Characterization of the Fishery Assemblages in a Suite of Eutrophic and Hypertrophic South African Dams

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Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

This report documents the findings of a two-year investigation that has examined the fish assemblages of six South African dams. This works stems from the hypothesis, developed during the Hartbeespoort Dam Remediation Project (DH Environmental Consulting, 2004), that impounded eutrophic waters tend to be dominated by coarse fish, such as carp and barbel, with such species imparting a generally-negative impact on the ecosystem structure (foodweb). The nature of individual or combined impacts brought about by coarse fish in enriched dams would be to exacerbate the effects of eutrophication. Furthermore, it is proposed that the ecological state and water quality of eutrophic dams can be improved through the re-shaping of imbalanced fish populations, brought about by the deliberate harvesting of target species. This process would, initially, remove bulk quantities of fish within a relatively-short period, followed by maintenance fishing in the long term. Removal of problematical, coarse fish, would allow populations of desirable species to resurge and to provide both an increased measure of natural controls within the ecosystem, as well as providing higher value game fish. The manner in which the fisheries of such dams could be sustainably and financially exploited so as to benefit ecosystem health remain to be determined while, at the same time, offering potential for income and food security.

The proposal on which this project is founded is intended to investigate the options for fish-directed biomanipulation of eutrophic dams as an in-lake management intervention. The rationale for the partial relief of eutrophication-induced pressures in enriched South African dams is founded on the following premises:

- The fish populations in these dams are imbalanced and dominated by what this study terms "coarse" species, either numerically or in terms of biomass. In the dams examined, coarse species are considered to be common carp (*Cyprinus carpio*), sharptooth catfish (*Clarais gariepinus*) and/or canary kurper (*Chetia flaviventris*);
- These coarse fish, when present in excess, are likely to exert either a top-down impact and/or a bottom-up disturbance in the lake foodweb, specifically:
    - ❖ The coarse fish species are typified as facultative zooplanktivores or have zooplanktivorous juvenile stages, i.e. species that may exert a top-down effect on the reservoir-lake foodweb. However, it is conceded that these feeding modes have not been demonstrated in South African dams and are belied by the phenomenal success of sharptooth catfish in dominating riverine systems;
    - ❖ Are species with a predominantly-benthic feeding behaviour will variously, increase turbidity, promote nutrient recycling and/or prevent the establishment of lake-stabilizing rooted aquatic macrophytes
    - ❖ Large populations of coarse species are expected to accelerate recycling of dissolved nutrients to the water column via excretion;
- These fish-induced imbalances augment and contribute to the eutrophication pressures within the dam, inclusive of the suppression of desirable fish species;
- The combined effect of this imbalance is a depleted zooplankton component and an increased availability of water column nutrients, as a consequence of increased excretion and bioturbation;
- The selective removal of the problem fish species, firstly by bulk removal and then maintenance fishing, will allow re-establishment of a more-balanced fish community and a measure of relief of the aforementioned pressures.

This project has examined the fish assemblages in six dams (Rietvlei, Roodeplaat, Bon Accord, Koster River, Lindleyspoort and Rust de Winter – with the last two serving as 'control' environments). Also included are comparative data from a similar, earlier study conducted at Hartbeespoort Dam and which provided the framework for this investigation. These dams were selected based on (a) their trophic condition and without any prior knowledge of the assemblage of fish present in each, and (b) their location within the same

geographic region, to remove potentially confounding biophysical and zoogeographical influences.

The findings of this research project may be summarized as follows

FINDINGS

Dams in the test set

The characteristics of the seven impoundments, including Hartbeespoort Dam, are summarized in **Table 1**:

Table 1: Summarized characteristics for each dam (Data from Harding, 2008; Van Ginkel et al., 2007 and DWAF, 2004 – NEMP). The data are ranked according on the basis of increasing median annual Total Phosphorus (TP). Nutrient and chlorophyll-a data are annual medians.

		Rust de Winter	Lindleyspoort	Koster	Hartbeespoort	Roodeplaat	Bon Accord	Rietvlei
Parameter	Units							
Vol (FSL)	MCM	28	14	12	193	41.2	4.4	12.3
Mean depth	m	5.7	7.4	4.8	9.6	10.6	3.6	6.2
Max depth	m	18	22	13	33	43	7.4	19
HRT	yr	0.3	0.5	-	0.81	1.28	-	0.4
Surface area	km^2	4.9	1.9	2.6	20	3.97	1.7	2.06
Min water temp	deg C	17	13	14	14	15	11	10
Max water temp	deg C	28	28	27	26	28	29	31
Sediment Content	% Volume	4.4	12.3	1.7	16	4.4	33	4.6
Total P	ppb	42	44	68	104	208	285	360
Ortho-P	ppb	20	20	24	55	118	102	223
Chlorophyll-a	ppb	2	4	4	12	33	113	27
Trophy		Mesotrophic	Mesotrophic	Eutrophic	Eutrophic	Hypertrophic	Hypertrophic	Hypertrophic

Fish populations

The fish assemblages found in the seven reservoirs are summarized in **Table 2**. The number of fish species per dam ranged from seven (Koster River) to thirteen (Lindleyspoort), with an average of 10 species per dam. Only three species, common carp (*C. carpio*), sharptooth catfish (*Clarias gariepinus*) and Mozambique tilapia (*Oreochromis mossambicus*) were found in all seven dams. The two biogenically clearwater control dams, Lindleyspoort and Rust de Winter, had the highest species diversity with, respectively, thirteen and twelve species. Koster River Dam, the turbid dam, had seven species, the lowest number in the set of seven dams. Although over a narrow range and with the exception of the highly-turbid Koster River Dam, there was a general progression of declining species number with increasing trophy.

Numerical density per species, as corrected for Catch per Unit Effort (CPUE) and expressed as a percentage of the total survey catch, is shown in **Table 3**, whilst biomass, similarly-corrected, is shown in **Table 4**. Graphical representations of both datasets are provided in **Figures 1 and 2**.

From **Figure 1** it is apparent that there was no trend in numerical dominance across all seven dams. Canary kurper (*Chetia flaviventris*) was dominant in Hartbeespoort and Rietvlei (55% and 42% of total catch, respectively), whereas the sharptooth catfish dominated in the shallower, sediment-rich Bon Accord and Koster River systems (respectively 61% and 41% of total catch). The numbers of these species were considerably less in the two control dams, as well as in Roodeplaat (a hypertrophic system).

A clear inter-reservoir pattern is apparent from the biomass data (**Figure 2**). The sharptooth catfish dominated the biomass in all seven dams, exceeding 50% in all but two (Rust de Winter, 34% and Bon Accord, 24%) and amounting to a maximum of 73% of total biomass in Koster River Dam. By contrast, common carp ranged from 2% in Rietvlei to 15% in Bon Accord. Despite its numerical predominance in Rietvlei and Hartbeespoort Dams, the small size of the canary kurper resulted in this species contributing only 3% and 6% of total biomass in these two reservoirs, respectively. Mozambique tilapia was the dominant in Rust de Winter (41% total biomass), as well as in Bon Accord (35% total biomass).

Fish biomass, expressed per unit area (see **Table 5**), considerably exceeded 200 kg/ha in six of the seven dams assessed, i.e. exceeding the threshold above which algal-dominance is expected to prevail). The seventh dam, the turbid Koster River, had an areal biomass of 202 kg/ha.

Table 2: Fish assemblages of the seven reservoirs assessed in this study (ranked as per Table 1).

Species	Common Name	Family	Rust de Winter	Lindleyspoort	Koster	Hartbeespoort	Roodeplaat	Bon Accord	Rietvlei
Barbus mattozi	Papermouth	Cyprinidae	X	X		X			
Barbus paludinosus	Straightfin barb	Cyprinidae		X	X	X	X	X	X
Barbus trimaculatus	Threespot barb	Cyprinidae	X	X		X		X	
Barbus unitaeniatus	Longbeard barb	Cyprinidae		X		X	X	X	
Chetia flaviventris	Canary kurper	Cichlidae	X	X		X	X		X
Clarias gariepinus	Sharptooth catfish	Clariidae	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Cyprinus carpio	Common carp	Cyprinidae	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Labeo molybdinus	Leaden labeo	Cyprinidae	X					X	
Labeobarbus aneus	Smallmouth yellowfish	Cyprinidae			X				
Labeobarbus marequensis	Largescale yellowfish	Cyprinidae	X	X		X	X	X	X
Labeobarbus polylepis	Smallscale yellowfish	Cyprinidae	X			X	X		X
Marcusenius macrolepidotus	Bulldog	Mormyridae	X	X					
Micropterus salmoides	Largemouth bass	Centrarchidae	X	X	X	X	X		
Oreochromis mossambicus	Mozambique (common) tilapia	Cichlidae	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Pseudocrenilabrus philander	Southern mouthbrooder	Cichlidae		X	X	X	X	X	X
Tilapia sparrmanii	Banded tilapia	Cichlidae	X	X		X	X		X
TOTAL SPECIES PER DAM			**12**	**13**	**7**	**13**	**11**	**9**	**9**

Table 3: Numerical dominance, expressed as a percentage of the total survey catch.

Species	Species code	**Rust de Winter**	**Lindleyspoort**	**Koster**	**Hartbeespoort**	**Roodeplaat**	**Bon Accord**	**Rietvlei**
Barbus mattozi	BM	6.6	25.3	0.001	1.1	0.001	0.001	0.001
Barbus paludinosus	BP	0.001	0.8	4.8	0.1	12.5	0.1	23.7
Barbus trimaculatus	BT	8.5	37	0.001	8.3	0.001	0.001	0.001
Barbus unitaeniatus	BU	0.001	0.001	0.001	3.9	36.1	0.001	0.001
Chetia flaviventris	CF	1.5	2.4	0.001	54.6	9.5	0.001	41.7
Clarias gariepinus	CG	10.3	8	41	2.2	11.7	61.2	10.9
Cyprinus carpio	CC	1.1	1.9	5.4	1.9	1.6	30.6	0.9
Labeo molybdinus	LM	0.1	0.001	0.001	0.001	0.001	5.5	0.001
Labeobarbus aneus	LA	0.001	0.001	34.4	0.001	0.001	0.001	0.001
Labeobarbus marequensis	LQ	3.5	5.2	0.001	8.5	16.3	0.1	0.001
Labeobarbus polylepis	LP	0.1	0.001	0.001	0.3	0.5	0.001	11.9
Marcusenius macrolepidotus	MM	40.5	0.6	0.001	0.001	0.001	0.001	0.001
Micropterus salmoides	MS	6.3	0.1	0.5	0.001	0.4	0.001	0.001
Oreochromis mossambicus	OM	21.4	17.7	13.4	18.9	10.6	2.5	0.001
Pseudocrenilabrus philander	PP	0.001	0.4	0.5	0.001	0.1	0.001	9.6
Tilapia sparrmanii	TS	0.1	0.6	0.001	0.001	0.7	0.001	1.3
Total # fish		**1556**	**2314**	**393**	**6390**	**2389**	**405**	**2316**

Figure 1: Graphical representation of fish numbers per dam – as a percentage of total catch (for fish codes please see Table 3).

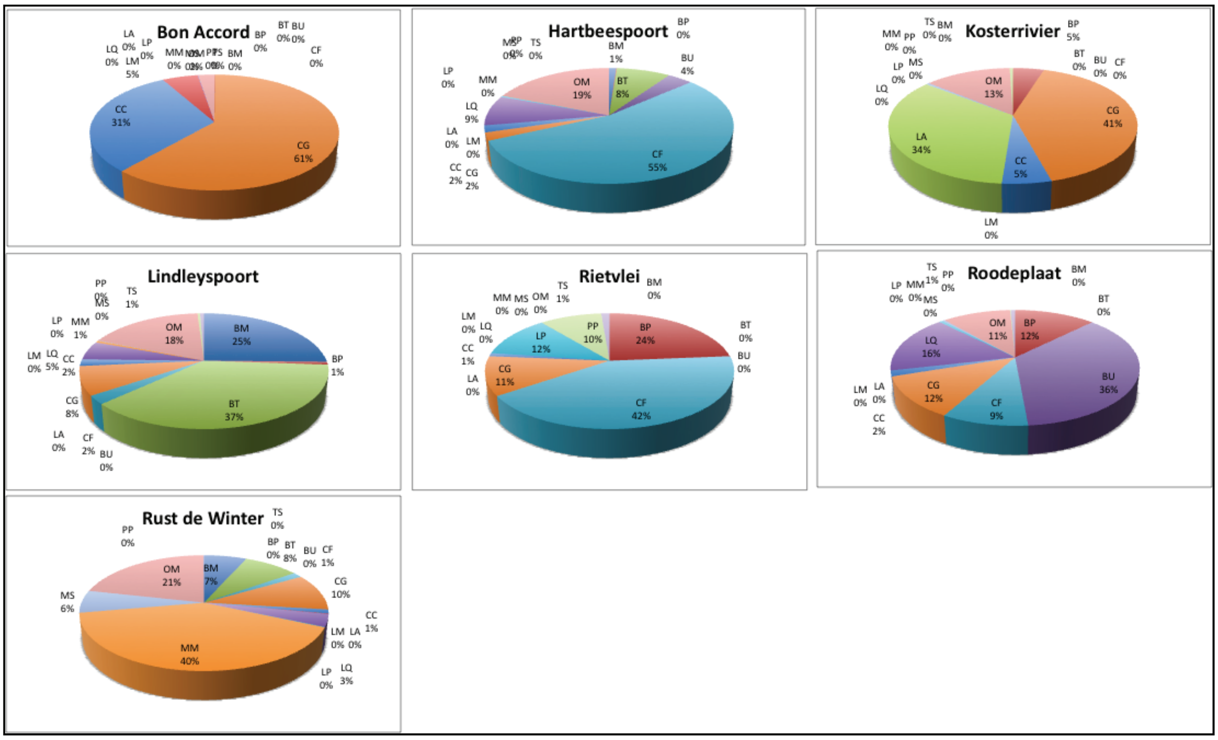

Table 4: Biomass dominance, expressed as a percentage of the total survey catch.

Species	Species code	**Rust de Winter**	**Lindleyspoort**	**Koster**	**Hartbeespoort**	**Roodeplaat**	**Bon Accord**	**Rietvlei**
Barbus mattozi	BM	3.5	6.4	0.001	0.7	0.001	0.001	0.001
Barbus paludinosus	BP	0.001	0.001	0.001	0.001	0.1	9.1	0.3
Barbus trimaculatus	BT	0.3	1.2	0.001	0.8	0.001	0.5	0.001
Barbus unitaeniatus	BU	0.001	0.001	0.001	0.3	0.3	3.1	0.001
Chetia flaviventris	CF	0.1	0.2	0.001	5.6	0.6	0.001	2.7
Clarias gariepinus	CG	33.8	59.6	72.6	53.5	63	24.1	59
Cyprinus carpio	CC	5.2	11.5	7.1	12.6	3.5	15.2	1.7
Labeo molybdinus	LM	0.2	0.001	0.001	0.001	0.001	10.9	0.001
Labeobarbus aneus	LA	0.001	0.001	12.8	0.001	0.001	0.001	0.001
Labeobarbus marequensis	LQ	3.1	8	0.001	13.2	16	0.9	0.2
Labeobarbus polylepis	LP	0.1	0.001	0.001	0.3	0.5	0.001	35.8
Marcusenius macrolepidotus	MM	5.6	0.2	0.001	0.001	0.001	0.001	0.001
Micropterus salmoides	MS	6.6	0.7	1.3	0.3	0.3	0.001	0.001
Oreochromis mossambicus	OM	41.3	12.2	6.2	12.7	15.5	35.4	0.001
Pseudocrenilabrus philander	PP	0.001	0.001	0.001	0.001	0.001	0.9	0.1
Tilapia sparrmanii	TS	0.001	0.1	0.001	0.001	0.1	0.001	0.1
Total biomass (kg caught)		**614**	**566**	**279**	**606**	**1070**	**650**	**997**

Figure 2: Graphical representation of fish biomass per dam – as a percentage of total catch (for fish codes please see Table 3).

