ECOCLASSIFICATION

**RIVER ECOCLASSIFICATION: MANUAL FOR ECOSTATUS DETERMINATION (Version 2)**

**Module D: Volume 1 Fish Response Assessment Index (FRAI)**

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# RIVER ECOCLASSIFICATION
# MANUAL FOR ECOSTATUS DETERMINATION
# (Version 2)


# MODULE D: VOLUME 1
# FISH RESPONSE ASSESSMENT INDEX
# (FRAI)

Obtainable from:

The manuals for ecostatus determination emanate from studies which were initiated within the WRC research consultancy, K8/619, titled: "*Designing a Riparian Vegetation Response Assessment Index as part of the existing EcoStatus determination process*".

# STRUCTURE OF THE DOCUMENT

The manual consists of the following modules:

- Module A: Ecoclassification And Ecostatus Models
- Module B: Geomorphological Driver Assessment Index (Gai)
- Module C: Physico-Chemical Driver Assessment Index (Pai)
- **Module D: Fish Response Assessment Index (Frai) Volume 1 & 2**
- Module E: Macro-Invertebrate Response Assessment Index (Mirai) (Volume 1)
- Module F: Riparian Vegetation Response Assessment Index (Vegrai)
- Module G: Index of Habitat Integrity

This report is Module D – <u>Volume 1</u> which provides the background to and scientific rationale for the FRAI and provides an explanation of the FRAI model.

Modules B, C E (Volume 2) and G will be published towards the end of 2008.

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### PURPOSE OF THE MANUAL: MODULE D

- Provides a step by step guideline to the appropriate specialists on how to use the FRAI.

### WHO SHOULD APPLY THESE MODELS?

- An experienced fish specialist.

NOTE: It is strongly recommended that the user participates in training courses and/or contacts the authors of this manual when applying the models

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The manual is structured in a main section which focuses on how to populate the models and appendices that provide the background, scientific rationale and the modelling approach.

The CD issued with this report "Fish Response" Module D Volume 1, (WRC Report TT330/08), contains an electronic copy of the report as well as its supporting models. The other modules in the series are also provided.  An inventory is given on the CD.

## 1.  RIVER ECOCLASSIFICATION MANUAL FOR ECOSTATUS DETERMINATION (VERSION 2)

**Module D: Volume 1:  Fish Response Assessment Index (FRAI)**
**(WRC Report TT 330/08)**

Manual describing the Fish Response Assessment Index:  **FRAI.doc**
The FRAI manual is supported by a FRAI model,  database and explanatory note on CD:
(i)     FRAI model
(ii)    Database: **FRAI.xls**
(iii)   Explanatory document

Also refer to the supporting report:
**Module D: Volume 2: Reference Frequency of Occurrence of Fish Species in South Africa (FROC) ( WRC Report TT 331/08)**
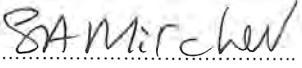
# APPROVAL FOR RELEASE OF REPORT

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# ACKNOWLEDGEMENTS

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# ABBREVIATIONS

| | |
|---|---|
| ASPT | Average Score Per Taxon |
| DWAF | Department of Water Affairs and Forestry |
| EC | Ecological Category |
| EcoSpecs | Ecological Specifications |
| EIS | Ecological Importance and Sensitivity |
| ER | Ecological Reserve |
| EWR | Ecological Water Requirements |
| FAII | Fish Assemblage Integrity Index |
| FHS | Fish Habitat Segment |
| FRAI | Fish Response Assessment Index |
| GAI | Geomorphology Driver Assessment Index |
| HAI | Hydrology Driver Assessment Index |
| IFR | Instream Flow Requirements |
| IHI | Index of Habitat Integrity |
| ISP | Internal Strategic Perspective |
| MCDA | Multi-Criteria Decision Analysis |
| MIRAI | Macro Invertebrate Response Assessment Index |
| PAI | Physico-chemical Driver Assessment Index |
| PES | Present Ecological State |
| RDM | Resource Directed Measures |
| REC | Recommended Ecological Category |
| RERM | Rapid Ecological Reserve Methodology |
| RHP | River Health Programme |
| RU | Resource Unit |
| RVI | Riparian Vegetation Index |
| SASS | South African Scoring System |
| VEGRAI | Riparian Vegetation Response Assessment Index |

# EXECUTIVE SUMMARY

## 1. ECOCLASSIFICATION

EcoClassification - the term used for the Ecological Classification process - refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers relative the natural or close to the natural reference condition. The purpose of the EcoClassification process is to gain insights and understanding into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river.

The steps followed in the EcoClassification process are as follows:
- Determine reference conditions for each component.
- Determine the Present Ecological State for each component as well as for the EcoStatus. The EcoStatus refers to the integration of physical changes by the biota and as reflected by biological responses.
- Determine the trend (i.e. moving towards or away from the reference condition) for each component as well as for the EcoStatus.
- Determine causes for the PES and whether these are flow or non-flow related.
- Determine the Ecological Importance and Sensitivity (EIS) of the biota and habitat.
- Considering the PES and the EIS, suggest a realistic and practically attainable Recommended Ecological Category (REC) for each component as well as for the EcoStatus.
- Determine alternative Ecological Categories (ECs) for each component as well as for the EcoStatus for the purposes of providing various scenarios

The EcoClassification process is an integral part of the Ecological Reserve determination method and of any Environmental Flow Requirement method. Flows and water quality conditions cannot be recommended without information on the predicted resulting state, the Ecological Category.

Biological monitoring for the River Health Programme (RHP) also uses the EcoClassification process to assess biological response data in terms of the severity of biophysical changes. However, the RHP focuses primarily on biological responses as an indicator of ecosystem health, with only a general assessment of the cause-and-effect relationship between the drivers and the biological responses.

## 2. ECOSTATUS INTRODUCTION

The EcoStatus is defined as

*'The totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services'.*

In essence the EcoStatus represents an ecologically integrated state representing the drivers (hydrology, geomorphology, physico-chemical) and responses (fish, aquatic invertebrates and riparian vegetation).

The development of methods to achieve the objectives of this study, focussed on a two-step process -
- Devising consistent indices for the assessment of the EC of individual biophysical components.
- Devising a consistent process whereby the EC of individual components can be integrated at various levels to derive the EcoStatus of the river.

The principle followed here is that the biological responses integrate the effect of the modification of the drivers and that this results in an ecological endpoint.

Indices are determined for all the Driver and Response components using a rule-based modelling approach. The modelling approach is based on rating the degree of change from natural on a scale of 0 (no change) to 5 (maximum relative change) for various metrics. Each metric is also weighted in terms of its importance for determining the Ecological Category under natural conditions for the specific river reach that is being dealt with.

## 3. ECOSTATUS SUITE OF MODELS

The following index models were developed following a Multi Criteria Decision Making Approach (MCDA):
- Hydrological Driver Assessment Index (HAI)
- Geomorphology Driver Assessment Index (GAI)
- Physico-chemical Driver Assessment Index (PAI)
- Fish Response Assessment Index (FRAI)
- Macro Invertebrate Response Assessment Index (MIRAI)
- Riparian Vegetation Response Assessment Index (VEGRAI)

Each of these models result in an Ecological Category expressed in terms of A to F where A represents the close to natural and F a critically modified condition.

## 4. ECOSTATUS DETERMINATION

The metrics of each driver component are integrated to provide an Ecological Category (EC) for each component. However, the three drivers are not integrated to provide a driver EC. The information required from the drivers refers to the information contained in individual metrics, and which can be used to interpret habitat required by the biota. This information can then be used to determine and interpret

biological responses.

The fish and invertebrate response indices are interpreted to determine an Instream Ecological Category using the Instream Response Model.  The purpose of this model is to integrate the EC information on the fish and invertebrate responses to provide the instream EC. The basis of this determination is the consideration of the indicator value of the two biological groups to provide information on -

- Fish: Diversity of species with different requirements for flow, cover, velocity-depth classes and modified physico-chemical conditions of the water column.
- Invertebrates: Diversity of taxa with different requirements for biotopes, velocity and modified physico-chemical conditions.

Due to time and funding constraints, various levels of Reserve determinations can be undertaken.  Each of these relates to an Ecological Water Requirement (EWR) method with an appropriate level of detail and EcoClassification process.

The EcoClassification process, and specifically the detail and effort required for assessing the metrics, varies according to the different levels.  The process to determine the EcoStatus also differs on the basis of different levels of information. There are five EcoStatus levels and they are linked to the different levels of Ecological Reserve determination as follows:

- Desktop Reserve method → Desktop EcoStatus level.
- Rapid I Ecological Reserve method → EcoStatus Level 1.
- Rapid II Ecological Reserve methods →  EcoStatus Level 2
- Rapid III Ecological Reserve methods → EcoStatus Level 3
- Intermediate and Comprehensive Reserve methods → EcoStatus Level 4

These five levels of EcoStatus determination are associated with an increase in the level of detail required to execute them. As the EcoStatus levels become less complex, less-complex tools must be used (such as the Index of Habitat Integrity). This set of manuals explains these different tools, how they work and when they should be applied.

# 1  FISH RESPONSE ASSESSMENT INDEX (FRAI)

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| *These guidelines assume that the reader has some experience of fish ecology.* |
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## 1.1  THE PRINCIPLES OF THE FRAI

### 1.1.1  Definition of the FRAI

- The FRAI is an assessment index based on the environmental intolerances and preferences of the reference fish assemblage and the response of the constituent species of the assemblage to particular groups of environmental determinants or drivers (Figure 1.1)
- These intolerance and preference attributes are categorised into metric groups with constituent metrics that relates to the environmental requirements and preferences of individual species.
- Assessment of the response of the species metrics to changing environmental conditions occur either through direct measurement (surveys) or are inferred from changing environmental conditions (habitat). Evaluation of the derived response of species metrics to habitat changes are based on knowledge of species ecological requirements. Usually the FRAI is based on a combination of fish sample data and fish habitat data.
- Changes in environmental conditions are related to fish stress and form the basis of ecological response interpretation (cf. **Appendix A**).
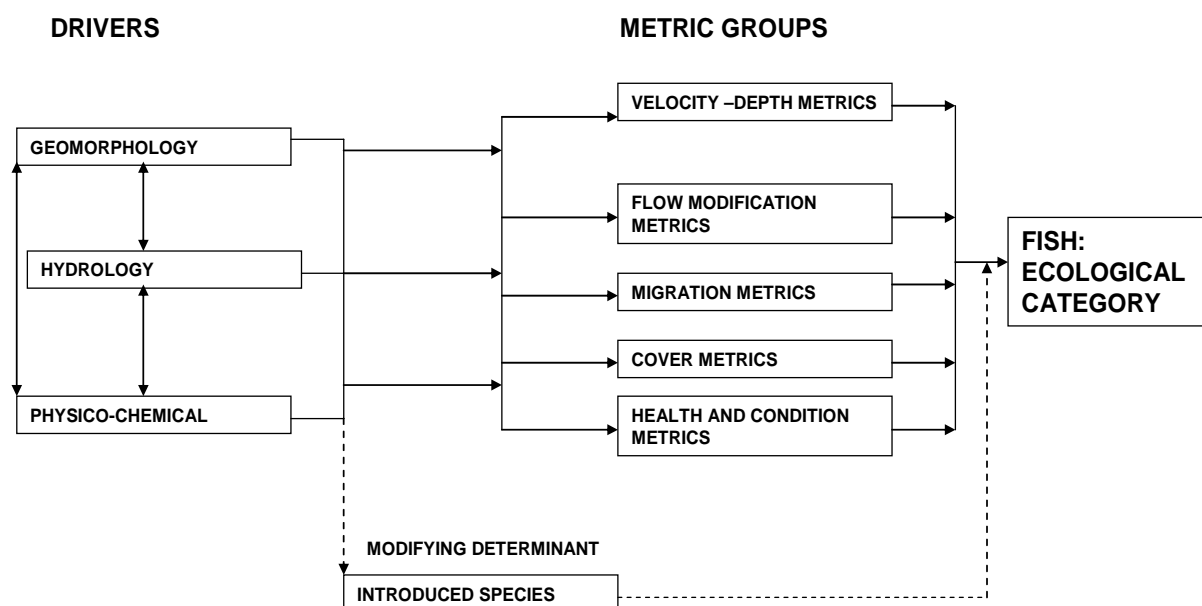


**Figure 1.1  The relationship between drivers and fish metric groups**

Although the FRAI uses essentially the same information as the FAII (Fish

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Assemblage Integrity Index; Kleynhans 1999), it does not follow the same procedure. The FAII was developed for application in the broad synoptic assessment required for the RHP and does not have a particularly strong cause-and-effect basis (cf. Kleynhans, 1999). The purpose of the FRAI, on the other hand, is to provide a habitat-based cause-and-effect underpinning to interpret the deviation of the fish assemblage from the reference condition.

## 1.2  FISH ECOLOGY AND DRIVER INFORMATION REQUIREMENTS

To relate drivers and the resulting fish habitat template to the stress response of fish, the life-history requirements and environmental preferences of species must be considered.  This is achieved by:

- Considering information on the life-history strategies and habitat preferences and requirements of each of the species in the assemblage.  An expert -knowledge database that includes a semi-quantitative rating of the intolerances, cover preferences and flow (velocity-depth) preferences is available for the majority of South African freshwater fish species (Kleynhans, 2003) and was built into the FRAI model. Where this database is not sufficient, available literature on South African freshwater fish, as well as local experts, should be consulted.
- Habitat features are evaluated in terms of their suitability to the requirements of the species constituting the assemblage.  This includes consideration of breeding requirements and early life-history stages, survival/abundance, frequency of occurrence in a river section, cover, health and condition and water quality.

This module is structured so as to provide the user hands-on access to the use of the FRAI model (developed in MS Excel 2003) with a condensed explanation of the rationale and ecological considerations on which it is based. The rationale of the FRAI is provided in Appendices, together with a simple example of its application and field forms that should be used to capture survey data.

Two versions of the FRAI will eventually be available. The version presented here is for general application. The River Health Programme (RHP) version will be customized for the RHP sites that have been identified in each Water Management Area (WMA) (Dallas, 2005b) and for which reference species list and frequency of occurrence was determined (Kleynhans *et al.,* 2007 in prep.).

## 1.3  STEPS IN THE DETERMINATION OF THE FISH EC

The eight steps followed in the calculation of the FRAI are indicated in Table 1.2.

**Table 1.1    Main steps and procedures in the calculation of the FRAI**

| STEP | PROCEDURE |
|---|---|
| River section earmarked for assessment | As for study requirements and design |
| Determine reference fish assemblage: species and frequency of occurrence | • Use historical data & expert knowledge<br>• Model: use ecoregional and other environmental information<br>• Use expert fish reference frequency of occurrence database if available |
| Determine present state for drivers | • Hydrology<br>• Physico-chemical<br>• Geomorphology<br>or<br>• Index of habitat integrity |
| Select representative sampling sites | Field survey in combination with other survey activities |
| Determine fish habitat condition at site | • Assess fish habitat potential<br>• Assess fish habitat condition |
| Representative fish sampling at site or in river section | • Sample all velocity depth classes per site if feasible<br>• Sample at least three stream sections per site |
| Collate and analyze fish sampling data per site | Transform fish sampling data to frequency of occurrence ratings |
| Execute FRAI model | • Rate the FRAI metrics in each metric group<br>• Enter species reference frequency of occurrence data<br>• Enter species observed frequency of occurrence data<br>• Determine weights for the metric groups<br>• Obtain FRAI value and category<br>• Present both modelled FRAI & adjusted FRAI. |

### 1.3.1    Study of the river section earmarked for assessment

This step is common to the overall EcoStatus assessment and will provide the necessary spatial framework for FRAI determination.

### 1.3.2    Determine reference fish assemblage: species and frequency of occurrence

Two main sources of information to determine fish species expected to be present under reference conditions (actual or derived) can be used:

• Historical information from the river delineation under consideration can be used to provide an indication of reference conditions. This includes unpublished records and reports by local experts and organizations. Often distribution information can be related to conditions prior to major impacts on rivers, thereby providing a good indication of pre-impact conditions.

- In the absence of actual data for the river delineation, information on other river reaches or neighbouring rivers can be used to compile a list of species expected under reference conditions. Filling of distribution gaps is also possible in the case of species such as *Anguilla* where absence in a river section can be used to derive presence upstream and downstream of such a section. In other cases the presence / absence of species within a different river in the same ecoregional context (Kleynhans et al., 2005) and considerations such as stream order and altitude can be used to derive reference presence in the river delineation being considered. Distribution modelling will be considered for this purpose in the future. A prototype of this is under development.

Interpreting fish assemblage responses within the reference situation is based on the fish habitat segment approach (FHS, Kleynhans, 1999). The FHS refers to a portion of a stream in which the fish assemblage remains "generally homogeneous due to the relative uniform nature of the physical habitat" (Ramm, 1988). The boundaries of a fish habitat segment can be expected to vary according to the temporal and spatial variability (natural and human-induced) of environmental conditions in a segment. The purpose of defining fish habitat segments is 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 (Kleynhans, 1999).

Reference species frequency of occurrence estimations can interrogate the expert opinion database that was compiled for all RHP sites in all WMAs, as well as some additional sites. This information is generally representative of the particular river ecoregion and geomorphological zone in which the site falls and will be built into the FRAI as a database (Kleynhans and Louw, in prep.).

Frequency of occurrence is rated according to the scale indicated in Table 1.2

**Table 1.2    Frequency of occurrence ratings used in the calculation of the FRAI**

| FREQUENCY OF OCCURRENCE RATING | DESCRIPTION |
|---|---|
| 0 | Absent |
| 1 | Present at very few sites (<10% of sites) |
| 2 | Present at few sites (>10-25%) |
| 3 | Present at about >25-50 % of  sites |
| 4 | Present at most sites (>50- 75%) |
| 5 | Present at almost all sites (>75%) |

### 1.3.3 Determine present state for drivers

The purpose is to provide information on the fish response and associated habitat condition and *vice versa* (i.e. fish responses that are possible, given certain habitat conditions). This assessment considers the whole river section to be studied.

If information on the drivers is available, these should be used. Otherwise the IHI should be run for the river section (cf. **Appendix A.5** and Module G)

### 1.3.4 Sampling site selection

Site selection should consider the following:

- Habitat present at the site should be representative of the RU or river delineation under consideration. This means that the velocity-depth and cover classes at a site should be as representative of the river delineation as possible.  However, for EC determination consideration should also be given to including sites with habitats that may actually be relatively uncommon in the river delineation, but which provide habitat for specialized or intolerant species or intolerant life-stages of some species (critical habitat). Information gleaned from such sites can provide a level of detail and sensitivity to the EC determination that may be lacking if only representativeness is considered.

- Preferably, sites should not be close to artificial structures such as bridges and weirs, as information from such sites may not necessarily be representative of the river delineation. Where no alternative is available, consideration of results from such sites should be regarded with caution. In certain cases sampling in weirs may be considered as the only option when the river is seasonal and permanent pool size is artificially enlarged by the construction of a weir. Downstream from such weirs, some limited flow may occur during the low flow season. Some fish species find habitat at such places and their presence may be useful for a limited assessment of river conditions (physico-chemical conditions for example, and even an indication that flows may at times be suitable for the completion of the life-cycle).

- Habitats at the site should be amenable to sampling. Factors such as the ease with which various sampling techniques such as electro-shocking and seine netting (including nets of various dimensions) can be used, should be considered. In the case of comprehensive and intermediate Reserve determination where detailed information is desirable, effort is usually focussed on a limited number of sites. Consequently the opportunity exists in such cases to do relatively intensive sampling (such as employing large seine nets and increasing sampling effort) than the case would be with rapid Reserves and for RHP purposes. Rapid Reserve determinations are usually limited to one or two sites in a reach that are easy and rapid to sample. The RHP strives to sample as many sites as possible as rapidly as possible in order to provide a representative or synoptic view of the health of the particular catchment.

- Factors such as accessibility and safety (in terms of dangerous animals and crime) are very important.

### 1.3.5 Fish habitat assessment at site

Arguments for the use of habitat as a surrogate in biological assessment can be found in **Appendix D.1**.

