of these habitat types for their continuous/sustained existence. Each species could therefore be listed in one or more of these habitat categories. The assumption is made that even if the water quality was within acceptable limits, degradation in any of these habitat components would result in the loss of the species reliant on that habitat.

***IBI Metric 2*: Number of species sensitive to loss/degradation of riffle/rapid/run (RRR-) habitats**.

Factors influencing the condition of /riffle/rapid/run habitats:

- Reduced flows (Water abstraction for irrigation, etc; diversions of water into channels): Loss of especially rapids and runs.
- Increased flows (Waste Water Treatment Works (WWTW) effluents; increased runoff from paved surfaces in built-up areas): Flooding and disturbance of riffle and rapid habitats.
- Increased erosion (overgrazing, agricultural activities, destruction of riparian vegetation): causes siltation of riffle/rapid habitats.
- Eutrophication (organic pollution): Causes increased algal growth, embedding substrates in rapid/riffle habitats.

Due to the following characteristics and requirements (Chapter 6), these species may be negatively affected by a loss/degradation of rapid/riffle/run habitats:

- *Labeobarbus aeneus* – favours clear flowing waters (runs), spawn on gravel beds.
- *Labeobarbus kimberleyensis* – favours flowing waters in deep channels (runs) or below rapids, spawn over gravel beds in running water.
- *Labeo capensis* – Prefers running waters, breeds in shallow rocky rapids, and often grazes from firm surfaces of rocks in rapids.
- *Austroglanis sclateri* – favours rocky habitats in flowing water, prefer rapids, feeds on invertebrates, especially in and below rapid/riffle areas.

***IBI Metric 3*: Number of species sensitive to loss/degradation of vegetated habitats**

Factors that may influence instream cover include the following:

- Water quality deterioration (Due to point or non-point pollution sources, herbicides used for agricultural purposes): Causes vegetation to die off.
- Flow reduction (as mentioned in metric 2): Roots become exposed; plant can't reach water.
- Increased flow (as mentioned in metric 2): Plants are uprooted and washed away; vegetated areas flooded.
- Eutrophication (as described in 2). Excessive growth of some species, loss of natural plant species diversity.
- Unnatural water level fluctuations: Influences natural growth of vegetation on banks.

Due to the following characteristics and requirements (Chapter 6), these species may be negatively affected by a loss/degradation of vegetated habitats:

- *Barbus pallidus* – prefers clear, rocky streams with emergent marginal vegetation; lay eggs in vegetation.
- *Barbus paludinosus* – prefers quiet, well-vegetated waters, spawn amongst vegetation.
- *Barbus anoplus* – often associated with vegetative cover/shelter, eggs attached to vegetation.
- *Tilapia sparrmanii* – prefer quiet or standing waters with submerged/emergent vegetation.
- *Pseudocrenilabrus philander* – favours vegetated areas.

***IBI Metric 4*: Number of species sensitive to loss/degradation of pool/slow flowing habitats:**

Factors that may influence the presence and quality of pools or slow flowing habitats include following:

- Increased flows – convert pools into runs.
- Decreased flows – results in increased siltation of pool substrates.
- Erosion & increased suspended solids - causes siltation and embedding of pool substrates.
- Eutrophication – results in unnaturally high growth of algae, embedding pool substrates.

Due to the following characteristics and requirements (Chapter 6), these species may be negatively affected by a loss/degradation of pool/slow flowing habitats:

- *Barbus paludinosus* – prefers quiet streams/waters
- *Barbus anoplus* – generally found in still habitats.
- *Barbus pallidus* – favours pools in clear, rocky streams.
- *Labeo umbratus* – prefer standing or gently flowing waters.
- *Clarias gariepinus* – favours floodplains, sluggish rivers, lakes and dams.
- *Tilapia sparrmanii* – prefer quiet or standing waters.

- *Pseudocrenilabrus philander* – often found in still, vegetated habitats on edge of rivers.

Measure of general tolerance to environmental change

In any aquatic ecosystem, every aspect of every organism is an important component for the system to be in a state of equilibrium. Each species has specific needs, and due to these needs, usually exhibits specific characteristics. A change in any aspect of their surroundings will cause a shift in equilibrium (Roux, 1999a), as all species are, in some way, inter-linked to complete the circle of life. A loss in one species is generally reflected by the composition of the remaining community. The specialities, or general characteristics of the different species, can therefore be used to monitor changes in aquatic ecosystems. All fish species are directly in contact with the ambient water, and to some extent sensitive to changes in this component. A change in the physico-chemical integrity (water quality) of an aquatic ecosystem will therefore have a major impact on the fish assemblage reliant on the resource. Some species are more sensitive to changes in their environment, and they will disappear first when changes occur. If the impact is, however, continuous and severe, even the most tolerant species will be influenced in some or other way. Although some species may survive changes in their environment, other aspects such as breeding and rearing success may be affected. Any change, no matter how small, will therefore be reflected in the fish assemblage of the aquatic ecosystem in some or other way. These differences in sensitivity between species were especially valuable in the development of the fish index, as conducted during this study. Furthermore, aquatic ecosystems vary in stability or fragility, which is a function of both time and degree of change. Roux (1999b) stated that the stability of a system could be described by concepts such as *resilience* (ability of system to recover from disturbance) and *elasticity* (speed with which the system returns to its original state after removal of the disturbance). The important issue is, however not whether an ecosystem can be classified as stable or fragile, but how much the particular ecosystem changes after a specific disturbance (Roux, 1999b).

***IBI Metric 5*: Relative abundance of individuals of tolerant species**

Some fish species are more sensitive to changes in their ambient environment, and will therefore disappear sooner from impacted sections of a river (Karr *et al*., 1986). Although perturbations – water quality and/or habitat degradation- might not be extreme enough to remove a species from a site, it may cause a shift in the balance of the individuals at the site. The assumption is made that, a shift towards more individuals belonging to tolerant species, would indicate environmental degradation.

For the purpose of classifying the expected fish species of the Klip River in different classes of sensitivity towards environmental degradation, the procedures as described by Kleynhans (1999) for the determination of intolerance ratings (IT's) were applied in this study. The term 'intolerance ratings' were, however renamed as sensitivity values (SV's) (Table 7.2) for the purpose of this study. In this approach, four components, namely habitat preferences and specialisation (HS), food preference and specialisation (TS), requirements for flowing water during different life-stages (FW) and water quality requirements (WQ) were taken into account in estimating the sensitivity of the each fish species. Each of these aspects was scored for a species by several specialists, according to low requirement/specialisation (rating=1), moderate requirement/ specialisation (rating=3) and high requirement/specialisation (rating=5). Then the mean rating (R) was used in the calculation of the sensitivity value for a species (Table 7.3). Each specialist also gave a confidence rating (C), based on the certainty of the appointed score for a given criterion, to indicate the reliability of the end product. The general sensitivity value (SV) of a fish species was then calculated as follows:

SV = (HS+TS+FW+WQ)/4

The following species of the Klip/Suikerbosrand System are generally tolerant to changes in the environment, and were therefore included in this metric:

- *Barbus anoplus*
- *Barbus paludinosus*
- *Labeo umbratus*
- *Clarias gariepinus*
- *Tilapia sparrmanii*
- *Pseudocrenilabrus philander*

The relative abundance of the tolerant individuals at a site was also calculated by using the CPUE's of the species.

Table 7.3: Sensitivity Values (SV's) calculated for the native fish species expected in the Klip River System.

NATIVE SPECIES	TROPHIC SPECIALIZATION (TS)		HABITAT SPECIALIZATION (HS)		FLOW DEPENDENCE (FW)		REQUIREMENT FOR UNMODIFIED WATER QUALITY (WQ)		**SV**	Mean Confidence
	R	C	R	C	R	C	R	C		
A. sclateri	4.0	2.0	3.0	2.0	3.0	2.0	2.4	2.0	**3.1**	2.0
Lb. aeneus	2.0	2.0	3.0	2.0	3.0	2.0	1.6	2.0	**2.4**	2.0
Lb.kimberleyensis	5.0	2.0	4.0	2.0	5.0	2.0	3.0	2.0	**4.3**	2.0
B. anoplus	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	**1.8**	2.0
B. pallidus	3.3	2.0	3.3	2.0	3.6	2.0	3.6	2.0	**3.4**	2.0
*B. paludinosus**	1.0	4.7	1.0	4.1	2.4	4.1	1.9	4.1	**1.6**	4.3
*C. gariepinus**	1.0	5.0	1.0	5.0	1.9	4.7	1.0	4.7	**1.2**	4.9
L. capensis	3.0	2.0	3.0	2.0	3.0	2.0	2.0	2.0	**2.8**	2.0
*L. umbratus**	2.1	4.1	1.6	4.4	2.7	3.9	1.0	3.9	**1.9**	4.1
*P. philander**	1.0	5.0	1.0	5.0	1.0	5.0	1.3	4.4	**1.1**	4.9
*T. sparrmanii**	1.3	5.0	1.0	5.0	1.0	4.7	1.3	4.4	**1.1**	4.8

*From Kleynhans (1999b). R – Mean rating.

SV- General Sensitivity Value
1-2=TOLERANT 2-3=MODERATELY TOLERANT 3-4=MODERATELY INTOLERANT 4-5=INTOLERANT

C-Confidence Rating
1-2=LOW CONFIDENCE 2-3=MODERATE CONFIDENCE 3-4=HIGH CONFIDENCE 4-5=VERY HIGH CONFIDENCE

***IBI Metric 6*: Relative abundance of omnivore individuals (only native species considered)**

Degradation in the integrity of a system usually leads to an increase in the proportion of individuals that are omnivores. The dominance of this trophic level under perturbed conditions, presumably arises as a result of degradation in the food base, especially of invertebrates. As a result, their opportunistic foraging ecology makes them successful, relative to more specialised foragers (Karr, 1981).

The following species of the Klip River has omnivorous feeding behaviour:

- *Labeobarbus aeneus*

- *Barbus anoplus*
- *Clarias gariepinus*
- *Tilapia sparrmanii*

The relative abundance of the omnivorous individuals at a site is calculated by using the CPUE's, as described previously.

Category C: Abundance and Condition

***IBI Metric 7*: CPUE of native species**

The amount of individuals collected at a locality depends on factors such as stream size, abundance of a habitat and the technique used for sampling. Kovalak (1981) states that some disturbances may cause a general decrease in numbers of individuals, even though other community characteristics do not change. For the purpose of this IBI, the assumption is made that degradation in the ecosystem could lead to a decrease in the number of individuals caught.

The CPUE at a site is calculated by dividing the total number of native individuals sampled at a site, by the number of efforts applied at a site. The scoring ranges were based on the expected number of individuals at a site under natural conditions. Expected abundances of fish were based on experience gained during the survey, and also by considering the abundance and diversity of habitats available at a site.

***IBI Metric 8*: Percentage of individuals with anomalies**

Sites with especially severe degradation often yield a high number of individuals in poor health (Karr et al., 1986). The percentage of fish with externally evident disease or other anomalies were used to score this metric. Again, only native species are used for the determination of this metric. Exotic and introduced species are excluded as they may be more hardened, and therefore they could possibly disguise the degree of health impairment on the native population at a site. Guidelines, as used by the IBI developed in North America (Fausch *et al*., 1990), and applied by Kleynhans (1999) were used in the application of this criterion. Allowance is made for the principle that, even in a fish population living under unperturbed conditions, a small percentage of individuals can be expected to be infested with parasites or to exhibit some anomalies. If less than two percent of the individuals at a site had anomalies, it was considered as natural, and a score of five was assigned to this metric. A proportion of more than five percent of individuals with anomalies at a site received a metric score of one.