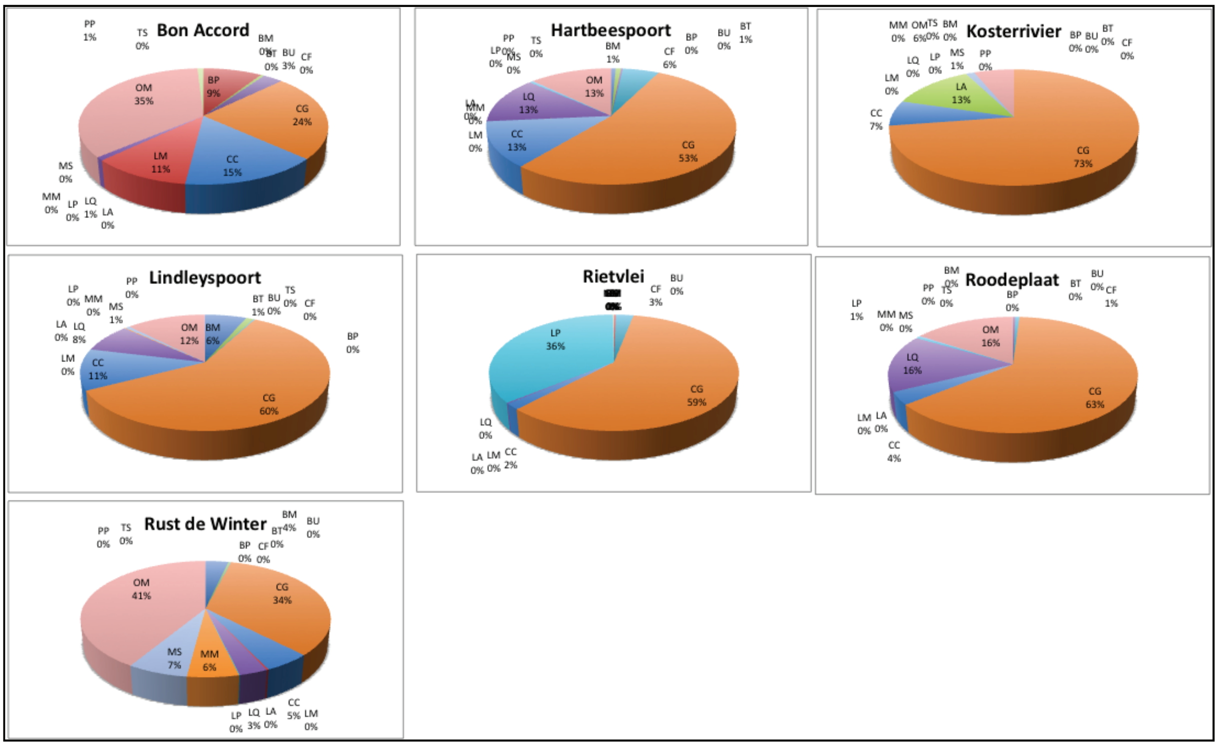

Table 5: Areal fish biomass (kg/ha) for each of the seven dams (dams ranked as before).

Rust de Winter	Lindleyspoort	Koster	Hartbeespoort	Roodeplaat	Bon Accord	Rietvlei
357	350	202	300	791	412	641

Identified problem (coarse) species

The catfish is dominant in all of the dams, with the exception of Rust De Winter, with carp present, at a lesser extent, in most of the dams. The catfish (all dams) and carp (especially for Bon Accord Dam) are dominant species and have very high fecundities. A single large (4 kg) female of each of the carp and catfish can produce in excess of one million larvae per spawning. *Chetia flaviventris* is an extremely efficient carnivorous fish, equivalent to bass, and will have a significant impact on zooplankton, other invertebrates and larval fish. It has been surmised that the larval stages of carp and catfish may tend towards obligate zooplanktivory. Empirical evidence for this, however, appears to be lacking and is not supported by the extremely successful dominance of zooplankton-poor river systems by *Clarias gariepinus*.

By targeting the above-mentioned fish species, the fish community will naturally shift towards *Oreochromis mossambicus* (Mozambique tilapia or blou kurper) as the most important species. From an ecological perspective this is a highly desirable species as it has an omnivorous feeding behaviour and is also an algal feeder.

Potential yields of fish per dam

This project has determined the possible tonnages of fish that could be harvested on a sustainable annual basis from each dam. These data are summarized in **Table 6**. It should be noted that the initial, bulk-removal tonnages required to re-set the fish population, are not shown but are included in the relevant section of this report. Where available, tonnages per species are shown.

Table 6: Biomass and yield characteristics, per dam.

	Biomass, tonnes (t)	Kg/ha	Yield, t/a	Catfish	Carp	Chetia	Tilapia	Yellowfish
Rietvlei	132	640	44	26	0.75	1.2		
Roodeplaat	314	790	104	66	3.7	0.6	4.1	17
Bon Accord	70	410	23	14	4.2			
Koster	52	200	18	13	3.3			
Lindleyspoort	67	370	22	13	6.2			
Rust deWinter	175	370	58	20	7.3			
Hartbeespoort	750	375	250					

Species selection for biomanipulation

All of dams examined in this project appear to provide a basis for biomanipulation linked to a community-based fishery. The latter would underpin an ongoing foodweb manipulation programme necessary to maintain target levels of problematical species. While the fish population of Rust de Winter Dam appears to be balanced, there is scope for harvesting of carp as a proactive management approach.

Target species for biomanipulation, as well as those species showing potential for sustainable utilization, are shown in **Table 7**.

Table 7: Target species for biomanipulation per dam

	Undesirable species	Desirable species
Bon Accord Dam	Sharptooth catfish, common carp	
Hartbeespoort Dam	Sharptooth catfish, common carp, canary kurper	
Koster River Dam	Sharptooth catfish, common carp	Smallmouth yellowfish, Mozambique tilapia
Lindleyspoort Dam	Sharptooth catfish, common carp	Mozambique tilapia
Rietvlei Dam	Sharptooth catfish, common carp, canary kurper	Smallscale yellowfish
Roodeplaat Dam	Sharptooth catfish, common carp, canary kurper	Largescale yellowfish
Rust de Winter Dam	Sharptooth catfish, common carp	Mozambique tilapia

Edibility of fish from Roodeplaat Dam

Samples of tissue from common carp and sharptooth catfish collected from Roodeplaat Dam were tested for the presence of endocrine disruptors and trace metals. The PCBs found in muscle of some of the fish from both species were just above the recommended guideline of 0.3 mg/kg in the edible portion of the fish. This indicates that the fish are not safe for human consumption. By contrast, the edible parts of the fish were deemed safe to eat based on the DDT, DDD and DDE levels, according to the guidelines set by the FDA and EPA. There are no guidelines for HCH and endosulfan, but the concentrations detected in the muscle were higher than the guidelines recommended in water.

There are no guidelines available for the metals tested for in the muscle of both fish species. However, the possible effects of the detected metals are discussed in brief, bearing in mind that the intake and the availability of the metals were not calculated according to a risk formulation for humans consuming wild fish.

In conclusion, if the fish are consumed over a long-term basis, adverse health effects are expected. However if consumption of fish is lower than that considered to be a “reasonable” exposure, these risks are considerably reduced. The risk assessment is a first-tier or screening exercise and indicates that more information is needed to make an informed decision.

SUMMARY

The fish biomass in all of the dams, including the controls, was dominated by sharptooth catfish. By contrast, the contribution made by common carp was considerably less than expected. The canary kurper was numerically dominant in only two dams, Hartbeespoort and Rietvlei. In a parallel investigation at Rietvlei, it is apparent that limited removal of zooplankton by fish is occurring – a finding that contradicts the hypothesis that top-down control is prevalent in the presence of this fish species.

All of the dams supported fish populations that exceed areal biomass levels commonly-associated with a swing towards algal dominance. As the control dams in this set also exceeded this level, further studies will be necessary to determine biomass levels peculiar to South African dams.

The fish populations of all seven dams were dominated by sharptooth catfish and common carp, as well as canary kurper in the cases of Hartbeespoort and Rietvlei Dams. All of these species are known to impart a variety of bottom-up negative stresses on the aquatic environments in which they are present. Accordingly, their deliberate management, through a process of fish-directed biomanipulation, should provide a measure of relief of these impacts and allow populations of desirable species to resurge.

This study estimates that a harvestable potential of coarse fish (carp, catfish) exists in all of the dams examined. Additionally, there is a potential for harvesting higher value species from five of the seven dams reviewed. This finding supports the original contention that efforts to reduce coarse fish pressure on these waters, in the process augmenting ecosystem health, may be underpinned by sustainable economic and food security incentives

This study concludes that there are sufficient grounds to support further research into the implementation of fishery-based interventions in nutrient-enriched South African dams as a means of providing in-lake relief from eutrophication pressure. This work will require a closer examination of the feeding pathways and mechanisms. Presumptions regarding food eaten by the different species requires empirical confirmation, for example using Stable Isotope Analysis (SIA), supported by some gut content analysis (at least for the 3 coarse species) in several of the study dams. In parallel, zooplankton:phytoplankton biomass ratios need explicit determination in a wider suite of dams, along with assessments of zooplankton composition (large vs. small-bodied taxa). Additionally, the health risks associated with the consumption of fish harvested from these eutrophic waters will require additional investigation.

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1 INTRODUCTION

This project arose out of findings arising from the Hartbeespoort Dam Remediation Project (Harding et al., 2004). During the Hartbeespoort Dam project, it became apparent that fish-induced imbalances, imparted through combinations of excessive grazing, bioturbation, enhanced nutrient recycling via excretion and other factors, in the reservoir foodweb might be contributing to the exacerbation of eutrophication pressure. This conclusion was supported by the project reviewers, SYKE (Finnish Limnological Institute). The project consultant, DH Environmental Consulting (DHEC), subsequently obtained additional funding and contracted Ecodynamics to undertake a fishery study, inclusive of a standing stock and potential harvestable yield determination.). The results of studies conducted on other systems (see Literature Review) suggested that the deliberate bulk removal of problem (coarse) fish species, following by sustained maintenance fishing over the longer term, could provide a potentially-significant measure of relief to the reservoir ecosystem. Based on the findings of the Hartbeespoort Dam work (Harding et al., 2004; Koekemoer et al., 2005), DHEC submitted a proposal to examine the fish assemblages of a further suite of reservoirs, ranging from oligo-mesotrophic to hypertrophic, located within the same ecoregion as Hartbeespoort.

It is acknowledged that the relevance of top-down relief via biomanipulation may be of limited value in warm, southern hemisphere lakes (Hart and Hart, 2006; Hart, 2006; Jeppesen et al., 2010). The absence of obligate zooplanktivores in South African lakes and the lack of empirical data describing feeding modes of facultative species, constrains this hypothesis. However, in the absence of specific data and information, the objectives of this study encompass the impacts of imbalanced fisheries from both top-down and bottom-up perspectives.

This project (WRC K5/1643), undertaken as a joint venture comprising DH Environmental Consulting and Koekemoer Aquatic Services (KAS), was commissioned to examine six dams – these being Rietvlei Dam; Roodeplaat Dam; Bon Accord Dam, Koster River Dam, Lindleyspoort Dam, and Rust De Winter Dam. The previous study on Hartbeespoort Dam was used as blueprint for the procedures followed in this study. The Lindleyspoort and Rust de Winter Dams were included as controls by virtue of their oligo-meso trophic status.

This study was conducted in order to assess the current status of the fish community and to evaluate the trophic structure for the purposes of possible future foodweb manipulation. Two seasonal surveys were conducted for each dam to include differences in the fish population in terms of seasonal trends, and distribution. Preliminary fish surveys were conducted on each dam during late August to November (spring or early summer/pre-rain season), and a second set of surveys were conducted during January-March 2008 (summer/rain and post-rain season).

Biomanipulation provides an attractive restoration and management method for the remediation of eutrophic lakes (Koekemoer and Steyn, 2004b). This report will aim to assess sampling gear selectivity in order to make recommendations towards the use of specific gears in targeting certain or unwanted species, in terms of biomanipulation and exploitation. The main focus is on gill net catches, as this fishing method seems to be the most effective, practical and cost effective – this statement made with reference to the current Hartbeespoort Dam fish removal project. Long line fishing is another effective fishing method for targeting certain fish species such as catfish. It was, however, not tested during this study as its effectiveness was proven during the antecedent study on Hartbeespoort Dam (Koekemoer *et al.,* 2005).

The findings of this study, in terms of sampling gear selectivity (gill net selectivity), will, therefore, provide guidelines in the design and implementation of a remedial biomanipulation programme where the culling and/or harvesting of fish biomass are to be considered as the key components of such a programme.

A reduction in the external nutrient load is always the primary measure to provide a sound basis for the recovery of any eutrophic lake. If external nutrient load, or the concentration of the limiting nutrient (most often phosphorus) is high, algal production can simply exceed the grazing potential of zooplankton. In general, the abundance of zooplankton is affected primarily by two factors: (i) the availability of edible algal food and (ii) the predation by planktivorous fish. However, in eutrophic waters there is generally no shortage of algae as food for zooplankton and in theory, therefore, the density of zooplankton may be increased by reducing the numbers of planktivorous fish. The quality and edibility of available algal food resources also plays a role. Ingestion of large colonial or filamentous blue-greens is physically-impossible even for large cladocerans.

As a result of eutrophication, the total biomass and species composition of a fish community change – with fish biomass positively correlated with nutrient availability. This process especially favours benthivorous fish such as catfish and carp – termed ‘coarse’ species in this report. While foraging in the benthic zone and reintroducing nutrients back into the overlying water, these fish may be of major importance behind the mass development of phytoplankton.

In order to assess the possible validity of biomanipulation of the fish communities in the afore- mentioned dams, two fish surveys per dam were conducted to make provision for seasonal induced distribution – as it is well-known that fish distribution plays a major role in certain aspects of fish population dynamics and the resulting biomass and yield estimates. This report will also focus on estimated biomass and yield figures for each dam in order to assess the potential for fisheries projects for each dam, which will be economically viable and sustainable.

