The development of a fish index to assess the biological integrity of South African rivers

CJ Kleynhans
Institute for Water Quality Studies, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001, South Africa

Abstract

A biological integrity index that uses attributes of fish assemblages was developed and applied to a part of the Crocodile River (Incomati System, Mpumalanga Province). Fundamentally, the fish assemblage integrity index (FAII) is based on the fish species expected to be present in biological (fish habitat) segments which are sections of river with relatively homogeneous fish habitat. Within this framework fish are categorised according to an intolerance index which takes into account trophic preferences and specialisation, habitat preferences and specialisation, requirement for flowing water during different life-stages and association with habitats with unmodified water quality. This intolerance index, the expected frequency of occurrence and expected health of fish species in a particular fish habitat segment was used to formulate an index for the situation expected under minimally impaired conditions which was used as the comparative basis for the observed (sampled) situation. The observed situation was expressed as a fraction of the expected situation to arrive at a relative FAII index value which was grouped into one of six descriptive fish assemblage integrity index classes. It was found that the index reflected several aspects of the modifications that have occurred in the Crocodile River, i.e. water quality modifications, flow modifications and introduction of alien fish. However, flow releases from Kwena Dam hampered fish sampling while the floods that occurred in the summer prior to the survey, extensively modified physical habitat conditions that existed for some years. It was concluded that the index provides a broad, synoptic estimation of the biological integrity of the river. It is highly likely that the index in its current form provides an underestimation of the biological integrity due to the species expected to be present, being based on all species listed for a segment, and not on the fish species expected to be present in the habitats actually sampled. It is suggested that refinement of the index should include development of improved methodology to determine not only the fish species expected per segment, but also species expected per habitat type. In its current form, the index 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 Law. The development of numerical criteria will, however, require development in terms of the statistical properties (i.e. statistical power) of the index.

Introduction

The South African Department of Water Affairs and Forestry (DWAF), as custodians of the water resources of the country, initiated the development of a National Aquatic Ecosystem Biomonitoring Programme during 1995 (Roux, 1997). The purpose of this programme is the determination of the integrity or health of aquatic systems using biota. However, it must be pointed out that a distinction can be made between biotic integrity which represents comparison with near-natural conditions, and health which represents conditions desired by humans but not necessarily natural (Karr, 1996). The emphasis of this paper is on biotic integrity which has been defined as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a full range of elements (genes, species and assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of the region" (Karr, 1996).

Macro-invertebrates have for some time been used as indicators of the biological integrity of flowing waters in South Africa. The most recent in this respect is the SASS community index (South African Scoring System; Chutter, 1998). Fish received general attention with reference to the intolerance of certain species to particular environmental conditions in South Africa (i.e. Kleynhans et al., 1992) but attributes of fish communities were never integrated into an index context.

In the Okavango River of the neigbouring Namibia, attempts were initiated (Hocutt et al., 1993) to select metrics for the development of an index that approximates the North American Index of Biotic Integrity. Hay et al. (1996) carried this attempt further but included water quality characteristics in their index. This deviates from the typical approach, which only considers biological components in terms of their reaction towards perturbations but does not take into account the perturbations themselves.

The purpose of the South African initiative is to develop an index that can use readily available and measurable fish assemblage attributes that are responsive to human-induced environmental changes. The first effort in the development of a fish integrity index will concentrate on rivers. Following this, natural lakes, wetlands, estuaries and impoundments will receive attention. In this context the following objectives of the envisaged fish index were specified:

- The index must, in conjunction with other indices of biotic integrity, provide information to inform the South African public of the state of the nation's rivers on a regular basis.
- It must be usable within the limits of the available information, labour, expertise and financial resources.
- It must be structured in a fashion that allows easy adaptation (i.e. recalculation of historic index values) when information on fish assemblages improves.
- It should provide information and answers within the context and framework of the recent (1998) legislation on South African water resources. This legislation makes provision for

* To whom all correspondence should be addressed
☎ (012) 808-0374; fax (012) 808-0338; e-mail eeo@dwaf-hri.pwv.gov.za
Received 1 December 1998; accepted in revised form 30 April 1999.

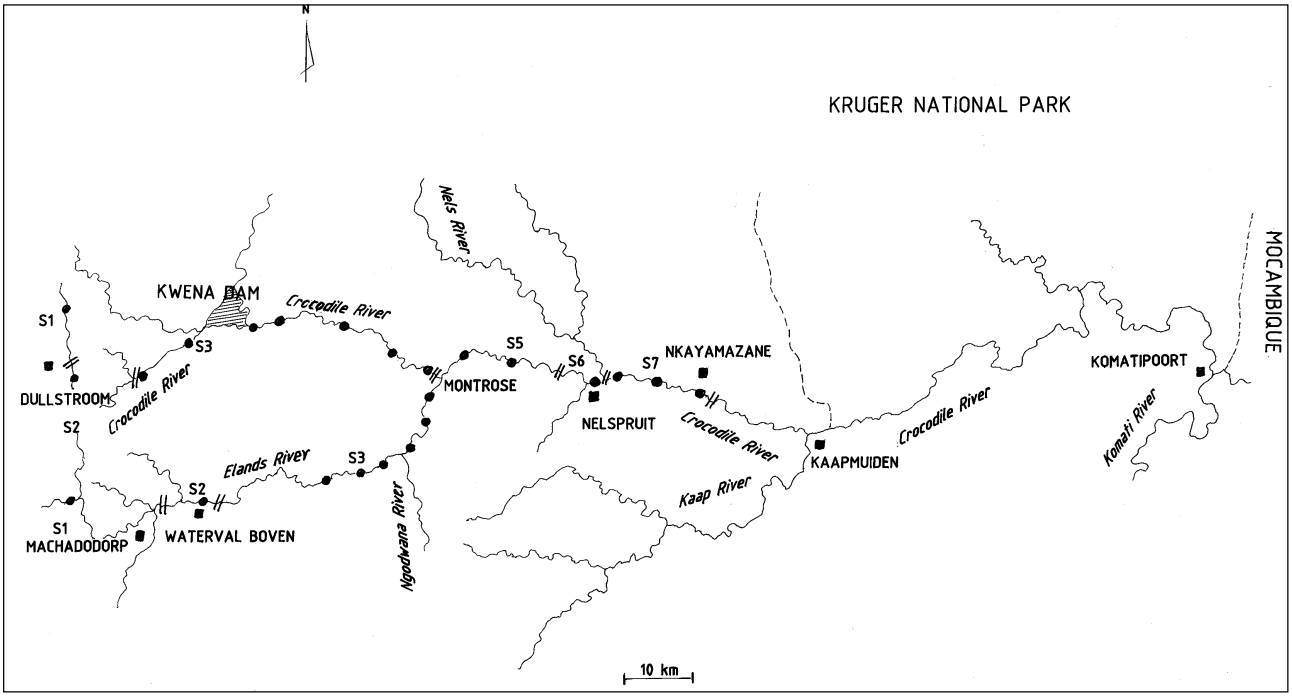

Figure 1

The Crocodile and Elands Rivers indicating sampling sites (•), segment numbers (S) and segment breaks (///)

the specification of the ecological requirements of the aquatic resource, the so-called ecological reserve. Monitoring of fish assemblages and interpretation of information by an index is regarded as one of the means by which the appropriateness of specified ecological requirements can be assessed.

- The index should be flexible enough to be useful in all the ecoregions of South Africa, i.e. the fundamental structure of the index should be generic and allow for the modification and adaptation of the index to make provision for specific environmental conditions.
- The index should be developed within a hierarchical framework. Different levels of monitoring intensity should be made provision for. At the early stage of the index development, the emphasis will be on an index that provides a synoptic assessment of the biotic integrity of rivers.

This paper reports on the development of a fish assemblage index using fish sampling information from a section of the Crocodile River, Mpumalanga Province, South Africa.

General description of study area

The Crocodile River rises at 2 150 m a.m.s.l. on the Steenkampsberg mountains in the Mpumalanga Province of South Africa. The river flows east through the Eastern Escarpment and mountainous plateau area before it enters the Lowveld close to the town of Nelspruit (600 m a.m.s.l.). After traversing the Lowveld it flows through the Lebombo mountains before entering Mocambique near Komatipoort (600 m a.m.s.l) (Fig. 1). The river has an approximate length of 320 km and drains a catchment area of 10 440 km^2.