7.2.5.3 Scoring ranges for IBI criteria

In this study, a metric score of one (1) indicates poor conditions, deviating largely from the expected scenario. A metric score of three (3) indicates moderate conditions, deviating slightly from the naturally expected condition, and a metric score of five (5) would indicate the minimally impacted scenario. The scoring for each metric differed from site to site, due to differences in expected conditions at the different sites, and was therefore determined separately. For metric values that were expected to increase or decrease linearly across a gradient of human influences (metrics 1,2,3,4 and 7), the expected values (Table 7.3) were trisected into three divisions, each representing criteria for assigning a score of 1, 3 or 5 [e.g. at locality 1 six native species were expected, six were trisected giving a three classes namely 1 to 2 species (score of 1), 3 to 4 species (score of 3) and 5 to 6 species (score of 5). If no species were observed, a score of zero were given to this metric] (Karr & Chu, 1997).

For metrics 5 (tolerant individuals) and 6 (omnivore individuals), the estimated expected percentages (Table 8.1) were used at the top end of the good scoring class 5. Scoring class 3 was seen as the transition between good (5) and poor (1), and a range of only 10% was therefore given to class 3, after which class 1 consisted of the remainder of the scale [e.g. at locality 7 the naturally expected composition of tolerant individuals was estimated to be 49% (Table 7.1). Any value below fifty percent (50%) would therefore attain a score of five for this criterion at this site. Percentages within the next 10 % range (50 to 60%) would attain a score of 3, while any percentage above 60% would attain a score of 1].

For metrics that were expected to indicate a more skewed pattern (metric 8), natural breakpoints (often unequal divisions) were used (Karr & Chu, 1997). For the purpose of this study, expected scoring ranges for metric 8 (proportion of individuals with anomalies) were based on ranges used in other fish indices (Karr *et al*., 1986; Lyons *et al*., 1996; Kleynhans, 1999). The scoring ranges of each IBI metric are summarised in Table 7.4.

Table 7.4: Scoring ranges summarised for the different metrics used in the IBI.

	SCORE		
LOCALITY	**1**	**3**	**5**
***Metric 1:* Number of native species**			
1	1-2 species	3-4 species	5-6 species
2	1-2 species	3-5 species	6-8 species
3	1-3 species	4-6 species	7-8 species
4	1-3 species	4-6 species	7-9 species
5,6,7,8,9 & 10	1-3 species	4-7 species	8-11 species
***Metric 2:* Number of species sensitive to loss/degradation of riffle/rapid habitats**.			
2			1 species
3 & 4		1 species	2 species
5,6,7,8,9 & 10	1 species	2-3 species	4 species
***Metric 3*: Number of species sensitive to loss/degradation of vegetated habitats**			
All (1 – 10)	1 species	2-3 species	4-5 species
***Metric 4:* Number of species sensitive to loss/degradation of pool/slow flowing habitats**			
1,2,3	1-2 species	3-4 species	5-6 species
4,5,6,7,8,9 & 10	1-2 species	3-5 species	6-7 species
***Metric 5*: Relative abundance of individuals of tolerant species**			
1	>90	85-90	<85
2	>75	65-75	<65
3	>80	70-80	<70
4 & 5	>70	60-70	<60
6, 7, 8, 9 & 10	>60	50-60	<50
***Metric 6*: Relative abundance of omnivore individuals**			
1, 2 & 3	>65	55-65	<55
4 & 5	>55	45-55	<45
6 & 7	>60	50-60	<50
8	>45	35-45	<35
***Metric 7*: CPUE of native individuals (individuals / effort)**			
1	<6	6-13	>13
2	<9	9-18	>18
3	<11	11-22	>22
4	<20	20-40	>40
5	<32	32-64	>64
6	<18	18-36	>36
7	<37	37-74	>74
8	<24	24-48	>48
9	<25	25-50	>50
10	<24	24-48	>48
***Metric 8*: Percentage of individuals with anomalies**			
All (1-10)	>5%	2-5%	<2%

7.2.6 THE FISH ASSEMBLAGE INTEGRITY INDEX (FAII)

Kleynhans (1999) developed an alternative approach, namely the Fish Assemblage Integrity Index (FAII) to use fish assemblages of southern African rivers in indicating the condition of fish habitat segments (a portion of a stream in which the fish community remains generally homogenous due to relative uniform nature of the physical habitat) of a river. The original Fish Assemblage Integrity Index (FAII) was applied in its original form to segments of the Klip River (Chapter 4), and was also adopted for application to site-specific conditions for comparison to IBI and SIBI scores. In this adopted version, the "*frequency of occurrence of a species within a segment*" criteria was omitted from calculations. The following procedures were used in the determination of the FAII scores:

7.2.6.1 Fish habitat segment identification

On the basis of gradient, geological similarities and concurrences in habitat structure, specific sites were grouped to distinguish between four fish habitat segments in the Klip River. These fish habitat segments coincided with the four habitat reaches of the Klip River, as determined in Chapter 4.

7.2.6.2 Intolerance

The relative intolerance of each species expected to occur in the Klip River was determined, following the criteria described by Kleynhans (1999), and were expressed as general sensitivity values (SV's) (Table 7.3).

7.2.6.3 Frequency of Occurrence in Segment

This aspect refers to the regularity with which a species occurs within a particular fish segment. The same information source, as for the assessment of *abundance*, was used. The frequency at which a species was expected to occur in a segment was assessed according to the following:

- Occurrence at <34% of sites in fish habitat segment, score = 1 (infrequent occurrence)

- Occurrence at 34 - 66% of sites in fish habitat segment, score = 3 (frequent occurrence)
- Occurrence at >66% of sites in fish habitat segment, score = 5 (widespread occurrence)

The same procedure was used to assess the observed frequency of occurrence of a species in a segment.

7.2.6.4 Health

The percentage of fish with externally evident disease or other anomalies was used to score this metric. The following procedure was used to score the health of individual species:

- Frequency of affected fish >5%, score = 1
- Frequency of affected fish 2 - 5%, score = 3
- Frequency of affected fish <2%, score = 5

The expected health for a species living under unperturbed conditions is assumed to be unimpaired and would score 5.

7.2.6.5 Calculation of final FAII score.

The FAII was calculated as follows:

The *expected index score* [FAII(exp.)] per segment:

FAII(exp.) = Σ SV x ((F+H)/2)

where: SV = Tolerance rating for individual species

F = Expected frequency of occurrence rating for individual species

H = Expected health rating for individual species.

The *observed index score* [FAII(obs)] is calculated on a similar basis, but is based on the information collected during the survey:

FAII(obs) = Σ SV x ((F+H)/2)

If only one site per segment was sampled, and for the site-specific application of the FAII, the '*frequency of occurrence'* was not considered in the above-mentioned calculations and the formulas seemed as follows:

FAII(exp) = Σ SV x H and FAII(obs) = Σ SV x H

To arrive at a relative FAII rating, the observed fish community index score for a segment is expressed as a percentage of the expected total FAII score:

Relative FAII score (%) = FAII(obs) / FAII(exp) x 100

Interpretation of the score was then done according to a descriptive procedure where the score is classified in a particular class (Kleynhans, 1999).

7.2.7 NEW APPROACH: THE SENSITIVITY-WEIGHTED INDEX OF BIOTIC INTEGRITY (SIBI)

In the application of the conventional IBI protocol to the Klip River System, it was observed that the IBI scores often did not depict changes in the fish community. Miller *et al.* (1988) also states that the IBI proved difficult to apply in regions with low species diversity. The aquatic ecosystem investigated in this study (Klip River) is a cool water system (summer temperatures ranging from 17 to 26°C), with a relatively low native species diversity (n=11). A new index was therefore developed (SIBI), built on the foundation of the IBI, but designed to be more sensitive to detect changes in the Klip River. The procedures followed in the development of the SIBI for the Klip River are outlined in Figure 8.2.

The basic principles of the IBI (as described in section 8.2.2) were followed, but the following changes were made:

- In most cases, scoring classes (1, 3 and 5) are used when the IBI is applied. With the use of these classes, small changes in the fish assemblage often do not change the score for a criterion. On the other hand, an increment of only 1 percent could mean the difference of 5 and 3, or 3 and 1in a metric score. The *first* change in the protocol was the use of a sliding scale (continuous scoring), whereby even small changes in a metric would result in a change in the metric score.

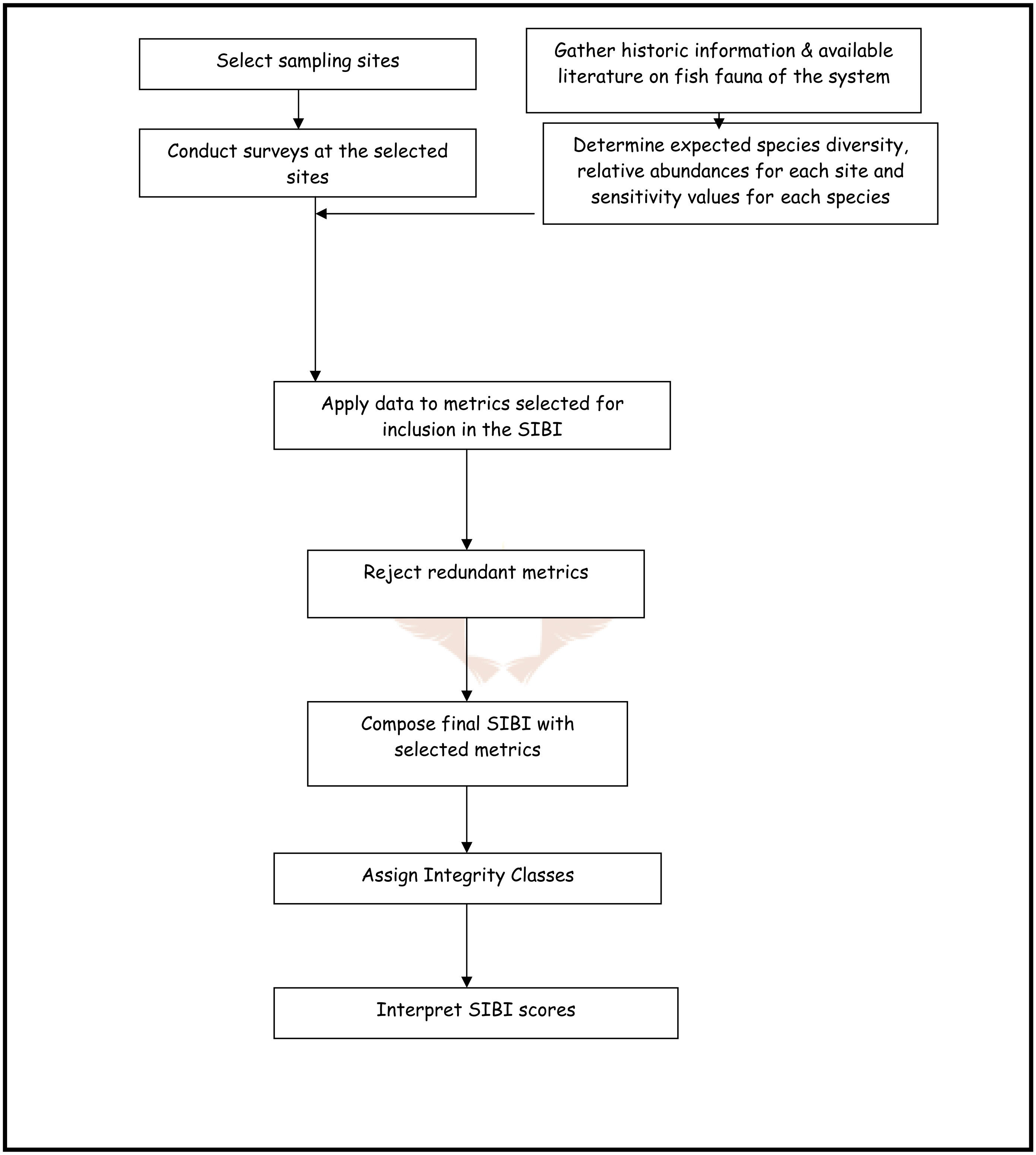

Figure 7.2: Sequence of activities involved in developing, calculating and interpreting the Sensitivity-weighted index of Biotic Integrity.