1.1 OBJECTIVES OF THE FISH STUDY

- To assess the species composition and densities of each dam;
- To compile a comprehensive fisheries document, which reports on the fish population dynamics of each dam;
- To assess the contribution each species made to the catches of the experimental fishing gears;
- To select the species that should be subjected to biomanipulation with the aid of an Index of Relative Importance (IRI) as described by Kolding (1998);
- To explore sampling gear selectivity and catch per unit effort (CPUE), for the selection of potential fishing gears;
- To conduct a desktop study on feeding behaviour of the relevant fish species (Appendix C);
- To conduct a fish stock assessment for each dam, and
- To make recommendations towards sustainable harvesting, and biomanipulation programmes for each dam.

1.2 ADDITIONAL OBJECTIVES

The following additional objectives were included during the course of the study, with the approval of the Water Research Commission:

- The compilation of a Literature Review (Appendix A);
- The determination of trace metal and endocrine disruptor compound biomarkers in fish tissue from the Roodeplaat Dam (Appendix B).

2 BACKGROUND

South Africa is largely dependent on water stored in dams for raw potable water supply, livestock watering and irrigation (WRC, 2006). Several of these dams, predominantly located in the economic heartland of South Africa, have been and remain subject to long-standing nutrient enrichment (eutrophication) (e.g. DWAF, 2001, 2002). Many South African waters subsist in an advanced state of eutrophication, and are resilient to remediation, requiring shock treatments to allow the system to reset. The deliberate harvesting and management of fish populations may provide a mechanism to alleviate eutrophication pressure.

Eutrophication constitutes the single greatest threat to South African impoundments. Imbalanced fish populations are a natural consequence of eutrophication, and eutrophic conditions are favoured by tolerant species that will dominate the system in the final stages of lake succession. These undesirable fish species ('coarse' fish) exert pressure on the ecosystem that is likely to exacerbate the process of eutrophication.

Fish communities in eutrophic lakes can potentially be restructured via a self-funding process of harvesting in order to improve ecosystem functioning and management of the negative effects of elevated trophy. Fish removal is the first step of a process referred to as bio- or (more correctly) foodweb-manipulation in eutrophic aquatic ecosystems. The process of fish removal entails two phases; firstly bulk removal of the coarse fish, followed by long-term harvesting of a variety of species from the rehabilitated fishery. Both phases have economic benefits as the catch from both is saleable and the value of the catch can increase depending on the species composition and the degree of rehabilitation achieved.

It is conceded that the logistics of fish removal from multi-functional reservoir lakes may well pose a significant constraint to biomanipulation via this approach.

2.1 APPROACH

Phase I of this project (WRC Project No: 1643) entails the examination and documentation of the degree of fishery imbalance existing in a selected suite of impaired South African dams and to identify the management options and actions required to restructure the fish population.

A suite of 6 dams was selected for this project, these being"

- Bon Accord Dam
- Koster River Dam
- Lindleyspoort Dam (Control Dam)
- Rietvlei Dam
- Roodeplaat Dam
- Rust de Winter Dam (Control Dam)

Three impacted dams were selected and studied in the Gauteng area, and two (one being a control) in the North West Province, and the results are discussed in this report. These dams are the Rietvlei, Bon Accord, and Roodeplaat Dams in Gauteng, and the Koster River and Lindleyspoort Dams in the North West Province. The second control dam, Rust De Winter, falls in the Limpopo Province.

2.2 OBJECTIVES OF WRC PROJECT NO: 1643

The detailed aims and objectives of the project are as follows:

- Census and document the fish assemblages of a suite of impacted dams and a control dam within the same fish EcoRegion. Couple this to a Trophic State and eutrophication impact assessment for each impoundment.

- Determine the harvesting requirements necessary to re-set the fishery to a desirable assemblage, and the harvesting requirements necessary to sustain the desired assemblage.
- Collect data on the feeding behaviour of the identified fish species.
- Compare and contrast the findings in terms of commonalities of ecosystem response and the degree of system (site) specificity.
- Compare and contrast the findings with those from northern and southern hemisphere evaluations.
- Assess in broad terms the economic and financial implications of the recommended approach. Identify constraints to the proposed rehabilitation methodology.
- Evaluate the findings in terms of the potential of this approach as method for impoundment rehabilitation coupled with commercial opportunities.

The following additional objectives were included during the course of the study, with the approval of the Water Research Commission:

- The compilation of a Literature Review;
- The determination of trace metal and endocrine disruptor compound biomarkers in fish tissue from the Roodeplaat Dam.

2.3 ASSESSED DAMS

This document provides information on the fisheries research aspects of the project. Each of the dams were surveyed during late August-November (spring or early summer/pre-rain season) and January-March (summer/rain and post-rain season) during 2007-2009. These dams are:

An overview of the dams in question provides a better understanding when focussing on the surveys. The dams are described in sections three to eight of this document.

2.4 FISH SPECIES EXPECTED TO OCCUR IN THE DAMS

This section focuses on the species most likely or expected to occur in the six dams. A short description and the habitat preferences of the species expected to occur are presented in Table 2.1 (Cochrane, 1985; Skelton, 1993). Comments are also made about the exploitation potential of the species. Subsistence fishery utilisation of the species in Table 2.1 refers to utilisation in systems elsewhere in Southern Africa.

The dams have a combined expected species diversity of around 13 species, although 20 species have been listed historically. Abbreviations and symbols used in Table 2.1 include FL = Fork Length, SL = Standard Length, TL = Total Length, and A = Alien or exotic. ??? – indicates unexpected species (in the sense that it would be surprising if they were found to occur) due to their distribution, rarity/uncommonness, and habitat preferences; these species are mostly warm water species with a wide distribution in sub-tropical and tropical areas towards the northern regions and north of SA's borders.

The most commonly expected fish species in the dams are shown in Figure 2.1.

Table 2.1: Species which are expected to occur in the three dams, with a short description and habitat preferences (Cochrane, 1985; Skelton, 1993).

No	Species	Expected Fish Species: Common Name and Short Description with Habitat Preference	Occurrence in Dam
A	**MORMYRIDAE**		
1	*Marcusenius macrolepidotus*	**Bulldog:** a small to medium species (300 mm SL, 0.5 kg). Relatively uncommon in SA. More common to the northern regions. Favours well vegetated, muddy bottomed marginal habitats. Major prey of catfish.	**???**
B	**CYPRINIDAE**		
2	*Cyprinus carpio* **(A)**	**Carp:** a large species (35 kg), hardy and tolerant, favours large water bodies. Thrives in dams. An **aquaculture** and **angling** species. This species is a **good candidate for exploitation**	**Expected**
3	*Labeobarbus marequensis*	**Largescale Yellowfish:** a medium to large species (470 mm TL, 6 kg), favours flowing waters, uncommon in dams. An **angling** species.	**Expected**
4	*Barbus mattozi*	**Papermouth:** medium to large species (400 mm SL), prefers quiet water, deep pools, and thrives in man-made impoundments. An **angling** species.	**Expected**
5	*Labeobarbus polylepis*	**Smallscale Yellowfish:** medium to large species (460 mm TL), a cool water species, occurs in deep pools, flowing waters of permanent rivers, and in dams. A popular **angling** species.	**Expected**
6	*Labeobarbus aeneus*	**Smallmouth Yellowfish:** medium to large species (500 mm FL, 7.8 kg), prefers clear flowing waters of rivers, also found in dams. A popular **angling** species. A **trans-located** species.	**???**
7	*Barbus paludinosus*	**Straightfin Barb:** small species (150 mm SL), hardy, preferring quiet well-vegetated water. **Utilised by subsistence fisheries** in Malawi.	**Expected**
8	*Barbus trimaculatus*	**Threespot Barb:** small species (110-150 mm SL), hardy and common, found in variety of habitats, prefers shallow vegetated areas.	**Expected**
9	*Barbus unitaeniatus*	**Longbeard Barb:** small species (140 mm SL), wide habitat preference, flowing and standing waters, thrives in dams.	**Expected**
10	*Mesobola brevianalis*	**River Sardine:** small species (75 mm SL), shoals and prefers well aerated open water. Used as **forage fish** in dams in Zimbabwe.	**Not Expected**
11	*Labeo molybdinus*	**Leaden Labeo:** a medium sized species (380 mm SL, 1.7 kg), favours deep pool habitat, angling and subsistence species.	**???**
C	**CHARACIDAE**		
12	*Micralestes acutidens*	**Silver Robber:** a small species of the tigerfish family (80 mm SL), shoals in clear open water.	**???**
D	**SCHILBEIDAE**		
13	*Schilbe intermedius*	**Silver Catfish:** a medium sized fish, (300 mm SL, 1.3 kg), a subtropical/tropical species. Shoals in open water, with vegetation. A subsistence species.	**???**
E	**CLARIIDAE**		
14	*Clarias gariepinus*	**Sharptooth Catfish:** large species (1.4-1.7 m SL, 59 kg), hardy, has a wide habitat preference and distribution. **Utilised by subsistence fisheries.** An important **angling** and **commercial food species. A good candidate for exploitation.**	**Expected**

No	Species	Expected Fish Species: Common Name and Short Description with Habitat Preference	Occurrence in Dam
F	**MOCHOKIDAE**		
15	*Synodontis zambezensis*	**Brown Squeaker:** a medium to large species (430 mm SL), prefers pools and slow flowing reaches of rivers, prefers riverine habitats.	**???**
G	**CICHLIDAE**		
16	*Pseudocrenilabrus philander*	**Southern Mouthbrooder:** small species (130 mm TL), has a wide distribution and wide habitat preference, usually favours vegetated areas.	**Expected**
17	*Tilapia sparrmanii*	**Banded Tilapia:** small to medium species (230 mm SL, 0.5 kg), tolerant of a wide range of habitats, but prefers quiet vegetated areas. **Utilised by subsistence fisheries.**	**Expected**
18	*Chetia flaviventris*	**Canary Kurper:** small to medium species (200 mm TL), favours standing or slow flowing pools, and thrives in impounded waters.	**Expected**
19	*Oreochromis mossambicus*	**Mozambique Tilapia:** medium to large species (400 mm SL, 3-4 kg), occurs in all but fast-flowing waters, hardy and tolerant, prefers slow-flowing or standing water in which it thrives. **Aquaculture, fisheries and angling** species. **Has potential for exploitation.**	**Expected**
H	**Centrarchidae**		
20	*Micropterus salmoides* **(A)**	**Largemouth Bass:** large species (600 mm TL, 5-10 kg), prefers clear, standing or slow flowing water, with submerged and floating vegetation. Does well in dams. Tolerant to low and high temperatures. **Major freshwater game fish species.**	**Expected**
TOTAL NUMBER OF FAMILIES = 8			
TOTAL NUMBER OF SPECIES = 20			

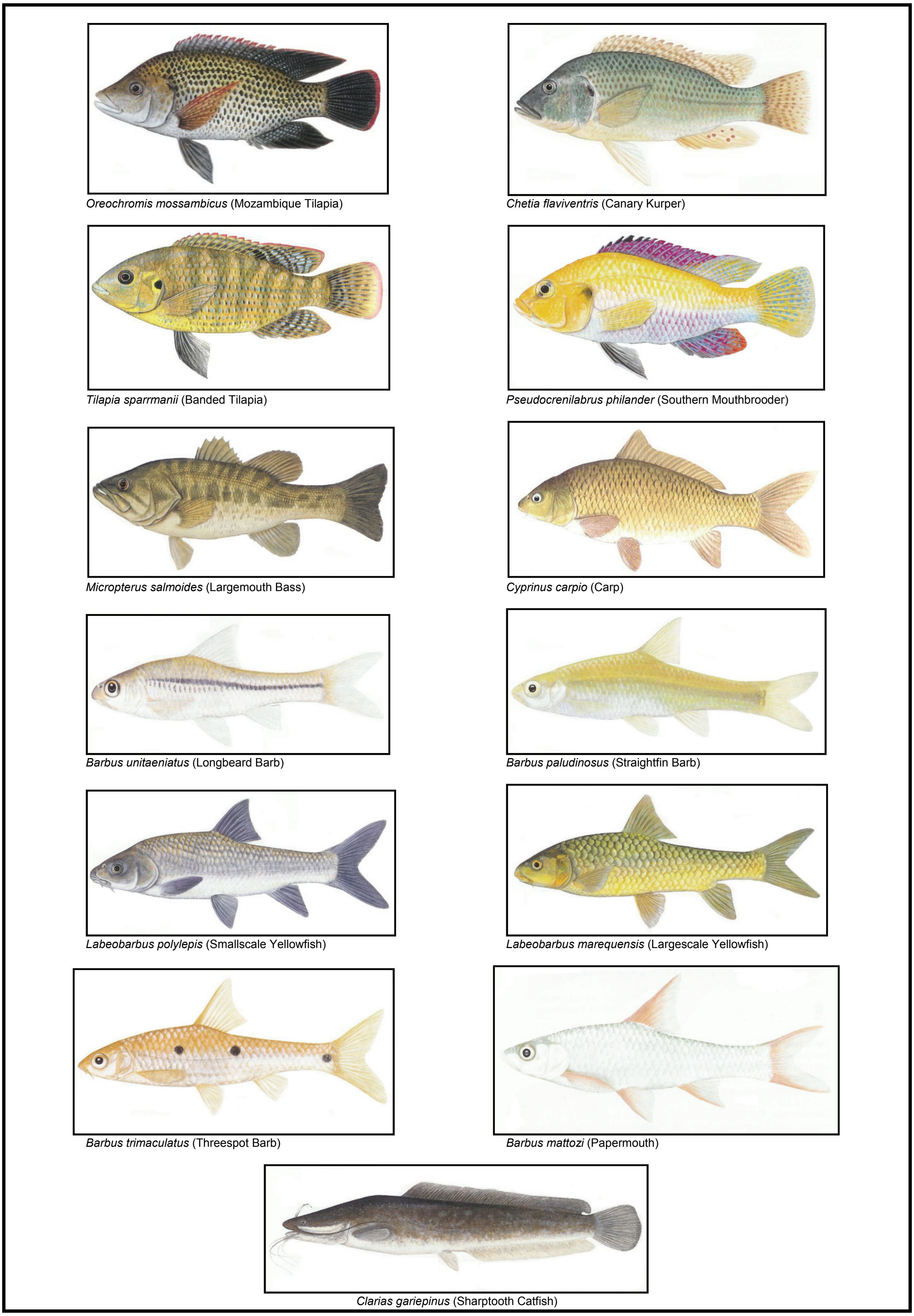

Figure 2.1: Fish species most commonly expected to occur in the dams, with common names in brackets (pictures from Skelton, 1993).

3 DESCRIPTION OF RIETVLEI DAM

3.1 LOCATION

Rietvlei Dam is situated in the Upper Crocodile sub-catchment of Water Management Area 3 (WMA 3), Quaternary catchment A21A, on the Hennops RIver. This dam falls within the Western Bakenveld EcoRegion (RHP, 2005). Rietvlei Dam currently supplies 27% of Pretoria's water requirements. The dam is supported by the smaller Marais Dam, which lies approximately 4 km upstream in the Sesmylspruit, with the two are separated by a wetland (Peacock, 2001). According to Delport and Mallory (2002) landuse within catchment A21A is dominated by:

- Irrigation (11.7 km^2)
- Urban areas (35 km^2)

Rietvlei Dam was built in 1934 for the purpose of urban water supply and is one of the main storage dams in the Upper Crocodile sub-catchment. The total capacity of the dam is 12.4 million m^3.