The following broad topographic zones can be distinguished in the Crocodile River catchment:

- The Eastern Highveld Plateau with its eastern outliers. This zone ranges from 1 400 to >2 000 m a.m.s.l.
- The Middleveld ranging from 800 to 1 400 m a.m.s.l.
- The Escarpment generally situated along the Eastern Highveld and Middleveld.
- The Lowveld situated at an altitude <800 m a.m.s.l.

The rainfall pattern in the Crocodile River basin is related to the topography and varies from 1 200 mm in the mountainous areas to 600 mm per year in the eastern Lowveld. The mean annual precipitation is 880 mm, with 83% occurring from November to April.

The following main forms of land use occur in the catchment (DWAF, 1995):

- **Forestry** - the western half of the catchment, with annual rainfall >800 mm, has the largest number of exotic plantations. Some 1 722 km^2, or 16.5 % of the catchment is covered by exotic plantations.
- **Dryland agriculture** - these activities are located primarily in the central parts of the catchment and take the form of maize, subtropical fruits, nuts, citrus, coffee and vegetable cultivation.
- **Irrigated agriculture** - the primary crops grown include maize, citrus, tobacco, sugar- cane and subtropical fruits. About 91 000 ha of crops are irrigated with sugar-cane (21 000 ha) and citrus (20 000 ha) being the most important. The largest areas of irrigation are located in the central and eastern regions of the catchment.
- **Nature conservation** - the major area of nature conservation activity in the catchment occurs within the southern portion of the Kruger National Park.
- **Mining and quarrying** - the majority of mining activity has occurred along the Kaap River and to some degree in the lower Crocodile River.
- **Domestic and industrial land use** - the towns of Nelspruit and White River are the focus of domestic and industrial land use in the catchment, with smaller centres at strategic points across the catchment. A large paper mill is situated at Ngodwana next to the Elands River.

The Crocodile River and its tributaries have a marked seasonal and year-to-year variation in flow. Highest flows occur during the wet summer months and the lowest towards the end of the dry winter months. Year-to-year variations may display a 3- to 5-fold difference. The natural mean annual runoff (MAR) of the Elands River is 251 x 10^6 m^3, and that of the total Crocodile River 1 446 x 10^6 m^3 (DWAF, 1995).

The current land-use practices are estimated to have reduced the natural MAR by at least 20 %. Afforestation played a major role in this decrease. The hydrological characteristics of the river have been changed considerably by the construction and commissioning of the Kwena Dam (capacity = 167 x 10^6 m^3). Generally, water is released from the dam during the dry winter months to ensure that a minimum flow of 7 m^3/s reaches irrigation farmers along the Crocodile River in the Lowveld. During the drought in 1993, no water could be released for irrigation for several months. Apart from the Kwena Dam, another seven major dams occur in the catchment, while more than 200 small farm dams are also present (1981 estimates). Increased afforestation and abstraction for agricultural use have resulted in a marked decrease in winter flows from many tributaries, with low flows having been almost eliminated during winter months (DWAF, 1995).

The upper Crocodile River (i.e. upstream from the Crocodile-Elands confluence) and the Elands River have generally good quality water all year round. However, in the upper Crocodile and Elands Rivers, trout farming has been identified as a source of eutrophication while in the upper Elands, eutrophication due to sewage treatment plants also occur. Downstream in the Elands River, high electrical conductivity and chlorine concentrations occur due to the presence of a paper mill at the confluence with the Ngodwana River (Heath and Claassen, 1999).

In the middle sections of the Crocodile River water quality deterioration occurs during the winter months. In the section from Montrose to Nelspruit, exotic afforestation in the catchment of the Nels River causes an increase in manganese background values, an increase in sediment loads and a decrease in pH values during logging operations. Agricultural runoff here is related to increases in electrical conductivity, trace elements and nutrients. A large quarry at the confluence with the Gladdespruit is used as a dumping site and is a source of increased manganese concentrations in the Crocodile River. The section from Nelspruit to the confluence with the Kaap River is associated with domestic runoff, littering and an increase in nutrients. Industrial effluents from Nelspruit cause an increase in manganese and boron concentrations, while major sewage treatment works at the towns of Nelspruit, Matsulu and Nkayamazane are sources of high nutrient loads in the river. Exotic macrophyte (hyacinth, *Eichhornia crassipes*) infestation is common in parts of this section (Heath and Claassen, 1999).

The lower Crocodile River (downstream from the Kaap River confluence) has poor water quality due to agricultural runoff, which is associated with pesticides, increased trace elements, nutrients and electrical conductivity. Hyacinth infestation is very common in parts of this section and has been associated with sporadic fish mortalities (probably due to low dissolved oxygen concentrations). The Kaap River has a potential impact on the lower Crocodile River due to agricultural runoff (increases in pesticides, trace elements and nutrients). Mining activities in the Kaap have a high impact on water quality in this river during low flows (increases in sulphate, electrical conductivity, iron, zinc, arsenic and cyanide, and a decrease in pH) (Heath and Claassen, 1999).

In general, a progressive decrease in water quality occurs in the river with increasing distance downstream. Water quality requirements for the conservation of aquatic ecosystems are easily satisfied in the upper sections of most rivers in the catchment. The middle sections of the Crocodile River are subjected to discharges of treated industrial and domestic effluent, which have been associated with stress on the aquatic ecosystems. In the lower sections, increased sediment loads as well as elevated dissolved salt concentrations have also been associated with stressed aquatic ecosystems (DWAF, 1995).

The capacity of the Crocodile River in terms of its ability to cope with anthropogenic disturbances without suffering adverse effects is inversely related to the existing water quality and directly related to the volume of water available. Where very little water is available during the dry winter months, there is a corresponding decrease in capacity of the river (DWAF, 1995).

This paper concentrates on the Crocodile River from its source near Dullstroom, downstream to the town of Nkayamazane. The Elands River from its source to its confluence with the Crocodile River at Montrose is included.

Methods

Index of biotic integrity

During the last 10 to 15 years, the Index of Biotic Integrity (IBI) gained considerable popularity as a method for the assessment of the integrity of fish communities in the US (Karr and Dudley, 1981; Karr et al., 1986; Plafkin et al., 1989; Fausch et al., 1990) as well outside the US (Hughes and Oberdorff, 1999) in countries such as Canada (Steedman, 1988), Mexico (Lyons et al., 1995), France (Oberdorff and Hughes, 1992) and Namibia (Hay et al., 1996). A typical version of the IBI would include a total of 12 community attributes (metrics) that are compared to values expected for a relatively unperturbed stream of the same size in the same ecological region (Plafkin et al., 1989). Metrics are scored according to the uneven integers 5, 3, and 1 respectively, representing conditions that deviates slightly, moderately or strongly from situations at reference sites (Fausch et al., 1990). The total score of metrics is categorised according to professional judgement and a description provided of the compositional attributes of the fish community in each class. Usually total scores are presented directly, or may be expressed as a percentage of the maximum (Lyons et al., 1995). Simon and Lyons (1995) point out that the IBI is not a community analysis but rather an analysis of several hierarchical levels of biology that uses a sample of the assemblage.

The IBI has been criticised by Suter (1993) but with strong counter arguments for the use of the index being presented by Simon and Lyons (1995), Karr and Chu (1997) and Hughes et al. (1998).

Although the ecological principles on which the IBI is based are sound, its application in its original form as well as adapted versions for use in different regions in the Northern Hemisphere, present a number of problems when considered for use in South African situations at this stage:

- Several of the metrics of the IBI require detailed historical and ecological information that is often not available. Metrics requiring proportionality are a particular problem as little pre-impact information on this is usually available. Similarly, Lyons et al. (1995) developed a preliminary IBI for streams in west central Mexico but expressed concerns on the scarcity of fish community data.
- The IBI as applied by certain environmental management organisations in the US obviously represents a very large

investment in equipment (special equipment being designed for unique situations), financial resources and in a sufficiently large and trained workforce (Ohio EPA, 1987).
- The north-eastern parts of the country represent environmental conditions which often make it dangerous (i.e. the presence of crocodiles, hippos, etc.) to do intensive sampling such as used in many regions of the US.
- In the US, it was found that in prairie streams, the IBI did not indicate a degradation of biotic integrity following the intensive testing of armoured vehicles. Fishes in that study were hardy and naturally adapted to droughts and flash floods. Their presence and the structure of the community depend on their rate of colonisation rather than habitat changes (Bramblett and Fausch, 1991). A similar situation can be expected in many South African rivers due to their high variability with regard to environmental conditions associated with the variability and unpredictability of rainfall and runoff within seasons and between years. Many South African rivers can be expected to have a naturally high disturbance regime to which the biota are adapted. Several anthropogenic changes may actually mimic these natural disturbance regimes.