- The *second* deviation from the general IBI in the development of the SIBI, was the incorporation of a weighting system. It is envisaged that some species are more sensitive to environmental change than others. Sensitivity ratings, based on a species' relative sensitivity to environmental change, were therefore applied to take these species differences into account. To determine a species precise sensitivity accurately, its response to an array of possible impacts would have to be evaluated. Furthermore, species can differ in sensitivity to impacts between different river systems, and impacts could be synergistic or antagonistic. For the purpose of this study, the method used by Kleynhans (1999) for the classification of fish according to sensitivity was used to derive a sensitivity value (SV) for each species expected in the Klip River System (Table 7.3).

7.2.7.1 Metrics used in the Sensitivity-weighted Index of Biotic Integrity (SIBI)

***SIBI Metric 1*: Native species diversity**

All the indigenous species expected to occur at a site were listed, and their general sensitivity values (Table 7.3) summed. The sum of the observed species sensitivity values was then divided by this value, to calculate the score for this metric.

$$\text{Metric}^{1} = \frac{\Sigma\ [\text{sensitivity values of observed spp.}]}{\Sigma\ [\text{sensitivity values of expected spp.}]}$$

***SIBI Metric 2*: Species sensitive to loss/degradation of riffle/rapid/run (RRR-) habitats.**

The native fish species, sensitive to degradation or total loss of riffle/rapid/run habitats were listed, and their sensitivity values were summed. The sum of the general sensitivity values (SV's) of the species in this group collected at a site was then divided by the expected value to calculate the score for this metric.

$$\text{Metric}^{2} = \frac{\Sigma\ [\text{sensitivity values of observed spp. sensitive to RRR-habitat degradation}]}{\Sigma\ [\text{sensitivity values of expected spp. sensitive to RRR-habitat degradation}]}$$

***SIBI Metric 3*: Species sensitive to loss/degradation of vegetated habitats.**

The expected native fish species, sensitive to degradation or total loss of vegetated habitats were listed and their sensitivity values summed. The sum of the general sensitivity values (SV's) of the species in this group collected at a site was then divided by the expected value to calculate the score for this metric.

$$\text{Metric}^{3} = \frac{\Sigma\,[\text{sensitivity values of observed spp. sensitive to vegetated habitat degradation}]}{\Sigma\,[\text{sensitivity values of expected spp. sensitive to vegetated habitat degradation}]}$$

***SIB Metric 4:* Species sensitive to loss/degradation of pool and slow flowing habitats.**

The native fish species, sensitive to degradation or total loss of pool and slow flowing habitats were listed, and their sensitivity values summed. The sum of the general sensitivity values (SV's) of the species in this group, collected at a site, was then divided by the expected value to calculate the score for this metric.

$$\text{Metric}^{4} = \frac{\Sigma\,[\text{sensitivity values of observed spp. sensitive to pool and slow flowing habitat degradation}]}{\Sigma\,[\text{sensitivity values of expected spp. sensitive to pool and slow flowing habitat degradation}]}$$

***SIBI Metric 5*: Relative abundance of tolerant individuals**

The relative abundance of individuals of tolerant species, as described in the section above (IBI criterion 5), was calculated. At each site it can be expected that under naturally expected conditions a proportion of the individuals would be of tolerant species. The score for this metric were therefore 1 (maximum), as long as the proportion of tolerant individuals stayed below this expected proportion. If this expected proportion was exceeded, an increase in the proportion of tolerant individuals would result in a continuous decrease in metric score. The upper range of the good class (5), of the IBI metric 5 (tolerant individuals), was used as the expected proportion of tolerant individuals at each site. The following formula was used to determine the score for SIBI metric 5 (maximum score of 1):

$$1 - \left[\frac{\text{proportion (\%) of tolerant individuals observed} - \text{proportion (\%) of tolerant individuals expected}}{100 - (\text{proportion (\%) of tolerant individuals expected})} \right]$$

***SIBI Metric 6*: Relative abundance of omnivorous individuals**

The scoring of this criteria was based on the assumption that an increase in the proportion of omnivores at a site would be indicative of decreasing biotic integrity, as their opportunistic foraging ecology makes them successful, relative to more specialised foragers (Karr, 1981). Again, the upper range of the good IBI class (5) was used as the estimated expected relative abundance of the omnivores at a site. It was calculated and the score for this metric was then determined as follows (maximum score of 1):

$$1 - \left[\frac{\text{proportion (\%) of omnivorous individuals observed} - \text{proportion (\%) of omnivorous individuals expected}}{100 - (\text{proportion (\%) of omnivorous individuals expected})} \right]$$

***SIBI Metric 7:* CPUE of native species**

The CPUE of native species at a site is calculated by dividing the total number of native individuals sampled at a site, by the number of efforts applied at that site.

One effort was comprised of:

- Twenty minutes electro-shocking (boat or wading) OR
- 1 hour of gill netting (100 m stretch with mesh sizes ranging between 70 and 110mm).

The lower CPUE range, as estimated for the good IBI class (IBI metric 7), was used as the expected CPUE for each site.

The score for SIBI metric 7 was then calculated as follows:

$\text{Metric}^{7} = \text{Observed CPUE}_{(\text{site } x)} / \text{expected CPUE}_{(\text{site } x)}$

A maximum value of 1 can be appointed to this metric.

***SIBI Metric 8*: Percentage of individuals with anomalies**

Fausch *et al*. (1990) and Kleynhans (1999) scored this metric as follows:

- Because a fish population would, even under natural conditions, have anomalies, the presence of less than two percent of individuals with anomalies were considered to be natural. A score of 5 was assigned to this metric under such conditions.
- If the percentage of individuals with anomalies exceeded five percent, it was seen as unacceptable, and a score of 1 was given to this criterion.

It is therefore evident that an increase in the proportion of individuals with anomalies indicates an exponential degradation of the biotic integrity of a system. The score for this metric were therefore calculated as follows:

- If the percentage of individuals with anomalies were less than 2%, a score of 1 was given to this metric.
- If the relative abundance of individuals with anomalies were equal to or greater than 2%, the following formula was applied to calculate the score:

$$\text{Metric}^{8} = 1 / \text{relative abundance of individuals with anomalies (\%)}$$

7.2.7.2 Calculation of SIBI score

The final score for the SIBI was calculated by adding the scores of all metrics used (see Table 7.5 for summary of metric score calculation methods), dividing it by the number of metrics used, and multiplying it by 100.

$$\text{SIBI}_{(\text{site a})} = \left(\frac{\Sigma\,[\text{Metric}^{1} + \text{Metric}^{2},\ldots\text{Metric}^{8}]}{\text{Number of metrics used (8)}} \right) \times 100$$

A step-by-step example of the calculation methods for the SIBI is given in Appendix 7.1.

Interpretation of SIBI Scores

Interpretation of the final SIBI score is then done according to a descriptive procedure in which the score is classified in a particular category, descriptive of the biological integrity reflected by the fish community of the site (Table 7.6). Further distinction can also be made within a category, by assigning a plus (+) if the score falls within the upper half of the category (e.g. score of 75 = C^{+}), and a minus (-) if it lies within the lower half of the category (e.g. score of 65 = C^{-}).

Table 7.5: Summary table of formulae used in the determination of the scores for each SIBI metric.

Metric 1: Number of native species
Σ [sensitivity values of observed spp.] / Σ [sensitivity values of expected spp.]
Metric 2: Number of species sensitive to loss and/or degradation of riffle-rapid-run habitats.
Σ [sensitivity values of observed spp. sensitive to riffle/rapid degradation] / Σ [sensitivity values of expected spp. sensitive to riffle/rapid degradation]
Metric 3: Number of species sensitive to loss and/or degradation of vegetated habitats
Σ [sensitivity values of observed spp. sensitive to vegetated habitat degradation] / Σ [sensitivity values of expected spp. sensitive to vegetated habitat degradation]
Metric 4: Number of species sensitive to loss and/or degradation of pool/slow flowing habitats
Σ [sensitivity values of observed spp. sensitive to pool and slow flowing habitat degradation] / Σ [sensitivity values of expected spp. sensitive to pool and slow flowing habitat degradation]
Metric 5: Relative abundance of individuals of tolerant species
$1 - \left(\frac{\text{proportion (\%) of tolerant individuals observed} - \text{proportion (\%) of tolerant individuals expected}}{100 - (\text{proportion (\%) of tolerant individuals expected})} \right)$
Metric 6: Relative abundance of omnivore individuals
$1 - \left(\frac{\text{proportion (\%) of omnivorous individuals observed} - \text{proportion (\%) of omnivorous individuals expected}}{100 - (\text{proportion (\%) of omnivorous individuals expected})} \right)$
Metric 7: CPUE of native individuals (individuals per effort)
Observed $CPUE_{(site\ x)}$ / expected $CPUE_{(site\ x)}$
Metric 8: Percentage of individuals with anomalies
Percentage of individuals with anomalies < 2%, a score of 1 is given for this criteria.
If the relative abundance of individuals with anomalies is equal to or greater than 2%: 1 / relative abundance of individuals with anomalies (%)

Table 7.6: Descriptive classes connected to the SIBI scores calculated (adapted from Kleynhans, 1999).

CATEGORY	BIOTIC INTEGRITY	DESCRIPTION OF GENERALLY EXPECTED CONDITIONS	SIBI (%)
A	Excellent	Unmodified, or approximates natural conditions closely. The fish assemblage compares to that expected under natural, unperturbed conditions.	90 - 100
B	Good	Largely natural with few modifications. A change in community characteristics may have taken place but species richness and presence of intolerant species indicate little modifications. Most aspects of the fish assemblage as expected under natural unperturbed conditions.	80-89
C	Fair	Moderately modified. A lower than expected species richness and presence of most intolerant species. Most of the characteristics of the fish assemblage have been moderately modified from its naturally expected condition. Some impairment of health may be evident at the lower end of this class.	60-79
D	Poor	Largely modified. A clearly lower than expected species richness and absence or much lowered presence of intolerant and moderately intolerant species. Most characteristics of the fish assemblage have been largely modified from its naturally expected condition. Impairment of health may become evident at the lower end of this class.	40-59
E	Very Poor	Seriously modified. A strikingly lower than expected species richness and general absence of intolerant and moderately tolerant species. Most of the characteristics of the fish assemblage have been seriously modified from its naturally expected condition. Impairment of health may become very evident.	20-39
F	Critical	Critically modified. Extremely lowered species richness and an absence of intolerant and moderately tolerant species. Only intolerant species may be present with complete loss of species at the lower end of the class. Most of the characteristics of the fish assemblage have been critically modified from its naturally expected conditions. Impairment of health generally very evident.	0-19

7.2.8 Fish Habitat Assessments

An evaluation of habitat quality is critical to any assessment of ecological integrity and should be performed at each site at the time of biological sampling (USEPA, 1996). For the purpose of evaluating the general quality of the physical habitats at a site, the USEPA habitat assessment protocol for low-gradient streams, and the Habitat Assessment Matrix (HAM) were applied (Chapter 5). Habitat assessments directly applicable to fish habitats, as used by Kleynhans (1997) in the application of the FAII protocol, were also applied in this study. They consisted of the Habitat Cover Ratings (HCR) and the Site Fish Habitat Integrity (SFHI). The first mentioned gives an indication of the diversity of fish habitats, their relative abundance and amount of fish cover at a site, while the SFHI is a measure of the extent of alteration on the fish habitats due to specific human activities, e.g. Inundation, channelisation, etc.