#### 1.3.5.1 Habitat potential assessment

Habitat assessment refers to an evaluation of fish habitat potential (i.e. the potential that the habitat provides suitable conditions for a fish species to live there) at a site in terms of the diversity of velocity-depth classes present and the presence of various cover types at each of these velocity-depth classes. This provides a framework within which the presence, absence and frequency of occurrence of species can be interpreted. Habitat assessment includes a general consideration of impacts that may influence the condition or integrity of fish habitat at a site.

Table 1.3 indicates the metrics and metric groups of the FRAI in terms of velocity-depth and cover. The four velocity-depth classes each provide the setting for five different types of cover. These classes can easily be recognised by experienced field workers.

Estimates of the relative ecological importance of velocity-depth and cover classes (Table 1.4) at a site are partly based on the area covered (estimated as a percentage). Depending on the size of the river, a site with a low percentage of a particular velocity-depth and cover class can still actually cover a substantial area at a site. A low rating is unrealistic in such a situation. This is compensated for by judging the qualitative value of depth-flow classes for fish. Percentage of area covered is only used, therefore, as a guideline in this estimation.

General flow conditions at the time of sampling are qualitatively assessed following the approach in Table 1.5.

**Table 1.3 Fish habitat assessment.**
Abundance of velocity-depth classes and cover are estimated according to: 0 – absent;
1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – very abundant
(cf Table 1.8 for specifications of classes)

| SLOW-DEEP | SLOW-SHALLOW | FAST-DEEP | FAST-SHALLOW |
|---|---|---|---|
| Overhanging vegetation: | Overhanging vegetation: | Overhanging vegetation: | Overhanging vegetation: |
| Undercut banks & root wads: | Undercut banks & root wads: | Undercut banks & root wads: | Undercut banks & root wads: |
| Substrate: | Substrate: | Substrate: | Substrate: |
| Instream vegetation: | Instream vegetation: | Instream vegetation: | Instream vegetation: |
| Water Column: | Water Column: | Water Column: | Water Column: |
| Remarks: | Remarks: | Remarks: | Remarks: |

**Table 1.4    Abundance scoring of velocity-depth and cover classes (adapted from Rankin, 1995)**

| Descriptor | Relative ecological value/abundance score | Occurrence (% of area covered) |
|---|---|---|
| None | 0 | 0 |
| Rare | 1 | 0-5 |
| Sparse | 2 | 5-25 |
| Common | 3 | 25-75 |
| Abundant | 4 | 75-90 |
| Very abundant | 5 | 90-100 |

**Table 1.5    Qualitative assessment of flow conditions during sampling (adapted from Dallas, 2005a)**

| Water level | Description |
|---|---|
| Dry | No water flowing. |
| Isolated pools | Pools that have a trickle of water between them, but no evident flow. |
| Low flow (dry season base flow) | Water well within the active channel; water probably not touching the riparian vegetation. |
| Moderate flow (wet season base flow) | Water within the active channel; water likely to be touching riparian vegetation in places. |
| High flow | Water filling the active channel; water completely into riparian vegetation. |
| Flood | Water above active channel. |

### 1.3.5.2   Habitat Condition

The purpose is to provide an indication of the deviation of the habitat from the reference condition.  In contrast to the assessment of driver conditions or the IHI in a river section, fish habitat condition assessment is done for the site and modifications that have a direct influence on fish habitat at the site are considered.

Forms used for capturing IHI (ver.2) and EcoStatus driver data can be used for this. The RHP manual also provides forms that can be used for this (Dallas, 2005a).

### 1.3.6   Fish sampling

The information provided here refers to minimum requirements. It is up to the operator to decide on the inclusion of additional information. Appendix D can be consulted on validation of the FRAI and sampling considerations.

Due to practical considerations, fish surveys are usually done during the low-flow period of the year.

Sampling effort and results are reported per velocity-depth class sampled. However, where the mosaic of velocity-depth classes makes it difficult or impossible to do this (combinations of fast-deep and fast-shallow classes, for instance), the dominant velocity-depth class should be used as the unit of reference for sampling effort, but

the presence of other velocity-depth classes should also be indicated.

The following apparatus are often used for catching fish in the different velocity-depth classes:

- Fast-deep: An electrical shocking apparatus one operator and two dip net handlers) is used in such habitat types. Capture results are recorded as number of fish caught per time unit (minutes) (e.g. AC 220v, 50 HZ, rated output=0.900 kva).
- Fast-shallow: Capture results are recorded as number of fish caught per time unit (minutes) with an electrical shocker
- Slow-deep: A large seine net (e.g. 70 m long, 1.5 m deep, mesh size 2.5 cm) can be used. A cast net, (diameter = 1.85 m, mesh size = 2.5 cm) can used in pools not suitable for beach seining. Capture results are recorded as number of fish caught during each effort
- Slow-shallow: A small seine net (5 m long, 1.5 m deep, mesh size = 1 mm) can be used to sample fish. An electrical shocking apparatus should preferably be used. Capture results are 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.

Although all these sampling methods are mentioned as options, it has been generally recommended that electrical shocking apparatus be used for fish integrity assessment (Pont et al., 2006; Kleynhans, 2007, **Appendix D**). Apparatus used in the different velocity-depth classes have not yet been standardized nationally. It can be expected that standardization will also have to be considered in terms of regional aspects such as EcoRegions, stream types, stream size and the fish species present. Manpower available for surveys will also play a role in the type of apparatus that can be used. Prior to any standardization, it is important that the apparatus and effort spent in sampling fish be kept similar in a particular river and for a particular study. This also applies to monitoring surveys.

All species sampled are counted and anomalies such as tumours, external parasites and other abnormalities are indicated. Although fish length is usually not measured, age groups can roughly be categorized according to juveniles and adults.

Although guidelines for representative sampling at a site needs specification for streams of different sizes and different fish species richness, sampling at sites in the Crocodile River (Kleynhans, 1999) and Elands River (**Appendix D**) followed the following general approach:

- Standard electro-shocking effort: 60-80 minutes per site (that is, time electricity was actually applied in the water). It is recommended that where possible, at least three stream sections be sampled per site (e.g. 3 sections each sampled for 20 minutes) and that the results be recorded separately. The three river sections should be spaced to avoid results from the one influencing the other. (Kleynhans, 2007).
- Standard small seine (see above) net effort: 2 efforts per site.
- Standard large seine (see above) net effort: 3 efforts per site.

- Cast net (see above) effort: 20 throws per site.

However, this is only generalization, and the effort will obviously also depend on the size of the river as well as the species richness. While electro-shocking is the sampling method of preference in all wadeable habitats and the RHP in particular, surveys for determination of the ecological reserve may possibly also make use of seine nets.

Other fish sampling methods (such as fish traps and fish fykes) can be used where suitable. Destructive sampling methods such as fish poisons and gill nets are not used. It is important to note that all velocity-depth classes are not necessarily present or possible to sample at a site, and that all sampling methods and apparatus are not necessarily applied at a site.

The RHP Rivers Database is currently under revision. It may be suitable for capturing certain aspects of the fish sampling but also incorporates data from the perspective of the RHP which may not be completely relevant to the EcoClassification-EcoStatus process followed in ecological Reserve determinations. The forms provided in this document (**Appendix B**) should be used to capture relevant fish related data.

The SURVEY_DATA sheet of the FRAI model provides a convenient way to summarize fish sampling data and have it available when the model is run. This sheet is an abstract of the fish sampling forms in the RHP manual (Dallas, 2005a).

### 1.3.7   Collate and analyze fish sampling data per site

Sampling data at different velocity-depth classes should be kept separate for analysis. If only certain velocity-depth classes were sampled, it is important to use the data and make conclusions within this limitation. This means that if, say slow-deep habitat was not sampled, species that would occur predominantly in this velocity-depth class should be excluded from the assessment in terms of the species expected under reference conditions. The sample must therefore be as representive as possible and reference conditions should only be set for the species that would occur in the habitats that were actually sampled.

Fish sampling data per site or per stream length sampled per site, is transformed to frequency of occurrence ratings. Where three or more sections were sampled per site, the following calculation should be done to transform data into frequencies of occurrence on a rating scale of 0-5 by:

$$FROC = (Nsp/Ns) \times 5$$

Where:
FROC= Frequency of occurrence of a species
Nsp=Number of sites in the reach or sampling points at a site where a species was sampled.
Ns=Number of sites sampled in the reach or number of points sampled at a site.
5= Maximum frequency of occurrence of a species.

The same calculation can be followed where more than 1 site were sampled per river reach.

See Table 1.2 for the interpretation of frequency of occurrence ratings.


## 1.4   EXECUTE THE FRAI MODEL

The FRAI model makes use of the fish intolerance and preference database that was compiled in 2001 (Kleynhans, 2003). This information was built into the FRAI. **Appendix A.4** provides information on the database and it structure. The approach followed in the ranking, weighting and rating of metric groups is similar to that indicated in Module A: EcoStatus. A large component of the FRAI is based on an automated calculation of ranks, weights and ratings (**Appendix A.6**). However, where this needs to be done manually the basic question is: Which metric would make the most significant contribution to improving (or degrading) the metric groups and the PES?

Table 1.6 provides a summary of metrics and metric groups, as well as their specification and relevance for fish assemblage assessment and guidelines for the rating of metrics.

Table 1.7 provides guidelines for the assessment of the impact of introduced species.

Table 1.8 provides a description of metric groups, metric responses, specification and relevance.

Table 1.9 indicates all the FRAI model sheets that are used during execution of the FRAI model, their purpose and relevance and provides a concise guideline for the application of the model.

Examples of all FRAI sheets are indicated in **Appendix C.**

**Table 1.6  Metric groups and considerations for their assessment based on habitat indicators and species responses**

| METRIC GROUP (EXCEL SHEET IN MODEL) | CONSIDERATIONS | | SPECIES RESPONSE METRICS: RATING CRITERIA |
|---|---|---|---|
| | HABITAT INDICATORS: COMPARED TO REFERENCE | SPECIES RESPONSE OBSERVED OR DERIVED FROM HABITAT INDICATORS: COMPARED TO REFERENCE | |
| **Velocity-depth (VEL_DEPTH)** | Changes in: Fast-deep, fast-shallow, slow-deep and slow-shallow. Causes – changes in hydrology; zero flows, base flows, moderate floods and freshes. Seasonality. Changes in sediment capacity and supply (sedimentation and scouring) | Depends on reference species in the fish assemblage able to utilize velocity-depth, cover, modified flow or physico-chemical conditions. | -5 or 5: Extreme loss (absent)/increase (completely dominant) from reference<br><br>-4 or 4:  Serious loss/increase from reference<br><br>-3 or 3: Large loss/increase from reference<br><br>-2 or 2: Moderate loss/increase from reference<br><br>-1 or 1: Small loss/increase from reference<br><br>**0: No change from reference** |
| **Cover (COVER)** | Changes in: 1. Overhanging vegetation. Causes – altered water levels, bank erosion or physical destruction of overhanging vegetation. Increase in vegetation due to increased nutrients and alien vegetation. 2, Undercut banks and root wads. Causes – altered water levels, bank erosion or physical destruction of overhanging vegetation. 3. Particular stream substrate type. Causes – changes in sediment transport (supply & capacity), benthic algal growth due to increased nutrients. 4. Instream vegetation. Causes – invasive alien macrophytes, changed water levels, physical destruction. 5. Water column. Causes – altered water levels or loss of depth due to sedimentation (in pools). | | |
| **Flow Modification (FLOW_MOD)** | Changes in hydrology: 1.Increase or decrease in no-flow conditions 2. Increase or decrease in low-flow conditions 3. Increase or decrease in moderate events 4.Increase or decrease in events (high flow, floods) Change in seasonality is considered for each. | | |
| **Physico-Chemical (PHYSCHEM)** | Changes in: 1. pH          2. Salts 3. Nutrients      4. Temperature 5. Turbidity     6. Oxygen 7. Toxics | | |
| **Migration (MIGRATION)** | Any modification that results in the fragmentation of fish populations is considered. The presence and extent of the following are considered in evaluating the impact on and response of migratory species – 1. Weirs and causeways 2. Impoundments 3. Physico-chemical barriers 4. Hydrological modifications | Depends on reference species in the fish assemblage | 0: None, or no potential impact on movement. 1:  Small; limited, with small potential impact. 2: Moderate; notable and with potential impact. 3: Large; clear potential impact. 4: Serious; clear and serious potential impact. 5: Extreme; clear and critical potential impact. |

**Table 1.7    Guidelines for the assessment of the impact of introduced species**

| METRIC GROUP | IMPACT GUIDELINES | FREQUENCY OF OCCURRENCE GUIDELINES |
|---|---|---|
| **Introduced species (INTRO)** | Predaceous species / habitat modifying species with a critical impact on native species = 5<br>Predaceous species / habitat modifying species with a serious impact on native species = 3-4<br>Predaceous species / habitat modifying species with a moderate impact on native species = 2-1<br>Predaceous species / habitat modifying species with no impact on native species, or are absent completely = 0 | 0 = absent<br>1 = present at very few sites (<10%)<br>2 = present at few sites (>10-25%)<br>3 = present at about >25-50 % of sites<br>4 = present at most sites (>50-75%)<br>5 = present at almost all sites (>75%) |

**Table 1.8    Description of fish metric responses, specification and relevance (cf. Appendix A.5)**

| METRIC GROUP (EXCEL SHEET IN MODEL) | METRICS | METRIC SPECIFICATION AND RELEVANCE |
|---|---|---|
| **Velocity-depth (VEL_DEPTH)** | Response of species with:<br>1. High to very high preference for fast-deep conditions<br>2. High to very high preference for fast-shallow conditions<br>3. High to very high preference for slow-deep conditions<br>4. High to very high preference for slow-shallow conditions<br>(Based on Oswood and Barber, 1992) | Interpreted as hydraulic habitat types, Jordanova, et al. (2004):<br>1.Fast-deep: >0.3 m deep; velocity >0.3m/s (deep runs, rapids and riffles).<br>2. Fast-shallow: <0.3 m deep; velocity >0.3m/s (shallow runs, rapids and riffles)<br>3. Slow-deep: >0.5 m deep; velocity <0.3m/s (deep pools and backwaters)<br>4. Slow-shallow:<0.5 m deep; velocity <0.3m/s (shallow pools and backwaters) |
| **Cover (COVER)** | Response of species with:<br>1, High to very high preference for overhanging vegetation.<br>2. High to very high preference for undercut banks and root wads<br>3. High to very high preference for a particular stream substrate type.<br>4.High to very high preference for instream vegetation<br>5. High to very high preference for the water column. | 1. 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)).<br>2. 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).<br>3. Stream substrate type: The degree to which various substrate components (rocks, boulders, cobbles, gravel, sand, fine sediment and woody debris ("snags")) provide cover for fish are judged qualitatively. No detailed assessment of the stream substrate and estimation of the contribution of individual components are attempted. The composition of the substrate is handled in a descriptive manner (Kleynhans, 1999).<br>4. Instream vegetation: .Submerged and emergent plants.  A qualitative estimate made of the cover value for fish.<br>5. Water column: Decreasing risk of aerial predation. Sufficient water depth and size of |

| METRIC GROUP (EXCEL SHEET IN MODEL) | METRICS | METRIC SPECIFICATION AND RELEVANCE |
|---|---|---|
| | | species important. |
| **Flow Modification (FLOW_MOD)** | Response of species: 1. Intolerant of no-flow conditions. 2. Moderately intolerant of no-flow conditions. 3. Moderately tolerant of no-flow conditions. 4. Tolerant of no-flow conditions. | This metric group is interpreted based on the level of requirement that various species (or life-stages of a species) have for flowing water. The aspects of the impact of flow modification on physical habitat attributes are considered under other metric groups such as cover and velocity-depth classes. |
| **Physico-Chemical (PHYSCHEM)** | Response of species: 1. Intolerant of modified physico-chemical conditions. 2. Moderately intolerant of modified physico-chemical conditions. 3. Moderately tolerant of modified physico-chemical conditions. 4. Tolerant of modified physico-chemical conditions. | Health and condition of species are a reflection of the well-being of fish. Adverse environmental conditions (caused by decrease in food availability, modified physico-chemical conditions, decrease in preferred habitat, for instance, all of which may be related to flow alteration) may result in physiological stress conditions that impact on the immune system of species, resulting in deterioration of health and condition. For the FRAI, modified physico-chemical conditions are the primary consideration. |
| **Migration (MIGRATION)** | Response of species: 1. Requiring catchment scale movements. 2. Requiring movement between reaches of fish habitats segments. 3. Requiring movement within a reach or fish habitat segment. | The severity of the impact of obstruction of fish movement on the distribution, abundance and survival of a fish species in the particular river forms the basis of the assessment. Migration can be related to breeding, feeding and survival life-history strategies |
| **Introduced species (INTRO)** | The impact of introduced species: 1. Competing or predaceous species. 2. Frequency of occurrence of predaceous or competing species. 3. Habitat modifying species. 4. Frequency of occurrence of habitat modifying species. | Introduced species may have a dominant impact on the native fish assemblage, while the physical drivers may actually be in a close to reference condition. They can have a severe effect on the habitat structure (indirectly influencing the natural fish assemblage) and the fish assemblage structure itself through predation. Modified habitat conditions may also be to the advantage of introduced species. |

**Table 1.9    FRAI model: Sheets, sequence, purpose and operation.**
Grey-shaded blocks in the model indicate where values should be entered. All other blocks are protected.

| FRAI MODEL SHEET | PURPOSE AND OPERATION |
|---|---|
| SURVEY DATA | Capturing and collation of data. The reference species list as well as the species sampled should be indicated here as well as the transformation of results to frequency of occurrence ratings. |
| SCIENTIFIC NAMES | The table provides the 4 letter abbreviation of freshwater species scientific names. Scientific names are also provided. Only for lookup purposes. Although the genus names of some species have changed (such as some large yellowfish changed from *Barbus* to *Labeobarbus*) the abbreviation used is the previous one. The scientific names have been updated |
| SPP INTOL_PREF | The 4 letter species abbreviation should be filled in here. Information on intolerance and preferences as well as migratory requirements will then be listed. Only species native to the stream should be entered in this species list (i.e. the reference species list). Other species (i.e. introduced species) abbreviations can be entered to provide information on their requirements, but should be deleted when the information has been perused. This species list as well as the intolerance and preference information are carried over to other sheets for calculation. |
| REF_OBS_SPP | The species entered in the previous sheet will be listed here. The reference frequency of occurrence of these species should be estimated according to the information in Kleynhans *et al*., 2007 (in prep.) if the river section and site under investigation is similar to the one in the Database. The frequency of occurrence is entered for each species (e.g. 1-5; cf. Table 1.2). Enter the observed species frequency of occurrence (e.g. 0-5 in this case; cf. Table 1.2). If there are good indications that a species were undersampled due to difficult habitat conditions (e.g. eels) consider increasing the frequency of occurrence based on habitat integrity information. However, the original sample information should be kept in the SURVEYDATA sheet. |
| INTRO_ALIEN | Two tables are provided: (1) Predaceous alien species (2) Habitat modifying or competing species. Indicate with a Y/N whether the species is present. A potential impact value (0-5) will appear. Only alien species should be indicated. Indigenous species that were introduced extra-limitally, do not appear in the tables and should be assessed separately |
| VEL_DEPTH (metric group) | Three tables:<br>1. Change in velocity-depth classes from the reference (cf. Table 1.8 for class specification) for the river section. Based on commonness of class under reference, its weight (most common=100%, rest comparatively lower) and the rating (from extremes: -5 and 5; reference = 0; cf. Table 1.6).<br>2. Automated calculation of the change in the four metrics based on the derived fish response according to intolerance and preference ratings. Consult the appendix for information on the approach followed for this. No entries are required.<br>3. A table where the automated calculation (Table 2) can be adjusted. Adjustment is based on the consideration of the change in velocity depth classes (Table 1). The ranks, weights and ratings can be modified here. |
| COVER (metric group) | Three tables (same approach as for VEL_DEPTH metric group):<br>1. Change in cover metrics from the reference.<br>2. Automated calculation. No entries are required.<br>3. A table where the automated calculation (Table 2) can be adjusted. |
| FLOW_MOD (metric group) | Three tables (same approach as for VEL_DEPTH metric group):<br>1. Change in flow modification metrics from the reference.<br>2. Automated calculation. No entries are required.<br>3. A table where the automated calculation (Table 2) can be adjusted. |
| PHYSCHEM (metric group) | Three tables (same approach as for VEL_DEPTH metric group):<br>1. Change in physico-chemical metrics from the reference. |

| FRAI MODEL SHEET | PURPOSE AND OPERATION |
|---|---|
| | 2. Automated calculation. No entries are required.<br>3. A table where the automated calculation (Table 2) can be adjusted. |
| MIGRATION (metric group) | Two Tables:<br>1. Stream modifications that can limit fish movement. Severity rated (-5 to 0).<br>2. Response of species observed or derived to have occurred due to migration limitations. The SPP INTOL_PREF sheet should be consulted for migratory requirements (Kotze, in prep) |
| INTRO (metric group) | Two Tables:<br>1. Introduced species impact. This should be ranked, weighted and rated.<br>2. This Table provides a summary of the INTRO_ALIEN sheet. |
| METRIC GROUP WEIGHTS | Metric group weight is determined according to an Analytical Hierarchical Procedure (AHP)(Saaty, 1980; US Army Corps of Engineers, 1980). The purpose of this approach is to provide a reasonably objective way to determine the weights of metric groups. An AHP approach is followed where the metric groups are compared pairwise on a 0 – 10 scale with 0.5 intervals. Metric group weights are determined in the FRAI model sheet: METRIC GROUP WEIGHTS.<br><br>The objective is to determine the weight of various metric groups as it relates to the natural attributes and requirements of the reference fish assemblage. Introduced species are not a natural attribute or requirement and is considered as an impact that will only decrease the frequency of occurrence of native species.<br>Rationale<br>Considering the natural characteristics of the fish assemblage and its habitat, and when comparing a pair of fish metric groups,<br>Which member in the pair would contribute most to a decline or improvement in the fish assemblage integrity if it was to change for whatever reason?<br>Approach:<br>The pair with the highest importance in this situation would then receive the highest rating out of 10 with the residue being awarded to the member with the lower contribution. If both members are equally important, both would receive a rating of 5<br>Considerations:<br>Metric groups: VEL_DEPTH, COVER, FLOW_MOD, PHYSCHEM, the number of species in each metric group, their intolerances as well as habitat characteristics should be taken as the basis of comparison between members of a pair.<br><br>Metric group: MIGRATION, the number of species with various migration requirements should be considered.<br><br>Metric group: INTRO, the characteristics and distribution of the introduced species should be considered together with the vulnerability of the indigenous species. This refers only to species that have already been introduced to system and not to species that can potentially be introduced. |
| EC RESULTS | The results (Ecological Category) of the FRAI assessment is provided here in terms of automated model assessment as well as the adjusted calculation. Both values should be reported with explanations as to the reasons for adjusting the automated assessment. A table with summary information on the species in the assemblage. |

# 2 FRAI INTERPRETATION OF EC RESULTS

Two examples of the FRAI EC results will be interpreted here. Only the contribution of metric groups' values to the FRAI index value will be discussed in terms of its significance and implications.