Following their work on the Kavango River, Namibia, Hocutt et al. (1993) came to similar conclusions and remarked that in the case of "information poor" situations such as are often found in Africa, it may be useful to have another look at more traditional approaches of assessing biological communities. One of the approaches mentioned was the Jaccard similarity coefficient. This index involves the observed number of species and the number expected (i.e., either based on historical information, between sites in the same region or in comparison with a reference site). In this regard, Ramm (1988) did develop his community degradation index (CDI) based on the principles of the Jaccard similarity index. However, he did not include ecological aspects (i.e. trophic specialisation, habitat specialisation and intolerance) in the CDI and considered abundance information unsuitable. The CDI is also formulated based on information theory.

The conclusion of Steedman (1988) that an approach based on species lists from which species richness and local indicator species can be obtained, can probably provide most key information for IBI analysis, was important in the decision to develop an alternative fish integrity index for South Africa.

The current approach

Fish habitat segments

Based on the above-mentioned considerations and the required synoptic nature of the index envisaged for South Africa, it was decided to develop the index based on the concept of the so-called biological segment which has been described as "… a portion of a stream in which the fish community remains generally homogeneous due to the relative uniform nature of the physical habitat" (Ramm, 1988). Biological segments are comparable to geomorphic segments which are defined as a portion of a stream flowing through a single bedrock type and bounded by tributary junctions or major waterfalls (Frissel et al., 1986). However, ecological aspects such as water temperature, water quality and available habitats also play an important role in determining the distribution and abundance of a fish species in a segment. The boundaries of a biological segment can be expected to vary according to the temporal and spatial variability (natural and human-induced) of environmental conditions in a segment. In the situation dealt with in this investigation, it was decided to refer specifically to fish habitat segments.

The purpose of defining fish habitat segments are to provide a basis that can be used to specify reference biological conditions in such segments with regard to the indigenous fish species that can be expected to occur, their frequency of occurrence and general health and well-being. In addition, it is potentially possible to define reference habitat conditions that can be expected to occur at a broad level.

For the current study, the following approach was followed in the identification and delineation of fish habitat segments:

- Maps (1:250 000 and 1:50 000) and personal knowledge of the river were utilised to divide the river into segments with relatively homogeneous physical habitats. Breaks between segments were often evident in the form of waterfalls, gorges, dominant substrate types and dominance of features such as pools, bedrock rapids and riffle areas. The approximate altitude of such breaks was also recorded.
- Available distribution records for fish species were collated according to sampling localities and took into account a provincial fish database (1950s to 1990s), as well as Gaigher (1969), Kleynhans (1984) and Kleynhans et al. (1992). This information was grouped according to the identified river sections and provided an estimation of fish habitat segments. Some fish species have obvious gaps in their distribution range over the length of the river and a certain degree of "patching" was applied in order to arrive at a realistic view of their "natural" distribution pattern. Eels (*Anguilla* spp.), for instance, migrate upstream in rivers from the sea when young and gaps in their distribution between the farthest upstream and downstream points where recorded, were accepted as reflecting insufficient sampling.

Although it cannot be claimed with total certainty that the final fish habitat segments represent the natural situation (i.e. before any development and disturbances occurred), it is surmised that this portrays at least a reasonable reconstruction of natural fish distribution patterns on a segment basis.

The fish assemblage integrity index (FAII)

The FAII aims to measure the biological integrity of a river as based on the attributes of the fish assemblages native to the river. Alien species (introduced indigenous and exotic species) are not included as metrics in the FAII. Their presence and distribution are noted but interpreted as possible causes for a decline in the FAII score.

The fish assemblage integrity index takes into account three aspects of a fish assemblage:

- The relative intolerance of the indigenous fish species expected to occur in every segment was estimated. Intolerance in this context refers to the degree to which a species is able to withstand changes in the environmental conditions under which it occurs. This includes modification of physical habitat characteristics (flow velocity, marginal vegetation, depth, bottom substrate, etc.), as well as chemical characteristics of the water habitat. Habitat and food preferences provide a large amount of information, which is useful in determining the degree to which a species can be regarded as tolerant, moderately intolerant and intolerant. Experimental information on the intolerance of various South African fish species is, however, largely lacking and the assessment of the degree to which species are tolerant or intolerant usually has to be based on field observations.

Four components were taken into account in estimating the intolerance of fish species, viz. habitat preferences and specialisation, food preferences and specialisation, requirement for flowing water during different life stages and association with habitats with unmodified water quality. Each of these aspects were scored for a species according to low requirement/ specialisation (rating = 1), moderate requirement/specialisation (rating = 3) and high requirement/ specialisation (rating = 5). The mean of these ratings for a species was calculated to obtain an intolerance score that can lie between 1 (tolerant) and 5 (intolerant). A mean value of about 3 would indicate moderate intolerance. Apart from personal experience, the work of Crass (1964), Gaigher (1969), Pienaar (1978), Kleynhans (1984), Bell-Cross and Minshull (1988), Skelton (1993), Russell and Rogers (1998) and Weeks et al. (1996) was utilised in intolerance estimations.

Only the mean intolerance ratings for species are provided in this paper.

- Abundance was not included as a metric in the index due to the difficulty in obtaining quantitative information on this. However, Johnson (1967) found that fish species that are the most frequently present in a certain habitat type, also tend to be the most common in habitats where they are found. Therefore, the frequency of occurrence of a species (i.e. the number of sampling sites in a segment or habitats at a site it occurs at as a ratio of respectively the total number of sites sampled in a fish habitat segment or specific habitats sampled at a site) were considered to be a useful metric on its own as well as a surrogate for abundance. For each species expected to be present in a fish habitat segment, the expected frequency of occurrence was estimated and the observed frequency of occurrence calculated:

  occurrence at <34% of sites in a segment, score = 1 (infrequent occurrence),
  occurrence at 34 to 67% of sites in a segment, score = 3 (frequent occurrence)
  occurrence at >67% of sites in a segment, score = 5 (widespread occurrence).

  The expected frequency of a species may differ from segment to segment and site to site within a segment due to differences in habitat availability and suitability. Where only one site was sampled in a segment, frequency of occurrence was not considered in the calculation of the index. Only intolerance ratings and health of species present were considered in such situations.

  The historic fish database for the river and professional judgment was used to estimate the expected frequency of occurrence of species per fish habitat segments.
- The rating of general health and well-being presented problems in the sense that few data exist that can be used to determine expected or reference conditions. Consequently, guidelines used in the application of the IBI in North America were followed (Fausch et al., 1990). The percentage of fish with externally evident disease or other anomalies was used in the scoring of this metric. Parasite infestation was noted but not used in this assessment due to the lack of correlation between parasite burden and environmental quality (Simon and Lyons, 1995). The following procedure was followed to score the health of individual species at a site:

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

  This approach is based on the principle that even under unimpaired conditions, a small percentage of individuals can be expected to exhibit some anomalies.

Fish habitats and fish sampling

Habitats were categorised according to flow-depth classes adapted from Oswood and Barber (1982):

- **Slow (<0.3 m/s), shallow (<0.5 m)**: This includes shallow pools and backwaters. A small seine net (5 m long, 1.5 m deep, mesh size = 1 mm) was used to sample fish. In some instances, an electrical shocking apparatus (AC) was used. Capture results were recorded as number of fish caught during each effort with a net, or the number of fish caught per time unit (minutes) with an electroshocker.
- **Slow (<0.3 m/s), deep (>0.5 m)**: This includes deep pools and backwaters. A large seine net (70 m long, 1.5 m deep, mesh size 2.5 cm) was used. A cast net (diameter = 1.85 m, mesh size = 2.5 cm) was used in pools not suitable for beach seining. Capture results were recorded as number of fish caught during each effort.
- **Fast (>0.3 m/s), shallow (<0.3 m)**: Shallow runs, rapids and riffles fall in this category. An electrical shocking apparatus was used in these habitat types. Capture results were recorded as number of fish caught per time unit (minutes).
- **Fast (>0.3 m/s), deep (>0.3 m)**: Deep runs, rapids and riffles fall under this category. An electrical shocking apparatus was used in these habitat types. Capture results were recorded as number of fish caught per time unit (minutes).