7.2.8.1 Fish Habitat Cover Rating (HCR)

This approach was developed to assess habitats according to different attributes that are surmised to satisfy the habitat requirements of various fish species (Kleynhans, 1997). At each site, the following depth-flow (df) classes were identified, namely:

Slow (<0.3m/s), shallow (<0.5m) - Shallow pools and backwaters.

Slow, deep (>0.5m) - Deep pools and backwaters.

Fast (>0.3m/s), shallow (<0.3m) - Riffles, rapids and runs.

Fast, deep (>0.3m) - Usually rapids and runs.

The relative contribution of each of the above mentioned classes at a site was estimated and indicated as:

0 = Absent

1 = Rare (<5%)

2 = Sparse (5-25%)

3 = Moderate (25-75%)

4 = Extensive (>75%)

For each depth-flow class, the following cover features (cf), considered to provide fish with the necessary cover to utilise a particular flow and depth class, were investigated:

- Overhanging vegetation
- Undercut banks and root wads
- Stream substrate
- Aquatic macrophytes

The amount of cover present at each of these cover features (cf) was noted as:

0 = absent

1 = Rare/very poor (<5%)

2 = Sparse/poor (5-25%)

3 = Moderate/good (25-75%)

4 = Extensive/excellent (>75%)

The fish habitat cover rating (HCR) was calculated as follows:

- The contribution of each depth-flow (df) class at the site was calculated (df/Σdf).
- For each depth-flow class, the fish cover features (cf) were summed (Σcf).

$HCR = df/\Sigma df \times \Sigma cf$

7.2.8.2 Site fish habitat integrity (SFHI)

This approach is based on the assessment of physical habitat disturbance and is directed towards the indirect qualitative evaluation of fish habitat integrity, compared to the expected natural condition (Kleynhans, 1997). The following impacts (cause for fish habitat integrity degradation) were investigated:

Water abstraction, flow modification, Bed modification, Channel modification, Inundation, Exotic macrophytes, Solid waste disposal, Indigenous vegetation removal, Exotic vegetation encroachment and Bank erosion. Estimation of the impact of each of these modifications on the fish habitat integrity at a site was scored as follows:

No Impact = 0

Small impact = 1

Moderate Impact = 3

Large impact = 5

The habitat integrity score per site (SFHI) was then calculated by summing individual scores for the different impacts of disturbance (id), expressing it as a percentage of the maximum total (50), and subtracting it from 100:
SHI = 100 - ((id/50) x 100)

7.2.9 Statistical analysis

The objective of biological monitoring is to detect human-caused deviation from baseline biological integrity and to evaluate the biological – not statistical – significance of those deviations and their consequences. In some cases, meaningful biological patterns can be lost by excessive dependence on the outcome of menu-driven statistical tests (Karr & Chu, 1997). Familiar statistical tests, such as *t*-tests or analysis of variances (ANOVA) can be applied to look for significant differences in multimetric index values, because the IBI satisfies the model's assumptions (Fore *et al*., 1994). The data set gathered during this study (four surveys) was too small for the application of multivariate statistical analyses. Pearson's correlation coefficient (r) was however used to determine if there was any correlation between different variables.

7.3 RESULTS

7.3.1 Comparison of indices

The Index of Biotic Integrity (IBI) scores for the Klip River ranged between 0% at locality 1, and 80% at localities 5 and 7 (Appendix 7.2 to 7.5). The IBI scores for locality 10, the reference site in the Suikerbosrand River ranged between 60 % and 70% (Appendix 7.2 to 7.5). Sensitivity-weighted Index of Biotic Integrity (SIBI) scores for the Klip River ranged between 0% at locality 1 and 75% at locality 7 (Appendix 7.2 to 7.5). In the Suikerbosrand River, SIBI scores of between 56% and 65% were calculated (Appendix 7.2 to 7.5). Fish Assemblage Integrity Index (FAII) scores ranged between 0% at locality 1, and 50% at locality 7 in the Klip River (Appendix 7.6 to 7.9). Locality 10 in the Suikerbosrand River had FAII scores of 28% to 58% (Appendix 7.6 to 7.9).

For the purpose of comparing the different fish indices (IBI, FAII and SIBI), the results were expressed on the same scale (Figure 7.3). Compared on the same scale, the FAII results were generally the lowest and the IBI results the highest (Figure 7.3). Although the general spatial and temporal trends were similar, some differences were observed. For both winter surveys (August 1997 and 1998), the FAII indicated that there was a decrease between locality 7 and 8, while the other indices indicated an increase. There were also differences between SIBI and IBI trends for the same criteria. An example is the "number of native species" metric for February 1998, where the IBI scores indicated similar scenarios for localities 6, 7 and 8, while the SIBI scoring indicated differences (Figure 7.4). For this same criterion, the IBI assigned the same score (5) for locality 5 and 10, while the SIBI attributed a higher score to locality 10 than at locality 5.

As expected, the correlations between the different fish indices were very strong, with the SIBI and the IBI having the strongest correlation (r=0.98) and IBI and FAII having the weakest correlation (r=0.87). Furthermore, there was a relatively strong correlation between the HAI habitat index and both the SIBI (0.61) and the IBI (0.62). There were no or very poor correlations between the fish and water quality guideline compliance index (Chapter 3). In general, the fish-related indices correlated stronger with habitat indices than with the water quality index (Table 7.7).

Table 7.7: Pearson correlation coefficients determined for indices of water quality (H_2O), habitat, invertebrates (INV) and fish.

COMPONENT		**HABITAT**				**INV**	**FISH**			**H_2O**
	Index	**HAI**	**HAM**	**SFHI**	**HCR**	**SASS4**	**SIBI**	**IBI**	**FAII**	**GCI**
HABITAT	**HAI**	1								
	HAM	0.71	1							
	SFHI	0.18	0.32	1						
	HCR	0.67	0.68	0.26	1					
INV	**SASS4**	0.56	0.55	0.20	0.34	1				
FISH	**SIBI**	0.61	0.45	-0.05	0.45	0.44	1			
	IBI	0.62	0.42	-0.07	0.43	0.39	0.98	1		
	FAII	0.55	0.51	0.02	0.45	0.47	0.90	0.87	1	
H_20	**GCI**	-0.03	0.12	0.39	-0.26	0.36	-0.27	-0.30	-0.17	1

HAI – US Environmental Protection Agency Habitat Assessment (Chapter 4)

HAM – Habitat Assessment Matrix (Chapter 4) SFHI – Site Fish Habitat Integrity (Chapter 7)

HCR – Habitat Cover Ratings (Chapter 7) SASS4 – South African Scoring System 4 Invertebrate Index (Chapter 5)

SIBI – Sensitivity-weighted Index of Biotic Integrity (Chapter 7) IBI – Index of Biotic Integrity (chapter 7)

FAII – Fish Assemblage Integrity Index (Chapter 7) GCI – Water quality Guideline Compliance Index (Chapter 3)

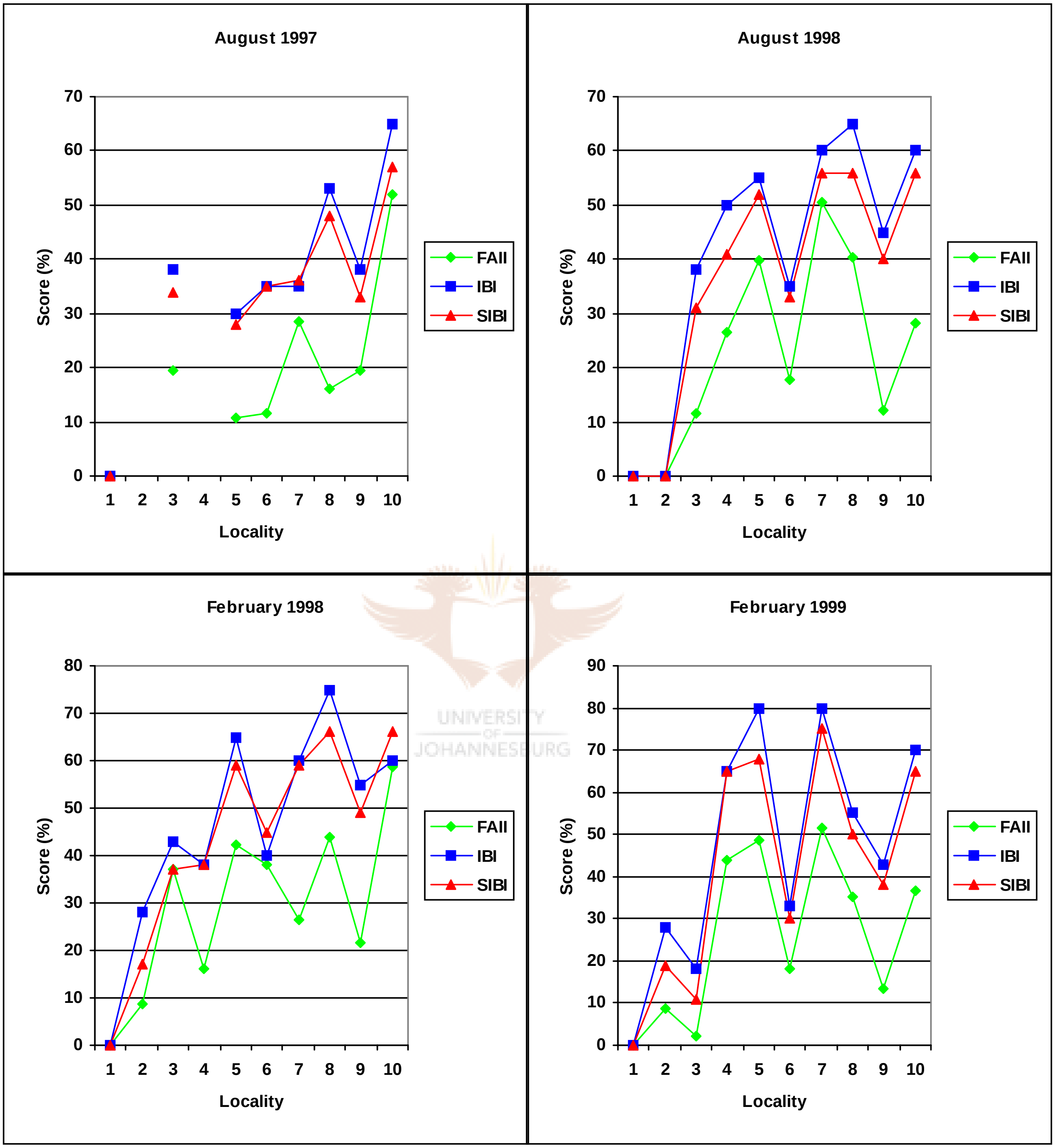

Figure 7.3: Comparison of different fish index scores (%) when expressed on similar scale.