## 2.1 EXAMPLE 1

Table 2.1 indicates the weights of the different metric groups. According to this, the flow modification metric group carries the most weight followed by the velocity-depth and physico-chemical metric groups. All of these have a strong link with flow. No introduced species are present.

**Table 2.1    Example 1, Metric group weights**

| METRIC GROUP | WEIGHT (%) |
|---|---|
| Velocity-depth | 92.65 |
| Cover | 82.35 |
| Flow modification | 100.00 |
| Physico-chemical | 98.53 |
| Migration | 55.88 |
| Impact of introduced species | 0.00 |

Table 2.2 indicates the EC results of the FRAI assessment. According to this species with a high preference for clear, flowing water and perennial flow decreased in frequency of occurrence compared to the reference. Habitat integrity assessment indicated that the flow in the river decreased considerably with a decrease in fast flowing habitats during the breeding season in particular. According to this information it is suspected that the decrease in the fish EC is primarily due to modified flow conditions which had a detrimental impact

**Table 2.2    Example 1, FRAI EC results.**

| AUTOMATED | | | |
|---|---|---|---|
| FRAI (%) | 65.6 | | |
| EC: FRAI | C | | |

| ADJUSTED | | | |
|---|---|---|---|
| FRAI (%) | 65.6 | | |
| EC: FRAI | C | | |
| **ABBREVIATIONS: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)** | **SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)** | **REFERENCE FREQUENCY OF OCCURRENCE** | **PES:OBSERVED & HABITAT DERIVED FREQUENCY OF OCCURRENCE** |
| CPRE | CHILOGLANIS PRETORIAE VAN DER HORST, 1931 | 5.00 | 2.00 |
| CBIF | CHILOGLANIS BIFURCUS JUBB & LE ROUX, 1969 | 3.00 | 1.00 |
| AURA | AMPHILIUS URANOSCOPUS (PFEFFER, 1889) | 5.00 | 1.00 |
| AMOS | ANGUILLA MOSSAMBICA PETERS 1852 | 3.00 | 2.00 |
| BPOL | LABEOBARBUS POLYLEPIS BOULENGER, 1907 | 4.00 | 3.00 |
| BARG | BARBUS ARGENTEUS GÜNTHER, 1868 | 5.00 | 2.00 |
| ANAT | AMPHILIUS NATALENSIS BOULENGER, 1917 | 3.00 | 1.00 |
| BMAR | LABEOBARBUS MAREQUENSIS SMITH, 1841 | 5.00 | 4.00 |

## 2.2   EXAMPLE 2

Table 2.3 indicates the weights of the different metric groups. The same native species as in example 1 are present. In this case a predaceous species with severe ecological impact was introduced.

**Table 2.3    Example 2, Metric group weights.**

| METRIC GROUP | WEIGHT (%) |
|---|---|
| Velocity-depth | 91.38 |
| Cover | 79.31 |
| Flow modification | 100.00 |
| Physico-chemical | 98.28 |
| Migration | 48.28 |
| Impact of introduced species | 86.21 |

Table 2.4 indicates the EC results of the FRAI assessment. The introduction of a predaceous species with a severe impact resulted in a considerable decrease in the frequency of occurrence of the reference fish assemblage with a consequent decrease in the FRAI value and category.

**Table 2.4    Example 2, FRAI EC results**

| AUTOMATED | | |
|---|---|---|
| **FRAI (%)** | 44.4 | |
| **EC: FRAI** | D | |
| **ADJUSTED** | | |
| **FRAI (%)** | 44.4 | |
| **EC: FRAI** | D | |
| **ABBREVIATIONS: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)** | **SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED)** | **REFERENCE FREQUENCY OF OCCURRENCE** | **PES: OBSERVED & HABITAT DERIVED FREQUENCY OF OCCURRENCE** |
| CPRE | CHILOGLANIS PRETORIAE VAN DER HORST, 1931 | 5.00 | 1.00 |
| CBIF | CHILOGLANIS BIFURCUS JUBB & LE ROUX, 1969 | 3.00 | 0.00 |
| AURA | AMPHILIUS URANOSCOPUS (PFEFFER, 1889) | 5.00 | 0.00 |
| AMOS | ANGUILLA MOSSAMBICA PETERS 1852 | 3.00 | 2.00 |
| BPOL | LABEOBARBUS POLYLEPIS BOULENGER, 1907 | 4.00 | 2.00 |
| BARG | BARBUS ARGENTEUS GÜNTHER, 1868 | 5.00 | 1.00 |
| ANAT | AMPHILIUS NATALENSIS BOULENGER, 1917 | 3.00 | 1.00 |
| BMAR | LABEOBARBUS MAREQUENSIS SMITH, 1841 | 5.00 | 3.00 |

# 3  FRAI: PREDICTIVE USES

Using the FRAI model, it is possible to make some qualitative predictions as to how the fish assemblage is likely to respond when changes in driver components, and specifically particular driver metrics, are changed. Essentially these predictions will be of a conceptual nature, with uncertain confidence of how close to reality they actually are.

Two questions can be posed as an example:

1. How would the fish assemblage react if certain flow characteristics were changed?

This may be an increase in low flow duration compared to the current situation and may, for instance, occur during the spawning season.  The attributes of the assemblage and the severity of increase in low flow periods would be key considerations. It would then be possible to predict how species dependent on particular habitat conditions, would respond to such changes when impacts on their spawning and nursery habitat, as well as physico-chemical conditions are considered.

2. What would an increase or decrease in the fish assemblage integrity relate to?

In such a case, one would attempt to relate such a change to particular driver changes. The PES of the fish assemblage may, for instance, be lower than desired or required (the REC). To increase the PES one would focus on particular metric groups and metrics in a group that were indicated by the FRAI as being prominent in the decrease of the assemblage integrity. To improve such metrics and metric groups would entail improving environmental conditions for the associated species and this would than be related to certain driver changes.

# 4   FRAI USES WITHIN MONITORING

The purpose of using the FRAI within a monitoring framework relates to posing hypotheses as to the REC for the river and the fish.  With such an approach the FRAI can be used in a predictive manner (cf. 3) to derive an REC as well as alternative ECs. These could then be used as the basis of monitoring the attainment of a particular REC in terms of the fish assemblage by considering the response of particular metrics and metric groups when an ecological Reserve is implemented. Monitoring will provide the basis to determine if the ecological objectives are being achieved in terms of the fish assemblage as it was derived based on the FRAI. Adaptive environmental monitoring and assessment can provide the framework within which the monitoring information can be used to re-assess and review the attainment of the ecological objectives for the river (Holling, 1978; Rogers and Bestbier, 1997; Roux et al., 1999).

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# A APPENDIX A: RATIONALE FOR FISH ASSEMBLAGE ASSESSMENT

## A.1 FISH STRESS

Fish stress is described and characterized as follows -

- It is viewed as a condition where the response to a stimulus or stressor results in a state where an extension of the physiological condition occurs beyond the normal resting phase (Brett, 1958).
- Stress is seen as a state of threatened homeostasis that is re-established by a complex of adaptive responses (Chrousos, 1998). In this sense, response to stress is an adaptive mechanism that permits the fish to cope with stressors in order to maintain its normal or homeostatic state and is not necessarily detrimental to the fish.
- The mechanism of stress response is complex and involves primary (neuroendocrine), secondary (metabolic) and tertiary responses. Tertiary responses involve whole-animal performance characteristics (growth, swimming capacity and disease resistance) and modified behavioural patterns (feeding and aggression). These three levels of stress response are integrated and interregulated (Barton *et al.*, 2002).

Stressors have been grouped according to Barton *et al.*, 2002 -

- Chemical (e.g. contaminant and pollution exposure, low oxygen concentrations and acidification),
- Physical (e.g. handling capture, confinement and transport),
- Perceived (e.g. stimuli evoking startle response and presence of a predator)
- The general adaptation syndrome (Selye, 1950) states that a fish passes through three stages of response to stress -
- An alarm phase during which the fish perceives the stimulus and recognition of it as a threat to homeostasis,
- A resistance stage when the fish mobilizes its resources to adjust to the disturbance and maintain homeostasis,
- An exhaustion phase that follows if the fish, in spite of activating a stress response, is incapable of coping with the disturbance.

The first two phases are manifested by measurable physiological changes. The last phase is the maladaptive phase, usually associated with the development of pathological states that influence the health and condition of fish and that can eventually result in mortality (Barton *et al.*, 2002).

Studies have shown that repeated exposure to mild stressors can habituate fish and attenuate the neuroendocrine and metabolic responses to subsequent exposure to stressors (Reid *et al.*, 1998). However, if the intensity of the stressor is very severe

or long-lasting, physiological response mechanisms may be compromised and can become detrimental to the fish's health and well-being, causing "distress" (Barton *et al.*, 2002). In this context the response of the immune system must also be considered. If this system is compromised, increased susceptibility to diseases will occur. Overcrowding, rapid changes in temperature, salinity and dissolved oxygen are common stressors affecting immuno-competence in fish (Rice and Arkoosh, 2002).

The detailed relationship between stress that impacts individual fish, then the population and eventually the assemblage or community, is highly complex. However, for the purposes of predicting and assessing the response of fish, it is assumed that stress on an individual fish will eventually be manifested in the population and assemblage.

## A.2 FISH HABITAT

The quantity and quality of available habitat can be used as an indirect indication of the effect of stressors on individual fish and populations. This relationship between habitat condition and fish condition is possible because characteristics of fish evolve in response to the properties of habitats. The habitat is the template on which life-history strategies are formed (Southwood, 1977; DeAngelis & Curnutt, 2002). Following this, predictions on the traits of individual fish species present (as well as assemblage characteristics such as species richness) can be made on basis of the habitat.

For the assessment and evaluation of the fish assemblage response to habitat conditions, it is important that fish habitat and its components be properly defined (Bain & Stevenson, 1999) -

- Habitat: "specific type of place within an ecosystem occupied by an organism, population or community that contains both living and nonliving components with specific biological, chemical, and physical characteristics including the basic life requirements of food, water, and cover or shelter."
- Habitat component: "single element (such as velocity, depth, or cover) of the habitat or area where an organism lives or occurs. Component is synonymous with attribute."
- Habitat diversity: The number of different habitat types within a given area.

More specifically for the purposes of this study, habitat is specifically defined as - Any particular combination of velocity, depth, substrate and associated cover (such as marginal and overhanging vegetation, undercut banks, root wads, aquatic macrophytes, water column), physico-chemical attributes (such as temperature, oxygen concentration, turbidity) and biological attributes (that is, food sources) that provide a fish with its life-stage requirements at that particular point in time and geographically.

Within the scope of this definition, consideration should be given to the duration of the combination of these habitat features to satisfy the requirements of particular life-

history stages of a species during particular seasons or events.

## A.3 INTERPRETATION OF FISH ASSEMBLAGE RESPONSES TO HABITAT CHANGES

Over evolutionary time, A particular habitat or a range of habitats used by fish species shape their characteristics.  It follows that species do best in the habitats in which they evolved and that changes in habitat extent and characteristics can impose various levels of stress on populations. Changes in habitat may, therefore, be indicators of the well-being or condition of particular species or assemblages (DeAngelis & Curnutt, 2002).

A particular combination of habitat features may not necessarily provide optimum conditions for the specific life-history stage requirements of a fish at the time, frequency, duration and place when they are required.  This may be the result of anthropogenic impacts on the habitat (such as flow reduction, sedimentation of habitat, and physico-chemical changes), or it may even be a situation where a particular species occurs only marginally and is, even under natural conditions existing under sub-optimal conditions.  This relates to stress, and will result in compensatory mechanisms being activated in order to establish homeostasis in response to these stressors.  It follows that species occurring marginally, and which are naturally already subject to higher stress than under optimal conditions, will have a narrow stress buffer.  In such as case, a relatively "small" decrease in the flow may, for example, already result in a pronounced stress effect due to particular critical habitats or critical habitat features being in limited supply naturally.  It follows that differences in the requirements of different species constituting the fish assemblage may result in a change in the assemblage when the natural flow regime changes (including natural disturbance regimes).

It is essential to consider all habitat features, both flow and non-flow related, even if they are difficult to measure and predict quantitatively (types of cover, physico-chemical attributes, flow, the food source, for instance).  Even when flow and the resulting hydraulic habitat seems suitable for a particular EC and species requirements, responses of features such as temperature, oxygen and the available food source may be so negative that the ability of a species to adapt to such conditions may become severely compromised.

Habitat assessment as an indirect indicator of stress as such can never be an ideal replacement for direct measurement of fish condition.  However, it is acknowledged that measuring responses of fish populations and assemblages to environmental disturbance can be very difficult, and that surrogate approaches (even if they are imperfect) are needed wherever possible to assess these changes (DeAngelis & Curnutt, 2002).

The approach followed here to assessing fish response to driver characteristics is

based on a qualitative combination of species attributes, habitat resulting from driver changes and fish survey information.

## A.4 FISH INTOLERANCE AND HABITAT PREFERENCE DATABASE

The sections that follow address the information contained in a database that was compiled in 2001 and the approach that was followed to obtain this information (Kleynhans, 2003). The database information used in the FRAI is contained in the FRAI spreadsheet model.

### A.4.1  Species intolerance ratings

Intolerance in this context refers to the degree to which a species is able to withstand alterations of the environmental conditions under which it occurs. This includes modification of physical habitat characteristics (such as depth, velocity, marginal vegetation, bottom substrate, food source), as well as physico-chemical characteristics of the water. Habitat preferences provide a large amount of information that 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 and expert knowledge.

Two components are taken into account in estimating the intolerance of fish species for calculation of the FRAI: requirement for flowing water during different life-stages; and association with unmodified physico-chemical conditions. Both of these aspects are scored for a species according to -
- Low requirement / specialisation (rating = 1),
- Moderate requirement / specialisation (rating = 3) and
- High requirement / specialisation (rating = 5).

Intolerance ratings for each of the two components provided by experts are averaged and the average interpreted as -
- 1-2 = Tolerant
- >2-3 = Moderately tolerant
- >3-4 = Moderately intolerant
- >4-5 = Intolerant

The assessment of the two components of species intolerance is approached in the following way:

### A.4.1.1          *Requirements for flowing water during different life-stages*

Species differ with regard to their requirements for flowing water during different life-stages. The work of Crass (1964), Gaigher (1969), Pienaar (1978), Kleynhans

(1984), Bell-Cross and Minshull (1988), Skelton (1993), Weeks *et al.* (1996), and Russel and Rogers (1998) should be consulted for information on habitat preferences. Three general groups are distinguished –

- Species not requiring flow during any part of the life-cycle. However, increased habitat suitability and availability resulting from increased flow can be expected to benefit such species. With some species, flow will stimulate breeding activities and stimulate migration. Score = 1
- Species requiring flow during certain phases of the life-cycle - to breed in particular habitats (often fast flows) for instance, or make nursery areas with suitable cover available. Generally, increased habitat suitability and availability resulting from increased flow can be expected to benefit such species. Flow will stimulate breeding activities and stimulate migration. Score = 3
- Species requiring flow during all phases of the life-cycle. Often prefer fast flow and clear water and use these conditions both for breeding and feeding purposes. Score = 5

### A.4.1.2 *Requirement for unmodified physico-chemical conditions*

Very little information on the physico-chemical requirements of South African fish is available. Consequently, resort has to be made to the previously-observed associations of certain fish species with modified and unmodified physico-chemical conditions as compared to the reference. This can take the form of the association of fish species with different habitats in a variety of geographical areas. For instance, the preference of some species for fast flowing, turbulent, clear water tend, in natural or minimally developed catchments, to be associated with habitats with unmodified physico-chemical conditions. Conversely, in catchments that are extensively developed and the water often polluted, some species will still be able to survive in habitats such as pools, which may even be stagnant. It is surmised that these species are relatively tolerant to impaired physico-chemical conditions. This approach is similar to that followed by Lyons *et al.* (1995) in information-scarce situations in Mexico. The following general rating approach is followed -

- Species that can survive and breed under severely modified physico-chemical conditions - Score = 1.
- Species that can survive and breed under moderately modified physico-chemical conditions -. Score = 3.
- Species that require largely unmodified physico-chemical conditions to survive and breed - Score = 5.

Due to the lack of any detailed information this approach must be seen at best as giving an indirect and relative indication of physico-chemical requirements.

### A.4.2 Species preference ratings

### A.4.2.1 *Velocity-depth preferences*

Fish species velocity-depth preferences were scored according to the preference for

the four velocity-depth classes (cf. 1.2.3) –

- Slow-shallow
- Slow-deep
- Fast-shallow
- Fast-deep

Each of these is scored according to –

- 0 = No preference/irrelevant
- 1 = Low  preference
- 3 = Moderate preference
- 5 = High preference

Velocity-depth preferences provided by experts are averaged and the average interpreted as –

-  0 = No preference / irrelevant
- >0 -1= Very  low preference – coincidental?
- >1-2 = Low preference
- >2-3 = Moderate preference
- >3-4 = High preference
- >4-5 = Very high preference

### A.4.2.2      *Cover preferences*

These features are considered to provide fish with the necessary cover (such as refuge from high flow velocity, predators and high temperatures) to utilise a particular velocity-depth class (Kleynhans, 1999):

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

Each of these is scored according to:

- 0 = No preference / irrelevant
- 1 = Low  preference
- 3 = Moderate preference
- 5 = High preference

## A.5  THE RELATIONSHIP BETWEEN DRIVERS AND FISH METRIC GROUPS

The following metric groups and metrics were selected as potentially good indicators of changes in fish assemblages and habitat conditions.