For each flow-depth class, the presence of features that provide cover for fish (i.e. refuge from high flow velocity, predators, high temperatures, etc.) was taken into consideration. Information on the general habitat and cover preferences of fish species was obtained from the available literature (Crass, 1964; Gaigher, 1969; Pienaar, 1978; Kleynhans, 1984; Bell-Cross and Minshull, 1988; Skelton, 1993; Russell and Rogers, 1998; Weeks et al., 1996) and personal experience. The following features were taken into consideration:

- Overhanging vegetation - thick vegetation overhanging water by approximately 0.3 m and not more than 0.1 m above the water surface (Wang et al., 1996). Marginal vegetation is included here.
- Undercut banks and root wads - banks overhanging water by approximately 0.3 m and not more than 0.1 m above the water surface (Wang et al., 1996).
- Stream substrate - various substrate components (rocks, boulders, cobbles, gravel, sand, fine sediment and woody debris "snags") that provide cover for fish.
- Aquatic macrophytes - submerged and emergent water plants were included.

Calculation of the FAII score

Fundamentally, the FAII consists of the calculation of an expected value, which serves as the baseline or reference, the calculation of an observed value and the comparison of the expected and observed scores which provides a relative FAII score.

The expected FAII rating for a fish habitat segment is calculated as follows:

FAII value (exp) = $\sum$ IT x ((F + H)/2)

where:

Exp = Expected for a fish habitat segment
IT = Intolerance rating for individual species expected to be present in a fish habitat segment and in habitats that were sampled
F = Expected frequency of occurrence rating for individual species expected to be present in a fish habitat segment and at sites that were sampled
H = Expected health rating for species expected to be present.

The observed situation is represented by:

FAII value (obs) = $\sum$ IT x ((F + H)/2)

where:

Obs = Observed for a fish habitat segment

The relative FAII score is calculated by:

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

TABLE 1
FAII ASSESSMENT CLASSES

Class rating	Description of generally expected conditions for integrity classes	Relative FAII score (% of expected)
A	Unmodified, or approximate natural conditions closely.	90 to 100
B	Largely natural with few modifications. A change in community characteristics may have taken place but species richness and presence of intolerant species indicate little modification.	80 to 89
C	Moderately modified. A lower than expected species richness and presence of most intolerant species. Some impairment of health may be evident at the lower limit of this class.	60 to 79
D	Largely modified. A clearly lower than expected species richness and absence or much lowered presence of intolerant and moderately intolerant species. Impairment of health may become more evident at the lower limit of this class.	40 to 59
E	Seriously modified. A strikingly lower than expected species richness and general absence of intolerant and moderately intolerant species. Impairment of health may become very evident.	20 to 39
F	Critically modified. An extremely lowered species richness and an absence of intolerant and moderately intolerant species. Only tolerant species may be present with a complete loss of species at the lower limit of the class. Impairment of health generally very evident.	0 to 19

Representativeness of the FAII score

The representativeness of the FAII is dependent on the sampling efficiency, the sampling of habitats in proportion to their presence at a site, and the degree to which the selected sampling sites are representative of a fish habitat segment.

Regarding sampling efficiency, the problems of attaining quantitative fish samples in rivers were pointed out by Hendricks et al. (1980). Within the context of the requirement for a rapid biotic integrity assessment procedure, the overall aim was to obtain a representative qualitative sample of the species present at a site (Hocutt, 1981). However, in several instances it was only possible to sample certain of the habitat types present at a site. It is unlikely, therefore, that all species potentially present at a site were actually caught.

Interpretation framework of the FAII score

Interpretation of IBI scores often follow a descriptive procedure in which the IBI score is classified into a particular class, labelled from excellent to very poor (i.e. Karr et al., 1986). A comparable approach was followed with the interpretation of relative FAII scores by basing this on the habitat integrity classes of Kleynhans (1996) (Table 1). The description of classes is of a more generic nature than that of Karr et al. (1986). A more detailed descriptive assessment of FAII classes will depend on the fish community characteristics of specific fish habitat segments.

Results and discussion

Fish habitat segments

From its source to the town of Nkayamazane, a total of seven fish habitat segments were distinguished in the Crocodile River. Three segments were discernible in the Elands River (Fig. 1 and Table 2). Under minimally impaired conditions, a total of 26 native fish species is expected to occur in these segments. A gradual increase in species richness is evident with a decrease in altitude (Table 3). The natural characteristics of fish habitat segments have been variously modified by agricultural, silvicultural, industrial, recreational and urban development (Table 4).

Fish sampling results

During the survey in September and October 1996, flows downstream from the Kwena Dam in the Crocodile River were higher than expected due to releases for irrigation. In addition, the Crocodile River had a high baseflow due to higher than normal rainfall that occurred during 1995/6. This resulted in several sites not being suitable for sampling. Sampling sites (Table 5) were mainly selected based on accessibility and availability of historical fish sampling information. At the majority of sites sampled, electroshocking in fast-flowing water was found to be the most suitable sampling technique.

The number of indigenous species expected in fish habitat segments of the Crocodile River varied from 1 to 20, while the number actually caught ranged from 1 to 13. In the Elands River the 3 to 8 species expected in the 3 segments were respectively caught (Table 3).

TABLE 2
GENERAL CHARACTERISTIC OF FISH HABITAT SEGMENTS IN THE CROCODILE AND ELANDS RIVERS

Fish habitat segments	Altitude (m a.m.s.l.)	General characteristics
Crocodile River		
1	>2 000	1-2 m wide. Small rocky pools with riffles; steep slope.
2	2 000-1 400	5-10 m wide. Rocky pools and runs with occasional riffles and rapids and some small waterfalls; steep slope; downstream boundary formed by a high (>50 m) waterfall.
3	1 400-1 200	10-15 m wide. Rocky pools, runs and small pools with occasional riffles; steep slope.
4	1 200-800	15-20 m wide. Large rocky pools interspersed abundantly with riffles and rapids; steep slope; large sections flow through a relatively narrow valley. Downstream boundary formed by a waterfall (Montrose).
5	800-650	20-30 m wide. Large rocky pools and runs with occasional rapids; riffles rare; moderate slope.
6	650-600	20-30 m wide. Large rocky pools and runs with occasional rapids; riffles rare; moderate slope. Downstream boundary formed by a waterfall.
7	600-500	30-40 m wide. Large rocky pools and runs with occasional rapids; riffles very rare; moderate slope.
Elands River		
1	>1 500	1-2 m wide. Small pools with occasional riffles. Moderate slope
2	1 500-1 200	15-20 m wide (mainstream). Large rocky pools with riffles and rapids. Downstream boundary formed by high waterfall. Steep slope.
3	1 200-800	15-20 m wide. Large rocky pools with abundant riffles and rapids. Downstream boundary formed by small waterfalls. Slope mostly steep.

Fish health ratings

Less than 2% of the fish caught had any indication of anomalies. Consequently, all fish were considered to be in good health. Anomalies that were observed were parasitic infections such as black spot and white spot.

Relative FAII score per segment

In the Crocodile River a general decrease in the relative FAII score per fish habitat segment was observed in a downstream direction, while the relative FAII per segment remained consistently high in the Elands River (Table 3).

Crocodile River: Segment 1

The one site sampled in the Crocodile River on the Verloren Vallei Nature Reserve, contained only *Barbus anoplus* and the relative FAII score was rated as Class A (unmodified, or approximates natural conditions closely). Other streams in this area are known to contain only exotic rainbow trout *Oncorhynchus mykiss* which may have exterminated *B. anoplus*. Nevertheless, rainbow trout, although a predaceous exotic, is considered an intolerant species due to its water quality requirements and preference for cool, clear water (Plafkin et al. 1989). Its presence is, therefore, generally indicative of good water quality and suitable cover in fast-flowing water.

Crocodile River: Segment 2

The one site sampled here contained *B. anoplus*. This site is within a popular trout angling area and although the relative FAII score was rated as Class A, only low numbers of *B. anoplus* were caught. This may be the result of predation by rainbow trout.

Crocodile River: Segment 3

Four of the six species expected were caught and the segment was rated as Class C (moderately modified) but very close to a Class B (79.6%). However, it must be emphasised that although *Anguilla mossambica* and *Amphilius uranoscopus* have not been recorded in this segment, their presence cannot be ruled out completely. The extent to which the distribution of these species has been influenced by the Kwena Dam is uncertain, but they do occur downstream from the dam.