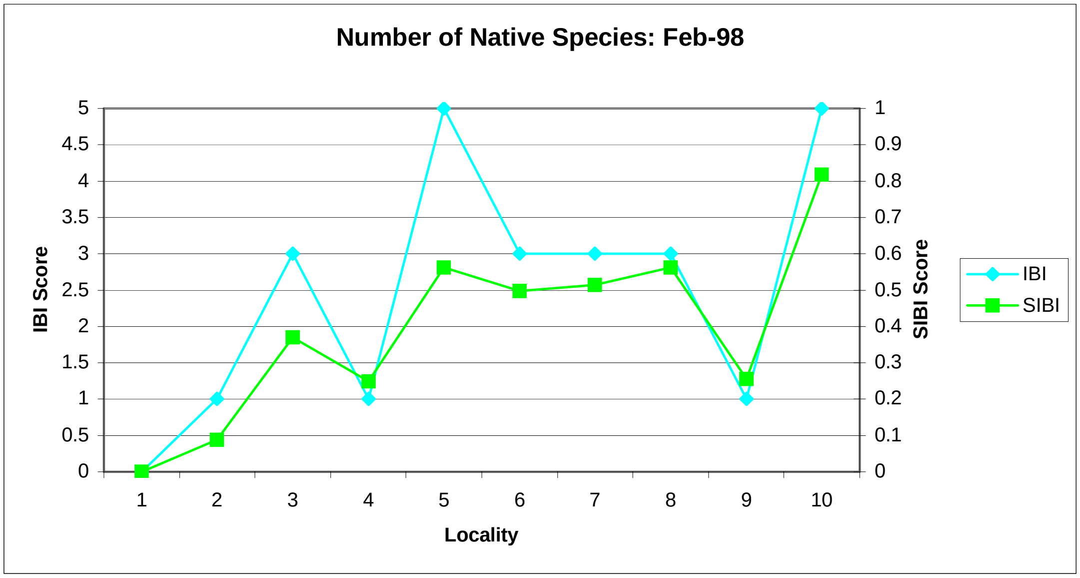

Figure 7.4: Comparison between IBI and SIBI scores for the metric – Number of Native Fish Species – for the February 1998 survey.

7.3.2 Temporal variation in biotic integrity (SIBI).

During the first survey, conducted in August 1997, sampling difficulties were experienced in the Klip River System, primarily due to the high flow of the river, especially in the middle and lower reaches. Sampling techniques were adapted for this system by the application of electro-fishing equipment to a small boat. Sampling success increased, and difficulties were thereby solved for the future monitoring. Due to the above-mentioned scenario, the result of the SIBI for the August 1997 survey was less accurate, and should be viewed with circumspection. More fish were also generally sampled at a site during the summer surveys (chapter 6) and emphasis was therefore placed on the results gained during these surveys.

At locality 1, the Sensitivity-weighted Index of Biotic Integrity (SIBI) scores were 0 for all surveys conducted, and fell within descriptive class F^- (Figure 7.5). All criteria used in the calculation of this index received a score of 0 (Appendix 7.2 to 7.5). At locality 2, SIBI scores were 0 during winter 1998, categorizing this locality in class F^- (no sampling were conducted at this site during the August 1997 survey.) The SIBI scores were slightly higher during the summer surveys, being 17 during February 1998 and 19 during February

1999, both falling within class F+. Most of the fish assemblage criteria assessed, received very low scores at this site (Appendix 7.2 to 7.5). Only the "percentage of individuals with anomalies" criteria received high scores.

Locality 3 was the only site investigated that had a higher median winter SIBI score than summer SIBI score. During August 1997, a SIBI score of 34 was attained, falling within the E+ class. A gradual decline in SIBI scores occurred at this site over the study period, decreasing with 26 points from February 1998 (37) to February 1999 (19) (Table 8.8). Most criteria received very low scores, with only "CPUE" and "proportion of individuals with anomalies" attaining excellent scores. During February 1998, the species sensitive to loss/degradation of vegetated habitats, and pools/slow flowing habitats received fair scores (Appendix 7.2 to 7.5).

Locality 4 was also not sampled during August 1997. There was a gradual increase in SIBI scores from February 1998 (38) to August 1998 (41) and February 1999 (65). The SIBI scores indicated a profound increase of 27 points, from February 1998 to February 1999. At locality four, metrics identified as contributing to the poor scores were "native species diversity", "species sensitive to loss/degradation of vegetated habitats" and "pool/slow flowing" habitats, "CPUE" and " proportion of individuals with anomalies" (Appendix 7.2 to 7.5).

The SIBI scores at locality 5 were higher during the summer surveys than during the winter surveys. The SIBI score increased with 9 points from February 1998 (59, category D+) to February 1999 (68, category C-). Metrics identified as primarily contributing to poor scores included "relative abundance of tolerant individuals, "CPUE" and "proportion of individuals with anomalies" (Appendix 7.2 to 7.5).

SIBI scores were generally very low at locality 6, falling within the very poor class (E+) during both winter surveys and also during summer 1999. A score of 45 attained during February 1998, categorized this site during that survey into the poor class (Table 7.8). Most metrics assessed were generally poor to fair, with especially "CPUE" and "proportion of individuals with anomalies" always being very poor (Appendix 7.2 to 7.5).

The SIBI scores at locality 7 were also lower during the winter surveys than during the summer surveys (Table 7.8). An improvement of 16 points in the SIBI score occurred from February 1998 (59, category D+) to February 1999 (75, category C+), which was also the highest SIBI score observed for all sites over the study period. For the summer surveys, “proportion of individuals with anomalies” always attained a very poor score while “species sensitive to a loss/degradation of riffle/rapid/run habitats” and “native species diversity” attained poor scores (Appendix 7.2 to 7.5).

SIBI scores determined for locality 8 ranged between 48 (class D-) and 66 (Class C-) (Table 7.8). The scores decreased with 16 points from February 1998 (66) to February 1999 (50). Criteria identified to be very poor included “species sensitive to a loss/degradation of vegetated habitats” and “ pool/slow flowing habitats, CPUE” and “% of individuals with anomalies” (Appendix 7.2 to 7.5).

The SIBI scores calculated for locality 9 were generally very poor (33 and 38) to poor (40 and 49), ranging between classes E+ and D- (Table 8.8). The scores decreased with 11 points from February 1998 (49) to February 1999 (38). At this site, the following criteria generally had very poor scores: “number of native species”, “number of species sensitive to loss/degradation of vegetated habitats” and “pool/slow flowing habitats”, “CPUE of native species” and “% of individuals with anomalies” (Appendix 7.2 to 7.5).

SIBI scores for locality 10 (Suikerbosrand River) ranged between 56 (August 1998) and 66 (February 1998). The SIBI scores for the winter surveys fell within descriptive class D+ (Poor) and during the summer surveys in descriptive class C- (Fair) (Table 7.8). The “CPUE” and “% of individuals with anomalies” criteria generally had very poor scores at this site (Appendix 7.2 to 7.5).

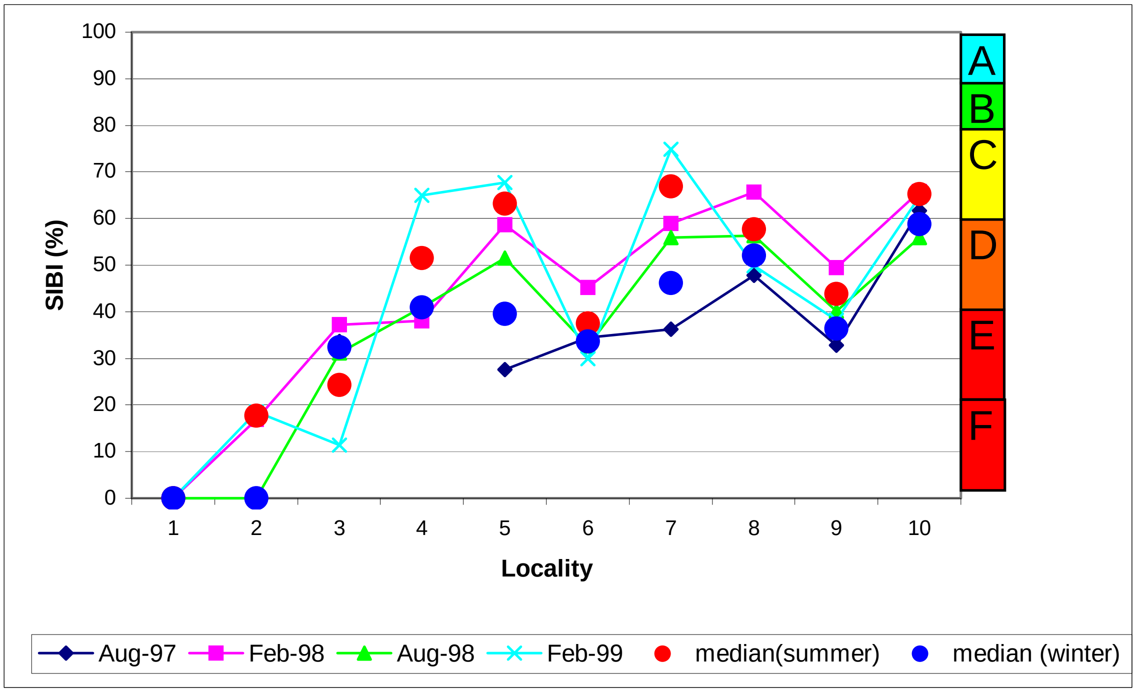

Figure 7.5: SIBI scores calculated for the different sites investigated over the study period.

Table 7.8: The SIBI scores (category in brackets) attained at each site, and the percentage of change observed from February 1998 to February 1999 (Deterioration / Improvement).

Locality	SIBI Score (Category)				% Change from summer to summer
	Aug-97	Feb-98	Aug-98	Feb-99	
1	0 (F-)	0 (F-)	0 (F-)	0 (F-)	0
2		17 (F+)	0 (F-)	19 (F+)	+2
3	34 (E+)	37 (E+)	31 (E+)	11 (F+)	-26
4		38 (E+)	41 (D-)	65 (C-)	+27
5	28 (E-)	59 (D+)	52 (D+)	68 (C-)	+9
6	35 (E+)	45 (D-)	33 (E+)	30 (E+)	-15
7	36 (E+)	59 (D+)	56 (D+)	75 (C+)	+16
8	48 (D-)	66 (C-)	56 (D+)	50 (D+)	-16
9	33 (E+)	49 (D-)	40 (D-)	38 (E+)	-11
10	57 (D+)	66 (C-)	56 (D+)	65 (C-)	-1

F – critical E – Very Poor D – Poor C - Fair

7.3.3 Spatial trends in biotic integrity of the Klip River.

For the purpose of identifying spatial variation in biotic integrity of the Klip River, the SIBI scores determined for the two summer surveys (February 1998 and February 1999) were used. In general, localities 1 (0) and 2 (17) had the lowest biotic integrity and localities 5 (68) and 7 (75), the highest. An increase in SIBI scores (17 and 19 points) occurred from site 1 to site 2 during the summer surveys (February 1998 and February 1999) (Figure 7.6, Table 7.9). During February 1998, the SIBI scores increased by 20 points from locality 2 to 3, but a decrease of 8 points was observed during February 1999 (Figure 7.6, Table 7.9). The SIBI score determined for locality 4 was only 1 point higher than at locality 3 during February 1998, but significantly higher (54 points) during February 1999 (Table 7.9). SIBI scores always increased from locality 4 to locality 5, with between 3 (Feb 1999) and 21 (February 1998) points (Figure 7.6, Table 7.9). There was always a decrease in SIBI scores from locality 5 to 6 (14 and 38 points). For the entire study period, SIBI percentages increased from locality 6 to 7 (Figure 8.6), with between 14 and 45 points. During February 1998, the SIBI increased by 7 points from locality 7 to 8, but a profound decrease of 25 points was observed during February 1999. SIBI scores always decreased towards locality 9 by between 12 and 17 points (Figure 7.6, Table 7.9).

Table 7.9: The percentage of spatial change and shift in categories observed in the SIBI scores at each site (Deterioration / Improvement).