### A.5.1 Velocity-depth classes

This metric group is assessed based on a change in the "commonness" of the velocity-depth classes compared to the reference condition, and the response of the fish assemblage to the changes. This assessment is based on baseflow (low flow) conditions usually within the dry season (when surveys usually occur). However, apart from considering conditions during sampling, the general change based on driver information should be derived for all seasons.

#### A.5.1.1        *Velocity-depth class changes*

Information from the geomorphological (sediment movement) and hydrological (flow modifications) driver groups are used to do the assessment. These changes can be based on empirical information supplemented by derived changes to the fish assemblage or based on the changes to driver components that will be reflected by particular fish species responses:
- Commonness of fast-deep conditions
- Commonness of fast-shallow conditions
- Commonness of slow-deep conditions
- Commonness of slow-shallow conditions

These changes are rated according the following scheme:
- -5 = Extreme loss from reference (absent)
- -4 = Serious loss from reference
- -3 = Large loss from reference
- -2 = Moderate loss from reference
- -1 =  Small loss from reference
- 0 = No change from reference
- 1 =  Small increase from reference
- 2 = Moderate increase from reference
- 3 = Large increase from reference
- 4 = Serious increase from reference
- 5 = Extreme increase from reference (completely dominant)

This assessment of the change of velocity-depth classes from the reference condition is used as a basis for the rating of  changes in the fish assemblage However, these ratings  are independent of the fish assemblage response, that is, the ratings are not factored into the fish response assessment in the FRAI model.

#### A.5.1.2        *Fish assemblage changes*

To provide a reasonable level of response interpretation, only fish species with a high or very high preference for the respective velocity-depth groups are considered.

Based on empirical fish data, as well as derived data (based on velocity-depth class

changes), and with reference to velocity-depth class preferences of the fish species, how did the following change?

- Response of species with high to very high preference for fast-deep conditions
- Response of species with high to very high preference for fast-shallow conditions
- Response of species with high to very high preference for slow-deep conditions
- Response of species with high to very high preference for slow-shallow conditions

The rating system follows the approach indicated under the velocity-depth class metric group.

### A.5.2  Cover

Species have particular requirements for habitat conditions that provide cover from adverse environmental conditions and predation. A modification in habitat may be related to flow changes (increase or decrease) or physical modification such as bank collapse and sedimentation.

#### A.5.2.1      *Cover class changes*

Information from the geomorphological and hydrological components and metrics, as well as the riparian vegetation, is used to do the assessment. These changes can be based on empirical information supplemented by derived changes to the fish assemblage, or based on the changes to driver components and metrics that will be reflected by particular fish species responses:

- Commonness of overhanging vegetation
- Commonness of undercut banks and root wads
- Commonness of substrate types that can serve as cover
- Commonness of instream vegetation
- Commonness of sufficient water column depth that can serve as cover

The rating system follows the approach indicated under the velocity-depth class metric group.

This assessment of the change of cover classes from the reference condition is used as a basis for the rating of changes in the fish assemblage. However, these ratings are independent from the fish assemblage response, that is, the ratings are not factored into the fish response assessment in the FRAI model.

#### A.5.2.2      *Fish assemblage changes*

To provide a reasonable level of response interpretation, only fish species with a high or very high preference for the respective cover classes are considered.

- Response of species with a very high to high preference for overhanging vegetation. Reduction may indicate lowered water levels, bank erosion or physical destruction of overhanging vegetation.

- Response of species with a very high to high preference for undercut banks and root wads. Reduction may indicate lowered water levels, bank erosion and bank collapse.
- Response of species with a high to very high preference for a particular substrate type. Reduction may indicate sedimentation (embedding of cobbles and gravel in riffles, for instance), or algal growth.
- Response of species with a high to very high preference for instream vegetation. Reduction may indicate lowered water levels or physical destruction of aquatic macrophytes.
- Response of species with a very high to high preference for the water column. Reduction of species may indicate lowered water levels or loss of depth due to sedimentation (in pools). Predation from aerial predators may be an important factor.

The rating system follows the approach indicated under the velocity-depth class metric group.

### A.5.2.3    Flow modification

This metric group is interpreted based entirely on the level of requirement that various species (or life-stages of a species) have for flowing water. The aspects of the impact of flow modification on physical habitat attributes are considered under other metric groups such as cover and velocity-depth classes.

### A.5.2.4    Changes in flow characteristics

Information from the hydrological driver group is used for the assessment. These changes can be based on empirical information supplemented by derived changes to the fish assemblage or based on the changes to driver components that will be reflected by particular fish species responses -
- Increase or decrease in no-flow conditions
- Increase or decrease in low-flow conditions
- Change in seasonality
- Increase or decrease in moderate events
- Increase or decrease in events (high flow, floods)

The rating system follows the approach indicated under the velocity-depth class metric group.

This assessment of the change of cover classes from the reference condition is used as a basis for the rating of  changes in the fish assemblage However, these ratings are independent from the fish assemblage response, that is, the ratings are not factored into the fish response assessment in the FRAI model.

### A.5.2.5    Fish assemblage changes

Fish response assessment is based on empirical information supplemented by derived changes to the fish assemblage, or based on hydrological driver changes that will be reflected by particular fish species responses.

- Response of species intolerant of no-flow conditions
- Response of species moderately intolerant of no-flow conditions
- Response of species moderately tolerant of no-flow conditions
- Response of species tolerant of no-flow conditions

Rating of these responses follows the approach indicated under velocity-depth class metric group.

## A.5.3 Response to physico-chemical conditions: health and condition

Health and condition of species are a reflection of the well-being of fish. Adverse environmental conditions (caused by decrease in food availability, modified physico-chemical conditions, decrease in preferred habitat, for instance, all of which may be related to flow alteration) may result in physiological stress conditions that impact on the immune system of species, resulting in deterioration of health and condition. For the FRAI, modified physico-chemical conditions are the primary consideration.

### A.5.3.1 *Changes in physico-chemical conditions*

The following physico-chemical driver information is used to assess potential responses of the fish assemblage:

- pH
- Salts
- Nutrients
- Temperature
- Turbidity
- Oxygen
- Toxics

In the absence of a specific physico-chemical assessment, ratings are done according to:

- 0 = No change from reference
- 1 =  Small change from reference
- 2 = Moderate change from reference
- 3 = Large change from reference
- 4 = Serious change from reference
- 5 = Extreme change from reference

### A.5.3.2 *Fish assemblage changes*

Direct observation of health assessment is based on observations on deformities, fin erosion, lesions and tumours (DELT) and consideration of driver status. Where such information is limited, information on the physico-chemical driver group should be

used to derive the expected response of the species expected under reference conditions. For the purpose of the FRAI determination, it is accepted that all species should be in a healthy condition (reference = 0) and that deviation from this could only be negative.

Health and condition responses are considered in terms of four metrics -
- Response of  species intolerant of modified physico-chemical conditions
- Response of species moderately intolerant of modified physico-chemical conditions
- Response of species moderately tolerant of modified physico-chemical conditions
- Response of  species tolerant of modified physico-chemical conditions

Rating of responses is as for the changes in physico-chemical conditions.

## A.5.4          Migration

The severity of the impact of obstruction of fish movement on the distribution, abundance and survival of a fish species in the particular river forms the basis of the assessment.  Migration can be related to breeding, feeding and survival life-history strategies.

### A.5.4.1          *Changes in population connectivity*

Any modification that results in the fragmentation of fish populations is considered.

The presence and extent of the following are considered in evaluating the impact on and response of migratory species:
- Weirs and causeways
- Impoundments
- Physico-chemical barriers
- Flow modifications

These changes are rated according the following -
- 0 = None, or no potential impact
- 1 =  Small; limited with small potential impact on movement.
- 2 = Moderate; notable and with potential impact on movement.
- 3 = Large; clear potential impact on movement.
- 4 = Serious; clear  and serious potential impact on movement.
- 5 = Extreme; clear and critical potential impact on the movement.

This assessment of the potential loss of connectivity is used as a basis for the rating of  changes in the fish assemblage However, these ratings  are independent from the fish assemblage response, that is, the ratings are not factored into the fish response assessment in the FRAI model.

### A.5.4.2          *Fish assemblage changes*

Distribution and abundance responses of migratory species are based on empirical information or can be derived from the potential impact of various geomorphological, hydrological and physico-chemical changes. Three broad levels of migratory requirements form the basis of the assessment :

- Response in terms of distribution/abundance of species with catchment scale movements
- Response in terms of distribution/abundance of species with requirement for movement between reaches or fish habitat segments
- Response in terms of  distribution/abundance of species with requirement for movement within reach or fish habitat segment

Ratings are done according to -

- 0 = No change from reference
- 1 =  Small change from reference; only a small part of the stream network or reach is inaccessible
- 2 = Moderate change from reference; moderate part of the stream network or reach is inaccessible
- 3 = Large change from reference; a large part of the stream network or reach is inaccessible
- 4 = Serious change from reference; an extensive part of the stream network or reach is inaccessible
- 5 = Extreme change from reference; the entire stream network or reach is inaccessible

### A.5.5   Introduced species

The relevance of this metric group is that introduced species may have a dominant impact on the native fish assemblage, while the physical drivers may actually be in a close to reference condition. In this sense, the introduced species metric can be seen as a modifying determinant that does not necessarily impact the fish assemblage through habitat changes as the other metric groups do.

Introduced fish species can have a severe effect on the habitat structure (indirectly influencing the natural fish assemblage) and the fish assemblage structure itself through predation. The potential impact of the species is based on the characteristics of the species (that is, its size, trophic preferences and feeding methods). The distribution (and indirectly the abundance) is considered to be another aspect that will determine the impact of an introduced species (that is, whether it has highly invasive properties and is generally tolerant to environmental conditions). The number of introduced species under each metric should also be considered.

The attributes of the native species present should be considered in terms of how vulnerable they are to the impact of introduced species. The habitat characteristics in the river delineation, in combination with the requirements of the introduced species, can also be used to derive the impact of such species on the native ones. For the

purpose of the FRAI determination, no introduced species should be present (reference = 0), and any deviation from this can only be regarded as resulting in a decrease in the frequency of occurrence of native species vulnerable to introduced species' impact..

Two groups of introduced species are considered in terms of competition (predation and competition for resources) and habitat modifying impacts -

- The potential competition impact of introduced (including predators) species.
- How widespread (frequency of occurrence) are introduced competitors
- The potential impact of introduced habitat modifying species.
- How widespread (frequency of occurrence) are habitat modifying species.

### A.5.5.1    Impact guidelines

- Predaceous species / habitat modifying species with a critical impact on native species = 5
- Predaceous species / habitat modifying species with a serious impact on native species = 3-4
- Predaceous species / habitat modifying species with a  moderate impact on native species = 2-1
- Predaceous species / habitat modifying species with no impact on native species, or are absent completely = 0

### A.5.5.2    Distribution guidelines

-  0 = absent
- 1 = present at very few sites (<10%)
- 2 = present at few sites (>10-25%)
- 3 = present at about >25-50 % of  sites
- 4 = present at most sites (>50-75%)
- 5 = present at almost all sites (>75%)

## A.6    RATING AND  WEIGHTING OF METRICS

### A.6.1  Rating

The principle of the approach was that the frequency of occurrence of a species in combination with its intolerance or preference, provides information on the change of the fish assemblage from the reference condition. For this calculation the reference frequency of occurrence must be estimated and the present (or observed) frequency of occurrence determined or derived from habitat conditions.

For the velocity-depth, cover, flow modification and physico-chemical metric groups the following procedure was followed to calculate ratings and weights for each metric:

$$Rt= \sum (RFr \times Int)/(25))/\sum(OFr \times Int)/25$$

Where:

Rts= rating for metric

RFr=reference frequency of occurrence for each species

I nt=Intolerance rating for each species (or preference rating)

The result of this calculation was transformed to a value between -5 to 5

## A.6.2  Weighting

This was determined by firstly proportioning the rating of a metric according to the number species in that metric:

$$Mp=Rt/Nsp$$

Where:

Mp=Metric proportion

Nsp=number of species

This was done for each metric in a group. The metric with the highest proportion was used as the basis to proportion the other metrics. This means that the metric with the highest proportion would be the one where the metric rating  was fully applied in the assessment (100% of the rating), and the ratings of the rest proportionally less.

## A.7    DETERMINING THE WEIGHT OF METRIC GROUPS

Metric group weight is determined according to an Analytical Hierarchical Procedure (AHP) (Saaty, 1980; US Army Corps of Engineers, 1980). The purpose of this approach is to provide a reasonably objective way to determine the weights of metric groups. An AHP approach is followed where the metric groups are compared pairwise on a 0 – 10 scale with 0.5 intervals. Metric group weights are determined in the FRAI model sheet: METRIC GROUP WEIGHTS.

The objective is to determine the weight of various metric groups as it relates to the natural attributes and requirements of the reference fish assemblage. Introduced species are not a natural attribute or requirement is  considered  in a different (negative) context.

The basic question is:

Considering
- The natural characteristics of the fish assemblage and its habitat, and
- when comparing a pair of fish metric groups,

which member in the pair would contribute most to a decline or improvement in the fish assemblage integrity if it was to change for whatever reason?

Approach:
The pair with the highest importance in this situation would then receive the highest rating out of 10 with the residue being awarded to the member with the lower contribution. If both members are equally important, both would receive a rating of 5

Considerations:

- Metric groups: VEL_DEPTH, COVER, FLOW_MOD, PHYSCHEM, the number of species in each metric group, their intolerances as well as habitat characteristics should be taken as the basis of comparison between members of a pair.
- Metric group: MIGRATION, the number of species with various migration requirements should be considered.
- Metric group: INTRO, the characteristics and distribution of the introduced species should be considered together with the vulnerability of the indigenous species. This refers only to species that have already been introduced to system and not to species that can potentially be introduced.

## A.8    FORMULATION OF THE FRAI

Metric groups (Mg):

1) For velocity-depth, flow modification, cover, physico-chemical and migration metric groups:

$$Mg = 100 - ((Obs \textstyle\sum Metric \; X \; w)/(Ref \; \textstyle\sum Metric \; X \; w) * 100)$$

Where:

Mg= Relative condition of metric group (%)
Obs=Observed rating for metric
Ref=Reference rating for metric
w   = Weight of metric

2) For introduced species metric group:

$$Pig = ((Obs \textstyle\sum metric \; x \; w)/(Max \textstyle\sum metric \; x \; w) * 100$$

Where;

Pig=Potential impact of introduced species group(%)

Obs= Rated potential impact of species observed to be present
Max=Maximum potential impact of species present
    w= Weight of metric

Fish Response Assessment Index (FRAI):

FRAI = (∑Mg X w) – (Pig X wi)

Where:

FRAI= Relative integrity of fish assemblage (%)
Mg   = Relative condition of metric group
  w   = Weight of metric group
Pig   = Potential impact of introduced species metric group(%)
  wi   = Weight of Pig metric group in terms of  vulnerability of native fish assemblage.

# B  APPENDIX B:  FISH DATA SHEETS

Table B.1        Site information (adapted from Dallas 2005)

| Assessor Name(s) | | | | |
|---|---|---|---|---|
| Organisation | | | Date | /          / |

**Site information -** assessed at the site

| RHP Site Code | | Project Site Number | |
|---|---|---|---|
| River | | Tributary of | |
| Farm Name: | | Farm Reg. Code: | |

Latitude and longitude co-ordinates:

Degrees-minutes-seconds      or  Decimal degrees       or  Degrees & decimal minutes

| S | ° | ' | . " | S | . | ° | S | ° | . | ' | Cape datum Clarke | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E 0 | ° | | . " | E 0 | . | ° | E 0 | ° | . | ' | WGS-84 datum HBH94 | |

| Site Description | | | | | |
|---|---|---|---|---|---|
| Map Reference (1: 50 000) | | Site Length (m) | | Altitude (m) | |

| Longitudinal Zone | Source zone | Mountain headwater stream | Mountain stream | Transitional | Upper foothill | Lower foothill | Lowland river |
|---|---|---|---|---|---|---|---|

| Rejuvenated cascades (gorge) | Rejuven-ated foothill | Upland floodplain | Other: | |
|---|---|---|---|---|

| Associated Systems: | Wetland | Estuary | Other: | | Distance: | |
|---|---|---|---|---|---|---|
| Additional Comments: | | | | | | |

**Desktop / spatial information** – data used for classifying a site and subsequent querying of data

| Political Region | | Water Management Area | |
|---|---|---|---|
| Ecoregion I | | Ecoregion II | |
| Secondary Catchment | | Quaternary Catchment | |
| Water Chemistry Management Region | | | |
| Vegetation Type | | Geological Type | |
| Contour Range (m): From: | | to: | |
| Source Distance (km) | | Stream Order | |
| Rainfall Region | Summer | Winter | Aseasonal | Other: |
| DWAF Gauging Station | Yes | No | Code: | | Distance Upstream | | Or Downstream | |

**Table B.2    Velocity-depth classes sampled and effort.**

Indicate which velocity-depth classes were sampled.  Where the mosaic of velocity-depth classes makes it difficult or impossible to sample classes separately (e.g. combinations of fast-deep and fast-shallow classes), the dominant velocity-depth class should be used as the unit of reference for sampling effort, but the presence of other velocity-depth classes should also be indicated.

| Sampling effort | Slow deep (SD) | Slow shallow (SS) | Fast deep (FD) | Fast shallow (FS) |
|---|---|---|---|---|
| Dominant velocity-depth class | | | | |
| Electro shocker (min) | | | | |
| Small seine (mesh size, length, depth, efforts) | | | | |
| Large seine (mesh size, length, depth, efforts) | | | | |
| Cast net (dimensions, efforts) | | | | |
| Gill nets (mesh size, length, time) | | | | |

Remarks:


**Table B.3    Fish caught (Indicate where velocity-depth combined)**

| Habitat (velocity-depth class(es) | |
|---|---|
| **Sampling method:** | |
| **Species** | **Number (J = juvenile, A = abnormality)** |
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# C  APPENDIX C:  FRAI SPREADSHEETS

## SURVEY DATA

**include information on site sampled**

| SITE NUMBER: | LATITUDE | LONGITUDE | QUAT | MAJOR RIVERS | TRIBUTARY | ECOREGION | GEOMORPH ZONE | ALTITUDE (m) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

| DATE | | TIME: | | | |
|---|---|---|---|---|---|
| WIDTH: | | GENERAL FLOW: | | | |

**FISH VELOCITY-DEPTH CLASSES AND COVER PRESENT AT SITE**
(Abundance: 0=absent; 1=rare; 2=sparse; 3=moderate; 4=abundant; 5=very abundant)

| SLOW DEEP: | SLOW SHALLOW: | FAST DEEP: | FAST SHALLOW: |
|---|---|---|---|
| Overhanging vegetation: | Overhanging vegetation: | Overhanging vegetation: | Overhanging vegetation: |
| Undercut banks & root wads: | Undercut banks & root wads: | Undercut banks & root wads: | Undercut banks & root wads: |
| Substrate: | Substrate: | Substrate: | Substrate: |
| Aquatic macrophytes: | Aquatic macrophytes: | Aquatic macrophytes: | Aquatic macrophytes: |
| Water Column: | Water Column: | Water Column: | Water Column: |
| Remarks: | Remarks: | Remarks: | Remarks: |

**HABITATS SAMPLED AND EFFORT**

| SAMPLING EFFORT | SLOW DEEP | SLOW SHALLOW | FAST DEEP | FAST SHALLOW |
|---|---|---|---|---|
| Electro schocker (min) | | | | |
| Small seine (mesh size, length, depth, efforts) | | | | |
| Large seine (mesh size, length, depth, efforts) | | | | |
| Cast net (dimensions, efforts) | | | | |
| Gill nets (mesh size, length, time) | | | | |

| SPECIES SAMPLED | SLOW DEEP | NUMBERS SLOW SHALLOW | FAST DEEP | FAST DEEP |
|---|---|---|---|---|
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## SCIENTIFIC NAMES