Rainbow trout do occur in the upper part of this segment, but based on the presence and abundance of indigenous species, evidently do not have a major detrimental effect. The absence of *Barbus argenteus* in the catch may, however, be related to the presence of rainbow trout. The two species have very similar habitat preferences and *B. argenteus* is known to be "troublesome" in trout streams as it readily takes artificial flies (Le Roux and Steyn, 1968). The presence of rainbow trout is considered to be indicative of good water quality and cool, clear water with suitable cover, while both *Amphilius natalensis* and *C. pretoriae* are species dependent on flowing-water habitats and have a preference for substrate cover. They are also associated with good water quality.

Chiloglanis bifurcus was sampled in this segment during 1978 (Kleynhans, 1984) but not in 1996. However, a single specimen was again caught in 1998 (Roux, 1998). If *C. bifurcus* is not considered the integrity increase to Class B (largely natural). Only two sites were sampled in this segment.

Exotic largemouth bass, *Micropterus salmoides*, exotic carp, *Cyprinus carpio* and sharptooth catfish, *Clarias gariepinus*, (indigenous but introduced to this part of the system) have been released

TABLE 3
FISH SPECIES EXPECTED TO BE PRESENT IN FISH HABITAT SEGMENTS 1 TO 7 OF THE CROCODILE RIVER, 1 TO 3 OF THE ELANDS RIVER UNDER MINIMALLY IMPAIRED CONDITIONS, AND AS WAS OBSERVED DURING THE 1996 SURVEY. PRESENCE INDICATED AS FREQUENCY OF OCCURRENCE RATINGS*

Species	Intolerance rating	Crocodile River fish habitat segments							Elands River fish habitat segments		
		Frequency of occurrence ratings									
		1	2	3	4	5	6	7	1	2	3
Anguillidae											
Anguilla bengalensis	3							1 (0)			
A. mossambica	3				5 (5)	3 (0)	+(0)	3 (1)			5 (3)
Amphiliidae											
Amphilius uranoscopus	5				5 (5)	3 (3)		1 (0)		+(+)	5 (5)
A. natalensis	5			5 (5)							
Cyprinidae											
Barbus anoplus	2.5	+(+)	+(+)	1 (1)	1 (0)				+(+)	+(+)	1 (1)
B. argenteus	4.5			3 (0)	1 (1)	1 (0)	+(+)	1 (0)			5 (5)
B. eutaenia	4.5							3 (3)			
B. marequensis	1.5					5 (5)	+(+)	5 (5)			
B. neefi	2.5			5 (5)							
B. pallidus	2.5				3 (3)						
B. polylepis	2.5					1 (0)	+(0)				1 (1)
B. trimaculatus	2						+(+)	5 (1)			
B. unitaeniatus	2							5 (0)			
B. viviparus	3							1 (0)			
Labeo cylindricus	3.5						+(0)	5 (1)			
L. molybdinus	3.5						+(+)	5 (3)			
Mesobola brevianalis	3.5							3 (0)			
Opsaridium peringueyi	4.5							3 (3)			
Mochokidae											
Chiloglanis pretoriae	5			5 (5)	5 (5)	5 (5)	+(+)	5 (5)			5 (5)
C. bifurcus	5			1 (0)	5 (5)	5 (5)					5 (1)
Clariidae											
Clarias gariepinus	1.5					3 (3)	+(+)	5 (3)			
Mormyridae											
Marcusenius macrolepidotus	2.5							3 (3)			
Cichlidae											
Oreochromis mossambicus	1					1 (0)	+(0)	5 (1)			
Pseudocrenilabrus philander	1				5 (5)	3 (3)	+(+)	3 (5)	+(+)		
Tilapia rendalli	1							3 (0)			
T. sparrmanii	1				1 (0)	3 (3)	+(+)	3 (3)	+(+)	+(+)	5(5)
Species richness per segment		1 (1)	1 (1)	6(4)	9 (7)	11 (7)	12 (8)	20 (13)	3 (3)	3 (3)	8 (8)
Number of sites sampled		1	1	2	5	2	1	3	1	1	6
Relative FAII score (%)		100	100	79.6	88.0	71.8	66.7	60.8	100	100	91.6
Integrity class rating		A	A	C	B	C	C	C	A	A	A

Observed frequency of occurrence indicated in parenthesis. *: 1 - present at <34% of sites; 3 - present at 34 - 67 % of sites; 5 - present at > 67% of sites; + - insufficient information to estimate frequency of occurrence

TABLE 4
SUMMARISED DESCRIPTION OF MODIFICATIONS RELATED TO THE DEGRADATION OF FISH HABITAT INTEGRITY IN FISH HABITAT SEGMENTS OF THE CROCODILE AND ELANDS RIVERS

Fish habitat segments	Altitude (m a.m.s.l.)	Description of modifications
		Crocodile River
1	>2 000	No modifications in Crocodile River (Verloren Vallei Nature Reserve); some inundation (small weirs) in parts of Lunsklip River.
2	2 000-1 400	Encroachment by exotic riparian vegetation along upper part. Some inundation (weirs) and development (angling resorts) in upper part (Dullstroom). Runoff reduced by exotic plantations.
3	1 400-1 200	Cultivated lands in sections (water abstraction), grazing (some erosion), and exotic riparian vegetation common in clumps along banks. Lower section inundated by Kwena Dam.
4	1 200-800	Cultivated lands in sections (water abstraction). Intensive flow regulation by Kwena Dam during drought years in particular. Exotic riparian vegetation encroachment in areas. Runoff reduced by exotic plantations in sections.
5	800-650	Cultivated lands common along several sections (water abstraction). Flow regulation by Kwena Dam - probably somewhat alleviated by Elands River. Exotic riparian vegetation encroachment in areas. Some inundation by weirs.
6	650-600	Cultivated lands common (water abstraction), as well as fruit processing. Flow regulation by Kwena Dam. Water hyacinth (*Eichhornia crassipes*) common during most years.* Exotic riparian vegetation encroachment in some sections.
7	600-500	Cultivated lands common along some sections (water abstraction). Weirs in some parts. Removal of bank vegetation in sections. Some erosion in sections. Runoff from urban areas and industries (e.g. Nelspruit). Flow regulation by Kwena Dam - somewhat dampened by Nels River. Water hyacinth common during most years.
		Elands River
1	>1 500	Grazing present in most areas. Exotic riparian vegetation encroachment in several sections. Small weirs present. Cultivated lands along some sections.
2	1 500-1 200	Grazing in most areas. Some cultivated lands, and some abstraction for urban areas (Machadodorp and Waterval Boven). Weirs in some sections. Exotic riparian vegetation encroachment along several areas.
3	1 200-800	Exotic riparian vegetation encroachment very common along most sections. Cultivated lands common along some parts. Water abstraction also from Ngodwana tributary (paper mill). Runoff also reduced by large exotic plantations.

*: Water hyacinth was not assessed based on its historic degree of infestation.

into the Kwena Dam (Kleynhans, 1988). These species which generally prefer standing or slow flowing water, were not recorded during the current survey and do not appear to pose a threat to the indigenous species of the riverine part of this segment.

Crocodile River: Segment 4

Seven of the nine species expected to be present were actually caught at the five sites sampled. *Barbus anoplus* and *Tilapia sparrmanii* were not found during the current survey. Both are expected to be present in low numbers and to have a low frequency of occurrence in this segment. Consequently, this segment was still rated as Class B (largely natural). The presence of intolerant species (i.e. *A. uranoscopus, C. bifurcus* and *C. pretoriae*) lends credibility to this rating. However, the low numbers or absence of species preferring slow-flowing habitats (i.e. *B. anoplus, Pseudocrenilabrus philander* and *T. sparrmanii*) may indicate the impact of the flow regulatory effect of the Kwena Dam during the survey when high flows were released prior to the start of the rain season. Sampling at most sites was hampered due to these high flows.