3.1.1 <u>Water Treatment Works</u>

The Hartbeesfontein Water Treatment Works (WTW) is operated from the dam by the Tshwane Metropolitan Council, supplementing the Rand Water supply to Pretoria (Delport and Mallory, 2002). Water quality upstream of the Marais and Rietvlei dams is influenced by domestic and industrial effluents. According to the River Health Programme (RHP, 2005) the EcoStatus for this area is **POOR**. This assessment is largely due to urbanization, high urban runoff, and sewage spills.

3.2 GENERAL CHARACTERISTICS

The general characteristics of Rietvlei Dam (Van Ginkel *et al*., 2007) are provided in Table 3.1 below.

Table 3.1: General characteristics of Rietvlei Dam

Latitude	25°52'34.8"S
Longitude	28°16'47.6"E
Climate	Temperate
Volume (FSL) ($10^6 m^3$)	12.88
Mean depth	6.2m
Surface area (km^2)	2.06
Mean air temperature (Min/Max ◘C)	-3.4/28.7
Water surface temperature (Min/Max ◘C)	10.1/30.7
Circulation type	Warm, monomictic

3.3 TROPHIC STATUS

According to Van Ginkel *et al*. (2007), Rietvlei Dam is known to experience dinoflagellate blooms, primarily *Ceratium hirundinella.* The trophic status of Rietvlei Dam is summarised in Table 3.2 (DWAF, 2002)

Table 3.2: Trophic status of Rietvlei Dam

Mean TP mg/L	n TP	Mean Annual Chlorophyll *a* (µg/l)	n Chl	Percent of time Chl *a* > 30 µg/l	Trophic status	Comment
0.36	20	63.7	21	33	Hypertrophic	Serious potential and significant current algal productivity

3.4 RIETVLEI RESERVE

The Rietvlei Nature Reserve lies between Pretoria and Johannesburg and is one of the world's largest urban nature reserves, 3 800 hectares in extent (www.gauteng.com). The Sesmylspruit flows into the Marais Dam and then overflows and joins the Grootvleispruit that flows through the reserve and forms an 8 km vlei or wetland (http://www.tshwane.gov.za/rietvlei_scientific.cfm). Developed out of the Rietvlei Water Scheme, it is solely responsible for conservation of the Sesmylspruit catchment area (http://www.tshwane.gov.za/rietvlei_history.cfm). According to Peacock (2001) the reserve is situated in the grassland biome and although avian species diversity is low, it does host many of the South African endemic bird species as this area has good open water and wetland habitats, and 240 bird species have been recorded.

The Rietvlei Nature Reserve has been restocked with game that is endemic to the Highveld. Black Wildebeest and the Blesbok are present. Other animals found in the Rietvlei Nature Reserve include the Eland, Burchell's Zebra, Red Hartebeest, Springbok, Waterbuck, Reedbuck, Ostrich, Buffalo, White Rhino, Bushpig, as well as a number of Black-backed Jackal, Mountain Reedbuck, Oribi, Grey Duiker, Steenbuck, Brown Hyena, Porcupine, Springhare, Aardwolf and Banded Mongoose. Recently a family group of five hippos as well as cheetah were introduced to Rietvlei Reserve (http://www.sa-venues.com/game-reserves/ga_rietvlei.htm).

Rietvlei Nature Reserve is important as:

- a proclaimed nature reserve in a city or urban setting.
- three of the ‘Big 5’ or 4 of the ‘Big 6’ game animals can be seen in the reserve, namely: rhino, buffalo, leopard and hippo.
- only 5% of the veld type is protected in conservation areas and more than 66% has already been changed, degraded or lost to development.
- Rietvlei has one of the largest peat lands in a protected area in South Africa.
- the reserve is unique as it is the only Proclaimed Bakenveld Nature Reserve on a Dolomite foundation in the World.
- it is a Nature Reserve on High Potential Agricultural Land with a high carrying capacity.
- the reserve has a high number of threatened Fauna and Flora species.

Source: (http://www.tshwane.gov.za/rietvlei_scientific.cfm).

3.5 FISH SPECIES

The species expected to be present in Rietvlei Dam under reference conditions are listed in Table 3.3 below (pers comm., Van Ginkel, 2007).

Table 3.3: Fish species expected in Rietvlei Dam under reference conditions

Fish	Common name
Clarias gariepinus	Sharptooth catfish
Chetia flaviventris	Canary kurper
Oreochromis mossambicus	Blue kurper
Labeobarbus marequensis	Largescale yellowfish
Cyprinus carpio	Carp
Barbus trimaculatus	Threespot barb
Barbus mattozi	Papermouth
Barbus unitaeniatus	Longbeard barb
Labeobarbus polylepis	Smallscale Yellowfish
Pseudocrenilabrus philander	Southern mouthbrooder
Micropterus salmoides	Largemouth bass
Barbus paludinosus	Straightfin barb
Tilapia sparrmanii	Banded tilapia
Mesobola brevianalis	River sardine

In 2000, the Pretoria City Council nature conservators translocated 19 000 indigenous fish and fingerlings from the Hartbeespoort Dam Breeding Station to the Rietvlei Dam to boost its fish population, and these included the red-breasted kurper (*Tilapia rendalli*), *Oreochromis mossambicus*, and *Pseudocrenilabrus philander* (Peacock, 2001).

The water quality and biotic response of the Rietvlei Reservoir constitute something of an anomaly in that despite very high levels of ambient total and dissolved phosphorus, the level of algal biomass, measured as chlorophyll-a, is relatively low. Work currently (2010/11) being conducted at Rietvlei has indicated problems at the foodweb level – with the cause and effect pathways not yet discerned (Harding and Hart, WRC Project 1918).

4 DESCRIPTION OF ROODEPLAAT DAM

4.1 LOCATION

Roodeplaat Dam is situated in the Apies/Pienaars sub-catchment of Water Management Area 3 (WMA 3), Quaternary Catchment A23A. This dam falls within the Eastern Bakenveld EcoRegion (RHP, 2005). According to Delport and Mallory (2002) landuse within this catchment A23A is dominated by:

- Irrigation (18.1 km^2)
- Urban areas (69 km^2) with a population of 18830

Roodeplaat dam was built in 1959 for the purpose of irrigation and domestic water supply and is along with Klipvoor Dam the major dams in the Pienaars River. The total capacity of the dam is 43.5 million m^3.

4.1.1 Water Treatment Works

The Roodeplaat WTW, operated by Magalies Water, is situated 5 km downstream of the dam. Raw water is abstracted from an irrigation canal downstream of the dam and treated water is supplied to the Wallmannsthal Military Base, Baviaanspoort Prison and smallholdings situated around Roodeplaat Dam (Delport and Mallory, 2002). Roodeplaat Dam supplies Klipdrift WTW via an irrigation canal on the west bank. From here water is pumped to Babalegi Reservoir, Pienaarsrivier, Warmbaths and Nylstroom (Delport and Mallory, 2002).

In 1998 the Northern Province Regional Office of the DWAF requested a study to determine the water quality status of the Roodeplaat Dam. Hohls *et al*. (1998) found that the two main point sources of phosphate contributing to the phosphate load in the Roodeplaat Dam were the Baviaanspoort and the Zeekoeigat wastewater treatment works (WWTWs). The Baviaanspoort WWTW, located approximately 10 km upstream of the Roodeplaat Dam on the eastern bank of the Pienaars River, and the Zeekoeigat WWTW is located immediately to the west of the Roodeplaat Dam. The treated effluent flows into the Roodeplaat Dam *via* a short earth canal, which passes through the Roodeplaat Dam Nature Reserve. An important reason for the Zeekoeigat WWTW being constructed in the Roodeplaat Dam catchment was that the DWAF had specifically requested that the treated water from the Zeekoeigat WWTW remain in the catchment due to expected increases in the water demand from this impoundment. Hohls *et al*. (1998) found that the phosphorus load to the Roodeplaat Dam was at that time point source dominated, and that the source was likely to become increasingly significant. Additionally the non-point source phosphate load was increasing due to growing informal residential areas in the vicinity.

Due to high levels of urbanization and landuse activities, the Pienaars River upstream from Roodeplaat Dam is subjected to flow and bed modification, and higher flows due to discharges of treated domestic and industrial effluent and the EcoStatus for this area is **POOR** (RHP, 2005).

4.2 TROPHIC STATUS

According to Van Ginkel *et al*. (2007), Roodeplaat Dam has shown the occasional presence of dinoflagellates. The trophic status of Roodeplaat Dam is summarised in Table 4.1 (DWAF, 2002).

Table 4.1: Trophic status of Roodeplaat Dam

Mean TP mg/ L	n TP	Mean Annual Chlorophyll *a* (µg/l)	n Chl	Percent of time Chl *a* > 30 µg/l	Trophic status	Comment
0.194	100	46.6	100	41	Hypertrophic	Serious potential and significant current algal productivity

4.3 GENERAL CHARACTERISTICS

The general characteristics of Roodeplaat Dam are provided in Table 4.2 below (Van Ginkel *et al*., 2007).

Table 4.2: General characteristics of Roodeplaat Dam

Latitude	25°38'12.4"S
Longitude	28°21'39.7"E
Climate	Temperate
Volume (FSL) ($10^6 m^3$)	41.9
Mean depth	10.6m
Surface area (km^2)	3.97
Mean air temperature (Min/Max ◘C)	1.8/36.2
Water surface temperature (Min/Max ◘C)	15.2/27.8
Circulation type	Warm, monomictic

4.4 ROODEPLAAT RESERVE

The Roodeplaat Reserve along the eastern shore of the dam is 795 ha. The vegetation consists of a mix of open savannah veld and dense savannah woodland located in the veld type classified as, sour mixed bushveld. The Reserve has a variety of game species and includes Burchell's Zebra, Kudu, Waterbuck, Warthog, Impala, Blue-wildebeest, Common Duiker, Steenbok, Black-backed Jackals. The Reserve is a good birding venue with over 170 species of birds having been recorded.

(http://www.gdace.gpg.gov.za/html/Roodeplaat.htm).

4.5 FISH SPECIES

The species listed in Table 4.3 (Malan, 1983) are expected to occur in Roodeplaat Dam.

Table 4.3: Fish species expected to occur in Roodeplaat Dam

Fish	Common name
Clarias gariepinus	Sharptooth catfish
Chetia flaviventris	Canary kurper
Oreochromis mossambicus	Blue kurper
Labeobarbus marequensis	Largescale yellowfish
Cyprinus carpio	Carp
Barbus trimaculatus	Threespot barb
Barbus mattozi	Papermouth
Labeobarbus polylepis	Smallscale Yellowfish
Micropterus salmoides	Largemouth bass
Barbus paludinosus	Straightfin barb
Tilapia sparrmanii	Banded tilapia

5 DESCRIPTION OF BON ACCORD DAM

5.1 LOCATION

Bon Accord Dam is situated in the Apies/Pienaars sub-catchment of Water Management Area 3 (WMA 3), Quaternary Catchment A23B. This dam falls within the Bushveld Basin (RHP, 2005). According to Delport and Mallory (2002) landuse within quaternary catchment A23B and C is dominated by:

- Irrigation (10.7 km^2).
- Urban development (43.2% of the catchment) and a population of 33320.

Bon Accord was built in 1923 for the purpose of irrigation and is a major dam situated in the Apies River. The total capacity of the dam is 4.4 million m^3. A significant proportion of the Apies River catchment is occupied by some form of industrial or urban land use and, as a result, there are several point sources discharging into the river upstream of Bon Accord Dam. Due to flow from irrigation upstream and downstream of the dam, these activities do affect water quality to some extent. The Apies River in this area has been canalised and straightened in the urban areas. Higher flows and urban and agricultural runoff are the main determinants for a **POOR** EcoStatus assessment, although some riffle and wetland habitats are present and sections of the river near Bon Accord Dam have been earmarked for rehabilitation (RHP, 2005).

5.2 TROPHIC STATUS

According to Van Ginkel *et al*. (2007), Bon Accord Dam has shown the occasional presence of Dinoflagellates. The trophic status of Bon Accord Dam is summarised in Table 5.1 (DWAF, 2002).

Table 5.1: Trophic status of Bon Accord Dam

Mean TP mg/ L	n TP	Mean Annual Chlorophyll *a* (µg/l)	n Chl	Percent of time Chl *a* > 30 µg/l	Trophic status	Comment
0.63	20	326.7	21	93	Hypertrophic	Serious potential and current algal productivity

5.3 GENERAL CHARACTERISTICS

The general characteristics of Bon Accord Dam are provided in Table 5.2 below (Van Ginkel *et al*., 2007).

Table 5.2: General characteristics of Bon Accord Dam

Latitude	25°37'45"S
Longitude	28°11'21.9"E
Climate	Temperate
Volume (FSL) ($10^6 m^3$)	4.293
Mean depth	3.6m
Surface area (km^2)	1.7
Mean air temperature (Min/Max ◘C)	0.8/35.0
Water surface temperature (Min/Max ◘C)	10.6/29.3
Circulation type	Warm, dimictic

5.4 FISH SPECIES

The following species list has been compiled from fish data listed in Kleynhans *et al*. (2007), as a species list for the fish in Bon Accord Dam is not available (Table 5.3 below).

Table 5.3: Fish species expected to occur in Bon Accord Dam

Fish	Common name
Clarias gariepinus	Sharptooth catfish
Chetia flaviventris	Canary kurper
Oreochromis mossambicus	Blue kurper
Labeobarbus marequensis	Largescale yellowfish
Cyprinus carpio	Carp
Barbus trimaculatus	Threespot barb
Barbus mattozi	Papermouth
Labeobarbus polylepis	Smallscale Yellowfish
Micropterus salmoides	Largemouth bass
Barbus paludinosus	Straightfin barb
Tilapia sparrmanii	Banded tilapia

6 DESCRIPTION OF KOSTER RIVER DAM

6.1 LOCATION

Koster River Dam is situated on the Koster River, a tributary of the Elands River in WMA 3, North West Province. Koster River Dam falls within the Selons/Koster study unit of the Elands sub-management area. The dam is situated in Quaternary Catchment A22B boundary in the Western Bakenveld EcoRegion. Major impacts in the Selons/Koster ecological study unit are river impoundments altering natural flow regimes and inefficient water abstraction for irrigation (RHP, 2005).

According to Delport and Mallory (2002) the catchment area is 284 km^2 with a mean annual precipitation of 599 mm per annum. Land use within catchment A22B is dominated by:

- Irrigation (2.75 km^2)
- Alien vegetation (0.03 km^2).

Koster River Dam was built in 1963 for the purpose of irrigation. The full supply capacity of the dam is 12.8 million m^3 and a full supply area of 2.61 km^2.

6.2 GENERAL CHARACTERISTICS

The general characteristics of Koster River Dam are provided in Table 6.1 below based on personal communications with Ms C van Ginkel and Harding (2008).