FRESHWATER SPECIES SCIENTIFIC NAME, ABBREVIATION AND COMMON NAME. SHADED BLOCKS INDICATE SPECIES FOR WHICH NO RATINGS WERE DONE (information provided by Skelton, 1997)
Light grey shading: Exotic and indigenous species for which ratings do exist
(ex) = exotic

| ABBREV | SCIENTIFIC NAME | ENGLISH COMMON NAME |
|---|---|---|
| AAEN | *AWAOUS AENEOFUSCUS* (PETERS, 1852) | FRESHWATER GOBY (M) |
| ABAR | *AUSTROGLANIS BARNARDI* (SKELTON, 1981) | BARNARD'S ROCK CATFISH |
| ABER | *ACANTHOPAGRUS BERDA* (FORSSKÅL, 1775) | RIVERBREAM (MS) |
| ABIC | *ANGUILLA BICOLOR BICOLOR* MCCLELLAND, 1844 | SHORTFIN EEL |
| ABRE | *ATHERINA BREVICEPS* VALENCIENNES, 1835 | CAPE SILVERSIDE |
| AGIL | *AUSTROGLANIS GILLI* (BARNARD, 1943) | CLANWILLIAM ROCK-CATFISH |
| AJOH | *APLOCHEILICHTHYS JOHNSTONI* (GÜNTHER, 1893) | JOHNSTON'S TOPMINNOW |
| AKAT | *APLOCHEILICHTHYS KATANGAE* (BOULENGER, 1912) | STRIPED TOPMINNOW |
| ALAB | *ANGUILLA BENGALENSIS LABIATA* PETERS, 1852 | AFRICAN MOTTLED EEL |
| AMAR | *ANGUILLA MARMORATA* QUOY & GAIMARD, 1824 | GIANT MOTTLED EEL |
| AMOS | *ANGUILLA MOSSAMBICA* PETERS, 1852 | LONGFIN EEL |
| AMYA | *APLOCHEILICHTHYS MYAPOSAE* (BOULENGER, 1908) | NATAL TOPMINNOW |
| ANAT | *AMPHILIUS NATALENSIS* BOULENGER, 1917 | NATAL MOUNTAIN CATFISH |
| ASCL | *AUSTROGLANIS SCLATERI* (BOULENGER, 1901) | ROCK-CATFISH |
| AURA | *AMPHILIUS URANOSCOPUS* (PFEFFER, 1889) | STARGAZER (MOUNTAIN CATFISH) |
| BAEN | *LABEOBARBUS AENEUS* (BURCHELL, 1822) | SMALLMOUTH YELLOWFISH |
| BFRI | *BARBUS AFROHAMILTONI* CRASS, 1960 | HAMILTON'S BARB |
| BAMA | *BARBUS AMATOLICUS* SKELTON, 1990 | AMATOLA BARB |
| BAND | *BARBUS ANDREWI* BARNARD, 1937 | WHITEFISH |
| BANN | *BARBUS ANNECTENS* GILCHRIST & THOMPSON, 1917 | BROADSTRIPED BARB |
| BANO | *BARBUS ANOPLUS* WEBER, 1897 | CHUBBYHEAD BARB |
| BARG | *BARBUS ARGENTEUS* GÜNTHER, 1868 | ROSEFIN BARB |
| BBIF | *BARBUS BIFRENATUS* FOWLER, 1935 | HYPHEN BARB |
| BBRI | *BARBUS BREVIPINNIS* JUBB, 1966 | SHORTFIN BARB |
| BCAL | *BARBUS CALIDUS* BARNARD, 1938 | CLANWILLIAM REDFIN |
| BCAP | *BARBUS CAPENSIS* SMITH, 1841 | CLANWILLIAM YELLOWFISH |
| BERU | *BARBUS ERUBESCENS* SKELTON, 1974 | TWEE RIVER REDFIN |
| BEUT | *BARBUS EUTAENIA* BOULENGER, 1904 | ORANGEFIN BARB |
| BGUR | *BARBUS GURNEYI* GÜNTHER, 1868 | REDTAIL BARB |
| BHOS | *BARBUS HOSPES* BARNARD, 1938 | NAMAQUA BARB |
| BIMB | *BRYCINUS IMBERI* (PETERS, 1852) | IMBERI |
| BKIM | *LABEOBARBUS KIMBERLEYENSIS* GILCHRIST & THOMPSON, 1913 | LARGEMOUTH YELLOWFISH |
| BLAT | *BRYCINUS LATERALIS* (BOULENGER, 1900) | STRIPED ROBBER |
| BLIN | *BARBUS LINEOMACULATUS* BOULENGER, 1903 | LINE-SPOTTED BARB |
| BMAR | *LABEOBARBUS MAREQUENSIS* SMITH, 1841 | LARGESCALE YELLOWFISH |
| BMAT | *BARBUS MATTOZI* GUIMARAES, 1884 | PAPERMOUTH |
| BMOT | *BARBUS MOTEBENSIS* STEINDACHNER, 1894 | MARICO BARB |
| BNAT | *BARBUS NATALENSIS* CASTELNAU, 1861 | SCALY |
| BNEE | *BARBUS NEEFI* GREENWOOD, 1962 | SIDESPOT BARB |
| BPAL | *BARBUS PALLIDUS* SMITH, 1841 | GOLDIE BARB |
| BPAU | *BARBUS PALUDINOSUS* PETERS, 1852 | STRAIGHTFIN BARB |
| BPOL | *LABEOBARBUS POLYLEPIS* BOULENGER, 1907 | SMALLSCALE YELLOWFISH |

| BRAD | *BARBUS RADIATUS* PETERS, 1853 | BEIRA BARB |
|------|-------------------------------|------------|
| BSER | *BARBUS SERRA* PETERS, 1864 | SAWFIN |
| BTOP | *BARBUS TOPPINI* BOULENGER, 1916 | |
| BTRE | *BARBUS TREURENSIS* GROENEWALD, 1958 | TREUR RIVER BARB |
| BTRI | *BARBUS TRIMACULATUS* PETERS, 1852 | THREESPOT BARB |
| BUNI | *BARBUS UNITAENIATUS GÜNTHER, 1866* | LONGBEARD BARB |
| BTRV | *BARBUS TREVELYANI* GÜNTHER, 1877 | |
| BVIV | *BARBUS VIVIPARUS* WEBER, 1897 | BOWSTRIPE BARB |
| CANO | *CHILOGLANIS ANOTERUS* CRASS, 1960 | PENNANT TAIL SUCKERMOUTH (OR ROCK CATLET) |
| CAUR | *CARASSIUS AURATUS* (LINNAEUS, 1758) | GOLDFISH (EX) |
| CBIF | *CHILOGLANIS BIFURCUS* JUBB & LE ROUX, 1969 | INCOMATI SUCKERMOUTH (OR ROCK CATLET) |
| CBRE | *CHETIA BREVIS* JUBB, 1968 | ORANGE-FRINGED LARGEMOUTH |
| CCAR | *CYPRINUS CARPIO* LINNAEUS, 1758 | CARP (EX) |
| CEMA | *CHILOGLANIS EMARGINATUS* JUBB & LE ROUX, 1969 | PONGOLO SUCKERMOUTH (OR ROCK CATLET) |
| CFLA | *CHETIA FLAVIVENTRIS* TREWAVAS, 1961 | CANARY KURPER |
| CGAR | *CLARIAS GARIEPINUS* (BURCHELL, 1822) | SHARPTOOTH CATFISH |
| CIDE | *CTENOPHARYNGODON IDELLA* (VALENCIENNES, 1844) | GRASS CARP (EX) |
| CMUL | *CTENOPOMA MULTISPINE* PETERS, 1844 | MANYSPINED CLIMBING PERCH |
| CPAR | *CHILOGLANIS PARATUS* CRASS, 1960 | SAWFIN SUCKERMOUTH (OR ROCK CATLET) |
| CPRE | *CHILOGLANIS PRETORIAE* VAN DER HORST, 1931 | SHORTSPINE SUCKERMOUTH (OR ROCK CATLET) |
| CSWI | *CHILOGLANIS SWIERSTRAI* VAN DER HORST, 1931 | LOWVELD SUCKERMOUTH (OR ROCK CATLET) |
| CTHE | *CLARIAS THEODORAE* WEBER, 1897 | SNAKE CATFISH |
| GAES | *GILCHRISTELLA AESTUARIA* (GILCHRIST, 1913) | ESTUARINE ROUND-HERRING |
| GAFF | *GAMBUSIA AFFINIS* (BAIRD & GIRARD, 1853) | MOSQUITOFISH (EX) |
| GCAL | *GLOSSOGOBIUS CALLIDUS* SMITH, 1937 | RIVER GOBY (M) |
| GGIU | *GLOSSOGOBIUS GIURIS* (HAMILTON-BUCHANAN, 1822) | TANK GOBY (M) |
| GZEB | *GALAXIAS ZEBRATUS* CASTELNAU, 1861 | CAPE GALAXIAS |
| HANS | *HIPPOPOTAMYRUS ANSORGII* (BOULENGER,1905) | SLENDER STONEBASHER |
| HCAP | *HYPORHAMPHUS CAPENSIS* (THOMINOT, 1886) | CAPE HALFBEAK (MS) |
| HMOL | *HYPOPHTHALMICHTHYS MOLITRIX* (VALENCIENNES, 1844) | SILVER CARP (EX) |
| HVIT | *HYDROCYNUS VITTATUS* CASTELNAU, 1861 | TIGERFISH |
| KAUR | *KNERIA AURICULATA* (PELLEGRIN, 1905) | SOUTHERN KNERIA |
| LCAP | *LABEO CAPENSIS* (SMITH, 1841) | ORANGE RIVER LABEO |
| LCON | *LABEO CONGORO* PETERS, 1852 | PURPLE LABEO |
| LCYL | *LABEO CYLINDRICUS* PETERS, 1852 | REDEYE LABEO |
| LMAC | *LEPOMIS MACROCHIRUS* RAFINESQUE, 1819 | BLUEGILL SUNFISH (EX) |
| LMCR | *LIZA MACROLEPIS* (SMITH, 1846) | LARGE-SCALE MULLET (MS) |
| LMOL | *LABEO MOLYBDINUS* DU PLESSIS, 1963 | LEADEN LABEO |
| LRIC | *LIZA RICHARDSONII* (SMITH, 1846) | SOUTHERN MULLET (MS) |
| LROS | *LABEO ROSAE* STEINDACHNER, 1894 (*LABEO ALTEVILIS*) | REDNOSE LABEO |
| LRUB | *LABEO RUBROMACULATUS* GILCHRIST & THOMPSON, 1913 | TUGELA LABEO |
| LRUD | *LABEO RUDDI* BOULENGER, 1907 | SILVER LABEO |
| LSEE | *LABEO SEEBERI* GILCHRIST & THOMPSON, 1911 | CLANWILLIAM SANDFISH |
| LUMB | *LABEO UMBRATUS* (SMITH, 1841) | MOGGEL |
| MACU | *MICRALESTES ACUTIDENS* (PETERS, 1852) | SILVER ROBBER |

| MARG | *MONODACTYLUS ARGENTEUS* (LINNAEUS, 1758) | NATAL MOONY (MS) |
|------|-------------------------------------------|------------------|
| MBRA | *MICROPHIS BRACHYURUS* BLEEKER, 1853 | OPOSSUM PIPEFISH (M) |
| MBRE | *MESOBOLA BREVIANALIS* (BOULENGER, 1908) | RIVER SARDINE |
| MCAP | *MYXUS CAPENSIS* (VALENCIENNES, 1836) | FRESHWATER MULLET (M) |
| MCEP | *MUGIL CEPHALUS* LINNAEUS, 1758 | FLATHEAD MULLET (M) |
| MCYP | *MEGALOPS CYPRINOIDES* (BROUSSONET, 1782) | OXEYE TARPON |
| MDOL | *MICROPTERUS DOLOMIEU* LACEPÈDE, 1802 | SMALLMOUTH BASS (EX) |
| MFAL | *MONODACTYLUS FALCIFORMIS* LACEPÈDE, 1801 | CAPE MOONY (MS) |
| MFLU | *MICROPHIS FLUVIATILIS* (PETERS, 1852) | FRESHWATER PIPEFISH (M) |
| MMAC | *MARCUSENIUS MACROLEPIDOTUS* (PETERS, 1852) | BULLDOG |
| MPUN | *MICROPTERUS PUNCTULATUS* (RAFINESQUE, 1819) | SPOTTED BASS (EX) |
| MSAL | *MICROPTERUS SALMOIDES* (LACEPÈDE, 1802) | LARGEMOUTH BASS (EX) |
| NORT | *NOTHOBRANCHIUS ORTHONOTUS* (PETERS, 1844) | SPOTTED KILLIFISH |
| NRAC | *NOTHOBRANCHIUS RACHOVII* AHL, 1926 | RAINBOW KILLIFISH |
| OAUR | *OREOCHROMIS AUREUS* (STEINDACHNER, 1864) | ISRAELI TILAPIA (EX) |
| OMAC | *OREOCHROMIS (NYASALAPIA) MACROCHIR* (BOULENGER, 1912) | GREENHEAD TILAPIA |
| OMOS | *OREOCHROMIS MOSSAMBICUS* (PETERS, 1852) | MOZAMBIQUE TILAPIA |
| OMYK | *ONCORHYNCHUS MYKISS* (WALBAUM, 1792) | RAINBOW TROUT (EX) |
| ONIL | *OREOCHROMIS NILOTICUS (LINNAEUS, 1758)* | NILE TILAPIA (EX) |
| OPER | *OPSARIDIUM PERINGUEYI* (GILCHRIST & THOMPSON, 1913) | SOUTHERN BARRED MINNOW |
| OPLA | *OREOCHROMIS PLACIDUS* (TREWAVAS, 1941) | BLACK TILAPIA |
| PAFE | *PSEUDOBARBUS AFER* (PETERS, 1864) | EASTERN CAPE REDFIN |
| PAMP | *PROTOPTERUS AMPHIBIUS* (PETERS, 1844) | EAST COAST LUNGFISH |
| PANN | *PROTOPTERUS ANNECTENS BRIENI* POLL, 1961 | LUNGFISH |
| PASP | *PSEUDOBARBUS ASPER* (BOULENGER, 1911) | SMALLSCALE REDFIN |
| PBUG | *PSEUDOBARBUS BURGI* (BOULENGER, 1911) | BERG RIVER REDFIN |
| PBUR | *PSEUDOBARBUS BURCHELLI* SMITH, 1841 | BURCHELL'S REDFIN |
| PCAT | *PETROCEPHALUS WESSELSI* KRAMER & VAN DER BANK, 2000 | SOUTHERN CHURCHILL |
| PFLU | *PERCA FLUVIATILIS* LINNAEUS, 1758 | EUROPEAN PERCH (EX) |
| PPHI | *PSEUDOCRENILABRUS PHILANDER* (WEBER, 1897) | SOUTHERN MOUTHBROODER |
| PPHL | *PSEUDOBARBUS PHLEGETHON* (BARNARD, 1938) | FIERY REDFIN |
| PQUA | *PSEUDOBARBUS QUATHLAMBAE* (BARNARD, 1938) | DRAKENSBERG MINNOW |
| PRET | *POECILIA RETICULATA* PETERS, 1859 | GUPPY (EX) |
| PTEN | *PSEUDOBARBUS TENUIS* (BARNARD, 1938) | SLENDER REDFIN |
| RDEW | *REDIGOBIUS DEWAALI* (WEBER, 1897) | CHECKED GOBY (M) |
| SBAI | *SANDELIA BAINSII* CASTELNAU, 1861 | EASTERN CAPE ROCKY |
| SCAP | *SANDELIA CAPENSIS* (CUVIER, 1831) | CAPE KURPER |
| SFON | *SALVELINUS FONTINALIS* (MITCHILL, 1815) | BROOK CHARR (EX) |
| SINT | *SCHILBE INTERMEDIUS* RÜPPELL, 1832 | SILVER CATFISH |
| SMER | *SERRANOCHROMIS MERIDIANUS* JUBB, 1967 | LOWVELD LARGEMOUTH |
| SSIB | *SILHOUETTEA SIBAYI* FARQUHARSON, 1970 | SIBAYI GOBY (M) |
| STRU | *SALMO TRUTTA* LINNAEUS, 1758 | BROWN TROUT (EX) |
| SZAM | *SYNODONTIS ZAMBEZENSIS* PETERS, 1852 | BROWN SQUEAKER |
| TREN | *TILAPIA RENDALLI* (BOULENGER, 1896) | REDBREAST TILAPIA |
| TSPA | *TILAPIA SPARRMANII* SMITH, 1840 | BANDED TILAPIA |
| TTIN | *TINCA TINCA* (LINNAEUS, 1758) | TENCH (EX) |
| VNEL | *VARICORHINUS NELSPRUITENSIS* GILCHRIST & THOMPSON, 1911 | INCOMATI CHISELMOUTH |
| XHEL | *XIPHOPHORUS HELLERI* HECKEL, 1848 | SWORDTAIL (EX) |