During droughts and prolonged low-flow periods created by the regulation of the Kwena Dam, it has been demonstrated that species not naturally present in this segment of the river (*Kneria*

TABLE 5
HABITATS SAMPLED AND COVER TYPES AVAILABLE AT SITES IN THE CROCODILE AND ELANDS RIVERS

	Habitats															
	Slow deep				Slow shallow				Fast deep				Fast shallow			
	OV	UB	SS	AM	OV	UB	SS	AM	OV	UB	SS	AM	OV	UB	SS	AM
Crocodile River (m a.m.s.l.)																
Segment 1 (2 000 - 2 200)																
Site 1					+			+								
Segment 2 (1 400 - 2 000)																
Site 1	+															
Segment 3 (1 200 - 1 400)																
Site 1					+	+	+						+		+	
Site 2													+		+	
Segment 4 (800 - 1 200)																
Site 1									+	+	+					
Site 2									+	+	+					
Site 3									+	+	+					
Site 4									+	+	+					
Site 5	+	+	+						+		+				+	
Segment 5 (650 - 800)																
Site 1	+	+	+	+					+	+	+	+				
Site 2	+	+	+						+	+	+	+				
Segment 6 (600 -650)																
Site 1	+	+	+										+	+	+	
Segment 7 (500 - 600)																
Site 1	+	+	+		+	+	+				+		+	+	+	
Site 2	+		+						+		+		+		+	
Site 3					+		+		+		+		+		+	
Elands River (m a.m.s.l.)																
Segment 1 (>1 500)																
Site 1					+	+	+						+	+	+	
Segment 2 (1 200 - 1 500)																
Site 1	+	+	+						+	+	+		+	+	+	
Segment 3 (800 - 1 200)																
Site 1	+	+	+						+		+		+		+	
Site 2	+	+	+						+	+	+		+	+	+	
Site 3	+	+	+						+	+	+					
Site 4	+	+	+						+	+	+		+	+	+	
Site 5	+	+	+						+	+	+		+	+	+	
Site 6		+	+						+		+		+		+	

OV: Overhanging vegetation,
UB: Undercut banks and rootwads
SS: Substrate
AM: Aquatic macrophytes

auriculata and *A. natalensis*) enter the Crocodile River from small tributaries, thereby increasing the species richness for a short distance downstream from the dam wall (Kleynhans, 1988). At this stage, it is not yet clear to what extent flow regulation will influence the fish community of this segment in the long term.

Crocodile River: Segment 5

As in Segment 4, sampling in Segment 5 was also hampered by the release of water from Kwena Dam with only the electro-shocker and a cast net employed. Sampling was limited to two sites only. Nevertheless, of the eleven species expected, seven were caught. Three of these are intolerant species with a preference for fast flowing water (*A. uranoscopus, C. bifurcus* and *C. pretoriae*) and their presence made a major contribution to this segment being rated as Class C (moderately modified) despite the absence of four species in the catch. Based on the flow conditions prevailing during the survey, this rating should be regarded as a minimum. If for instance, the tolerant *O. mossambicus* and moderately tolerant *B. polylepis* are not taken into account in the calculation of the index, the integrity increases to Class B (largely natural).

This segment was subject to a large spill from a paper mill in the Elands River in 1989 (Kleynhans et al., 1992). The presence of intolerant species does indicate a considerable degree of recovery since 1989.

Crocodile River: Segment 6

Although it has a fish community very similar to Segment 5, species such as *Labeo cylindricus, L. molybdinus* and *B. trimaculatus* make their appearance in Segment 6. There is some uncertainty regarding the possible historic (pre-development) presence of *C. bifurcus* in Segment 6. It is known to be present in the middle parts of the Gladdespruit tributary (Appleton, 1974; Kleynhans, 1984) which joins the Crocodile River here, but has never been recorded in the Crocodile itself in this area. A large weir (Mataffin) situated a small distance downstream from the Crocodile River confluence with the Gladdespruit, cause inundation here and together with urban and industrial pollution originating from Nelspruit, may have led to the disappearance of *C. bifurcus*.

The Mataffin Weir somewhat moderated the flow releases from the Kwena Dam during the survey and it was possible to sample more effectively than in Segment 5. Twelve species were expected in this Segment, eight of which were captured. Sampling success in the weir impoundment was poor but downstream the presence of the intolerant *C. pretoriae* indicates suitable riffle habitat and water quality conditions during the survey. It must be emphasised, however, that the relatively high abundance of *C. pretoriae* in this segment is partly due to good cover provided by a riffle created by cobbles and rubble apparently related to the construction of the weir. This segment is characterised by bedrock rapids rather than riffles.

The exotic species that have been recorded in this segment previously, carp (*Cyprinus carpio*) and swordtail (*Xiphophorus helleri*) (Kleynhans et al., 1992), were not caught during the current survey. Carp is considered to be tolerant and is known for its substrate disturbing feeding habits, while the swordtail is also tolerant and may prey on fish larvae and damage indigenous fish populations (Skelton, 1993). Carp is notoriously difficult to catch with most sampling methods, while the absence of swordtail may be related to low population numbers following the floods during 1996.

Although the relative FAII score for this segment is lower than for Segment 5, it still falls within the limits of Class C (moderately modified). As this assessment is based on one site only, this rating must be considered as preliminary.

Crocodile River: Segment 7

Of the 20 species expected in this segment, 13 were captured. These included the intolerant *Barbus eutaenia, C. pretoriae* and *Opsaridium peringueyi*. The absence or low abundance of some tolerant species (e.g. *Barbus unitaeniatus, Oreochromis mossambicus* and *Tilapia rendalli*) is most likely related to the strong flows that occurred and which made the sampling of deep runs in the mainstream of the river, in particular, very difficult. However, the relative FAII score still places this segment marginally in Class C (moderately modified). Under more suitable sampling conditions a somewhat higher relative score (but still in Class C) would not be unreasonable to expect.

This segment was also influenced by the paper mill effluent spill in the Elands River in 1989 (Kleynhans et al., 1992) while prior to the 1996 floods, the stream substrate just downstream from Nelspruit was covered by a black manganese containing deposit, presumably related to the operations of a manganese processing factory (Thirion, 1996). During the survey, however, the stream substrate was clean.

Exotic carp and swordtail are known to occur here but were not caught during the survey.

Elands River: Segment 1

All three species expected in the upper source stream of the Elands River were caught which resulted in a relative FAII rating of Class A (unmodified, or approximates natural conditions closely). Juvenile rainbow trout present at this site were probably stocked for angling purposes and at this stage do not appear to exert any influence on the native fish species.

Elands River: Segment 2

All three species expected for the Elands River were captured, resulting in a relative FAII rating of Class A. Rainbow trout were also captured here but evidently do not have a major detrimental effect on the indigenous species. This intolerant exotic and the presence of the flow and high water quality dependent *A. uranoscopus* indicate that instream habitats are in a good condition.

Elands River: Segment 3

Six sites were sampled in this segment and all eight species expected to be present were caught. This contributed largely to the relative FAII rating of Class A (unmodified, or approximates the natural condition). Rainbow trout occur in the upper parts of this segment, while juvenile largemouth bass and sharptooth catfish (*C. gariepinus*; indigenous but artificially introduced into the Elands River) have been recorded in the middle parts in the past (Kleynhans et al., 1992). Apparently, these introduced species do not have a large impact on the indigenous species of the segment. More intensive monitoring is required, however, to assess their impact properly.

During 1989, a large paper mill effluent spill occurred in this segment at the confluence of the Elands and Ngodwana Rivers. This caused massive fish mortalities in this part of the river (Kleynhans et al., 1992). An attempt was made to assess the degree of recovery of the river since 1989 by comparing the relative FAII of the three sites upstream from the paper mill (1 200 - 900 m a.m.s.l.) with three sites downstream from the mill (900 - 800 m a.m.s.l.). As high flows due to local rainfall made the pools in the upper section of this segment difficult to sample, only results from electroshocker efforts in riffles and rapids were taken into account. This indicated a relative FAII rating of Class A for both sections of this segment. The presence and commonness of *B. argenteus, A. uranoscopus, C. bifurcus* and *C. pretoriae* in the 900 - 800 m

a.m.s.l. section, is a good indication that the water quality and habitat conditions in fast flowing habitats have improved considerably since 1989.

Conclusions

The integrity of the Crocodile River

The current investigation was complicated by floods and high flows that occurred in the river during 1996. This evidently reset habitat conditions in the river to be comparable to near natural conditions, e.g. excessive accumulation of sediment was washed away, water hyacinth was dramatically reduced in abundance and low-flow and flow-regulation associated problems (water quality and physical habitat) were largely reduced. Although physical fish habitat conditions were in prime condition, the fish species in the different segments of the river were, to different degrees, probably still adapting to these improved environmental conditions. Thus, fish communities of the river as observed during this survey, must be regarded as a complicated result of pre-flood, flood and post-flood, high-flow conditions and do not reflect the current habitat conditions completely. If these improved conditions last long enough, the fish communities should be able to re-establish themselves to be close to natural conditions. However, the main driving forces that can cause problems still remain and will exert their impact again when demands put on the river by development increase and droughts and low flows recur.