Table 6.1: General characteristics of Koster River Dam

Latitude	25°42'0.00"S
Longitude	26°54'15"E
Volume (FSL) ($10^6 m^3$)	12.8
Surface area (km^2)	2.6
Mean depth (m)	4.9
Water surface temperature (Min/Max ºC)	13.7/27.1
Circulation type	Dimictic

6.3 TROPHIC STATUS

According to Van Ginkel (2003) and DWAF (2002), the trophic status of Koster River Dam is oligotrophic with a low occurrence of nuisance algal blooms, but with a moderate potential for significant plant productivity. Data from these studies were based on the Water Management System (WMS) data as well as a once off screening survey conducted by DWAF: Resource Quality Services (D:RQS) during 2002. The results are summarized in Table 6.2. The first three variables were used to determine the trophic status of the impoundments and provides an indication of the potential for plant (algal or macrophyte) growth in the water body. The forth variable, namely the percent of time that cyanobacteria constitute more than 30 per cent of the phytoplankton population, gives an indication of the potential of toxin production in each dam (Van Ginkel, 2003).

During the 2002 D: RQS study, dominant toxin-associated cyanobacteria occurring in the dam were *Anabaena, Microcystis* and *Oscillatoria. Merismopedia* and *Chroococcus* occurred in low numbers.

Table 6.2: Trophic status of Koster River Dam based on Van Ginkel (2003)

Mean TP mg/ L	n TP	Mean Annual Chlorophyll *a* (µg/l)	n Chl	Per cent of time Chl *a* > 30 µg/l	Trophic status
0.045	36	3	26	14	Oligotrophic

Harding (2008) studied thirty impoundments throughout South Africa to evaluate a chemical-specific criterion (phosphorus) in order to establish allowable nutrient loads. According to this study, based on data from 1990-2005 (using the 90%ile values for total phosphorus and chlorophyll-a) Koster River Dam was classified as eutrophic, according to the Trophic State boundaries defined by (Van Ginkel *et al*., 2001). Total phosphorus and chlorophyll-a concentrations were determined to be stable. The results are summarised in Table 6.3.

Table 6.3: Trophic status of Koster River Dam based on Harding (2008)

Mean TP mg/ L	n TP	Mean Annual Chlorophyll *a* (µg/l)	n Chl	Trophic status
0.136	437	19	279	Eutrophic

6.4 KOSTER RIVER DAM RESERVE/SURROUNDS

From personal observations made during this project, the Koster River Dam is mainly surrounded by private game farms. The main agricultural activity in the area seems to be cattle and sheep farming, the extent of which is uncertain. The dam also lies downstream of the town Koster, and water quality related impacts can mainly be associated with urban run-off. Informal settlements also have an impact, as well as resorts in the catchment area.

6.5 FISH SPECIES

The following species list has been compiled from fish data listed in Kleynhans *et al*. (2007), as a species list for the fish in Koster Dam is not available (Table 6.4 below).

Table 6.4: Fish species expected in Koster River Dam under reference conditions

Fish	Common name
Clarias gariepinus	Sharptooth catfish
Chetia flaviventris	Canary kurper
Oreochromis mossambicus	Blue kurper
Labeobarbus marequensis	Largescale yellowfish
Cyprinus carpio	Carp
Barbus trimaculatus	Threespot barb
Barbus mattozi	Papermouth
Barbus unitaeniatus	Longbeard barb
Labeobarbus polylepis	Smallscale Yellowfish
Pseudocrenilabrus philander	Southern mouthbrooder
Micropterus salmoides	Largemouth bass
Barbus paludinosus	Straightfin barb
Tilapia sparrmanii	Banded tilapia
Mesobola brevianalis	River sardine

7 DESCRIPTION OF LINDLEYSPOORT DAM

7.1 LOCATION

Lindleyspoort Dam is situated on the Elands River, north of Swartruggens, in the Crocodile (West) Marico Water Management Area (WMA 3), North West Province. WMA 3 is divided into six sub-areas, with Lindleyspoort Dam falling within the Upper Elands ecological study unit of the Elands sub-management area. The dam is situated in quaternary catchment A22A boundary in the Western Bakenveld EcoRegion. Major impacts in the Upper Elands ecological study unit are sedimentation, resulting from the slate quarries and agriculture, high rates of alien plant infestation and inadequate management of some sewage treatment facilities (RHP, 2005). In addition the Swartruggens WWTW has been a source of problems since 1999 (C van Ginkel, pers comm.).

According to Delport and Mallory (2002) the catchment area is 707 km^2 with a mean annual precipitation of 604 mm per annum. Land use within catchment A22A is dominated by:

- Irrigation (2.75 km^2)
- Alien vegetation (3.26 km^2).

Lindleyspoort Dam was built in 1938 for the purpose of irrigation. The full supply capacity of the dam is 14.34 million m^3 and a full supply area of 1.8 km^2.

7.2 GENERAL CHARACTERISTICS

The general characteristics of Lindleyspoort Dam are provided in Table 3.1 below based on personal communications with Dr. C van Ginkel and Harding (2008).

Table 7.1: General characteristics of Lindleyspoort Dam

Latitude	25^{o}30'52.8"S
Longitude	26^{o}41'31.3"E
Volume (FSL) (10^{6}m^3)	14.34
Surface area (km^2)	1.8
Mean depth (m)	8
Water surface temperature (Min/Max ºC)	12.8/27.6
Circulation type	Monomictic

7.3 TROPHIC STATUS

According to Van Ginkel (2003) and DWAF (2002), the trophic status of Lindleyspoort Dam is oligotrophic with a low occurrence of nuisance algal blooms, but with a potential for significant plant productivity. Data from these studies were based on the Water Management System (WMS) data as well as a once off screening survey conducted by DWAF: Resource Quality Services (D:RQS) during 2002. The results are summarized in Table 7.2. The first three variables were used to determine the trophic status of the impoundments and provides an indication of the potential for plant (algal or macrophyte) growth in the water body. The forth variable, namely the percent of time that cyanobacteria constitute more than 30 per cent of the phytoplankton population, gives an indication of the potential of toxin production in each dam (Van Ginkel, 2003).

During the 2002 D: RQS study dominant toxin-associated cyanobacteria occurring in the dam was *Anabaena, Microcystis* and *Merismopedia. Cylindrospermopsis*, *Oscillatoria*, *Spirulena* and *Chroococcus* occurred in low numbers.

Table 7.2: Trophic status of Lindleyspoort Dam based on Van Ginkel (2003)

Mean TP mg/ L	n TP	Mean Annual Chlorophyll *a* (µg/l)	n Chl	Per cent of time Chl *a* > 30 µg/l	Trophic status
0.060	47	3.1	29	0	Oligotrophic

Harding (2008) studied thirty impoundments throughout South Africa to evaluate a chemical-specific criterion (phosphorus) in order to establish allowable nutrient loads. According to this study, based on data from 1990-2005 (using the 90%ile values for total phosphorus and chlorophyll-a) Lindleyspoort Dam was classified as eutrophic, according to the Trophic State boundaries defined by (Van Ginkel *et al*., 2001). Total phosphorous and chlorophyll a concentrations were determined to be stable. The results are summarised in Table 7.3.

Table 7.3: Trophic status of Lindleyspoort Dam based on Harding (2008)

Mean TP mg/ L	n TP	Mean Annual Chlorophyll *a* (µg/l)	n Chl	Trophic status
0.060	237	9.9	161	Eutrophic

7.4 LINDLEYSPOORT RESERVE/SURROUNDS

From personal observations (JH Koekemoer), Lindleyspoort Dam is surrounded by private game reserve areas in the north, west and south, and bordered by DWAF property towards the east. The surrounding area is in a relatively natural state, and very low density housing developments are present (private log cabins). Boats are not allowed, and limited fishing areas are available.

7.5 FISH SPECIES

The following species list has been compiled from fish data listed in Kleynhans *et al*. (2007), as a species list for the fish in Lindleyspoort Dam is not available (Table 7.4 below).

Table 7.4: Fish species expected in Lindleyspoort Dam under reference conditions

Fish	Common name
Clarias gariepinus	Sharptooth catfish
Chetia flaviventris	Canary kurper
Oreochromis mossambicus	Blue kurper
Labeobarbus marequensis	Largescale yellowfish
Cyprinus carpio	Carp
Barbus trimaculatus	Threespot barb
Barbus mattozi	Papermouth
Barbus unitaeniatus	Longbeard barb
Labeobarbus polylepis	Smallscale Yellowfish
Pseudocrenilabrus philander	Southern mouthbrooder
Micropterus salmoides	Largemouth bass
Barbus paludinosus	Straightfin barb
Tilapia sparrmanii	Banded tilapia
Mesobola brevianalis	River sardine

8 DESCRIPTION OF RUST DE WINTER DAM

8.1 LOCATION

The Rust de Winter Dam is situated in the Elands River, which is a tributary of the Crocodile River, in WMA 4. Rust de Winter falls within Quaternary Catchment B31C of the Elands River catchment. The Elands River catchment, in the western part of the WMA, has a high rural population that exceeds the urban population, since most of the former Kwandebele Homeland is situated in the catchment (DWAF 2003).

This dam falls within EcoRegion 3.02, characterised by Mixed Lowveld Bushveld and Sour Lowveld Bushveld vegetation types (Kleynhans *et al*., 2007). This is an area of middle slopes (800-1 500 m) with mixed bushveld overlying shallow coarse sandy soils on mudstone, sandstone and shale. Average annual precipitation is 400-800 mm and temperatures range from 16-22°C (RHP, 2001)

According to DWAF (2003) the catchment area is 1145 km^2 with a mean annual precipitation of 600 mm/ annum. Land use within catchment B31C is dominated by:

- Irrigation (2.75 km^2)
- Alien vegetation (0.03 km^2)

Rust de Winter Dam was built in 1933 to supply water for domestic use to the Western Highveld Region and for irrigation. The full supply capacity of the dam is 26.94 million m^3 and a full supply area of 473 ha.

8.2 GENERAL CHARACTERISTICS

The general characteristics of Rust de Winter Dam are provided in Table 8.1 below based on personal communications with Ms C van Ginkel and DWAF (2003).

Table 8.1: General characteristics of Rust de Winter Dam

Latitude	25°14'0.2"S
Longitude	28°30'58"E
Volume (FSL) ($10^6 m^3$)	27.2
Surface area km^2	4.73 (473 ha)
Mean depth (m)	5.7
Water surface temperature (Min/Max ºC)	17/28
Circulation type	Unknown

8.3 TROPHIC STATUS

The greatest portion of the catchment is undeveloped bushveld, utilised for cattle ranching. Currently there is no development that can have a major impact on the dam. Irrigation is the dominant water user from the dam and agriculture is the major landuse in the area. Agricultural activity is restricted to an area close to Zonderwater and to farms near the impoundment itself (Theron, Prinsloo, Grimsehl and Pullen, 1991). Algal data shows no evidence of algal blooms and toxin-associated cyanobacteria occur sporadically but in very low numbers. There is little literature available for this dam and it is assumed that this dam is oligotrophic.

8.4 RUST DE WINTER RESERVE

From personal observations (JH Koekemoer), the water of the dam is clear, and the dam lies in a conservation area surrounded by game farms. Aquatic vegetation is abundant and the ecosystem is diverse, with abundant wildlife and birds in the area. The fish population of this dam will probably provide a good indication/example of the expected fish population structure in non-eutrophic (non-polluted) conditions.

One of the major impacts on the dam may come from a proposed housing and golf course development (personal communication with local residents in the area).

8.5 FISH SPECIES

From fish data listed in Kleynhans et al., 2007, the following species list has been compiled as no species list of fish is available for Rust de Winter and is listed in Table 8.2 below.

Table 8.2: Fish species expected in Rust De Winter Dam under reference conditions

Fish	Common name
Clarias gariepinus	Sharptooth catfish
Chetia flaviventris	Canary kurper
Oreochromis mossambicus	Blue kurper
Labeobarbus marequensis	Largescale yellowfish
Cyprinus carpio	Carp
Barbus trimaculatus	Threespot barb
Barbus mattozi	Papermouth
Barbus unitaeniatus	Longbeard barb
Labeobarbus polylepis	Smallscale Yellowfish
Pseudocrenilabrus philander	Southern mouthbrooder
Micropterus salmoides	Largemouth bass
Barbus paludinosus	Straightfin barb
Tilapia sparrmanii	Banded tilapia
Synodontis zambezensis	Brown Squeaker
Schilbe intermedius	Silver Catfish
Micralestes acutidens	Silver Robber
Marcusenius macrolepidotus	Bulldog
Mesobola brevianalis	River sardine

9 MATERIALS AND METHODS

Two fish surveys were conducted on each of the six dams. The Rietvlei, Roodeplaat, Bon Accord, Koster River, Lindleyspoort and Rust De Winter Dams were surveyed during late August-November and again during January-March during 2007-2009, to make provision for seasonal trends and distributions in the fish population. This final report details the combined findings of both the surveys for each dam. This report will also provide information on the status of the fish community, and the contribution each species (2007-2009) make in terms of numbers and weight. Fish data was recorded; and analysed with the aid of fisheries database models designed for the specific use in fishery data exploration. Historical data were also reviewed.

9.1 THE INDEX OF RELATIVE IMPORTANCE (IRI)

An *Index of Relative Importance* (Kolding, 1998) was used to indicate the contribution each fish species made to the catch composition of each dam.

The IRI table gives total catch composition in percentage numbers and weight (kg), as well as frequency of occurrence (FREQ) in the settings or sampling efforts (i.e. whether the species was present or not irrespective of the abundance). As a measure of relative abundance or commonality of each species (j) in the catch composition an index of relative importance ($\%IRI$, Kolding, 1998) was used:

$$\%IRI_j = \frac{(\%W_j + \%N_j) \bullet \%F_j}{\sum_{i=1}^{S} (\%W_i + \%N_i) \bullet \%F_i} \bullet 100$$

where $\%W_j$ and $\%N_j$ is percentage weight and number of each species in the total catch, $\%F_j$ is percentage frequency of occurrence of each species in total number of settings (samples), and S is total number of species. The index is shown in table form and graphically. Graphically it combines and shows simultaneously the relative numeric abundance in percentage (%*N*), the percentage weight (%*W*) contribution to the total weight sampled, and the commonness (%*F*) of a species (Pinkas *et al.,* 1971, see also Caddy & Sharp, 1986), displayed as a rectangle:

$$IRI = (\%N + \%W) * \%F$$

The relative area of a rectangle is given in percentage to all the other species present. The percentage commonness, $\%F$ or %FREQ represents the percentage probability of a species occurring in the catch composition if similar sampling methods were used.

The total catch, in numbers and weight, is given at the end of the tables. The species were sorted in descending order in the tables according to their contribution either to the numbers or weight sampled, or from the highest to the lowest IRI value. The IRI value is a numerical value (also given in percentage of the total of the IRI values calculated) assigned to a specific species in the catch composition. The IRI depicts the relative importance of a species in the fish population in terms of its abundance and weight contribution in the relevant catch composition.

9.2 ESTIMATION OF YIELD

One of the aims of this report is to estimate the potential yield of the fish populations in each of the dams. A holistic approach rather than an analytical approach was followed in the process of biomass and yield estimation. An analytical approach requires several fish parameters to be known, such as age, mortality rates, and length frequency data over a long period of time, which is currently not available. The lack of available data, therefore, renders us to view the fish stock as a whole, or a homogenous biomass, the yield of which will be estimated with a holistic approach.

It is important to note that analytical models are based on a more detailed description of the stock, and are more demanding in terms of quality and quantity of input data, and therefore tend to give more reliable results and estimates concerning the fish stock (Gayanilo & Pauly, 1997). Analytical models will, therefore, be useful only after several years of sampling and recording of data.