# SPP INTOL PREF

| SPP (SPECIES EXPECTED: REFERENCE (NOT INTRODU)) | SCIENTIFIC NAMES | VELOCITY-DEPTH PREFERENCE | | | | FLOW INTOLERANCE | | | | COVER PREFERENCE | | | | | TOLERANCE: MODIFIED PHYSICO-CHEM | | | | MIGRATION | | | CONFIDENCE | Distance migrating (km) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PREFERENCE: FD | PREFERENCE:FS | PREFERENCE:SD | PREFERENCE:SS | INTOLERANT: NO-FLOW (>4) | MODERATELY INTOLERANT: NO FLOW (>3-4) | MODERATELY TOLERANT: NO FLOW (>2-3) | TOLERANT: NO FLOW (1-2) | OVERHANGING VEGETATION: HIGH->VERY HIGH (>3) | BANK UNDERCUT: HIGH->VERY HIGH (>3) | SUBSTRATE: HIGH->VERY HIGH (>3) | AQUATIC MACROPHYTES: HIGH->VERY HIGH (>3) | WATER COLUMN: HIGH->VERY HIGH (>3) | INTOLERANT: MODIFIED VQ (>4) | MODERATELY INTOLERANT: MODIFIED VQ (>3-4) | MODERATELY TOLERANT (>2-3): MODIFIED VQ | TOLERANT: MODIFIED VQ (1-2) | 5 -Species with requirement for catchment scale migrations | 3 - Species with requirement for movement between reaches / fish habitat segments | 1 - Species with requirement for movement within reaches / fish habitat segments | | |
| AURA | AMPHILIUS URANOSCOPUS (PFEFFER, 1889) | 4.60 | 4.60 | FALSE | FALSE | 4.80 | FALSE | FALSE | FALSE | FALSE | FALSE | 5.00 | FALSE | FALSE | 4.80 | FALSE | FALSE | FALSE | | | 1.00 | 3.00 | Very local |
| AMOS | ANGUILLA MOSSAMBICA PETERS 1852 | 3.40 | 3.30 | 3.40 | FALSE | FALSE | FALSE | 2.80 | FALSE | FALSE | 4.10 | 4.90 | FALSE | FALSE | FALSE | FALSE | 2.50 | FALSE | | | 5.00 | 3.00 | Up to watershed, >100km |
| AMAR | ANGUILLA MARMORATA QUOY & GAIMARD 1824 | FALSE | 4.40 | 4.40 | FALSE | FALSE | FALSE | 2.80 | FALSE | FALSE | 3.90 | 4.20 | FALSE | FALSE | FALSE | FALSE | 2.50 | FALSE | | | 5.00 | 3.00 | >100km (C1Up to 100 miles) |
| BANN | BARBUS ANNECTENS GILCHRIST & THOMPSON, 1917 | FALSE | FALSE | 5.00 | FALSE | FALSE | FALSE | 2.80 | FALSE | FALSE | FALSE | FALSE | FALSE | 4.70 | FALSE | FALSE | 3.00 | FALSE | | | 3.00 | 3.00 | Far (50km?) |
| BBIF | BARBUS BIFRENATUS FOWLER, 1935 | FALSE | FALSE | 3.30 | 4.70 | FALSE | FALSE | 2.50 | FALSE | 4.40 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | 3.00 | FALSE | | | 1.00 | 3.00 | Local |
| BEUT | BARBUS EUTAENIA BOULENGER, 1904 | 4.30 | 4.70 | FALSE | FALSE | 4.60 | FALSE | FALSE | FALSE | 4.10 | 4.40 | 4.10 | FALSE | FALSE | 4.90 | FALSE | FALSE | FALSE | | | 3.00 | 3.00 | Local |
| BMAR | LABEOBARBUS MAREQUENSIS SMITH, 1841 | 4.10 | 4.40 | 4.40 | 3.40 | FALSE | 3.20 | FALSE | FALSE | FALSE | FALSE | 4.50 | FALSE | 4.10 | FALSE | FALSE | 2.30 | FALSE | | | 3.00 | 3.00 | Far (100km?) V26km reported / specialist thinks much further (50km) |
| BPAU | BARBUS PALUDINOSUS PETERS, 1852 | FALSE | FALSE | 3.90 | 3.90 | FALSE | FALSE | 2.30 | FALSE | 4.20 | FALSE | FALSE | FALSE | 3.50 | FALSE | FALSE | FALSE | FALSE | | 180 | | 3.00 | Far (50+km?) |
| BTRI | BARBUS TRIMACULATUS PETERS, 1852 | FALSE | 3.90 | 3.90 | 3.20 | FALSE | FALSE | 2.70 | FALSE | 3.90 | FALSE | 4.90 | 3.60 | FALSE | FALSE | FALSE | FALSE | FALSE | | 180 | | 3.00 | Far (50+km?) |
| BUNI | BARBUS UNITAENIATUS GÜNTHER, 1866 | FALSE | FALSE | 5.00 | 4.30 | FALSE | FALSE | 2.30 | FALSE | 4.60 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | 2.20 | FALSE | | | | 3.00 | Far (50km?) |
| BVIV | BARBUS VIVIPARUS WEBER, 1897 | FALSE | FALSE | FALSE | 4.80 | FALSE | FALSE | 2.30 | FALSE | 4.90 | FALSE | FALSE | 3.20 | FALSE | FALSE | FALSE | 3.00 | FALSE | | | | 3.00 | 0-10km |
| CANO | CHILOGLANIS ANOTERUS CRASS, 1960 | 4.30 | 4.90 | FALSE | FALSE | 4.80 | FALSE | FALSE | FALSE | FALSE | FALSE | 4.90 | FALSE | FALSE | 4.70 | FALSE | FALSE | FALSE | | | | 3.00 | Local, 8km |
| CGAR | CLARIAS GARIEPINUS (BURCHELL, 1822) | FALSE | FALSE | 4.30 | 3.40 | FALSE | FALSE | FALSE | 1.70 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | | | 100 | 3.00 | Long distances |
| CPAR | CHILOGLANIS PARATUS CRASS, 1960 | 4.20 | 4.90 | FALSE | FALSE | 4.80 | 3.20 | FALSE | FALSE | FALSE | FALSE | 4.90 | FALSE | FALSE | FALSE | 3.10 | FALSE | FALSE | | | | 3.00 | Local |
| CSWI | CHILOGLANIS SWIERSTRAI VAN DER HORST, 1931 | FALSE | 4.70 | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | FALSE | 4.90 | FALSE | FALSE | FALSE | 3.30 | FALSE | FALSE | | | | 3.00 | Local |
| LCYL | LABEO CYLINDRICUS PETERS, 1852 | 3.40 | 4.80 | FALSE | FALSE | FALSE | 3.10 | FALSE | FALSE | FALSE | FALSE | 4.90 | FALSE | FALSE | FALSE | 3.10 | FALSE | FALSE | | | | 3.00 | Far (50km?) |
| LMOL | LABEO MOLYBDINUS DU PLESSIS, 1963 | 3.30 | 4.30 | 3.70 | FALSE | FALSE | 3.30 | FALSE | FALSE | FALSE | FALSE | 4.70 | FALSE | FALSE | FALSE | 3.20 | FALSE | FALSE | | | | 3.00 | Far (50km?) |
| MACU | MICRALESTES ACUTIDENS (PETERS, 1852) | FALSE | FALSE | 4.30 | 4.30 | FALSE | FALSE | FALSE | FALSE | 3.10 | FALSE | FALSE | FALSE | 4.00 | FALSE | 3.10 | FALSE | FALSE | | | | 3.00 | 50 km |

## REF_OBS_SPP

| ABBREVIATIONS: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED) | SCIENTIFIC NAMES: REFERENCE SPECIES (INTRODUCED SPECIES EXCLUDED) | REFERENCE FREQUENCY OF OCCURRENCE | PES:OBSERVED & HABITAT DERIVED FREQUENCY OF OCCURRENCE |
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## INTRO_ALIEN

| INTRODUCED ALIEN PREDACEOUS SPP | PRESENCE=Y; ABSENCE=N | The potential impact of introduced competing /predaceous spp | | INTRODUCED ALIEN HABITAT MODIFYING SPP | PRESENCE=Y; ABSENCE=N | The potential impact of introduced habitat modifying spp |
|---|---|---|---|---|---|---|
| GAFF | | | | CAUR | | |
| LMAC | | | | CCAR | | |
| MDOL | | | | CIDE | | |
| MPUN | | | | HMOL | | |
| MSAL | | | | OAUR | | |
| OMYK | | | | OMAC | | |
| ONIL | | | | PRET | | |
| PRET | | | | TTIN | | |
| SFON | | | | | | |
| STRU | | | | | | |
| XHEL | | | | | | |
| PFLU | | | | | | |

## VEL_DEPTH

| CHANGE IN COMMONNESS OF VELOCITY-DEPTH CLASSES | | | |
|---|---|---|---|
| **VELOCITY-DEPTH CLASSES METRICS** WITH REFERENCE TO FLOW MODIFICATIONS AND CHANGES IN SEDIMENT MOVEMENT, WHAT ARE THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE? | UNDER REF COND | %WEIGHT | RATINGS |
| Commonness of FAST-DEEP conditions | | | |
| Commonness of FAST-SHALLOW conditions | | | |
| Commonness of SLOW-DEEP conditions | | | |
| Commonness of SLOW-SHALLOW conditions | | | |
| **Absolute sum** | | | |
| **Absolute overall weighed % velocity-depth change** | | | |
| **AUTOMATED** | | | |

| CHANGES IN COMMONNESS OF SPECIES WITH HIGH TO VERY HIGH PREFERENCE FOR VELOCITY DEPTH CLASSES | | | | | |
|---|---|---|---|---|---|
| **VELOCITY-DEPTH CLASSES METRICS** BASED ON OBSERVED AND DERIVED DATA, AND WITH WITH REFERENCE TO VELOCITY-DEPTH CLASS PREFERENCES, HOW DID THE FOLLOWING CHANGE? | RANK | %WEIGHT | RATINGS | REF NUMBER OF SPP WITH PREFERENCE | PRESENT NUMBER OF SPP WITH PREFERENCE |
| Response of species with high to very high preference for FAST-DEEP conditions | | | | | |
| Response of species with high to very high preference for FAST-SHALLOW conditions | | | | | |
| Response of species with high to very high preference for SLOW-DEEPconditions | | | | | |
| Response of species with high to very high preference for SLOW-SHALLOW conditions | | | | | |
| **Absolute sum** | | | | | |
| **Absolute overall weighed % assemblage change** | | | | | |
| **ADJUSTED** | | | | | |

| **VELOCITY-DEPTH CLASSES METRICS** BASED ON OBSERVED AND DERIVED DATA, AND WITH WITH REFERENCE TO VELOCITY-DEPTH CLASS PREFERENCES, HOW DID THE FOLLOWING CHANGE? | RANK | %WEIGHT | RATINGS |
|---|---|---|---|
| Response of species with high to very high preference for FAST-DEEP conditions | | | |
| Response of species with high to very high preference for FAST-SHALLOW conditions | | | |
| Response of species with high to very high preference for SLOW-DEEPconditions | | | |
| Response of species with high to very high preference for SLOW-SHALLOW conditions | | | |
| **Absolute sum** | | | |
| **Absolute overall weighed % assemblage change** | | | |

**COVER**

| CHANGE IN COMMONNESS OF FISH COVER FEATURES | | | |
|---|---|---|---|
| **COVER METRICS:** **CHANGES IN FISH COVER FEATURES IN COMPARISON TO THE REFERENCE CONDITION** | COMMONNESS ORDER UNDER REF COND | %WEIGHT | RATINGS |
| Commonness of overhanging vegetation | | | |
| Commonness of undercut banks and root wads | | | |
| Commonness of substrate types that can serve as cover | | | |
| Commonness of instream vegetation | | | |
| Commonness of sufficient water column depth that can serve as cover | | | |
| **Absolute sum** | | | |
| **Absolute overall weighed % velocity-depth change** | | | |
| **AUTOMATED** | | | |

| CHANGE IN COMMONNESS OF SPECIES WITH PREFERENCE FOR SPECIFIC COVER FEATURES | | | | | |
|---|---|---|---|---|---|
| **COVER METRICS:** **WITH REFERENCE TO CHANGES IN FISH COVER FEATURES, WHAT ARE THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE?** | RANK | %WEIGHT | RATINGS | REF NUMBER OF SPP WITH PREFERENCE | PRESENT NUMBER OF SPP WITH PREFERENCE |
| Response of species with a very high to high preference for overhanging vegetation | | | | | |
| Response of species with a very high to high preference for undercut banks and root wads | | | | | |
| Response of species with a high to very high preference for a particular substrate type | | | | | |
| Response of species with a high to very high preference for instream vegetation | | | | | |
| Response of species with a very high to high preference for the water column | | | | | |
| **Absolute sum** | 0 | | | | |
| **Absolute overall % assemblage change** | | | #DIV/0! | | |
| **ADJUSTED** | | | | | |

| CHANGE IN COMMONNESS OF SPECIES WITH PREFERENCE FOR SPECIFIC COVER FEATURE | | | |
|---|---|---|---|
| **COVER METRICS:** **WITH REFERENCE TO CHANGES IN FISH COVER FEATURES, WHAT ARE THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE?** | RANK | %WEIGHT | RATINGS |
| Response of species with a very high to high preference for overhanging vegetation | | | |
| Response of species with a very high to high preference for undercut banks and root wads | | | |
| Response of species with a high to very high preference for a particular substrate type | | | |
| Response of species with a high to very high preference for instream vegetation | | | |
| Response of species with a very high to high preference for the water column | | | |
| **Absolute sum** | | | |
| **Absolute overall % assemblage change** | | | |

## FLOW_MOD

| FLOW MODIFICATIONS | | |
|---|---|---|

| FLOW MODIFICATION METRICS: WHAT IS THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE? (CARRIED OVER FROM DRIVER ASSESSMENT) | RANK | %WEIGHT | RATINGS |
|---|---|---|---|
| Increase or decrease in low-flow conditions | | | |
| Increase or decrease in zero-flow conditions | | | |
| Change in seasonality | | | |
| Increase or decrease in moderate events | | | |
| Increase or decrease in events (high flow, floods) | | | |
| **Absolute sum** | | | |
| **Absolute overall weighed % change in flow metrics** | | | |

| AUTOMATED | |
|---|---|

| FLOW MODIFICATION METRICS: IMPACT ON SPECIES WITH DIFFERENT LEVELS OF FLOW DEPENDANCE | | | | | |
|---|---|---|---|---|---|

| FLOW DEPENDANCE METRICS: BASED ON OBSERVED AND DERIVED DATA, AND WITH WITH REFERENCE FLOW DEPENDANCE, HOW DID THE FOLLOWING CHANGE? | RANK | %WEIGHT | RATINGS | REF NUMBER OF SPP WITH PREFERENCE | PRESENT NUMBER OF SPP WITH PREFERENCE |
|---|---|---|---|---|---|
| Response of species intolerant of no-flow conditions | | | | | |
| Response of species moderately intolerant of no-flow conditions | | | | | |
| Response of species moderately tolerant of no-flow conditions | | | | | |
| Response of species tolerant of no-flow conditions | | | | | |
| **Absolute sum** | | | | | |
| **Absolute overall % assemblage change** | | | | | |

| ADJUSTED | |
|---|---|

| FLOW MODIFICATION METRICS: IMPACT ON SPECIES WITH DIFFERENT LEVELS OF FLOW DEPENDANCE | | | |
|---|---|---|---|

| FLOW DEPENDANCE METRICS: BASED ON OBSERVED AND DERIVED DATA, AND WITH WITH REFERENCE FLOW DEPENDANCE, HOW DID THE FOLLOWING CHANGE? | RANK | %WEIGHT | RATINGS |
|---|---|---|---|
| Response of species intolerant of no-flow conditions | | | |
| Response of species moderately intolerant of no-flow conditions | | | |
| Response of species moderately tolerant of no-flow conditions | | | |
| Response of species tolerant of no-flow conditions | | | |
| **Absolute sum** | | | |
| **Absolute overall % assemblage change** | | | |

## PHYSCHEM

| PHYSICO-CHEMICAL CONDITIONS | | | |
|---|---|---|---|
| **PHYSICO-CHEMICAL METRICS:** <br> **WHAT IS THE CHANGES TO THE FOLLOWING OBSERVED OR EXPECTED TO BE? (CARRIED OVER FROM PHYSICO-CHEMICAL DRIVER ASSESSMENT)** | RANK | %WEIGHT | RATINGS |
| pH | | | |
| SALTS | | | |
| NUTRIENTS | | | |
| TEMPERATURE | | | |
| TURBIDITY | | | |
| OXYGEN | | | |
| TOXICS | | | |
| **Absolute sum** | | | |
| **Absolute overall % change in physico-chemical conditions** | | | |
| **AUTOMATED** | | | |

| IMPACT ON SPECIES WITH DIFFERENT INTOLERANCE LEVELS TO CHANGE IN PHYSICO-CHEMICAL CONDITIONS | | | | | |
|---|---|---|---|---|---|
| **PHYSICO-CHEMICAL METRICS:** <br> **BASED ON OBSERVED AND DERIVED DATA, AND WITH REFERENCE TO INTOLERANCE TO MODIFIED PHYSICO-CHEMICAL CONDITIONS, HOW DID THE FOLLOWING RESPOND IN TERMS OF FISH HEALTH AND CONDITION?** | RANK | %WEIGHT | RATINGS | REF NUMBER OF SPP WITH PREFERENCE | PRESENT NUMBER OF SPP WITH PREFERENCE |
| Response of  species intolerant of modified physico-chemical conditions | | | | | |
| Response of  species moderately intolerant of modified physico-chemical conditions | | | | | |
| Response of  species moderately tolerant of modified physico-chemical conditions | | | | | |
| Response of  species tolerant of modified physico-chemical conditions | | | | | |
| **Absolute sum** | | | | | |
| **Absolute overall % impact on assemblage** | | | | | |
| **ADJUSTED** | | | | | |

| IMPACT ON SPECIES WITH DIFFERENT INTOLERANCE LEVELS TO CHANGE IN PHYSICO-CHEMICAL CONDITIONS | | | |
|---|---|---|---|
| **PHYSICO-CHEMICAL METRICS:** <br> **BASED ON OBSERVED AND DERIVED DATA, AND WITH REFERENCE TO INTOLERANCE TO MODIFIED PHYSICO-CHEMICAL CONDITIONS, HOW DID THE FOLLOWING RESPOND IN TERMS OF FISH HEALTH AND CONDITION?** | RANK | %WEIGHT | RATINGS |
| Response of  species intolerant of modified physico-chemical conditions | | | |
| Response of  species moderately intolerant of modified physico-chemical conditions | | | |
| Response of  species moderately tolerant of modified physico-chemical conditions | | | |
| Response of  species tolerant of modified physico-chemical conditions | | | |
| **Absolute sum** | 4 | | |
| **Absolute overall % impact on assemblage** | | | 32.3 |

## MIGRATION

| CHANGES IN SYSTEM CONNECTIVITY | |
| --- | --- |
| **MIGRATION METRICS:** <br> **WHAT IS THE EXTENT OF THE FOLLOWING** | RATINGS |
| Weirs and causeways | |
| Impoundments | |
| Physico-chemical barriers | |
| Flow modifications | |

| IMPACT ON SPECIES WITH DIFFERENT LEVELS OF MIGRATORY REQUIREMENTS | | | | | |
| --- | --- | --- | --- | --- | --- |
| **MIGRATION METRICS:** <br> **BASED ON OBSERVED AND DERIVED DATA, AND WITH REFERENCE TO CHANGES IN SYSTEM CONNECTIVITY, HOW DID THE FOLLOWING CHANGE?** | RANK | %WEIGHT | RATINGS | REF NUMBER OF SPP WITH PREFERENCE | PRESENT NUMBER OF SPP WITH PREFERENCE |
| Response in terms of distribution/abundance of spp with catchment scale movements | | | | | |
| Response in terms of distribution/abundance of spp with requirement for movement between reaches or fish habitat segments | | | | | |
| Response in terms of distribution/abundance of spp with requirement for movement within reach or fish habitat segment | | | | | |
| **Absolute sum** | 0 | | | | |
| **Absolute overall % change in assemblage longitudinal continuity** | | | 0.0 | | |

## INTRO

| INTRODUCED SPECIES IMPACT | | | |
| --- | --- | --- | --- |
| **INTRODUCED SPECIES METRICS:** <br> **WITH REFERENCE TO THE TYPES OF INTRODUCED SPECIES, THE CHARACTERISTICS OF THE HABITAT AND THE NATIVE SPECIES, WHAT IS THE FOLLOWING OBSERVED OR EXPECTED TO BE?** | RANK | %WEIGHT | RATINGS |
| The impact/potential impact of introduced competing/predaceous spp? | | | |
| How widespread (frequency of occurrence) are introduced competing/predaceous spp? | | | |
| The impact/potential impact of introduced habitat modifying spp? | | | |
| How widespread (frequency of occurrence) are habitat modifying spp? | | | |
| **Absolute sum** | 0 | | |
| **Absolute overall potential % assemblage change** | | | 0.0 |

# METRIC GROUP WEIGHTS

The purpose of this approach is to provide a reasonably objective way to determine the weights of metric groups. An AHP approach is followed where the metric groups are compared pairwise on a 0 – 10 scale with 0.5 intervals.

The objective is to determine the weight of various metric groups as it relates to the natural attributes and requirements of the reference fish assemblage. Introduced species are not a natural attribute or requirement is considered in a different (negative) context.

The basic question is:

Considering

• The natural characteristics of the fish assemblage and its habitat, and
• When comparing a pair of fish metric groups,

which member in the pair would contribute most to a decline or improvement in the fish assemblage integrity if it was to change for whatever reason?

Approach:

The pair with the highest importance in this situation would then receive the highest rating out of 10 with the residue being awarded to the member with the lower contribution. If both members are equally important, both would receive a rating of 5

Considerations:

1. Metric groups: VEL_DEPTH, COVER, FLOW_MOD, PHYSCHEM, the number of species in each metric group, their intolerances as well as habitat characteristics should be taken as the basis of comparison between members of a pair.

2. Metric group: MIGRATION, the number of species with various migration requirements should be considered.

3. Metric group: INTRO, the characteristics and distribution of the introduced species should be considered together with the vulnerability of the indigenous species. This refers only to species that have already been introduced to system and not to species that can po[...]