Although the river has been developed and has been impacted by various activities (e.g. water quality, flow regulation, invasion by water hyacinth), intolerant species were to various degrees still present in all of the segments. Even some intolerant species not found in certain segments, have the potential to recover in such segments by re-colonisation from neighbouring segments. In total then, refugia are still present and the fish communities have the potential to recover substantially if favourable conditions occur for long enough.

The fish assemblage integrity index

Currently the FAII only provides an indication of the overall biological integrity in segments of a river. This information is suitable for a synoptic level of assessment. However, the following realities must be emphasised and represent areas that require further research:

- The FAII is probably in most cases an under-estimation of the biological integrity of a segment. This can be ascribed to the expected list of species being compiled based on historical presence in all habitat types in a segment. This list represents the maximum number of species that can be expected. Due to time, labour and equipment limitations, only some habitats were sampled during the survey. The results of such sampling efforts were considered to represent the observed situation. This is obviously an approximation of the real situation and it follows that it would be more realistic to base the expected situation on the species expected in a segment as well as the habitats that are actually sampled. The requirement for this approach would be that at least the general habitat preferences of fish with regard to flow, depth and cover type is known. Although mostly not based on experimental information, most references on South African fish do provide a broad indication on habitat preferences. This information can be supplemented by mobilising the knowledge and experience of experts on local fish assemblages in a structured fashion. This will make improved interpretation of the FAII possible.
- The FAII is based on an assessment of the attributes of native fish assemblages and is therefore directly related to the measurement of the ecological integrity of a river in the sense that it uses as a reference the natural or close to natural characteristics of fish assemblages (Karr, 1996). However, some introduced species (both indigenous and exotic) may be valuable indicators of either "good" or "poor" habitat and water quality conditions where they have already become established. In this sense intolerant exotic species such as trout may be suitable indicators of particular physical habitats and water quality conditions and may indeed in certain situations represent the condition a stream is desired to be in. In this context it would be short-sighted not to use the indicator value of introduced species, and in particular situations the FAII should be adapted to use attributes of such species as metrics. However, as pointed out by Karr (1996) this would primarily represent a measure of the health of a river according to a particular desired state and not necessarily of the ecological integrity.
- Fish abundance is problematic to interpret due to the dynamic nature of fish populations and was not incorporated in the FAII. However, the possibility of using the abundance of certain fish species as indicative of certain habitat conditions should not be ignored. In this respect, the *Chiloglanis* spp. occurring in the Crocodile River provide a possibility of using catch per unit effort data in habitats (riffles, runs and rapids) that are generally easy to sample during low-flow conditions, as indicators of certain environmental conditions (i.e. flow conditions, general water quality).
- The FAII is strongly based on the intolerance index for fish species. The factors used in the compilation of this index are predominantly based on incidental observations and professional judgment. A more objective approach to assess intolerance should be investigated. The possibility of increasing the number of intolerance classes from three to four or more should be considered as this will enhance the responsiveness of the intolerance index considerably. In this respect, Whittier and Hughes (1998) distinguished intolerant, moderately intolerant, moderately tolerant and tolerant classes.
- The FAII is not considered suitable for the assessment of streams with a naturally low fish species richness. Consequently, the FAII cannot be considered highly responsive to a change in biological integrity in the upper segments of the Crocodile River. As for the IBI (Fausch et al., 1990), a natural fish species richness of less than five is probably not amenable to assessment with the FAII. For such situations it is advisable that an index be developed that uses metrics of population attributes of species considered to be suitable indicators of particular environmental stressors. The use of the attributes of established populations of introduced species can also be considered as surrogates in such situations.
- Considering biological integrity assessment and the use of fish assemblages for this purpose, South Africa is currently in a situation where there will be strong dependence on narrative biological criteria and it will take some time and research to develop numerical biological criteria. This is comparable to the situation in the USA where states were first required to adopt narrative criteria and after some time numerical criteria. Numerical biological criteria will require research on the statistical properties of indices (i.e. power analysis) (Fore et al., 1994; Hughes et al., 1998). The indicator value of various metrics of different fish species should also be investigated in terms of its

responsiveness to various degrees of human influence (Karr and Chu, 1997).

- The possibility of using a combination of fish and instream macro-invertebrate metrics to assess the biological integrity of a stream is an aspect that requires further investigation. Approaches that makes use of a visual presentation (i.e. multivariate presentations such as star diagrams) to combine various indices used for biological integrity estimation have been proposed (USEPA, 1996). However, the use of a rule-based decision support system based on an array of metrics (fish, invertebrate, habitat, etc.) and professional judgment represents an alternative that should receive attention for application in South Africa.
- It is not possible to develop a fish index that can be applied directly and without any adaptation or modification to all South African rivers. Some grouping of rivers based on ecological similarities which include both physical components and information on fish, can allow equivalent fish indices (i.e. FAIIs) to be developed for similar river sections or in rivers in certain parts of the country. The development of a suitable river typing approach, such as the ecoregion approach used in the USA (Omernik, 1987, Omernik and Bailey, 1997) will enable such a grouping of rivers. The FAII developed for the Crocodile River must in this respect be seen as an example of what should be considered in the development of a fish index in other rivers or groups of rivers in South Africa. This is in contrast to the general situation with the macro-invertebrate index, SASS (Chutter, 1998), where the modifications required for local conditions are limited due to the index being based on families.
- The FAII or any other biological integrity assessment index, must not be regarded as providing a final and unequivocal answer as to the biological integrity of a river. Rather it must be seen as part of a system that will lead to more questions being asked in an attempt to solve a particular problem. If particular specified Thresholds of Potential Concern (Rogers and Bestbier, 1997) are reached, more intensive sampling and alternative approaches will probably be required to determine cause-and-effect relationships that can be used to solve or manage a particular problem. With reference to fish, this can include more intensive sampling (including more sites and more effort per site) and then applying the FAII per site rather than only on a segment level and relating this information to smaller scales of the geomorphologic hierarchy (e.g. at the reach level; Rogers and Bestbier, 1997). In certain instances, the monitoring of population characteristics of indicator species in a segment may be required to determine certain cause-and-effect relationships (Munkittrick and Dixon, 1989). In essence, it is recommended that an increasing amount of resources and effort is spent and focused depending on the seriousness, nature and extent of the perceived problem as initially indicated by the FAII.

Acknowledgements

The following persons are thanked for their contributions during the field survey:

- Dr A Deacon, Dr J Engelbrecht, Mr F Roux, Mr G Schulz, Mr D Roux, Mr P Kotze, Ms C Thirion, Ms L Hill and the fish sampling teams of Mpumalanga Parks Board and the Kruger National Park. Mr D Roux also made constructive comments on an early draft of the manuscript.
- Prof K Rogers (University of the Witwatersrand) and Mr I Russell (South African National Parks) made available draft copies of reports relating respectively to the desired state of riverine systems of South Africa and the fish of the Kruger National Park. Mr R Heath made available unpublished information on the Crocodile River.
- I am grateful to Dr R Hughes (ManTech Environmental Technology, Corvallis, Oregon) and Prof JR Karr (University of Washington, Seattle) for kindly providing recent literature on the IBI, and sharing some of their thoughts on biological assessment.
- Dr H van Vliet (Department of Water Affairs and Forestry) is thanked for his support for the project and comments on the manuscript.

References

APPLETON CC (1974) A checklist of the flora and fauna of the Gladdespruit, Nelspruit district Eastern Transvaal. *Newslet. Limnol. Soc. South. Afr.* **22** 49-58.

BELL-CROSS G and MINSHULL JL (1988) *The Fishes of Zimbabwe*. Trustees of the National Museums and Monuments of Zimbabwe, Harare, Zimbabwe.

BRAMBLETT RG and FAUSCH KD (1991) Variable fish communities and the index of biotic integrity in a Western Great Plains river. *Trans. Am. Fish. Soc.* **120** 752-769.

CHUTTER FM (1998) Research on the Rapid Biological Assessment of Water Quality Impacts in Streams and Rivers. Report to the WRC. Environmentek, CSIR. WRC Report No. 422/1/98.

CRASS RS (1964) *Freshwater Fishes of Natal*. Shuter & Shooter, Pietermaritzburg.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF) (1995) *Crocodile River Catchment, Eastern Transvaal: Water Quality Assessment*. Vol. 1-9. DWAF. Pretoria.

FAUSCH KD, LYONS J, KARR JR and ANGERMEIER, PL (1990) Fish communities as indicators of environmental degradation. *Am. Fish. Soc. Symp.* **8** 123-144.