Yield estimation with a holistic approach:
In data sparse situations, for example when initiating the exploitation of a hitherto unexploited resource or in cases of limited sampling capability, one solution would be to establish the collection of the data types required for the analytical approach and then wait until a sufficient amount of data is available (Gayanilo et al., 1997). However, it might take years for an analysis to emerge, while advice on an exploitation or development strategy might be required in the short term. In order to cover such data limited situations, a holistic approach could be considered. Holistic models use fewer parameters, and they consider fish as a homogeneous biomass and do not take into account length or age composition. Three models may be used to calculate the sustainable yield:

9.2.1 Swept-area method:

A *swept-area method* was used (Pauly, 1984), based on the catch per unit area sampled by research or experimental gear. From the densities of fish observed, we obtain an estimate of the biomass, through extrapolation, in a water body, from which an approximate estimate of potential yield can be obtained.

9.2.2 Potential yield estimation with an approximate model based on primary production (as described by Pitcher *et al.*, 1996):

With this model sustainable fishery yields are estimated in the absence of catch/effort and survey data. The starting point is an estimate of sustainable yield of fish in another large lake in the region, the baseline lake. This is used to estimate the potential yield of fish in an analogous second lake, the target lake. Several baseline lakes may be used to provide results for the target lake. This model for estimating potential yield was specifically introduced to assess fisheries in the African lakes (Pitcher *et al.*, 1996).

To estimate potential sustainable yield in a fishery for a target lake, the model uses information from a well-analysed fishery in a second lake, termed the baseline lake. In fact, several baseline lakes may be used in the model to improve estimates. The model assumes that ecological similarities are sufficient to make a prediction based on the ratio of the log primary production levels in the target and baseline lakes. This model is likely to give reasonable results only when both target and baseline lakes have some characteristics in common. The calculation of potential sustainable annual yield takes the annual yield of fish per square kilometre in the base lake and multiplies this by the area of the target lake. The result is then scaled by the ratio of average annual primary production in the two lakes:

$$Yt = \frac{Yb}{Ab} At \frac{\ln(Pt)}{\ln(Pb)}$$

where *Yt* is estimated annual sustainable yield in target lake (t $year^{-1}$), *Yb* is sustainable annual yield in baseline lake (t $year^{-1}$), *Ab* is area of baseline lake (km^2), *At* is area of target lake (km^2), *Pt* is average primary production of target lake (g C m^{-2} day^{-1}) and *Pb* is average primary production of baseline lake (g C m^{-2} day^{-1}).

Table 9.1 provides an example of the parameters used for baseline and target lakes, and which is used in the model. In this example the yield for Calueque Dam (target dam) was estimated at 6.52 t/km^2/yr (65.2 kg/ha/yr), with all the other parameters known (Koekemoer and Steyn, 2004a).

Table 9.1: Example of parameters needed for estimation of yield.

Lake	Lake area (km²)	Primary production (g C m^{-2} day^{-1})	Estimated MSY (t km^{-2})
Baseline			
Lake Kariba	5364	1.7	5.87
Target			
Calueque Dam	175	1.8	Value to be calculated with model

MSY = Maximum Sustainable Yield

9.2.3 Potential yield estimated with the Morpho-Edaphic Index (MEI) (Ryder, 1965):

Ryder (1965) uses the following method (Morpho-Edaphic Index: MEI) to estimate yield:

$$MEI = \frac{C}{AD}$$ then

$$Y = 14.3136 \bullet (MEI)^{0.4681}$$ where

C is conductivity (μScm^{-1}), AD is average depth, and Y is estimated yield (kg/ha/yr).

9.3 CPUE

The species composition for the experimental gear was recorded in numbers and weight. The mean standard catch per unit effort (CPUE) by species, with standard deviations (SD) of the estimated CPUE's are presented for the sampling gear.

$$CPUE = \frac{1}{y}\sum_{i=1}^{n} W_i \bullet \left(\frac{SU}{U_i}\right)$$ where

y = effort, e.g. number of net panel (or gear) settings and n = number of samples. If effort is not a variable then y = n. W_i = catch (in weight or numbers) in set_i or $sample_i$, SU = standard relative effort unit (size) of a net panel , and U_i = actual effort unit (size) of net_i (Kolding, 1998).

Standard deviations (SD) of the estimated CPUE's are presented. In case where the absolute effort is a recorded variable for each observed catch and the estimated CPUE is the ratio of two variables (usually with other gear such as seine nets), then SD's were calculated from the Taylor series approximation by the following formula (Cochran, 1977; Krebs, 1989 as cited by Kolding, 1998):

$$SD(CPUE) = \frac{1}{Y}\sqrt{\frac{\sum x^2 - 2\hat{R}\sum xy + \hat{R}^2\sum y^2}{n-1}}$$

where $$\hat{R} = CPUE = \frac{\bar{x}}{\bar{y}}$$

and x is standardised catch, y is effort, and n is sample size (= number of observations).

Each gill net unit had a standard net area (100 m^2)**2**^{2}, and was set at a standard time of 12 hours, and therefore had a standard effort.

9.4 SAMPLING GEAR

A variety of gill nets were used to limit selectivity and to prevent a biased representation of the fish population.

Fish were weighed and measured directly after sampling, and the weight recorded was the wet weight of the fish. Electronic scales were used to measure the weight of each fish sampled in grams. Fork length was recorded for fish with forked caudal fins, and total length for species with rounded caudal fins.

A wide range of experimental gill nets was used to limit gear selectivity:

1. Multifilament gill nets with stretched mesh sizes of 22, 28, 35, 45, 57, 73, 93, 118, and 150 mm were used, and each net had a length of 10m and a depth of 2.5m. Gill nets were set during the night for approximately 12 hours.
2. A monofilament gill net with a stretched mesh sizes of 147 mm was used to sample larger specimens in deep water.

Other gears (active gear) such as seine nets, cast nets, and electro shocking were not used during this study, as conclusions on the selectivity of these gears cannot be made, as the catches are the result of fishing activity (*i.e.* where, how, time, area, etc.), and the effort is not standardised. The efficacy of these sampling methods is however known and is discussed in the Fish Community Study of Hartbeespoort Dam Report for 2005 (Koekemoer *et al.,* 2005).

The primary focus of this study was on gill net catches as the gill net catches are standardised, and the catch data can be used in biomass and yield estimates. By studying the gill net selectivity, the correct gill nets can also be selected for use in a fisheries project, to target and remove certain species.

9.5 GILL NET SELECTIVITY

The aim is to study the catches of the experimental gill nets used to determine the gill net selectivity. This is important for the regulation of gill net mesh sizes allowed for harvesting.

The number of fish sampled in each length class is indicated for each gear used, in table format.

Gill net selectivity curves for selected species and the combined estimated selectivity curves for the mesh sizes are given (four types of selection curves were used to explore gill net selectivity).

Length frequency distribution is given for selected species and each mesh size in the experimental nets in table form.

9.5.1 <u>Indirect estimation of gill net selectivity</u>

The fish retained in a gear is usually only an unknown proportion of the various size classes available in the fished population. Selectivity is a quantitative expression of this proportion and represented as a probability of capture of a certain size of fish in a certain size of mesh, Kolding (1998).

The mesh selectivity was indirectly estimated from comparative data of observed catch frequencies across a series of mesh sizes. The statistical model (SELECT) is described in Millar (1992), and the specific application on gill nets is described in Millar & Holst (1997).

For a given length class, j, the number of fish, Y_{ji}, that encounter gill net i are assumed to be observations of independent Poisson variables

$$Y_{ji} \sim Po(p_i\lambda_j)$$

where the expected count, $p_i\lambda_j$, is the product of the abundance of length class j fish, and the relative fishing intensity of gill net i. Fishing intensity can also be considered as a combination of fishing effort and fishing power (Millar, 1992).

We denote the relative selectivity (catch or retention probability) of a length class j fish in gill net i by $s_i(j)$. The number of length j fish caught in gill net i is then Poisson distributed (Millar & Holst, 1997)

$$N_{ji} \sim Po(p_i\lambda_j s_i(j))$$

Without loss of generality it can be assumed that the selection curves $s_i(\cdot)$ for each net have unit height because any difference in fishing powers is modelled through the relative fishing intensities p_i. This is the full general model (Kolding, 1998).

The nets were fished with equal effort, and the relative fishing intensities p_i is considered equal with standardized effort (i.e. number of settings of standardized panel area and time set). The form of the population length distribution is not assumed.

Four selection curves $s_i(\cdot)$ were used: normal, log-normal, gamma and bi-modal, to determine selectivity. The principle of geometric similarity (i.e. length of maximum retention and spread of selection curve are both proportional to the mesh size (Baranov, 1948)) applies to the normal scale shift selection curve.

The other three models all include asymmetrical retention modes (i.e. skewed distributions). The bi-modal curve is appropriate if the fish were caught by different mechanisms, e.g. both wedged by the gills and entangled in the mesh sizes.

A) Normal scale shift $$\exp\left(-\frac{(L_j - k_1 \bullet m_i)^2}{2(k_2 \bullet m_i)^2}\right)$$

where both the modes (maximum retention length) and the spreads of the selection curves are increasing with mesh size m_i (i.e. the principle of geometric similarity).

B) Log Normal: $$\frac{1}{L_j}\exp\left[\mu_1 + \log\left(\frac{m_i}{m_1}\right) - \frac{\sigma^2}{2} - \frac{\left(\log(L_j) - \mu_1 - \log\left(\frac{m_i}{m_1}\right)\right)^2}{2\sigma^2}\right]$$

C) Gamma: $$\left(\frac{L_j}{(\alpha - 1) \bullet k \bullet m_i}\right)^{\alpha - 1} \bullet \exp\left(\alpha - 1 - \frac{L_j}{k \bullet m_i}\right)$$

D) Bi-modal: $$\exp\left(-\frac{(L_j - k_1 \bullet m_i)^2}{2(k_2 \bullet m_i)^2}\right) + w \bullet \exp\left(-\frac{(L_j - k_3 \bullet m_i)^2}{2(k_4 \bullet m_i)^2}\right)$$

where μ_i = mean size (length) of fish caught in mesh size $i = k_1 \bullet m_i$

σ_i = standard deviation of the size of fish in mesh $i = k_2 \bullet m_i$ or $\alpha \bullet m_i$

L_j = mean size of fish in size (length) class j

In all cases of the above considerations and models, the Poisson distribution of N_{ji} was used to apply maximum likelihood for purposes of statistical inferences and estimation fits.

In order to explore the possible shapes of the selection curve $S_i(\bullet)$ and whether the principle of geometric similarity seems applicable, the mean, standard deviation and degree of skewness were estimated for each of the observed catch frequencies in mesh size i. Two models or function types were used. A standard normal model:

$$E(n_{ij}) = \frac{n_i}{\sigma_i\sqrt{(2\pi)}}\exp^{-(L_j - \mu_i)^2/2\sigma_i^2}$$

and a skew-normal function type (Helser *et al.,* 1991;1994), for species that also have some degree of entanglement:

$$E(n_{ij}) = \frac{n_i}{\sigma_i\sqrt{(2\pi)}}\exp^{-(L_j-\mu_i)^2/2\sigma_i^2} \cdot \left\{1 - \frac{1}{2} q_i\sigma_i^{2/3}\left[\frac{(L_j-\mu_i)}{\sigma_i} - \frac{(L_j-\mu_i)^3}{\sigma_i^3}\right]\right\}$$

q_i = skewness coefficient of the distribution of fish in mesh i, when $q_i = 0$ the model reduces to the standard normal distribution.

n_{ij} = catch of fish of size class j in mesh i

n_i = total catch if fish in mesh $i(= \sum_j n_{ij})$

The model parameters (μ_i, σ_i, q_i) are estimated by an iterative numerical search of the minimum sum of squares, $\left(= \sum (observed - predicted)^2\right)$ between the expected catch based on the model, $E(n_{ij})$, and the observed catch (n_{ij}).

The total relative selectivity (catch or retention probability) of the gear is computed as:

$$S_{ij} = \sum_i s_i(j)/\max_j$$

where each estimated mesh specific selectivity curve$_i$ (j) is weighed by the number of settings (effort) of that net. The total relative selectivity is used to estimate the corrected catch frequency in each size class (N_j) from the observed catches, computed as

$$N_j = \sum_i n_{ij}/S_{ij} \quad \text{where} \quad S_{ij} = 1 \quad \text{if} \quad S_{ij} \leq 0.1$$

S_{ij} = total relative selectivity by length groups (Kolding, 1998).

9.6 ASSESSMENTS

The following assessments were undertaken for this project:

- Fish population dynamics;
- Selection of the species most suitable for exploitation, using the Index of Relative Importance as described by Kolding (1998);
- Sampling gear selectivity and catch per unit effort (CPUE) were explored with the aid of methods described by Kolding (1998);
- Fish yield, using the swept area method (Pauly, 1984).

10 RESULTS AND DISCUSSION

10.1 RIETVLEI DAM

10.1.1 <u>Rietvlei Dam Sampling Sites</u>

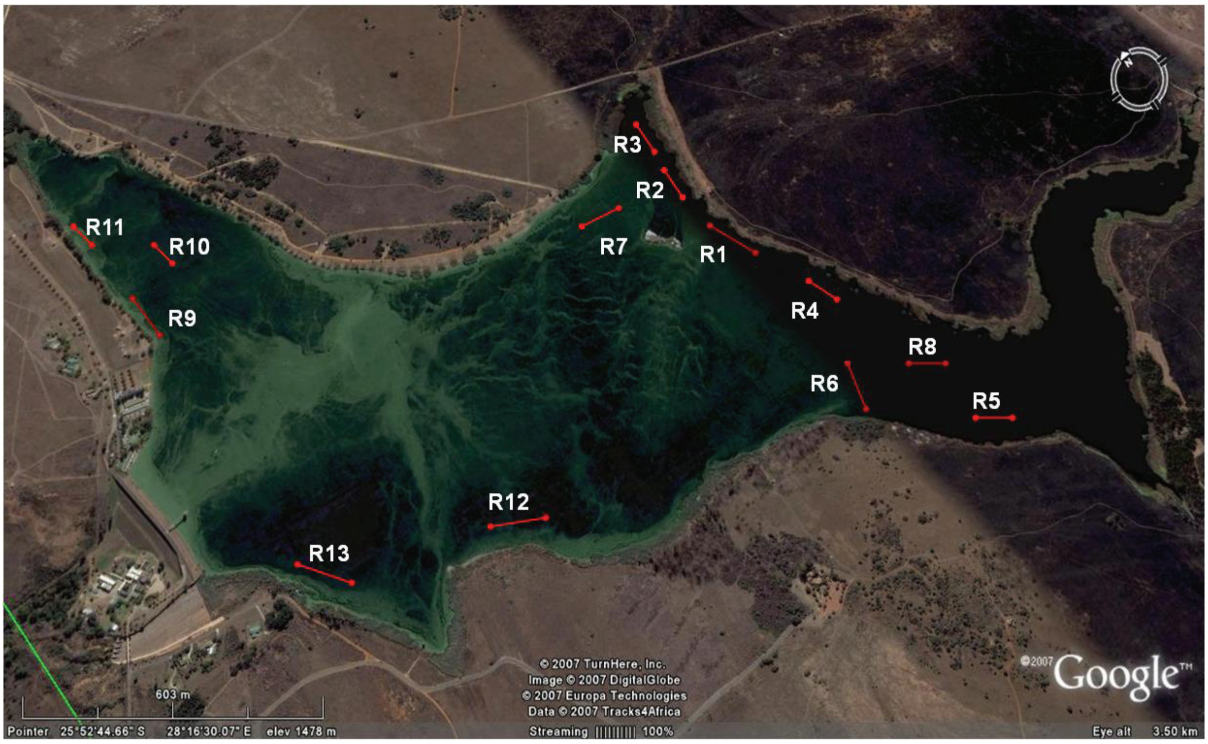

Figure 10.1: Rietvlei Dam sampling sites

Thirteen (13) stations were identified and surveyed during both surveys with the aim to obtain data representative of the fish population in the dam (Figure 10.1).