Locality	Survey	% change	Shift in category
1 to 2	Feb-98	**+17**	**F- to F+**
	Feb-99	**+19**	**F- to F+**
2 to 3	Feb-98	**+20**	**F+ to E+**
	Feb-99	**-8**	**F+ to F+**
3 to 4	Feb-98	**+1**	**E+ to E+**
	Feb-99	**+54**	**F+ to C-**
4 to 5	Feb-98	**+21**	**E+ to D+**
	Feb-99	**+3**	**C- to C-**
5 to 6	Feb-98	**-14**	**D+ to D-**
	Feb-99	**-38**	**C- to E+**
6 to 7	Feb-98	**+14**	**D- to D+**
	Feb-99	**+45**	**E+ to C+**
7 to 8	Feb-98	**+7**	**D+ to C-**
	Feb-99	**-25**	**C+ to D+**
8 to 9	Feb-98	**-17**	**C- to D-**
	Feb-99	**-12**	**D+ to E+**

7.3.4 Fish Habitat Assessments

Fish Habitat Cover Ratings (HCR's)

The amount of cover available to fish at a site (Habitat Cover Ratings-HCR's) ranged between 2 (locality 1, Feb-98) and 9 (locality 10-August 1997). Locality 1 generally had the smallest amount of fish cover, whilst localities 4, 5, 7, 9 and 10 had a greater amount of fish cover (Figure 7.6).

The number of different flow-depth classes indicates the diversity of habitats available for fish. Localities 1 and 2 generally had a very low diversity of fish habitat types. Furthermore, habitat diversity for fish at locality 5, 6 and 10 was also low at times. The fast-deep habitat type generally dominated habitat diversity at localities 5 to 9 in the Klip River. Slow-shallow habitats were also very scarce at these sites. At localities 1 and 2 in the Klip River, and 10 in the Suikerbosrand River, the fast-deep habitat type was generally absent.

Site Fish Habitat Assessment (SFHI)

The fish habitat integrity index indicates the extent of various human activities on the habitat of fish. It investigates qualitatively the extent to which certain impacts have changed the fish habitats from their natural condition. The most concerning impact on both the Klip and Suikerbosrand Rivers is flow modification, having a large impact on the integrity of fish habitat at all sites investigated (Table 7.10). The second most obvious negative impact is bank erosion, moderately affecting fish habitat integrity at sites 2 to 6 and 9 and 10. Exotic vegetation encroachment moderately impacted fish habitats at sites 2, 3, 4 and 9, while the removal of indigenous vegetation had a rather negative impact at locality 6. Another factor having moderate impacts on the fish habitat, and therefore the physical habitat in general, is riverbed modifications at localities 4, 8, 9 and 10. Water abstraction, solid waste disposal and removal of indigenous vegetation were generally low, with a small impact on the fish habitat integrity of most sites. Channel modifications, inundation and exotic macrophytes usually had no discernable impact on fish habitat integrity. The median site fish habitat integrity was the lowest at locality 4 (69%), and the highest at localities 1 and 7 (78%) (Table 7.10).

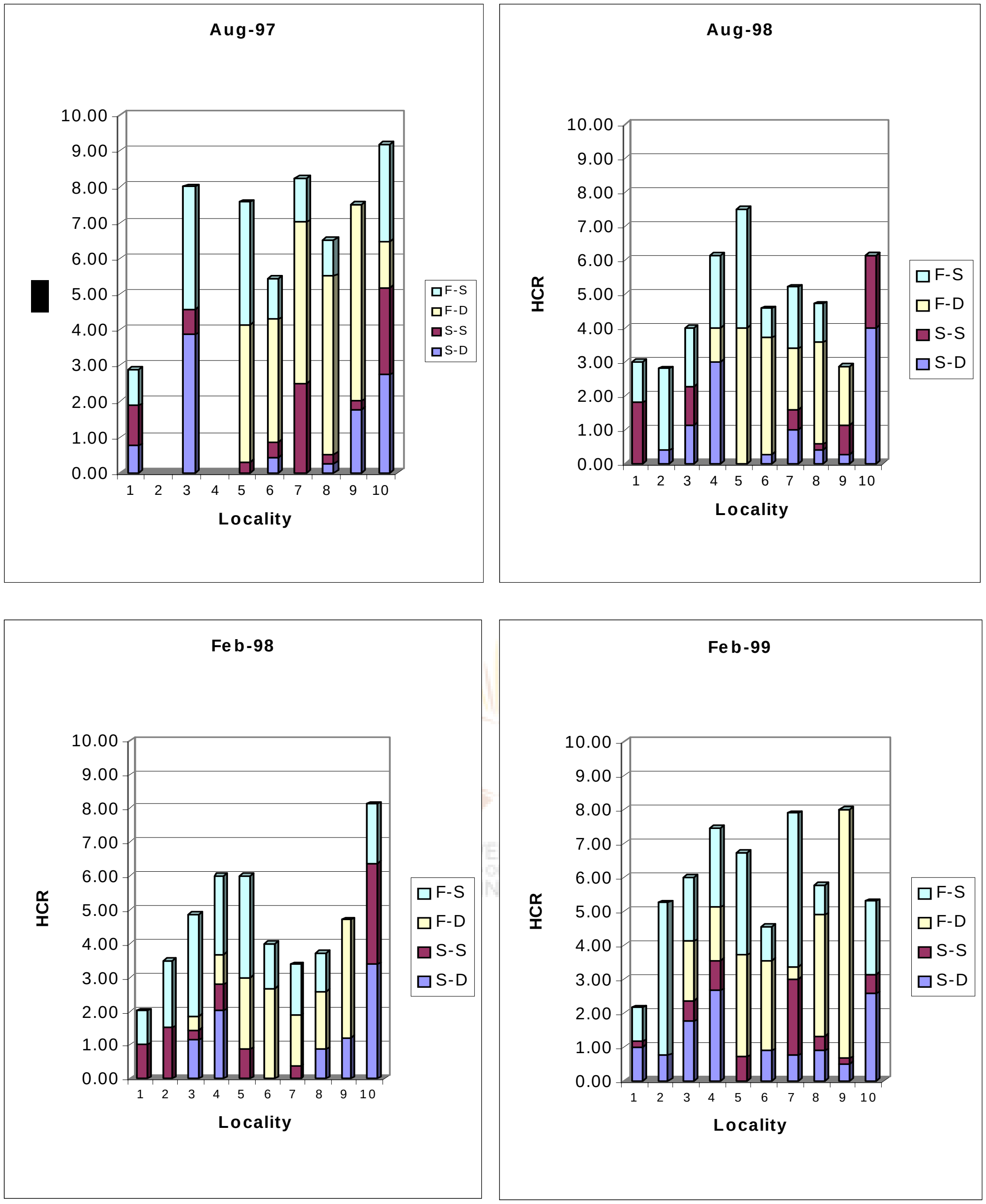

Figure 7.6: Habitat Cover Ratings calculated for each survey at the sites investigated (F-S: Fast Shallow; F-D: Fast Deep; S-S: Slow Shallow; S-D: Slow Deep).

Table 7.10: Site Fish Habitat Integrity Index (SFHI) scores indicating the extent of human activities (None, Small, Moderate, Large) on the fish habitat integrity.

IMPACTS/ACTIVITIES	LOCALITIES									
	1	2	3	4	5	6	7	8	9	10
Water abstraction	1±1	1±1	1±1	1±1	1±1	1±1	1±2	1±1	1±2	1±2
Flow modification	5±2	4±2	4±2	5±2	5±1	5±2	4±2	4±2	5±2	5±1
Bed modification	1±0	1±2	1±1	2±1	1±1	1±1	1±1	3±2	3±2	2±1
Channel modification	0	0±1	1±1	0±1	0	0±1	0	0	0±1	0
Inundation	0±1	0±1	1±1	0	1±1	0±1	0±1	1±1	0	1±1
Exotic macrophytes	0	0	0±1	0±1	0±1	0	0±1	0	1±1	0±1
Solid waste disposal	0	0±1	1±0	1±1	1±1	1±1	1±1	1±1	1±1	1±1
Indigenous vegetation removal	1±2	1±2	1±2	1±1	1±1	2±2	1±1	0±1	1±2	1±1
Exotic vegetation encroachment	1±2	3±2	3±2	2±2	0	1±2	1±1	1±2	2±2	1±1
Bank Erosion	1±1	2±2	3±2	3±1	2±2	3±1	1±1	1±1	3±2	3±2
SFHI (%)	78±7	70±8	74±11	69±7	73±7	73±7	78±5	72±8	72±12	73±4

7.3.5 Fish Habitat Segment evaluation (FAII)

The FAII index was developed for the application to fish habitat segments in a river. On the basis of gradient and geological similarities, specific sites were grouped to distinguish between four different segments. The first segment (A) had an average slope of more than 4 m/km, over a complex geology of quartzite, shale and Ventersdorp Supergroup lavas, and included localities 1 and 2. Segment B included localities 3, 4 and 5 and had an average slope of 2 to 4 m/km, over dolomite and fluvial sediments. The third segment (C) had an average slope of between 1 and 3 m/km over dolomite, and included localities 6 and 7. Segment D included localities 8 and 9 and had an average slope of less than 1 m/km, over primarily dolomite. The flow was slow to moderate in the first segment, but increased through segment B to C. Segment A included some wetlands, while segment B consisted almost exclusively out of wetland habitats (see Chapter 4).

Fish segment A (localities 1 & 2) had relative FAII scores that ranged from 0% to 7.26%, falling within descriptive class F (Critically modified) (Figure 7.7). There was a profound increase towards fish segment B (localities 3 to 5) where relative FAII scores ranged from 18.14% to 34.90%, falling mainly within class E (Seriously modified). Slight increases in relative FAII scores were generally observed towards fish segment C (localities 6 & 7). The relative FAII scores for segment C ranged from 25.67% to 46.32%, and fell mainly within class E (Seriously modified), although the February 1999 score fell within class D (Largely modified). Relative FAII scores generally decreased towards fish segment D (localities 8 & 9), especially during February 1999. Scores at this site ranged between 28.99% and 38.79% (Class E – Seriously modified) (Figure 7.7).

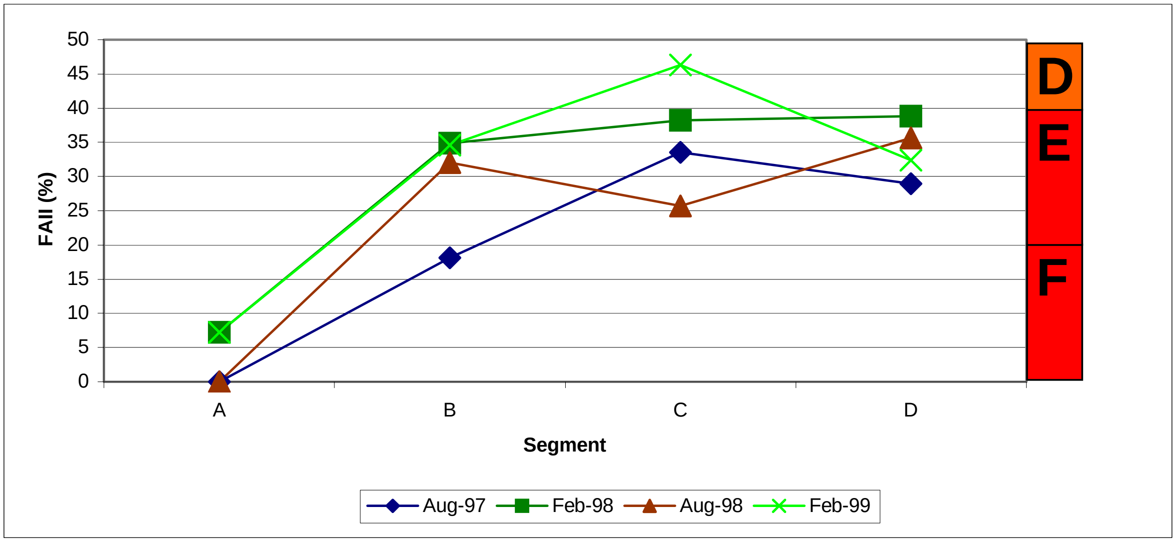

Figure 7.7: Relative Fish Assemblage Integrity Index (FAII) ratings for the fish segments of the Klip River.