FORE LS, KARR JR and CONQUEST LL (1994) Statistical properties of an index of biological integrity used to evaluate water resources. *Can. J. Fish. Aquat. Sci.* **51** 1077-1087.

FRISSEL CA, LISS WJ, WARREN CE and HURLEY MD (1986) A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environ. Manage.* **10** 199-214.

GAIGHER IG (1969) Aspekte met Betrekking tot die Ekologie, Geografie en Taksonomie van Varswatervisse in die Limpopo- en Incomatiriviersisteem. (In Afrikaans). Ph.D. Thesis, Rand Afrikaans Univ., Johannesburg.

HAY CJ, VAN ZYL BJ and STEYN GJ (1996) A quantitative assessment of the biotic integrity of the Okavango River, Namibia, based on fish. *Water SA* **22** 263-284.

HEATH R and CLAASSEN M (1999) The Use of Indigenous Fish Species for the Determination of Pesticide and Heavy Metal Loads. Water Research Commission Report No 428/1/99, Pretoria.

HENDRICKS ML, HOCUTT CH and STAUFFER JR (1980) Monitoring of fish in lotic habitats. In: CH Hocutt and JR Stauffer (eds.) *Biological Monitoring of Fish*. Lexington Books, DC Heath & Co., Lexington, Massachusetts, Toronto. 205-231

HOCUTT CH (1981) Fish as indicators of biological integrity. *Fisheries* **6** 28-30.

HOCUTT CH, JOHNSON PN, HAY C and VAN ZYL BJ (1993) Biological basis of water quality assessment: The Kavango River, Namibia. Unpublished paper delivered at the Int. Symp. on Biol. Diversity in Afr. Fresh and Brackish Water Fishes (PARADI), Dakar, Senegal.

HUGHES RM, KAUFMANN PR, HERLIHY AT, KINCAID TM, REYNOLDS L and LARSEN DP (1998) A process for developing and evaluating indices of fish assemblage integrity. *Can. J. Fish. Aquat. Sci.* **55** 1618-1631.

HUGHES RM, and OBERDORFF T (1999) Application of IBI concepts and metrics to waters outside the United States and Canada. In: TP Simon (ed.) *Assessing the Sustainability and Biological Integrity of Water Resources using Fish Communities.* CRC Press LLC. 79-93.

JOHNSON DS (1967) Distributional patterns in Malayan freshwater fish. *Ecology* **48** 722-730.

KARR JR (1981) Assessment of biotic integrity using fish communities. *Fisheries* **6** 21-27.

KARR JR (1996) Ecological integrity and ecological health are not the same. In: C Schulze (ed.) *Engineering Within Ecological Constraints*. National Academy Press, Washington D.C. 97-109.

KARR JR and DUDLEY DR (1981) Ecological perspective on water quality goals. *Environ. Manage.* **5** 55-68.

KARR JR, FAUSCH FD, ANGERMEIER PL, YANT PR and SCHLOSSER IJ (1986) Assessing Biological Integrity in Running Waters: A Method and Its Rationale. Illinois Natural History Survey. Special Publication **5**.

KARR JR and CHU EW (1997) Biological Monitoring and Assessment: Using Multimetric Indexes Effectively. EPA 235-R97-0001. Univ. of Washington, Seattle.

KLEYNHANS CJ (1984) Die Verspreiding en Status van Sekere Seldsame Vissoorte van die Transvaal en die Ekologie van Sommige Spesies (In Afrikaans). D.Sc. Thesis, Univ. of Pretoria, Pretoria.

KLEYNHANS CJ (1988) Aspects of the ecology of *Kneria auriculata* (Pellegrin, 1905) (Pisces: Kneriidae) from the eastern Transvaal, South Africa. *J. Limnol. Soc. South. Afr.* **14** 108-118.

KLEYNHANS CJ (1996) A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo system, South Africa). *J. Aquat. Ecosystem Health* **5** 41-54.

KLEYNHANS CJ, SCHULZ GW, ENGELBRECHT JS and ROUSSEAU FJ (1992) The impact of a paper mill effluent spill on the fish populations of the Elands and Crocodile Rivers (Incomati System, Transvaal). *Water SA* **18** 73-80.

LE ROUX P and STEYN L (1978) *Fishes of the Transvaal*. Cape & Transvaal Printers Ltd. Cape Town.

LYONS J and WANG L (1996) Development of and index of biotic integrity for coldwater streams in Wisconsin. *North Am. J. Fish. Manage.* **16** 241-256.

LYONS J, NAVARRO-PEREZ S, COCHRAN PA, SANTANA E and GUZMAN-ARROYO M (1995) Index of biotic integrity based on fish assemblages for the conservation of streams and rivers in West-Central Mexico. *Conserv. Biol.* **9** 569-584.

MUNKITTRICK KR and DIXON DG (1989) A holistic approach to ecosystem health assessment using fish population characteristics. *Hydrobiol.* **188/189** 123-135.

OBERDORFF T and HUGHES RM (1992) Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin, France. *Hydrobiol.* **228** 117-130.

OHIO EPA (1987) Biological criteria for the protection of aquatic life. Volume 1: The role of biological data in water quality assessment. Ohio EPA, Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, Ohio.

OMERNIK JM (1987) Ecoregions of the conterminous United States. *Ann. Assoc. Am. Geogr.* **77** 118-125.

OMERNIK JM and BAILEY RG (1997) Distinguishing between watersheds and ecoregions. *J. Am. Water Resour. Assoc.* **33** 935-949.

OSWOOD ME and BARBER WE (1982) Assessment of fish habitat in streams: Goals, constraints, and a new technique. *Fisheries* **7** 8-11.

PIENAAR U DE V (1978) *The Freshwater Fishes of the Kruger National Park.* The National Parks Board of South Africa.

PLAFKIN LP, BARBOUR MT, PORTER KD, GROSS SK and HUGHES RM (1989) Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish. U.S. Environmental Protection Agency. Washington, DC.

RAMM AE (1988) The community degradation index: A new method for assessing the deterioration of aquatic habitats. *Water Res.* **22** 293-301.

ROGERS KH and BESTBIER R (1997) Development of a Protocol for the Definition of the Desired State of Riverine Systems in South Africa. Department of Environmental Affairs and Tourism, Pretoria.

ROUX DJ (1997) National Aquatic Ecosystem Biomonitoring Programme: Overview of the Design Process and Guidelines for Implementation. NAEBP Report Series no. 6. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

ROUX F (1998) Personal communication. Nature Conservator, Mpumalanga Parks Board, Lydenburg.

RUSSEL LA and KH ROGERS (1998) Monitoring the Conservation Status and Diversity of Fish Assemblages in the Major Rivers of the Kruger National Park. Report No. 1/1997. Centre for Water in the Environment, University of the Witwatersrand, South Africa.

SIMON TP and LYONS J (1995) Application of the index of biotic integrity to evaluate water resource integrity in freshwater ecosystems. In: WS Davis and TP Simon (eds.), *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis Publishers, Boca Raton, London, Tokyo. 245-262.

SKELTON PH (1993) *A Complete Guide to the Freshwater Fishes of Southern Africa.* Southern Book Publishers, Halfway House, South Africa.

STEEDMAN RJ (1988) Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. *Can. J. Fish. Aquat. Sci.* **45** 492-501.

SUTER GW (1993) A critique of ecosystem health concepts and indexes. *Environ. Toxicol. Chem.* **12** 1533-1539.

THIRION T (1996) Personal communication. Specialist Scientist, Institute for Water Quality Studies, DWAF, Pretoria.

USEPA (1996) Revision of rapid bioassessment protocols for use in stream and rivers: Periphyton, benthic macroinvertebrates, and fish. Document on Internet for comment. http://www.epa.com

WANG L, SIMONSON TD and LYONS J (1996) Accuracy and precision of selected stream habitat estimates. *North Am. J. Fish. Manage* **16** 340-347.

WEEKS DC, O'KEEFFE JH, FOURIE A and DAVIES BR (1996) A Pre-impoundment Study of the Sabie-Sand River System, Mpumalanga with Special Reference to Predicted Impacts on the Kruger National Park. Volume One. The Ecological Status of the Sabie-Sand River System. Water Research Commission Report No. 294/1/96, Pretoria.

WHITTIER TR and HUGHES RM (1998) Evaluation of fish species tolerances to environmental stressors in lakes in the Northeastern United States. *North Am. J. of Fish. Manage.* **18** 236-252.