During both surveys the water level of the dam was at approximately 100% of its full supply level.

Table 10.1 presents the station statistics, and sampling gears used in the different habitat types during the two surveys.

Table 10.1: Station statistics for Rietvlei Dam (2007-2008).

Date	St. code	Latitude	Longitude	Gear	Set type
16/10/2007	1	25°52'39.19"S	28°16'46.60"E	147 mm	Lake deep littoral zone, veg
16/10/2007	2	25°52'39.19"S	28°16'46.60"E	Gill nets	Lake deep littoral zone, veg
16/10/2007	3	25°52'29.18"S	28°16'48.06"E	Gill nets	Lake deep littoral zone, veg
17/10/2007	4	25°52'52.28"S	28°16'52.14"E	Gill nets	Lake deep littoral zone, veg
18/10/2207	5	25°53'0.05"S	28°16'47.56"E	Gill nets	Lake deep littoral zone, rocky
18/10/2007	6	25°52'56.67"S	28°16'45.44"E	147 mm	Lake deep pelagic
19/10/2007	7	25°52'33.17"S	28°16'32.10"E	Gill nets	Lake deep pelagic
19/10/2007	8	25°53'2.78"S	28°16'56.46"E	147 mm	Lake deep pelagic
21/10/2007	9	25°52'16.51"S	28°15'59.24"E	Gill nets	Lake shallow lit zone, roc
21/10/2007	10	25°52'11.53"S	28°15'58.90"E	Gill nets	Lake shallow lit zone, roc
21/10/2007	11	25°52'7.13"S	28°15'58.52"E	147 mm	Lake shallow lit zone, roc
22/10/2007	12	25°52'55.77"S	28°16'26.60"E	Gill nets	Lake deep littoral zone, veg
22/10/2007	13	25°52'49.46"S	28°16'14.80"E	Gill nets	Lake deep littoral zone, veg
14/01/2008	7	25°52'33.17"S	28°16'32.10"E	Gill nets	Lake deep littoral zone, veg
15/01/2008	2	25°52'39.19"S	28°16'46.60"E	Gill nets	Lake deep littoral zone, veg
16/01/2008	1	25°52'39.19"S	28°16'46.60"E	Gill nets	Lake deep littoral zone, veg
17/01/2008	12	25°52'55.77"S	28°16'26.60"E	Gill nets	Lake deep littoral zone, veg
18/01/2008	11	25°52'7.13"S	28°15'58.52"E	Gill nets	Lake shallow littoral zone, veg
19/01/2008	10	25°52'11.53"S	28°15'58.90"E	Gill nets	Lake deep pelagic
20/01/2008	13	25°52'49.46"S	28°16'14.80"E	Gill nets	Lake deep pelagic
21/01/2008	12	25°52'55.77"S	28°16'26.60"E	Gill nets	Lake deep pelagic

Shallow < 1.5m
Deep > 1.5m

10.2 RIETVLEI DAM SAMPLING STATISTICS

10.2.1 IRI for Rietvlei Dam

An **Index of Relative Importance** (IRI) as described by Kolding (1989) was used to indicate the contribution each fish species made to the catch compositions.

The *percentage commonness* or frequency of occurrence, $\%F$ or %FREQ represents the *percentage probability* of a species occurring in the catch composition of an area if similar sampling methods were used. The $\%F$ for all the species combined does not add up to 100%.

The species were sorted descending in the tables from the highest to the lowest IRI value. The IRI value is a numerical value assigned to each specific species and is given in percentage of the total of the IRI values calculated for the relevant area. The IRI depicts the relative importance of a species in the fish population in terms of its abundance and weight contribution in the relevant catch composition.

A low IRI score does not necessarily mean that a species is less important. The IRI gives an indication of the fish population composition, and the weight each species carries in the population, in terms of its contribution to the total catch.

IRI for the Gill Nets Used in Rietvlei Dam (2007-2008):
Eight (8) species were sampled in Rietvlei Dam (Table 10.2). *Clarias gariepinus* received the highest IRI score overall of 48.2%, followed by *Chetia flaviventris* with 22.9%, and *Labeobarbus polylepis* with 22.6%. *Clarias gariepinus* received the highest IRI score due to its contribution in weight (63.4%) to the total catch. *Chetia flaviventris* received a high IRI score due to its contribution to the total numbers sampled (39.9%), but it is a small species and it did not make a large contribution to the total weight recorded (2.1%). *Labeobarbus*

polylepis also made a relatively large contribution to the total weight sampled (32.6%). *Clarias gariepinus* and *Labeobarbus polylepis* both made relatively large contributions to the total numbers sampled (13.5% and 12.7% respectively).

Two small species *Barbus paludinosus* and *Pseudocrenilabrus philander* made considerable contributions to the total numbers recorded for Rietvlei Dam (Table 10.2). The other remaining species were sampled in low numbers. *Cyprinus carpio* contributed 1.4% to the total weight sampled.

Clarias gariepinus and *Chetia flaviventris* are both undesirable species and tend to dominate a system either in weight or numbers if conditions are favourable. Both may have a negative effect on zooplankton populations, and *Clarias gariepinus* contributes to bioturbation and re-suspension of nutrients back into the water column due to its benthic feeding behaviour.

A total of 2423 fish were sampled during the study, of which *Chetia flaviventris* was the most abundant species (39.9%), followed by *Barbus paludinosus* (22.6%) (Table 10.2). Other fish species that made considerable contributions to the total numbers recorded are *Clarias gariepinus* (13.5%), *Labeobarbus polylepis* (12.7%), and *Pseudocrenilabrus philander* (9.2%).

A total weight of 1312 kg was recorded during the study, of which *Clarias gariepinus* (63.4%) and *Labeobarbus polylepis* (32.6%) were the major contributors (Table 10.2).

Table 10.2: IRI for Rietvlei Dam, 2007-2008.

Species	NO	% NO	W(kg)	% W	FRQ	% FRQ	IRI	% IRI
Clarias gariepinus	327	13.5	831.75	63.4	69	43.9	3380	48.2
Chetia flaviventris	966	39.9	27.307	2.1	60	38.2	1603	22.9
Labeobarbus polylepis	307	12.7	427.506	32.6	55	35	1585	22.6
Barbus paludinosus	548	22.6	2.614	0.2	19	12.1	276	3.9
Pseudocrenilabrus philander	222	9.2	0.937	0.1	22	14	129	1.8
Cyprinus carpio	22	0.9	18.512	1.4	18	11.5	27	0.4
Tilapia sparrmanii	30	1.2	0.952	0.1	17	10.8	14	0.2
Labeobarbus marequensis	1	0	2.3	0.2	1	0.6	0	0
Total	**2423**	**100**	**1311.878**	**100**	**-**	**-**	**7015**	**100**

%IRI = Percentage of Total of IRI values calculated for each species in area
%N = Contribution in Percentage to Total Numbers sampled
%W = Contribution in Percentage to Total Weight sampled
%F = Frequency of Occurrence

Rietvlei Dam does not seem to have excessive algal growth problems or algal blooms – despite the very high level of phosphorous, at least not to the extent of Hartbeespoort Dam, but the local nature conservation office did report small sporadic algal blooms (*pers comm.* Riaan Marais, 2007-2008). The low numbers of carp sampled may be the reason for less bioturbation occurring in the dam. Aquatic macrophytes are also abundant (filtering and reduction in nutrients). A dam upstream of Rietvlei Dam (also in the reserve) may also serve as sediment trap, reducing the inflow of nutrients into Rietvlei Dam. High volumes of water are abstracted every day for the Tshwane Metropolitan area and the type of extraction i.e. bottom or top, may also play a role in nutrient removal/outflow from the dam. A set of epilemnetic mixers (*SolarBees*) were installed in the dam during July 2008.

Figure 10.2 indicates the large contribution in weight that *Clarias gariepinus* (species 1 in graph) and *Labeobarbus polylepis* (species 3 in graph) made to the total catch. *Chetia flaviventris* (species 2 in graph) made a large contribution to the total numbers recorded.

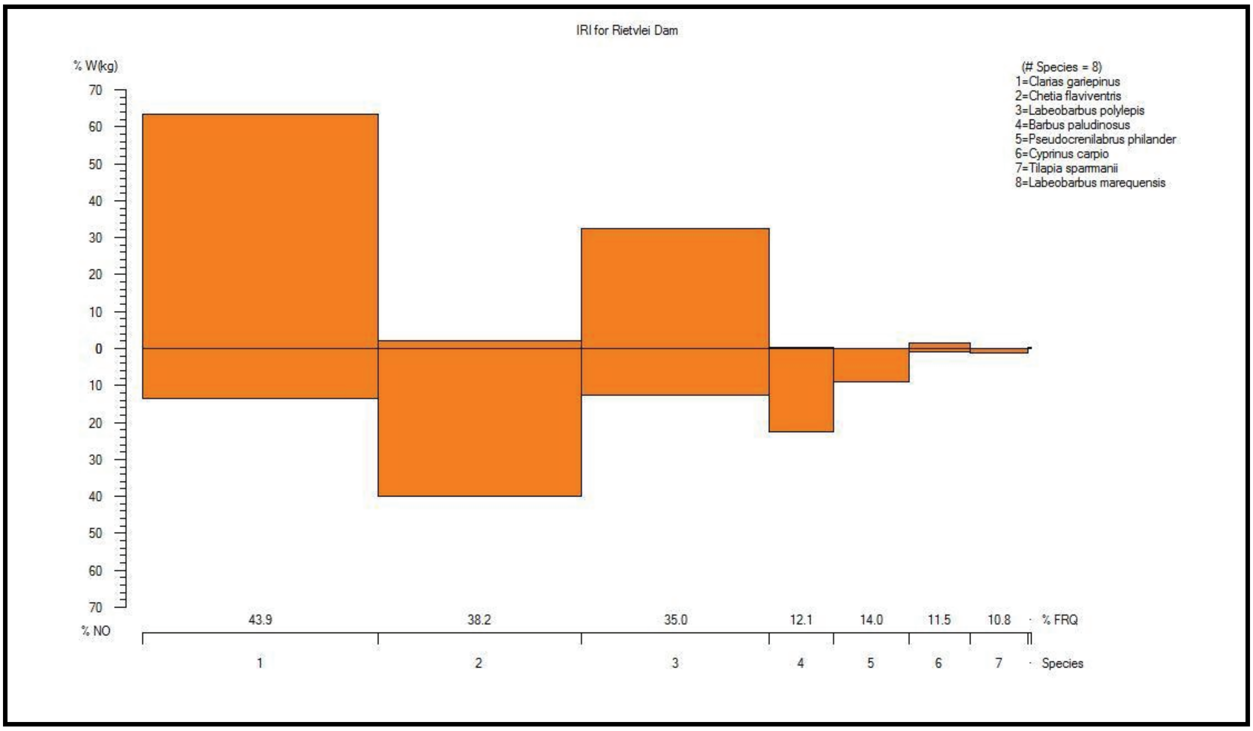

Figure 10.2: IRI for Rietvlei Dam, 2007-2008.

10.2.2 <u>Catch Statistics for the Gill Nets in Rietvlei Dam, 2007-2008</u>

Table 10.3 indicates the number of each species sampled in each mesh size (upper section of table). *Pseudocrenilabrus philander* was effectively sampled in the 22 and 28 mm mesh sized gill nets, and *Chetia flaviventris* was effectively sampled in the 28-57 mm meshes, and the most effective being the 45 mm mesh gill net for *Chetia flaviventris*.

Clarias gariepinus and *Cyprinus carpio* was sampled in a wide range of mesh sizes, the larger meshes being the most effective for *Clarias gariepinus* (93-150 mm) (Table 10.3). Low numbers of *Cyprinus carpio* were recorded, but the 45 mm and 150 mm meshes seem to be the most effective for catching this species.

The larger meshes were also effective in sampling *Labeobarbus polylepis,* but the 93 mm and 118 mm meshes were the most effective (Table 10.3). *Barbus paludinosus* was sampled in high numbers (543) in the 22 mm mesh.

For fish removal the 45 mm mesh seems to be the most effective for targeting *Chetia flaviventris* and *Cyprinus carpio* with the least effect on other species (Table 10.3). The 118 mm, 147 mm (monofilament) and 150 mm gill nets seem to be the most effective for targeting *Clarias gariepinus* (carp was also sampled in the 150 mm mesh, although in low numbers). *Labeobarbus polylepis* is, however, also targeted with these nets, but their catch can be reduced by strategically placing the nets in the correct habitats (close to banks away from open water as the yellowfish seem to frequent open water). Long lines should also be considered for targeting catfish.

The second section (lower section) of Table 10.3 indicates the total number of fish sampled in each of the gill nets, the contribution in percentage each mesh made to the total number recorded, the number of settings for each mesh, the average number of fish sampled in each mesh, and the mean lengths and weight sampled in each mesh.

Table 10.3: Catch Statistics for the Gill Nets in Rietvlei Dam, 2007-2008.

Species	Gill Net Mesh Size (MM)										Total
	22	28	35	45	57	73	93	118	147	150	
Pseudocrenilabrus philander	115	105	2								222
Chetia flaviventris	24	125	234	405	175	3					966
Clarias gariepinus		2	1	3	9	17	46	83	85	81	327
Cyprinus carpio		1	2	7		1		2	1	8	22
Labeobarbus polylepis				3	8	39	112	86	36	23	307
Barbus paludinosus	543	5									548
Tilapia sparrmanii	1	1	12	11	4	1					30
Labeobarbus marequensis								1			1
Total	683	239	251	429	196	61	158	172	122	112	2423
% NO	28.2	9.9	10.4	17.7	8.1	2.5	6.5	7.1	5	4.6	100
No of settings for each mesh	17	17	17	17	17	17	17	17	4	17	157
AV NO/Mesh	40.2	14.1	14.8	25.2	11.5	3.6	9.3	10.1	30.5	6.6	15.4
ML(mm)/Mesh	72.3	95.9	131.5	159.6	201	406.3	429.8	526	645.8	634	225.4
MW(g)/Mesh	5	11	28	86	177	1190	1083	1903	2946	2936	677

MW = Mean Weight in grams
ML = Mean Length in mm

10.2.3 Species Statistics for the Gill Nets in Rietvlei Dam, 2007-2008

Table 10.4 provides the total number of each species sampled, their average weight and length, and the biomass (g) contribution each species made to the gill net series (or range, from 22 mm to 150 mm, all meshes included) per setting. The biomass contribution was calculated for each mesh with a length of 10m. *Clarias gariepinus* and *Labeobarbus polylepis* made the largest contribution to the biomass recorded. *Clarias gariepinus* was sampled with a mean weight of 2551 g (2.55 kg) and a mean length of 636 mm (63.6 cm).