7.4 DISCUSSION

7.4.1 Optimizing biomonitoring results

In any assessment, it is of utmost importance that the results are reliable. This necessitates the incorporation of quality control procedures in many aquatic monitoring programs. The primary aspect of concern when using fish as biomonitors, is the effective sampling to include all species present. Insufficient sampling could lead to inaccurate results, and if applied to fish indices, inaccurate assessments of changes in aquatic ecosystem (Paller, 1995; Paller *et al.*, 1996). It is therefore essential to determine the sampling efforts necessary at a site or reach, and to keep it as constant as possible during future monitoring. Paller (1995) determined that in small (4.5m wide), species rich (n=30) streams, approximately 20% of the fish were collected during a single electro-fishing pass. Seven passes of the same area yielded 60 – 90% of the fish. Reach lengths of 235 – 555m (equivalent to 35 – 158 stream widths) were needed to collect all species. Species occurring sporadically were largely responsible for the long reaches needed to represent all species. It was concluded that, in terms of time and effort, it was more efficient to sample a large area with one pass than to sample a smaller area with many passes (Paller, 1995). No such research was conducted on the system under investigation, and probably also not in other aquatic systems of South Africa. It might therefore present a major gap in the information required to institute the successful application of fish indices in South African aquatic systems, and further attention should be given to this aspect in future research. It can be expected that the sampling effort will vary from one system to another, with species diversity and habitat structure being decisive determinants of the sampling effort required. In the current study, it was attempted to sample at least two different areas of each habitat type (riffle/rapid/run/pool etc.) present at a site or reach.

7.4.2 Comparison and Validation of fish indices

The assessment of aquatic health by the sampling of biological communities in the field is a promising approach being applied more often and cosmopolitan (Karr, 1991; Roux, 1997; Schleigher, 2000). The inclusion of biological assessments to present and future aquatic health assessments would ensure a more comprehensive and accurate evaluation of aquatic resources. The inclusion of a range of biological communities in an assessment increases the validity of investigations and ensures that more reliable conclusions are drawn. In South Africa, the most popular and widely used biological index is the macro-invertebrate based South African Scoring System (SASS) (Roux, 1997). Kleynhans (1999) developed the Fish Assemblage Integrity Index (FAII) to incorporate a fish index in the biomonitoring of South African rivers. This index provided an indication of the overall biological integrity of segments of a river. Each segment was broadly defined as a portion of a stream in which the fish community remained generally homogenous, due to the relatively uniform nature of the physical habitat of that section of the stream. Some of the aspects of concern regarding this index were that in most cases it provided an underestimation of the biological integrity of a segment and it was not considered suitable for the assessment of streams with a naturally low fish species diversity (Kleynhans, 1999). Furthermore, the FAII was developed for the application to fish segments, which should include a few sites, and not for site–specific investigations. When this index was applied to site-specific data, the "*Frequency of occurrence within segment*" criterion was omitted from the calculations. This would imply that a certain amount of accuracy and sensitivity was lost when used for site-specific evaluation (Kleynhans, 1999).

One of the main suggestions made by Kleynhans (1999) is that the FAII needs to be refined to include the species expected per habitat type. The Index of Biotic Integrity (IBI) and Sensitivity-weighted Index of Biotic Integrity (SIBI) applied in this study addressed this shortcoming by the inclusion of three habitat related metrics namely:

- Species sensitive to a loss/degradation of RRR-habitats (Riffle/Rapid/Run-habitats),
- Species sensitive to a loss/degradation of vegetated habitats and
- Species sensitive to a loss/degradation of pool/slow flowing habitats

These metrics would therefore only apply if these habitats have been sampled at a site. It should also be included that, if the possibility existed, that these habitats could be found at a site before anthropogenic activities occurred, e.g. loss of pools and slow flowing habitats due to flooding by unnaturally high releases from dams or wastewater treatment plants.

The main objective of a multimetric fish index is to use fish assemblage attributes to monitor aquatic ecosystem health. Aspects such as water and habitat quality are determining factors of biotic integrity, and are not necessarily indicators thereof. This would therefore imply that only characters of the fish assemblage should be utilized in the determination of biotic integrity with the use of fish indices. For this reason, other aquatic components, such as water quality criteria as used by Hay *et al.* (1996) were not included in the current IBI and SIBI. Kleynhans (1999) furthermore excluded the use of introduced fish species (indigenous & exotic), but mentioned their possible value as indicators of poor or good water and/or habitat quality. The presence of these introduced species in a system should always be seen as degrading to the biotic integrity, and should be dealt with accordingly. The IBI and SIBI thus also excluded introduced fish species from the metrics, and thus viewed them as an impact rather than an indicator of biotic integrity.

Most versions of the IBI have been developed for warm water streams (>24°C mean maximum during summer) (Simon & Lyons, 1995). Versions of the IBI applied to coldwater (<22°C) and cool water (22-24°C) systems of the high-gradient United States streams generally included between 8 and 10 metrics, while warm water IBI's generally consisted of 10 to 12 metrics (Simon & Lyons, 1995). Lyons *et al.* (1996) developed an IBI for a coldwater stream consisting of only five metrics. The reduction of metrics from warm water to coldwater systems is attributed to the more simplified structure and functioning of coldwater fish communities relative to warm water communities (Simon & Lyons, 1995). For South African conditions, the Klip River system can be seen as a cool water system, with summer temperatures ranging between 17°C in the headwaters to 26°C in the lower reaches (as observed during the study period – see Chapter 3). The IBI developed for the Klip River system also included 8 metrics, therefore coinciding with the previous versions applied to cool water systems in other parts of the world.

A study by Schleiger (2000) indicated that different anthropogenic impacts negatively influenced different aspects of the fish assemblage, which was then reflected by the relevant metrics based on those aspects of the fish community. In that study, point and non-point sources of pollution from low-density urban areas negatively influenced the "number of fish species" and "proportion of specific groups/species" metrics. Increased turbidity and suspended solids caused changes in the "proportion of tolerant species" and "proportion of individuals with anomalies" metrics (Schleiger, 2000). The use of a multi metric fish index, such as the IBI and SIBI, is therefore valuable due to the fact that impacts could be reflected by changes in different metrics. This could therefore improve the possibility of being able to identify the possible causes and sources responsible for the biotic degradation at a site.

Many investigations require site-specific evaluations, such as upstream and downstream from a pollution source. It would therefore be valuable if a fish index can be applicable for such investigations, similar to the SASS4 invertebrate index. Both the SIBI and IBI comply with this requirement. For the Klip River System, it was determined that the SIBI was the most accurate and useful indicator of biotic integrity for site-specific investigations.

The strong correlations observed between different fish indices applied in this study could be expected, due to the fact that they are all based on fish assemblage characteristics. However, the variation in correlations between the different fish indices used in this study indicates that, although small, there are differences in the results gained with different indices, which could influence the accuracy of aquatic health assessments. The poor correlation of the fish indices with the water quality index stresses the fact that the fish assemblage is a reflection of long-term impacts, and not only of the water quality at the time of biological sampling. The fish indices are furthermore a reflection of the aggregate impacts of an array of influences, and not only changes in water quality. Habitat availability and quality is an important determinant of the state of a fish assemblage, and was reflected in the strong correlation between the SIBI and IBI with the HAI habitat assessment (see Chapter 4). This furthermore indicates that the HAI habitat index might be more reliable than the HAM index, especially when used in conjunction with fish assessments. Habitat destruction is one of the most significant threats to southern African aquatic environments and their respective organisms (Skelton, 1983), and it is therefore important that fish assemblage indices are sensitive to these changes. The SIBI index's strong correlation with the HAI habitat quality index might be an indication that it has the ability to indicate habitat changes more effectively than the other indices tested.

Although the general spatial and temporal trends were similar for the different fish indices applied, some important differences were however observed. For both winter surveys (August 1997 and 1998), the FAII indicated that there was a decrease between locality 7 and 8, while the IBI and SIBI indicated an increase. The proportion of individuals of tolerant species, and omnivorous individuals, which could be indicative of degradation, were much greater at locality 7 than 8 for these surveys. The difference between the indices could therefore be attributed to the use of proportional metrics (e.g. proportion of individuals of tolerant species) included in the IBI and SIBI indices, but not used in the FAII. There were further spatial differences between the SIBI and the IBI for the same metric, such as the "number of native species" metric for the February 1998 where the IBI indicated similar scenarios for locality 5 and 10, while the SIBI attributed a higher score to locality 10. This difference can be attributed to the fact that more sensitive fish species were observed at locality 10 (reference site), and the SIBI was able to detect this due to the use of a weighting system, which is based on the sensitivity of the fish species. The use of a continuous scoring system (sliding scale) by the SIBI, as opposed to the class type scoring system for the IBI, furthermore optimized the possibility of the SIBI to reflect changes in its metrics, and final index scores. It was therefore evident that the SIBI was more sensitive to depict changes than the IBI and FAII for site-specific evaluation of the Klip River Systems, and further assessments were based on the SIBI results.

7.4.3 Biotic Integrity of the Klip River

For the purpose of long-term biomonitoring, temporal comparisons should be based on results from similar seasons. With summer seasons generally delivering more fish species and individuals, it was decided to use the result from these surveys to investigate possible trends in deterioration or improvement in biotic integrity. Results of the SIBI, as with the IBI, are a reflection of the aggregate impact that human activities in the catchment have on the fish assemblage on a section of the river. Steedman (1988) indicated that the land use immediately upstream of sampling localities was most strongly associated with stream quality, as measured by an IBI for that system. SIBI scores calculated for the Klip River system should therefore be of value to determine the relative impact of anthropogenic activities throughout the Klip River, as sites were selected from its headwaters to the confluence with the Vaal River. Similar to many other aquatic systems around the world, the expected species diversity of the lower order section (upstream sites) was lower than for the higher order section (downstream sites) in the Klip River (Paller, 1994; Kleynhans, 1999). These differences are primarily related to longitudinal changes in habitat structure, climate and gradient, and determined the expected criteria and their ranges at each site.

Spatial and temporal variability in IBI can generally be related to specific habitat or water quality perturbations of either natural or anthropogenic origin (Karr *et al*., 1987). The authors state that long-term sampling is required to define the range of sampling variation in the IBI so that techniques can be developed to distinguish between natural and anthropogenic causes of variations, as well as the relative magnitudes of variation induced by these two sources under various circumstances. Karr (1981) indicated that in the United States of America, fish communities tend to be relatively stable over time in natural streams, while they tend to be unstable in disturbed areas. It can therefore be expected that natural causes would be responsible for seasonal variation in SIBI scores. In the Klip River less fish were generally sampled during the winter surveys (Chapter 7). This might be attributed to natural longitudinal movement of fish due to decreased water temperature. It is envisaged that some fish move towards deeper pools and weirs where the temperature fluctuations are less during the colder winter months. Another theory is that their metabolism decreases with decreasing water temperature, and that when stunned by electro-fishing, they simply overturn and sink to the bottom, making them difficult to sample in deep habitats. Most river plants die off in winter, although some remain green but have much smaller populations or shoots (Haslam, 1987). The decrease in fish cover during winter times can further influence the species diversity and abundance at a site. The comparison of SIBI scores annually for the same seasons would exclude this natural variability between different seasons, and therefore be more accurate to indicate possible degradation due to anthropogenic activities. In general, more fish species and individuals were sampled during the summer surveys in the Klip River System. Summer surveys were therefore identified as the best time to conduct long-term biomonitoring of cold and cool water systems such as the Klip River. Winter surveys could, however, also be conducted to gather baseline information.