## VELOCITY-DEPTH METRIC GROUP

| | | |
|---|---|---|
| VELOCITY-DEPTH | COVER | 10.00 |
| VELOCITY-DEPTH | FLOW MODIFICATION | 10.00 |
| VELOCITY-DEPTH | PHYSICO-CHEMICAL | 10.00 |
| VELOCITY-DEPTH | MIGRATION | 10.00 |
| VELOCITY-DEPTH | IMPACT OF INTRODUCED | 10.00 |

## COVER METRIC GROUP

| | | |
|---|---|---|
| COVER | FLOW MODIFICATION | 10.00 |
| COVER | PHYSICO-CHEMICAL | 10.00 |
| COVER | MIGRATION | 10.00 |
| COVER | IMPACT OF INTRODUCED | 10.00 |

## FLOW MODIFICATION METRIC GROUP

| | | |
|---|---|---|
| FLOW MODIFICATION | PHYSICO-CHEMICAL | 10.00 |
| FLOW MODIFICATION | MIGRATION | 10.00 |
| FLOW MODIFICATION | IMPACT OF INTRODUCED | 10.00 |

## PHYSICO-CHEMICAL METRIC GROUP

| | | |
|---|---|---|
| PHYSICO-CHEMICAL | MIGRATION | 10.00 |
| PHYSICO-CHEMICAL | IMPACT OF INTRODUCED | 10.00 |

## MIGRATION METRIC GROUP

| | | |
|---|---|---|
| MIGRATION | IMPACT OF INTRODUCED | 10.00 |

| METRIC GROUP | WEIGHT (%) |
|---|---|
| VELOCITY-DEPTH | 0.00 |
| COVER | 20.00 |
| FLOW MODIFICATION | 20.00 |
| PHYSICO-CHEMICAL | 60.00 |
| MIGRATION | 80.00 |
| IMPACT OF INTRODUCED | 100.00 |

**EC RESULTS**

| AUTOMATED | |
|---|---|
| FRAI (%) | 74 |
| EC: FRAI | C |
| **ADJUSTED** | |
| FRAI (%) | 74 |
| EC: FRAI | C |

# D  APPENDIX D:  VALIDATION OF THE FRAI

## D.1   INTRODUCTION AND BACKGROUND

Monitoring data forms the basis of natural resource decisions. There must be confidence in reliability of the data and the interpretations that can be made from it. A fundamental criterion in the selection of numeric values for indicators considers measurability of habitat variables which refers to the ability to achieve desirable levels of accuracy (also expressed as bias) and precision (repeatability). The combination of natural variability and method sample error influences the signal-to-noise ratio while accuracy and precision inherently differ with the monitoring method used (Bauer & Ralph, 2001).

An objective of the RHP is the validation of indices used to assess the health and integrity of rivers. This includes the fish response assessment index (FRAI; Kleynhans *et al*., 2005) which is an extension of the fish assemblage integrity index (FAII; Kleynhans, 1999). The purpose of the FRAI is to assess present frequency of occurrence of native species in a river reach in comparison to the reference (natural) frequency of occurrence in terms of environmental intolerances and preferences. The FRAI is based on presence-absence of species and is not a fish stock assessment approach. Although abundances are recorded, it is not directly used in the calculation of the FRAI.

Data validation has been defined as a method for ensuring that environmental test results are of known quality. It involves reviewing data against a set of criteria to provide assurance that data is adequate for its intended use.
(http://www.epa.gov/swerffrr/documents/data_quality/dod_oig_2f.htm:
accessed January 2007).

The key issues in terms of validation of the FRAI relates to:

Determination of the similarity between the sampling results of different sampling teams within and between different sites in an ecologically homogenous river reach.

This can be specified in terms of:
- Ho: There are no significant differences in the FRAI results between the sites sampled on the same reach of river.
- Ho: There are no significant differences in the FRAI results between different sampling teams on the same reach of river for any site sampled.

This approach is similar to that followed by Dickens and Graham (2002) in the testing of the SASS (ver.5) index.

## D.2    RIVER REACH SELECTED FOR VALIDATION

A reach of the Elands River (tributary of the Crocodile River, Inkomati System) between the Elands River waterfall and its confluence with the Ngodwana River was selected for validation (Figure 1). Characteristics of the sites are indicated in Table D.1. Ecoregion and geomorphic zone delineation respectively follows Kleynhans *et al.* (2005) and Rowntree & Wadeson (1999).

**Table D.1    Site characteristics.**

| SITE | DISTANCE BETWEEN SUCCESSIVE SITES (km) | LATITUDE | LONGITUDE | ECOREGION | GEOMORPH ZONE | ALTITUDE |
|------|------|------|------|------|------|------|
| 1 |  | -25.644 | 30.3756 | 10.02 | *D: Lower foothill | 1225 |
| 2 | 9.6 km | -25.5960 | 30.4481 | 10.03 | D: Lower foothill | 1105 |
| 3 | 10.3 km | -25.6052 | 30.5255 | 10.02 | D: Lower foothill | 1025 |
| 4 | 3.8 km | -25.5992 | 30.5525 | 10.02 | D: Lower foothill | 1005 |

*: Valley form:V4,V6; gradient class=0.005-0019;typical channel features= Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plain-bed,  pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar.  Narrow flood plain of sand, gravel or cobble often presents (Rowntree & Wadeson, 1999).

The river reach selected is upstream from the influence of a paper mill at the confluence of Elands and Ngodwana Rivers. The river downstream from the mill was subjected to a severe pollution spill in 1989 (Kleynhans et al., 1992).

The Elands River is perennial and 5-15 m wide in the reach investigated. No large flow regulation structures occur in the river. The town of Waterval-Boven is situated approximately 5 km upstream from site 1.  Sewage spills from the town are known to have occurred in the past. However, fish kills have not been reported in this section of river.

Land use are mostly devoted to eucalypt and pine plantations, vegetable and fruit farming and some tourist accommodation. Alien riparian vegetation is abundant along some sections.

The instream habitat integrity of this river reach (Kleynhans, 1996) was estimated as Class B (largely natural) and for the riparian zone as Class D (largely modified) (Kleynhans, 2000).

Overall, impacts on this river reach are generally homogenous and are considered to be minimal to low as far as impacts on the fish assemblages are concerned. This, together with the presence of a fish assemblage and fish habitat features which are similar at all sites, resulted in this reach being selected for FRAI validation.
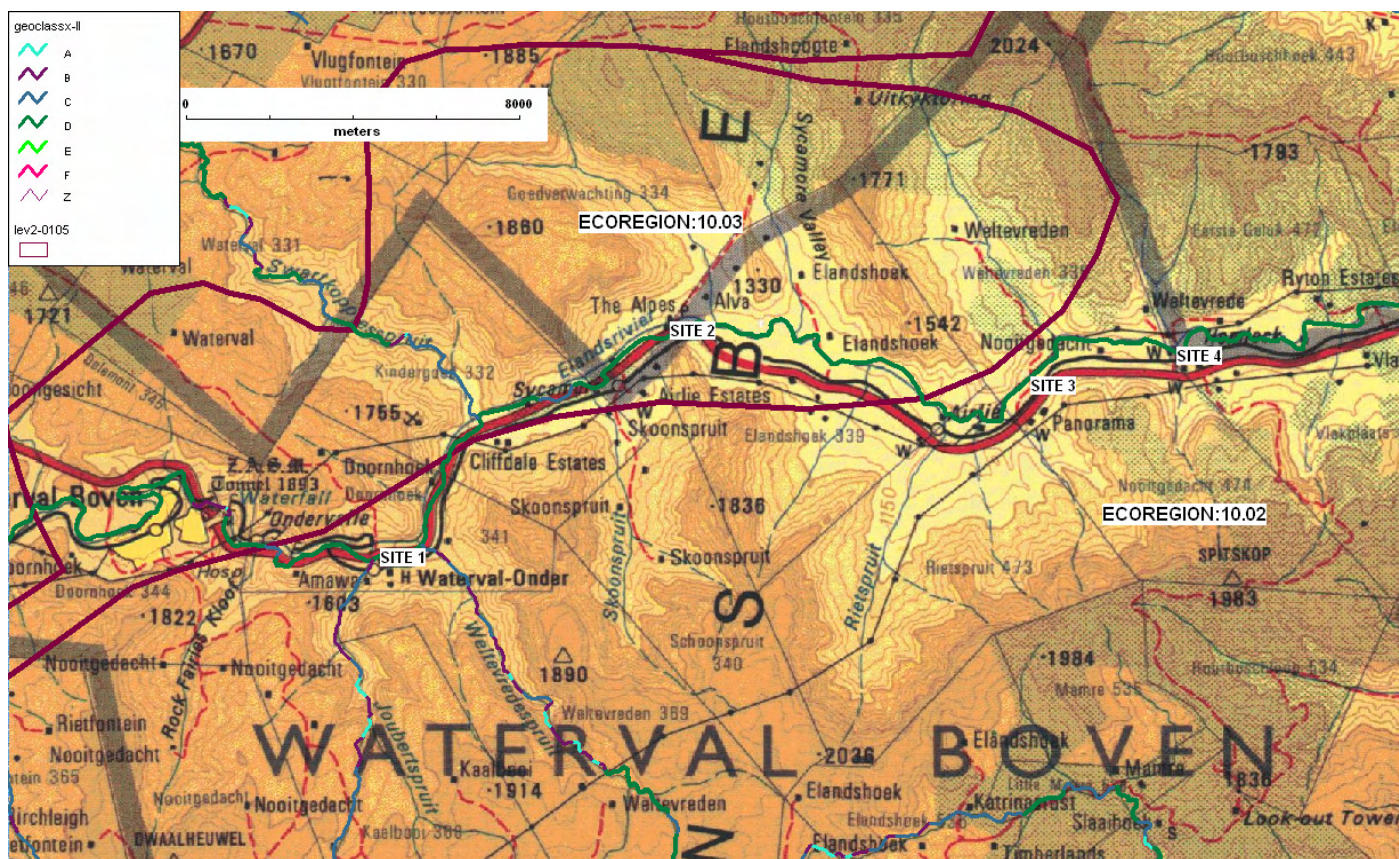
**Figure D-1: Sites sampled in the Elands River for FRAI validation.**

## D.3    METHODS

### D.3.1   Fish Sampling

Sampling was done on 11 August 2006 when natural dry season base flow conditions occurred.

Three teams were available to do fish sampling at each site. Only portable AC generators were available for this exercise. The characteristics of the sampling equipment were:

<u>Team 1:</u>
- Electro-shocker: Honda 10I, eu inverter, AC 220v, 50 HZ,  rated output=0.900 kva; max output= 1.000 KVA phase1.
- Two circular dipnets:. Diameter = 45 cm; mesh size=1 cm.
- Operators: one handling the electrodes mounted on a fixed A-frame, two handling the dipnets, and situated behind each electrode.

Team 2:

- Electro-shocker:  Robin R650; AC 220, 60 HZ, output=0.55 KVA.
- Two circular dipnets:. Diameter = 45 cm; mesh size=1 cm
- Operators: one handling the electrodes mounted on a fixed A-frame, two handling the dipnets, and situated behind each electrode

Team 3:

- Electro-shocker: Honda, AC 220 V, output=5.6 KVA
- Dipnets: one pentagonal, diameter=35 cm, one square, diameter = 40 cm. An additional operator followed these two with a "D" shaped dipnet, dimensions, 60 x 75 cm.
- Operators: Electrodes were separate (not mounted on an A frame) with each operator with a pentagonal net also handling an electrode.

Electro-shocking was done in an upstream direction and following a general zigzag pattern. Fish caught were regularly transferred to buckets.

Effort was recorded as:
The time (to nearest minute) electro-shocking was applied. In this case, Catch per unite effort was expressed as fish caught per minute (Kleynhans, 1999; Rogers *et al.*, 2005)

River length sampled (m) was recorded by teams 1 & 2. This measure was not used for CPUE calculation. However, the correlation between the time sampled and the river length sampled was calculated.

The majority of fish species in the river have a preference for fast flowing water. In addition these species are also the most intolerant of environmental changes. Consequently, sampling concentrated on fast flowing habitats, e.g. fast-deep (velocity > 0.3 m/s; depth>0.3 m) and fast-shallow (velocity > 0.3 m/s; depth<0.3 m) (Kleynhans, 1999). Species with a preference for slow-deep habitat (velocity <0.3 m/s; depth>0.5 m) or slow-shallow habitat (velocity <0.3 m/s; depth<0.5 m) occasionally occurred in the catch.

Only one pass per team per site was done. Sampling was done concurrently by all three teams per site. To prevent the sampling results of the teams from influencing each other, a distance of approximately 50-100 m (at least 1 riffle and pool  length) separated teams.

**D3.2   Data  Analysis**

The following approaches were followed:

Within sites

- 1. Determination of the similarity between the sampling results of different teams

at each of the sites.

- 2. Analysis of variation of sampling results between teams at each of the sites.
- 3. Calculation of the FRAI per site based on the pooled team data per site. For this the frequency of occurrence of species was based on within site variation (e.g. variation between the results of the 3 teams). This resulted in four FRAI values for the reach (one for each site).
- 4. Calculation of an overall FRAI based on the pooled data per site (cf. point 3). This provided an overall FRAI value for the reach.

Between sites
- 1. Determination of the similarity of the sampling results of each team between the 4 different sites.
- 2. Analysis of variation of sampling results of each team between the 4 different sites.
- 3. Analysis of variation of sampling results between sites when teams' sampling results per site are pooled.
- 4. Calculation of the FRAI based on the pooled sampling results of each team. This resulted in 3 FRAI estimates for the river reach (one for each team).
- 5. Calculation of an overall FRAI based on the pooled results for each team (cf. point 4).

The two "overall" FRAI values indicated above are considered to be the closest approximation of the "real" FRAI.

Similarity analysis of sampling results was based on the presence-absence of both introduced and native fish species. The qualitative version of the Dice-Sorenson index was used (Magurran, 1988).

Analysis of CPUE data at all sites indicated that data deviated severely from a normal distribution. Consequently a one-way ANOVA could not be done and the non-parametric Kruskal-Wallis analysis of variance was followed.

PAST software was used for statistical analysis (Hammer et al., 2001).

The FRAI was calculated according to the approach indicated Kleynhans *et al.* (2005). The reference species list and their reference frequency of occurrence for this reach of river used the results of a workshop (Kleynhans *et al.*, 2007, in prep.) during which local experts used available data and expert knowledge to determine these (Table 1). The intolerance and preference ratings for these species are the result of a workshop conducted in 2001 (Kleynhans, 2003) (Table 2).

Calculation of frequency of occurrence is based on 2 approaches:

- Per site: the number of sampling sections at a site where a species was sampled expressed as a proportion of the total number of sampling sections at a site. In

this exercise each site consisted of 3 sampling sections (1 per team).

- Per reach: the number of sites in the reach where a species was sampled expressed as a proportion of the total number of sites in the reach. In this exercise, four sites were sampled.

For the calculation of the FRAI, frequency of occurrence ratings are categorized as indicated in Table D.2.

**Table D.2    Reference species list and frequency of occurrence in the Elands River. Based on Kleynhans & Louw (in prep)**

| SPECIES | ABBREVIATION USED IN TEXT | REFERENCE FROC |
|---|---|---|
| *Anguilla mossambica* | AMOS | 4 |
| *Amphilius uranoscopus* | AURA | 5 |
| *Barbus anoplus* | BANO | 5 |
| *Barbus argenteus* | BARG | 5 |
| *Labeobarbus polylepis* | BPOL | 5 |
| *Chiloglanis bifurcus* | CBIF | 4 |
| *Chiloglanis pretoriae* | CPRE | 5 |
| *Pseudocrenilabrus philander* | PPHI | 4 |
| *Tilapia sparrmanii* | TSPA | 3 |

**Table D3    Native fish species recorded in the study reach, and their rated preferences and intolerances**

| SPECIES | VELOCITY-DEPTH *PREFERENCE | | | | **INTOLERANCE TO NO FLOW | | | | COVER PREFERENCE | | | | | **INTOLERANCE: MODIFIED PHYSICO-CHEMICAL CONDITIONS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FAST- DEEP | SLOW-SHALLOW | SLOW-DEEP | SLOW-SHALLOW | INTOLERANT: (>4) | MODERATELY INTOLERANT: ( >3-4) | MODERATELY TOLERANT: (>2-3) | TOLERANT: (1-2) | OVERHANGING VEGETATION: HIGH->VERY HIGH (>3) | BANK UNDERCUT: HIGH->VERY HIGH (>3) | SUBSTRATE: HIGH->VERY HIGH (>3) | AQUATIC MACROPHYTES: HIGH->VERY HIGH (>3) | WATER COLUMN: HIGH->VERY HIGH (>3) | INTOLERANT: (>4) | MODERATELY INTOLERANT: (>3-4) | MODERATELY TOLERANT (>2-3) | TOLERANT: MODIFIED WQ (1-2) |

| | | | | | | | | | | | | | | | | | |
|------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AMOS** | 3.4 | 3.3 | 3.4 | | | | 2.8 | | | 4.1 | 4.9 | | | | | 2.5 | |
| **AURA** | 4.6 | 4.6 | | | 4.8 | | | | | | 5 | | | 4.8 | | | |
| **BANO** | | | 4.1 | 4.3 | | | 2.3 | | 4 | | | 3.2 | | | | 2.6 | |
| **BARG** | 3.7 | 4.3 | | | 4.6 | | | | | | 5 | | | 4.1 | | | |
| **BPOL** | 3.7 | 4.3 | 4.2 | | | 3.3 | | | | | 5 | | 3.6 | | | 2.9 | |
| **CBIF** | 5 | 3.3 | | | 4.9 | | | | | | 5 | | | 4.9 | | | |
| **CPRE** | 4.3 | 4.9 | | | 4.8 | | | | | | 4.9 | | | 4.5 | | | |
| **PPHI** | | | | 4.3 | | | | 1 | 4.5 | 3.2 | | | | | | | 1.4 |
| **TSPA** | | | | 4.3 | | | | 0.9 | 4.5 | | | 3.6 | | | | | 1.4 |

*Preference: 0=no preference, irrelevant; >0 -1= very low preference - coincidental?;>1-2 = low preference;
>2-3=moderate preference; >3-4=high preference; >4-5=very high preference
**Intolerance: 1-2=tolerant; >2-3=moderately tolerant; >3-4=moderately intolerant; >4-5=intolerant.

**Table D.4    FROC ratings used in the calculation of the FRAI**

| FROC | DESCRIPTION |
|------|-------------|
| 0 | Absent |
| 1 | Present at very few sites (<10% of sites) |
| 2 | Present at few sites (>10-25%) |
| 3 | Present at about >25-50 % of  sites |
| 4 | Present at most sites (>50- 75%) |
| 5 | Present at almost all sites (>75%) |

Sampled species data were transformed into frequencies of occurrence on a rating scale of 0-5 by:

$$FROC = (Nsp/Ns) \times 5$$

Where:
FROC; Frequency of occurrence
Nsp=Number of sites in the reach or sampling points at a site where a species was sampled
Ns=Number of sites sampled in the reach or number of points sampled at a site.
5= Maximum frequency of occurrence of a species.

The following introduced species occur in this reach of the river:

*Oncorhynchus mykiss* (OMYK) (sporadically in the upper part of the reach)
*Micropterus salmoides* (MSAL)
*Clarias gariepinus* (CGAR)
*Cyprinus carpio* (CCAR)

The potential impact factor for introduced species metrics in the FRAI were fixed at 10% for all sites in the reach. The weights for the FRAI metric groups were set as indicated in Table 4 (cf. Kleynhans *et al.,* 2007).

**Table D.5    Metric group weights applied to the FRAI for the study reach**

| METRIC GROUP | WEIGHT (%) |
|---|---|
| Velocity-depth preferences | 95.71 |
| Cover preferences | 78.57 |
| Flow modification | 87.14 |
| Physico-chemical changes | 100.00 |
| Migration | 48.57 |
| Impact of introduced species | 12.86 |

Sampling effectiveness:
Species-accumulation curves relate sampling effort (e.g. time electro-fished) to the cumulative number of fish species to evaluate sampling effectiveness. Such a curve was constructed by arranging data according to the time spend sampling by each team and the number of species added during each sampling period. For this purpose the time spend sampling was arranged in ascending order with number of new species added at each time period. This was done for all species (native and introduced) as well as for species with a preference for fast habitat separately. The purpose was to provide an indication of the sampling effort required for the estimation of the FRAI.

## D4    RESULTS AND DISCUSSION

### D4.1    Catch per unit effort

The species sampled per site by each team is indicated in Table 5. Catch per unit effort is indicated as fish sampled per minute for each species (note that time was not recorded by team 3 at site 2).