The biotic integrity, as determined by the SIBI, was critical at locality 1, and there were no sign of improvement at this site over the study period. The catchment feeding this site drains a highly populated formal residential area. Sewerage system leaks have also been observed to run into the Klip River upstream of this site. The water quality observed at this site was however, in general, good and higher than most other sites in the Klip River. The instream channel habitat condition was only fair and contributed to the poor biotic integrity. It is however envisaged that the habitat available at this site would be able to sustain most expected fish species. The poor biotic integrity, based on fish, is therefore primarily attributed to long-term poor water quality. Very poor water quality and weirs built in the river furthermore act as chemical and physical barriers, preventing fish from recolonising upper reaches of the river, even if water and habitat condition improve and become suitable. Habitat constraints contributed secondarily to the poor biotic integrity observed at this site.

Conditions in the Klip River did not increase much towards locality 2, where the biotic integrity was still critical, and there was also no indication on improvement over the study period at this site. The water quality was generally very poor at this site, probably due to the gold mining activities in the area. Habitat condition was fair to good, and it can be expected to be able to sustain most expected fish species. Sedimentation of pools could have contributed to fish community deterioration, but the poor biotic integrity, based on fish, at this site is primarily attributed to the poor water quality.

The biotic integrity increased slightly towards locality 3 but was still identified as being very poor to critical. All the upstream impacts influencing localities 1 and 2, together with informal settlement runoff, contributed to the degradation of biotic integrity at this site. Instream habitat conditions were generally good at this site and the poor biotic integrity is therefore primarily contributed to water quality degradation. The further deterioration in the biotic integrity over the study period was alarming due to the already very poor conditions, and was probably attributed to extension of human settlements and increased construction activities upstream of the site.

The biotic integrity at locality 4 was generally higher than at locality 3, and improved over the study period from very poor to fair. The habitat potential, based on Habitat Cover Ratings (HCR's), was higher at locality 4 than 3 and therefore could have contributed to the increase in biotic integrity between these sites. Apart from poor water quality, alteration of the natural flows, due mainly to water care work effluent discharge and urban runoff, are identified as the cause for the state of the biotic integrity at locality 4.

The increase in biotic integrity from locality 4 to 5 could probably be attributed to a slight general improvement in water quality at locality 5. This improvement in water quality can be attributed to the purifying impact of the vast wetland between localities 4 and 5. Habitat condition and potential was generally very similar at both these sites, again stressing that water quality must have been the determining factor. The biotic integrity improved over the study period and can be classified as fair.

A decrease in biotic integrity was always evident from locality 5 to 6. Karr et al., (1985) indicated by the use of an IBI that biotic integrity often decreased downstream of wastewater treatment plants. The negative impact on the biota was primarily attributed to the use of chlorine in the secondary treatment processes. In the Klip River, wastewater treatment plants discharge effluents upstream of 4, as well as upstream of locality 6 (in the Rietspruit). The Rietspruit is furthermore impacted by mining, industrial and urban runoff. The decreases in biotic integrity between sites 5 and 6 may be attributed to the influence of the Rietspruit on the Klip River. Habitat potential was, however lower at locality 6 than at 5, and could possibly also have contributed to the decrease in scores between locality 5 and 6. The deterioration at locality 6 over the study period might be an indication of deteriorating conditions in the Rietspruit catchment, as locality 5 (upstream of the Rietspruit confluence) improved over the study period. Dysfunctional WWTW's directly upstream of locality 6 was also identified as releasing high levers of sludge at times. Fish kills occurred in the vicinity of locality 6, as well as downstream from this site, over these periods of pollution.

The biotic integrity at locality 7 was higher than at locality 6, and improved over the study period, to become fair. This locality had the best biotic integrity of all sites investigated in the Klip River. This site is directly downstream of a weir that could be a major migration barrier to fish in the Klip River. This might therefore cause the crowding of fish that could result in an overestimation of biotic integrity at this site. The habitat potential and diversity was very good at this site, and water quality deterioration can again be seen as the most probable cause for the state of the biotic integrity, based on fish, at this site.

The biotic integrity of locality 8 decreased over the study period from fair during February 1998 to poor in February 1999. This might be an indication that human activities upstream of this catchment are responsible for increased pressure on the river. Habitat condition and diversity was generally good and stayed stable throughout the study period. The SIBI indicated that there was a general absence of fish species reliant on pool/slow flowing habitats, as well as species favouring vegetated habitat. These habitat components are highly disturbed by the excessive flows, originating from the water care works and urban runoff. Water quality, as well as flow modification can be seen as the major cause for decreased biotic integrity at this site.

The biotic integrity of the Klip River decreased towards the lower reaches, before the confluence with the Vaal River, with conditions at locality 9 ranging between poor and very poor. Furthermore, there was an indication that the biotic integrity decreased at this site over the study period. Flow modification had an especially high impact on the biotic integrity of this site, and the unnaturally high flow was again responsible for the eradication of fish species reliant on pool/slow flowing habitats and vegetated areas. This site is furthermore not only affected by the aggregate impact of the upstream activities, but also by the downstream barrage area. This dammed barrage area creates favorable habitats for exotics such as *C. carpio* and *M. salmoides* to thrive, being a source for these exotics to infest the Klip River. It can be expected that especially *M. salmoides*, with its vicious predatory feeding, could further decrease the biotic integrity, by impacting on indigenous fish populations.

The biotic integrity of locality 10 (reference site in Suikerbosrand River) was generally fair. The water quality at this site was good, and was not seen as a limiting factor to biotic integrity. This site was, however, also impacted by flow modification, but the scenario being the opposite to that of the Klip River. The flow in the Suikerbosrand River is greatly reduced due to upstream damming and water abstraction for irrigation and livestock. Conditions deteriorated over the study period, and a slight decrease was also observed in the SIBI score.

9.4.3. Fish Habitat Segment Evaluation (FAII).

The FAII has the potential to provide qualitative, descriptive criteria for the desired ecological condition or integrity of rivers for management purposes, in terms of the new South African Water Act (Kleynhans 1999). It provides an indication of the overall biological integrity of a river and is suitable for a synoptic level of assessment (Kleynhans 1999). In its current form, it should thus give an overall indication of integrity of a system, and should not be applied to measure specific anthropogenic impacts on specific sites or reaches. The component metrics of the index can, however, be used separately to provide more insight into possible causes of degradation.

The FAII indicated that the integrity of segment A (localities 1 & 2) of the Klip River was critically modified from its natural condition. It was reflected by the presence of only the most tolerant species being present during the summer months, and the total absence of all species during the winter months. The low habitat diversity, and amount of cover at these sites (Figure 7.7), could have contributed to the poor fish assemblage at these sites, but is should still be adequate to sustain a more diverse fish population than was observed. The absence of fish is therefore more likely attributed to water quality deterioration of the area, especially at locality 2 where mining activities impact on the river (see Chapter 3). Although the water quality at locality 1 was generally good, the downstream area (locality 2) might be creating a chemical barrier, preventing fish from recolonising the upper reaches of this segment.

There was a profound improvement of integrity towards segment B (localities 3 to 5), and again a further slight increase in relative FAII scores towards segment C (localities 6 & 7). Both of these segments fell within category E, indicating that seriously modified conditions prevailed. The fish species richness of these segments was strikingly lower than expected, and intolerant and moderately intolerant fish species were generally absent. Although some habitat alterations were observed at these sites, the diversity and abundance should have been adequate to sustain viable populations of most of the fish species expected. Fluctuating flows and embeddedness of the substrates in these segments could have contributed to the degradation of the fish assemblage, together with water quality deterioration (see Chapters 3 and 4).

Relative FAII scores generally decreased towards fish habitat segment D (localities 8 & 9), where the scores were always in category E (seriously modified). Extremely high flows, primarily due to unnatural effluent discharges in the catchment, caused a degradation of the natural habitats of this segment of the river. This, together with water quality deterioration contributed to the general degradation of the fish assemblages of this segment of the Klip River. The Vaal Barrage furthermore contributed to the degradation by sustaining large numbers of exotic *Cyprinus carpio*, and to a lesser extent *Micropterus salmoides*, which then migrate up the Klip River via this segment. The overall synopsis of the Klip River, based on the FAII evaluation, indicates that this river is presently seriously to critically modified, which necessitates actions to increase its integrity, increasing its sustainability.

7.5 CONCLUSION

Fish Assemblage Indices

This study indicated that the principles of the Index of Biotic Integrity could be applied with success to the Klip River, which has a relatively low species diversity (n=11), if the objective is to monitor change in biotic integrity. The newly developed Sensitivity-weighted Index of Biotic Integrity (SIBI) was identified as a reliable index for the use of fish as indicators of biotic integrity of the cool water Klip River System with a low fish species diversity. The SIBI was also found to be valuable for application to site-specific data as to investigate upstream impacts. It is envisaged that the SIBI could, with minor adaptations, be applied to other aquatic systems than the Klip River, and could possibly be used as an alternative fish index for South African rivers, especially when investigations necessitate site-specific evaluations. The Fish Assemblage Integrity Index (FAII) on the other hand, was found to be of great value for investigating the general biotic integrity of segments of a river. It is of cardinal importance to include the use of multimetric fish indices in any biomonitoring program, as this would result in more comprehensive assessments of biotic integrity, and could therefore contribute to better management of aquatic resources.

Although most of South African Fish species have been taxonomically described, there is still limited information available on the ecology of many species. Aspects such as optimal habitat requirements and sensitivity to environmental change of many South African species are still uncertain. Better understanding of the specific needs and requirements of each species would optimize utilization of fish as indicators of environmental degradation. Research on indigenous fish biology should therefore be continued and aim to address this in future, as it would increase the accuracy with which fish indices could be used to monitor environmental change. It is also recommended that investigations should be conducted to determine the sampling effort needed to collect reliable data on fish assemblages of South African river systems. This could furthermore increase the applicability and reliability of fish index results.

It should be kept in mind that the IBI and SIBI are tools designed, only to be used when the objective is to monitor biotic integrity at specific sites, and it must therefore be used appropriately. It is furthermore stressed that these indices were applied to a relatively small data set, and that their true value would only be determined over long term testing.

Biotic integrity of the Klip River System

From the results gained during this study, it can be concluded that the biotic integrity of the Klip River System is presently, based on fish assemblage characteristics, moderately to critically modified. The upper reaches of the river, where fish communities have been critically modified from their natural condition, had especially poor biotic integrity. Migration barriers in the form of weirs, as well as areas with very poor water quality, may presently prevent the recolonisation of upper reaches by native fish species. Degradation in the natural fish assemblage characteristics of the Klip River can be ascribed to both reduced water and habitat quality. The primary anthropogenic activities responsible for the decreased biotic integrity were identified as gold mining in the upper catchment, WWTW's effluents throughout the catchment, agricultural activities as well as runoff from formal and informal settlements. Flow modification in the form of unnaturally high flows was also identified as a major cause of decreased biotic integrity. It is recommended that fish surveys in cold and cool water systems, such as the Klip River, should be conducted annually during the summer months to gain more reliable results for application to fish indices.

It is furthermore advised that actions should be taken to rectify the habitat alterations due to the high flows. The creation of backwaters, as well as more slow shallow and fast shallow areas would provide better habitat for the fish and would probably improve the biotic integrity of the system. The artificial creation of habitats would not only be beneficial to the aquatic ecosystem, but also for humans through job creation possibilities.

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