**Table D.6  Species sampled per min (electro-shocker) at each of the 4 sites**

| SPECIES | SITE 1 | | | | SITE2 | | | | SITE3 | | | | SITE4 | | | | TOTAL FOR ALL SITES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TEAM 1 | TEAM 2 | TEAM 3 | TOTAL | TEAM 1 | TEAM 2 | TEAM 3* | TOTAL | TEAM 1 | TEAM 2 | TEAM 3 | TOTAL | TEAM 1 | TEAM 2 | TEAM 3 | TOTAL | |
| AURA | 0.45 | 0.46 | 0.22 | 0.38 | 0.44 | 0.71 | (30) | 0.82 | 0.38 | 0.36 | 1.15 | 0.57 | 0.55 | 0.20 | 0.75 | 0.50 | **0.58** |
| AMOS | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | (0.00) | 0.00 | 0.00 | 0.07 | 0.00 | 0.02 | 0.05 | 0.00 | 0.00 | 0.02 | **0.01** |
| CPRE | 3.02 | 3.18 | 1.75 | 2.67 | 0.78 | 1.27 | (37) | 1.32 | 1.06 | 1.67 | 2.85 | 1.73 | 2.05 | 1.20 | 2.70 | 1.98 | **1.89** |
| CBIF | 0.00 | 0.00 | 0.13 | 0.04 | 0.02 | 0.00 | (0.00) | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.01** |
| CGAR | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | (0.00) | 0.00 | 0.02 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | **0.001** |
| BARG | 0.55 | 0.11 | 0.28 | 0.34 | 1.70 | 1.88 | (33) | 2.07 | 2.73 | 7.56 | 4.24 | 4.78 | 1.10 | 2.15 | 1.15 | 1.47 | **2.42** |
| BANO | 0.05 | 0.07 | 0.06 | 0.06 | 0.00 | 0.00 | (2.00) | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.07 | **0.03** |
| BPOL | 0.00 | 0.07 | 0.13 | 0.06 | 0.11 | 0.04 | (19) | 0.25 | 0.04 | 0.00 | 0.09 | 0.04 | 0.00 | 0.00 | 0.05 | 0.02 | **0.10** |
| MSAL | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | (0.00) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 0.00 | 0.00 | 0.08 | **0.01** |
| TSPA | 0.02 | 0.00 | 0.03 | 0.02 | 0.51 | 0.00 | (11.0) | 0.38 | 0.10 | 0.64 | 0.35 | 0.35 | 0.95 | 0.20 | 0.00 | 0.38 | **0.28** |
| PHI | 0.02 | 0.07 | 0.03 | 0.04 | 0.05 | 0.04 | (0.00) | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.03 | **0.03** |
| TOTAL | 4.12 | 3.96 | 2.63 | 3.61 | 5.51 | 6.20 | (202) | 7.59 | 6.35 | 0.36 | 11.24 | 9.78 | 7.95 | 6.90 | 7.25 | 7.37 | 5.37 |
| TIME (min) | 42.00 | 28.00 | 32.00 | 102 | 63.00 | 51.00 | - | 114 | 52.00 | 45.00 | 34.00 | 131 | 20.00 | 20.00 | 20.00 | 60.00 | 406.00 |
| LENGTH (m) | 50 | 42 | - | 92 | 57 | 64 | - | 121 | 53 | 61 | - | 114 | 40 | 39 | - | 79 | (407.00) |
| NATIVE SPP | 6 | 6 | 8 | 8 | 7 | 5 | 6 | 8 | 5 | 5 | 5 | 6 | 5 | 5 | 5 | 8 | 9 |
| TOT NO SPP** | 6 | 6 | 8 | 8 | 7 | 5 | 6 | 8 | 6 | 5 | 5 | 7 | 6 | 5 | 5 | 9 | 11 |

**\*Only Numbers Caught**
**\*\* Indigenous and Introduced**

Analysis of CPUE data at all sites indicated that data deviated severely from a normal distribution. Consequently a one-way ANOVA could not be done and the non-parametric Kruskal-Wallis analysis of variance was followed. In addition, the FRAI is based on frequency of occurrence in combination with intolerance and preferences and not on abundances as such. It follows that statistical analyses based on ranking and presence-absence would be appropriate.

The correlation between the time and the distance (river length; only for teams 1 and 2) was calculated as $r = 0.8560$.

## D4.2 Analysis of Variance

Table 6 indicates the level of statistical significance for the Kruskal-Wallis for all 4 sites (team data pooled for each site) as well as for all sites pooled. The following is evident:

Within site variance:
- All species considered: A significant difference between teams at sites 1 and 2 when all species (native and introduced, and regardless of velocity depth preference) are considered.
- Only native species with preference for fast habitat (Table 2): No significant differences between teams at any of the sites.

Between site variance (all sites and team data pooled):
- No significant difference between sites.

**Table D.7     Kruskal-Wallis analysis of variance of sampling results at the four sites and all 4 sites combined**

| SITE | ALL SPECIES | | ONLY INDIGENOUS SPP WITH PREFERENCE FOR FAST FLOWING HABITAT (AMOS, AURA, BARG, BPOL, CPRE, CBIF) | |
|---|---|---|---|---|
| | KRUSKAL-WALLIS p-LEVELS | KRUSKAL-WALLIS SIGNIFICANCE | KRUSKAL-WALLIS p-LEVELS | KRUSKAL-WALLIS SIGNIFICANCE |
| **1** | 0.25 | S | 0.09 | NS |
| **2** | 0.42 | S | 0.0 | NS |
| **3** | 0.003 | NS | 0.14 | NS |
| **4** | 0.09 | NS | 0.06 | NS |
| **All sites combined** | 0.08 | NS | 0.01 | NS |

## D4.3 Similarity Indices

Tables 7 & 8 respectively indicate the Sorenson-Dice similarity coefficients between teams at the sites and between sites (all team data pooled per site) for all species and native species with a fast flow preference. Especially where only native species with a preference for fast flows were considered, similarity coefficients were very high.

**Table D.8** Sorenson-Dice similarity coefficients for all four sites and teams: All species and only native species with a fast flow preference included.

| SITE | TEAM | ALL SPECIES | | | ONLY NATIVE SPP WITH PREFERENCE FOR FAST FLOWING HABITAT (AMOS, AURA, BARG, BPOL, CPRE, CBIF) | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 1 | 2 | 3 |
| **1** | 1 | - | | | - | | |
| | 2 | 0.83 | - | | 0.89 | - | |
| | 3 | 0.73 | 0.73 | - | 1 | 0.89 | - |
| **2** | 1 | - | | | - | | |
| | 2 | 0.73 | - | | 0.89 | - | |
| | 3 | 0.73 | 1.00 | - | 0.89 | 1 | - |
| **3** | 1 | - | | | - | | |
| | 2 | 0.89 | - | | 0.86 | - | |
| | 3 | 0.80 | 0.89 | - | 0.75 | 0.86 | - |
| **4** | 1 | - | | | - | | |
| | 2 | 0.86 | - | | 0.86 | - | |
| | 3 | 0.86 | 0.75 | - | 1 | 0.86 | - |

**Table D.9** Sorenson-Dice similarity coefficients between sites: all species and only native species with a fast flow preference included.

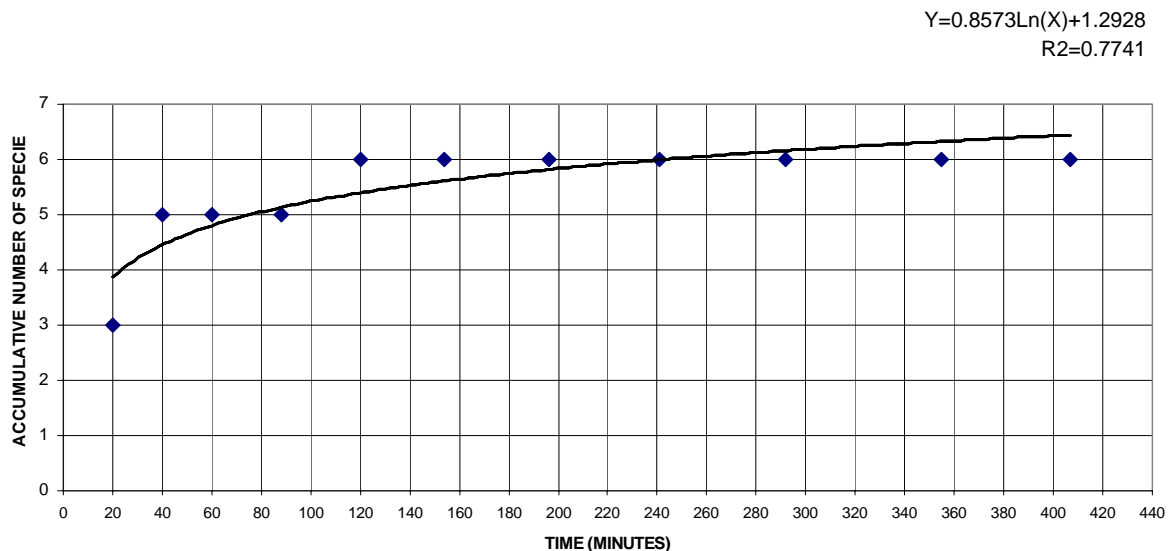| SITE | ALL SPECIES | | | | ONLY NATIVE SPECIES WITH FAST FLOW PREFERENCE | | | |
|---|---|---|---|---|---|---|---|---|
| | SITE | | | | SITE | | | |
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **1** | - | | | | - | | | |
| **2** | 0.93 | - | | | 1 | - | | |
| **3** | 0.71 | 0.77 | - | | 0.80 | 0.8 | - | |
| **4** | 0.77 | 0.67 | 0.73 | - | 0.89 | 0.89 | 0.89 | - |

## D4.4 Sampling effectiveness:

The maximum number species known from this reach of river is 11. The species accumulation curve in Figure 2 indicates an asymptote at about 8-9 species and an accumulative sampling effort of 60-80 minutes. At this sampling effort, more than 80% of all species are sampled. At this stage, 80% of all species is assumed to provide enough information to calculate a representative FRAI. However, this needs to be confirmed for a river with higher species richness.

The maximum number of native species with a preference for fast flowing water is 6. The species accumulation curve in Figure D.2 indicates an asymptote at 5 species with an accumulative sampling effort of 60- 80 minutes.

$$y = 1.5141 \ln(x) + 1.9223$$
$$R^2 = 0.8049$$
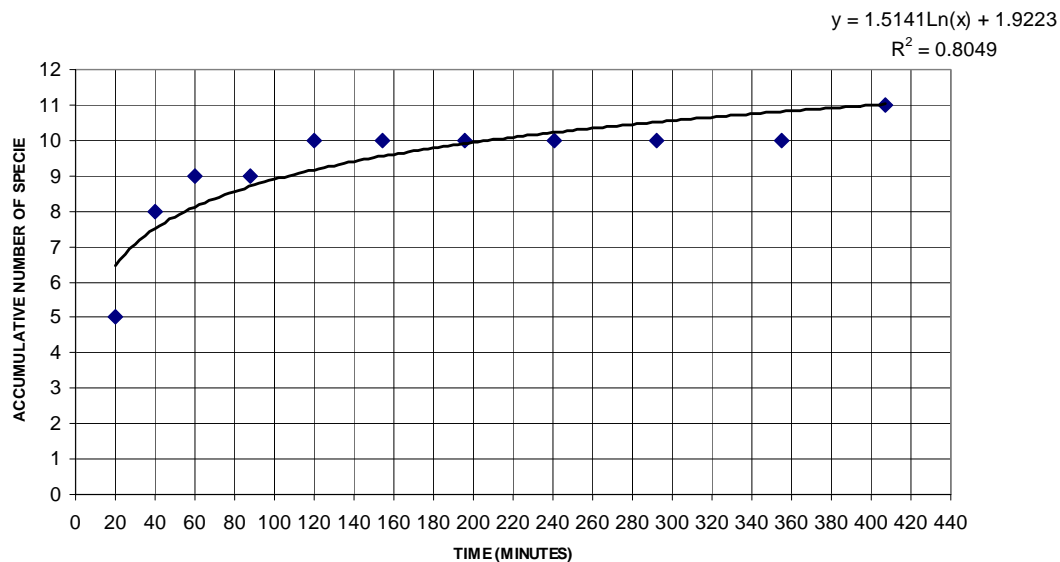


**Figure D.2    Number of species (introduced and native) caught per accumulative effort**

$$Y = 0.8573 \ln(X) + 1.2928$$
$$R^2 = 0.7741$$



**Figure D.3    Number of native species with a preference for fast flowing water caught per accumulative effort**

### D4.5    FRAI assessments

From Tables 9 & 10 it is evident that data pooled for all sites or for teams, indicate a FRAI category of B/C when only native species with a high preference for fast flows are considered. This is considered to be a better indication of the FRAI category than a scenario including all native species. Species with a preference for slower flowing habitats were mainly caught at quiet spots in fast flowing sections. Due to time limitation, slow flowing habitats were not specifically targeted for sampling. However, intolerant species and species with particular habitat preferences were predominantly present in fast flowing habitats (Table D.2).

When data from all sites are pooled or the data from all teams were pooled, a FRAI category of "A" is arrived at. This is judged to be a high confidence indication of the "real" FRAI value and category for this reach of the river. The implication of this is that the FRAI value based on either pooled data per site or individual team data pooled is an underestimation of the real FRAI. This underestimation can be "adjusted" for by also considering the habitat integrity of the river reach as is discussed in Kleynhans, *et al.* (2007). Expert knowledge is used to consider the likely presence of low abundance species (e.g. *Chiloglanis bifurcus*) or species that are difficult to sample (e.g. *Anguilla mossambica*). This judgment is based on assessment of present habitat conditions and interpretation of its suitability for species when considering their intolerances and preferences. The assessment of available habitat conditions limits the amount of time and sampling effort required to provide a high confidence estimation of the FRAI.

Two approaches can be followed to adjust the FRAI calculated by the model:
- 1. The habitat integrity is considered and the ratings for each of the appropriate metric groups (velocity-depth, cover, flow modification and physico-chemical) are changed where judged necessary.
- 2. The habitat integrity is considered and the observed frequency of occurrence ratings for each species is adjusted accordingly.

The habitat adjusted FRAI based on approach (1) above, increases the site-pooled and team-pooled FRAI values to 91.8% (category A/B) (Tables D.10 & D.11) which is comparable with the 94.4% which is considered the "correct" FRAI value.

Assessment of the macro-invertebrate integrity based on SASS5 indicates a category of A/B to A for this river reach (Thirion pers. comm., 2007).

**Table D.10    FRAI values based on team data pooled per site and all sites pooled**

|  | SITE 1 POOLED | SITE 2 POOLED | SITE 3 POOLED | SITE 4 POOLED | ALL SITES POOLED |
|---|---|---|---|---|---|
| **ALL SPECIES** | 82.7 | 82.7 | 59.3 | 63 | 90.4 |
| **FAST FLOW SPECIES** | 81.2 | 81.2 | 80.5 | 80.5 | 94.4 |
| **FRAI CATEGORY: FAST FLOW SPECIES** | B/C | B/C | B/C | B/C | A |
| **TIME SAMPLED (min)** | **102** | **114** | **131** | **60** | **407** |

**Table D.11 FRAI values for team data pooled for all sites and all team data pooled.**

|  | TEAM 1 POOLED | TEAM 2 POOLED | TEAM 3 POOLED | TEAMS POOLED |
|---|---|---|---|---|
| **ALL SPECIES** | 71.2 | 65.1 | 76.2 | 91.3 |
| **FAST FLOW SPECIES** | 81.4 | 78.2 | 78.8 | 94.4 |
| **FRAI CATEGORY: FAST FLOW SPECIES** | B/C | B/C | B/C | A |
| **TIME SAMPLED** | 147 | 144 | 116 | 407 |

## D.5    CONCLUSIONS

- 1. Although mainly fast flowing habitats were sampled, the same principles would apply if slow flowing habitats were sampled. This means that the reference frequency of occurrence for species in slow flowing habitats would be compiled against the observed and derived present frequency of occurrence.
- 2. Considering native species only, within site and between site variance is not statistically significant. This means that despite the differences in sampling apparatus, the data of  teams at different sites and from different teams are comparable and largely similar. This applies to the presence of native species with a preference for fast flow in particular.
- 3. The calculation of the FRAI based on species with a preference for fast flow and using different combinations of pooled data (Tables 9 & 10), indicates that the FRAI calculated per site and per team is in a "B/C" category. However, when all data is pooled the FRAI category increases to "A" which is considered to be the "actual" FRAI category for the reach. This indicates that sampling on which the pooled data (per site and per team) was not sufficient to provide the "actual" FRAI value and category.
- 4. When taking habitat integrity in this reach into account, the FRAI category for the pooled site and team data increases to "A/B".

## D.6    GUIDELINES AND RECOMMENDATIONS FOR APPLICATION AND INTERPRETATION OF THE FRAI

Based on the investigation on this particular river, it is recommended that the following be followed for determining the FRAI in rivers in general and the RHP in particular:

- 1. The river reach assessed (resource unit or assessment unit), should be relatively homogenous in terms of its natural features. If necessary, the

assessment unit should be subdivided into sections of homogenous impact. The approach followed for this purpose is described in the VEGRAI module of the EcoStatus manual (Kleynhans et al., 2007.). The objective is that the site selected for FRAI assessment should be as representative of the river reach or sub section as possible.

- 2. In practice it is usually not possible to select more than one site per assessment unit for River Health Programme purposes. As this investigation indicated, this is likely to provide an underestimation of the FRAI. This underestimation can be reduced by sampling different separate section of river length at each site. At least three such sections should be sampled and results recorded separately. This will provide data that can be used to calculate the frequency of occurrence of species at the site (which is assumed to be representative of the reach).

- 3. The sampling effort per site should be at least 60-90 minutes (e.g. 3 sections each sampled for 20-30 minutes). However, it is recommended that the distance sampled should also be recorded. In terms of distance, the time shocked will relate to a total distance of approximately 60 m to 75 m.

- 4. Where only one site per assessment unit can be surveyed (as indicated above), it is essential that the habitat integrity of the unit be assessed at as many points as possible to get a representative picture of fish habitat condition. This information should be used to assess whether any of the frequency of occurrence of species should be adjusted, or whether the metrics within certain metric groups (velocity-depth, cover, flow modification and physico-chemical), should be changed from the model results. The decision to adjust the FRAI ratings should consider whether the site is sufficiently representative of the whole assessment unit. If this is not the case, it may be necessary to subdivide the assessment unit into appropriate units to ensure that representativeness (cf. point 1).

- 5. It is essential that the fish sampling data that is used in the FRAI be interpreted in terms of the velocity-depth classes that were sampled. In this investigation, fast flowing habitats were sampled, but species with a preference for slow flows can be present at 'slow' spots in fast flowing sections. The presence of such species should be recorded but not taken into account in the calculation of the FRAI that will in this case be based on species with a preference for fast habitat. In cases where the fish assemblage is constituted mainly from species with a preference for slow flow, these velocity-depth classes should be concentrated on when sampling. Usually, species with a preference for fast flow are also those most intolerant and indicative of environmental changes. This consideration is taken account of in the EcoStatus models.

- 6. From point 5 it follows that a representative survey of fish at a site should ideally sample all habitats (e.g. fast and slow) and this data should be included in the overall assessment of the FRAI.

- 7. Electro-shocking is considered to be the most practical way for sampling fish in wade-able streams (<0.7 m deep). This includes both fast and slow flowing habitats. . It is suggested that where-ever possible, sampling be conducted by electro-shocking in both fast and slow flowing habitat. In slow flowing habitat,

information can be augmented by using small seine nets.

- 8. Larger non wade-able rivers or sections of rivers can also be sampled by electro-shocking from a boat (usually concentrating on the river margins) (Pont *et al.,* 2006) but guidelines for the application of this sampling approach should be developed and assessed separately.

- 9. From this investigation it appears that the type of electro-shocking apparatus did not have a major influence on the sampling results as far as requirements for FRAI calculation was concerned. Only AC electro-shockers were used and this necessitated a team of at least three people. It is necessary that other electro-shockers, such as small, back pack, battery powered apparatus be evaluated for use in FRAI determination. Such equipment is often used where there is a labour limitation. The FRAI is based on presence-absence and frequency of occurrence and the type of shocker is not expected to have a large influence on the sampling results. However, single operator back-pack shockers will have to be tested and compared with AC shockers as used during the current validation.

## D.7    ACKNOWLEDGMENTS

## D.8    REFERENCES

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