Table 10.4: Species Statistics for the Gill Nets in Rietvlei Dam 2007-2008.

Species	Total	% NO	MW(g)	ML(mm)	Biomass(g)/set
Pseudocrenilabrus philander	222	9.2	4.7	74.1	7
Chetia flaviventris	966	39.9	46	147.9	283
Clarias gariepinus	327	13.5	2551.4	636.4	5314
Cyprinus carpio	22	0.9	974.3	274	137
Labeobarbus polylepis	307	12.7	1389.1	417.7	2716
Barbus paludinosus	548	22.6	5.6	73.3	19
Tilapia sparrmanii	30	1.2	43.3	123.5	8
Labeobarbus marequensis	1	0	2300	520	15
Total	**2423**	**100**	**676.7**	**225.4**	**8499**

MW = Mean Weight in grams
ML = Mean Length in mm

10.3 SPECIES SELECTION FOR A FISHERY IN RIETVLEI DAM

This section aims to identify and select the most appropriate species, which are likely to succeed in terms of a fisheries exploitation project. The species selected all have potential for exploitation in a fisheries project, however, some more than others.

Gill net selectivity was explored for the species. A multifilament gill net range of nine (9) meshes were used during the survey, which included a 22 mm, 28 mm, 35m, 45 mm, 57 mm, 73 mm, 93 mm, 118 mm and a 150 mm mesh. Each of these meshes has a length of ten metres. A 147 mm mesh monofilament gut gill net was also used, and it has a length of 80 metres. The length of the 147 mm mesh were standardised to 10m during calculations.

The fish retained in a gear is usually only an unknown proportion of the various size classes available in the fished population. Selectivity is a quantitative expression of this proportion and represented as a probability of capture of a certain size of fish in a certain size of mesh. The mesh selectivity was indirectly estimated with methods as described by Kolding, 1998.

10.3.1 Species selection

Four species may be considered for selection as species with potential for utilisation in a fisheries project. The IRI was used as a guideline, as it highlights the important species in terms of their contribution to weight and numbers (section 10.2.1). The species, which may be considered, are *Chetia flaviventris, Clarias gariepinus, Labeobarbus polylepis,* and *Cyprinus carpio. Cyprinus carpio* did not make large contributions to the total numbers and weight recorded; however, it is an undesirable alien (introduced) species with negative impacts on the environment and habitat of other species, as it is a habitat altering species (as described by Kleynhans, 1999 and 2001)

The first three species are well represented in the Rietvlei Dam, and *Chetia flaviventris* occurs in high numbers. This species could be exploited to lessen pressure on the zooplankton population, which in turn may positively affect water quality.

Clarias gariepinus and *Cyprinus carpio* produce high numbers of offspring due to their high fecundity. High numbers of juvenile fish after the spawning season may have a significant impact on the zooplankton population due to predation, and the exploitation of the breeding stock of these species, may benefit the zooplankton population.

The feeding habits of carp and catfish may also negatively influence water quality, as it tends to re-suspend organic materials and small sediment particles back into the water column (through its constant churning of bottom sediments in search of food), which makes it available for use by other organisms, such as algae.

10.3.2 Length frequencies recorded for selected species

CPUE was calculated for each of the meshes at a standard effort. The standard effort for a mesh was 10m² net area set for 12 hours.

Chetia flaviventris:
Chetia flaviventris was effectively sampled within its length range with the 22 mm to 57 mm mesh sized gill nets (Figure 10.3). The highest number (405) of fish was recorded in the 45 mm mesh gill net. This species was sampled in a length range of 7 cm to 23 cm.

Figure 10.3 graphically displays the length frequencies recorded for *Chetia flaviventris* in the different gill nets, as well as the mean length for each mesh size. *Chetia flaviventris* is a small species, and it was therefore not sampled in the larger mesh sizes (73-150 mm meshes).

The length frequencies recorded (Figure 10.3) gives an indication of length cohorts, in the 8 cm, 10 cm, 12-13 cm, 14-16 cm and 17-21 cm ranges, representative of age classes, and successful breeding and recruitment during previous seasons. Large specimens of this species were sampled. The green line in Figure 10.3 represents the mean length of the fish sampled in the different nets.

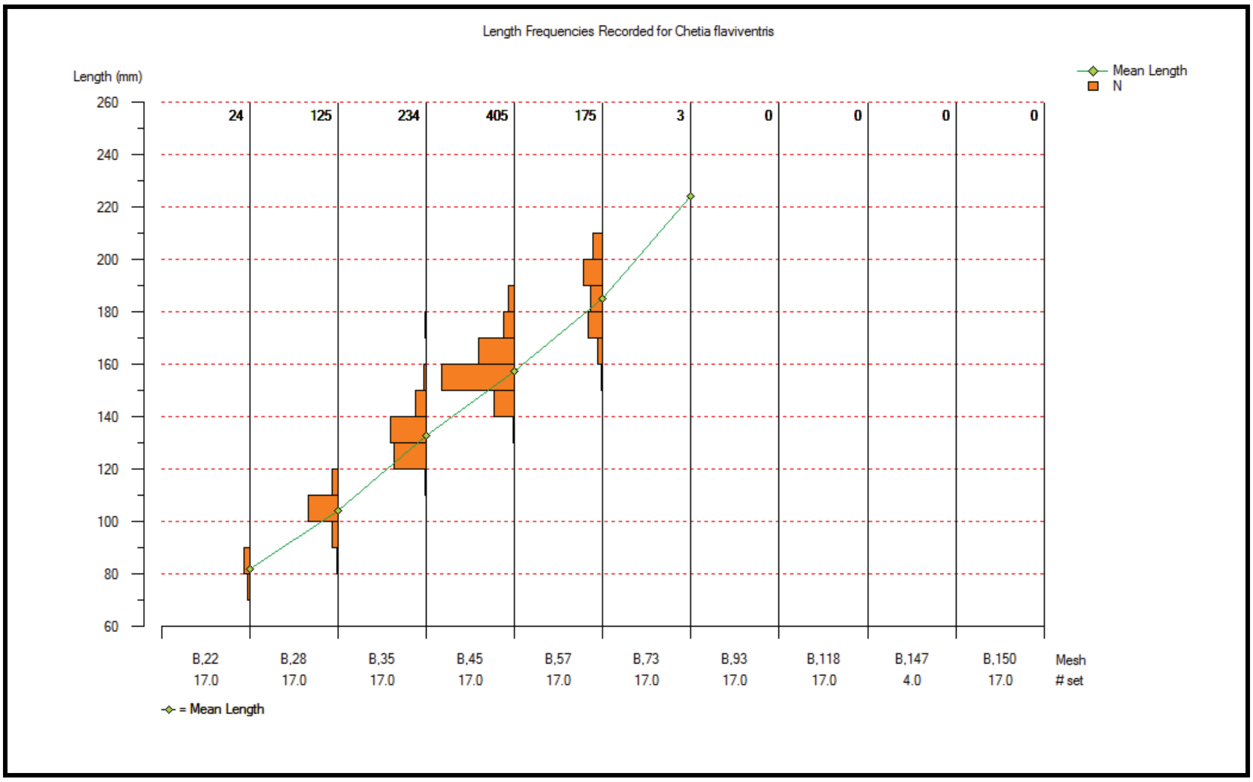

Figure 10.3: Length frequencies recorded for *Chetia flaviventris*.

Labeobarbus polylepis

This species was most effectively sampled with the 73 mm to 150 mm mesh sized gill nets (Figure 10.4), and it was sampled in a length range of 19-68 cm. The highest numbers were recorded in the 93 and 118 mm meshes.

Figure 10.4 gives an indication of the length frequencies sampled in the meshes. Relatively large specimens were sampled in the 30-50 cm length range. Length cohorts can be seen in Figure 10.4, which indicates to successful breeding during previous seasons. *Labeobarbus polylepis* was not sampled in the 22-35 mm gill nets, small specimens were, however, sampled in low numbers in the larger nets.

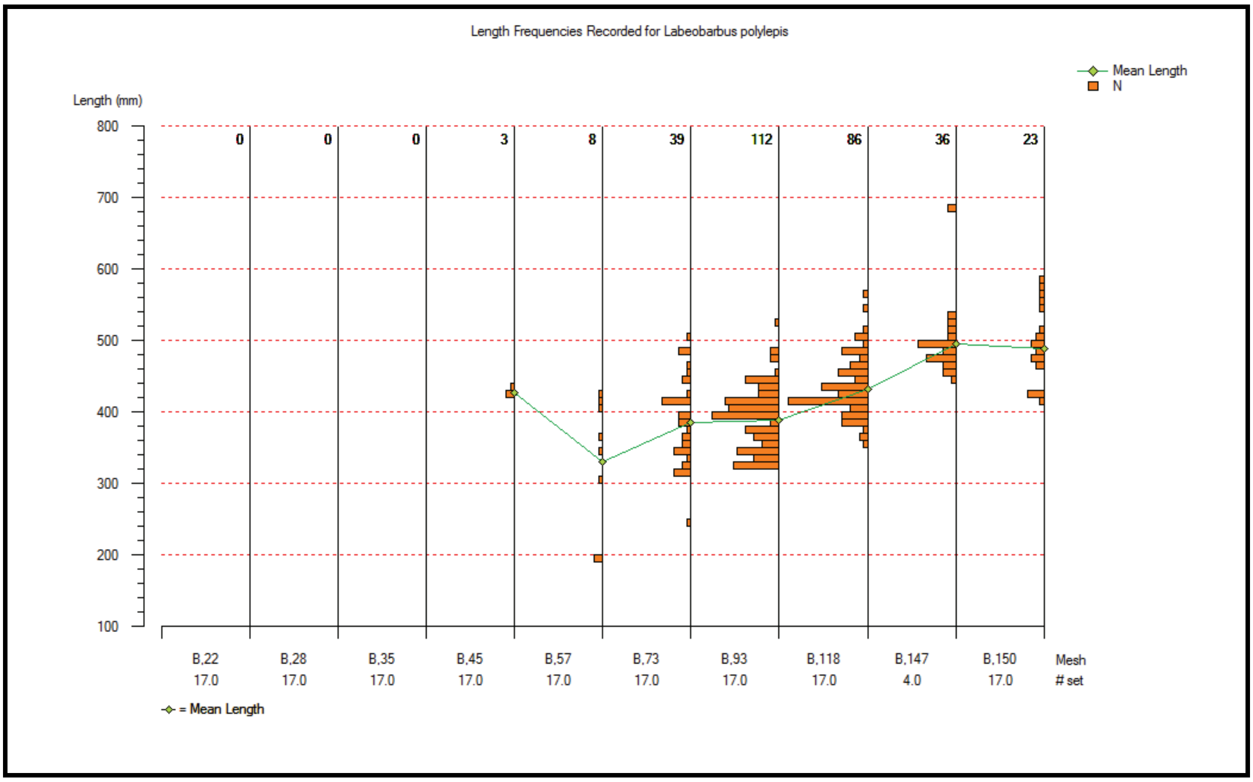

Figure 10.4: Length frequencies recorded for *Labeobarbus polylepis.*

Cyprinus carpio:
Specimens were sampled in a length range of 9-48 cm in the gill nets (Figure 10.5). The highest number of fish was recorded in the 45 and 150 mm meshes. Large specimens (N=8) were sampled in the 150 mm mesh.

Cyprinus carpio was sampled in low numbers, but several length cohorts were recorded, indicating successful breeding during previous seasons (Figure 10.5).

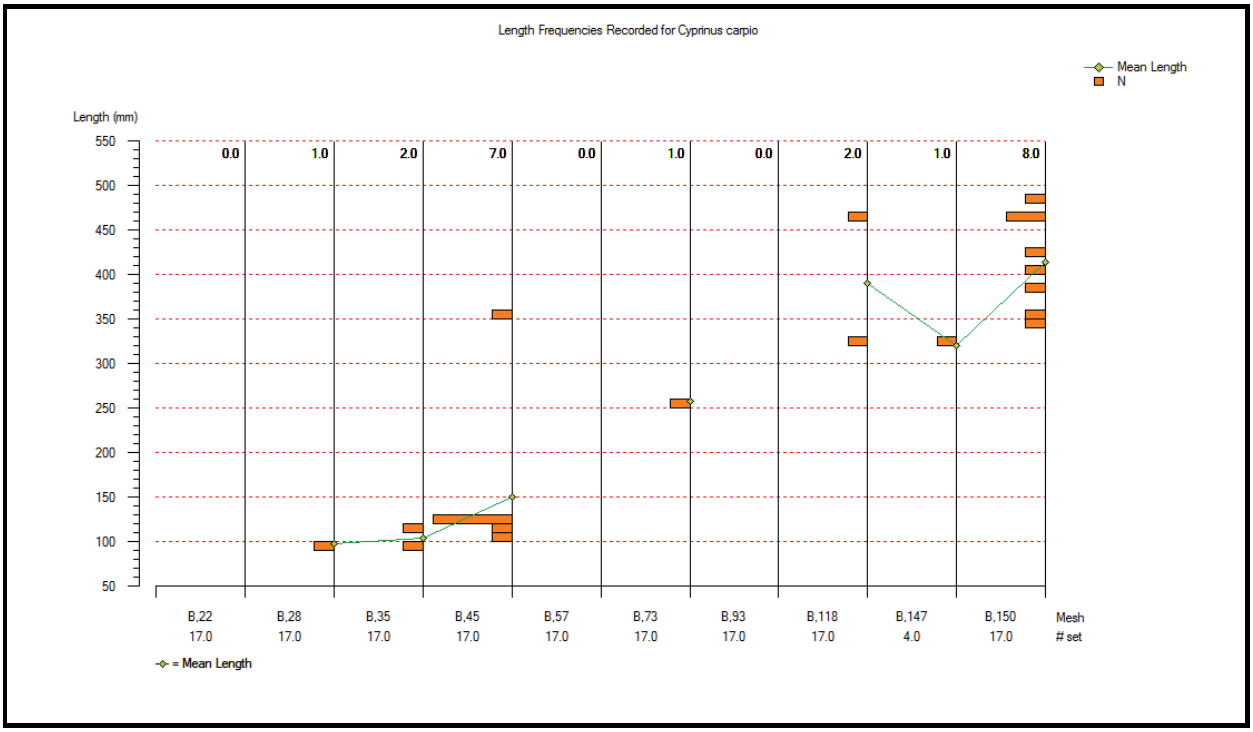

Figure 10.5: Length frequencies recorded for *Cyprinus carpio*.

Clarias gariepinus:
A total number of 327 specimens in a length rage of 17 cm-1m were sampled in the 28-150 mm mesh gill nets. The 118-150 mm meshes were the most effective in sampling large specimens. There seems to be a healthy breeding population, as several length cohorts were recorded (Figure 10.6). Large specimens are present in the system.

The 118 mm, 147 mm and 150 mm mesh gill nets have potential as target gear as mature specimens were sampled in these nets (Figure 10.6).

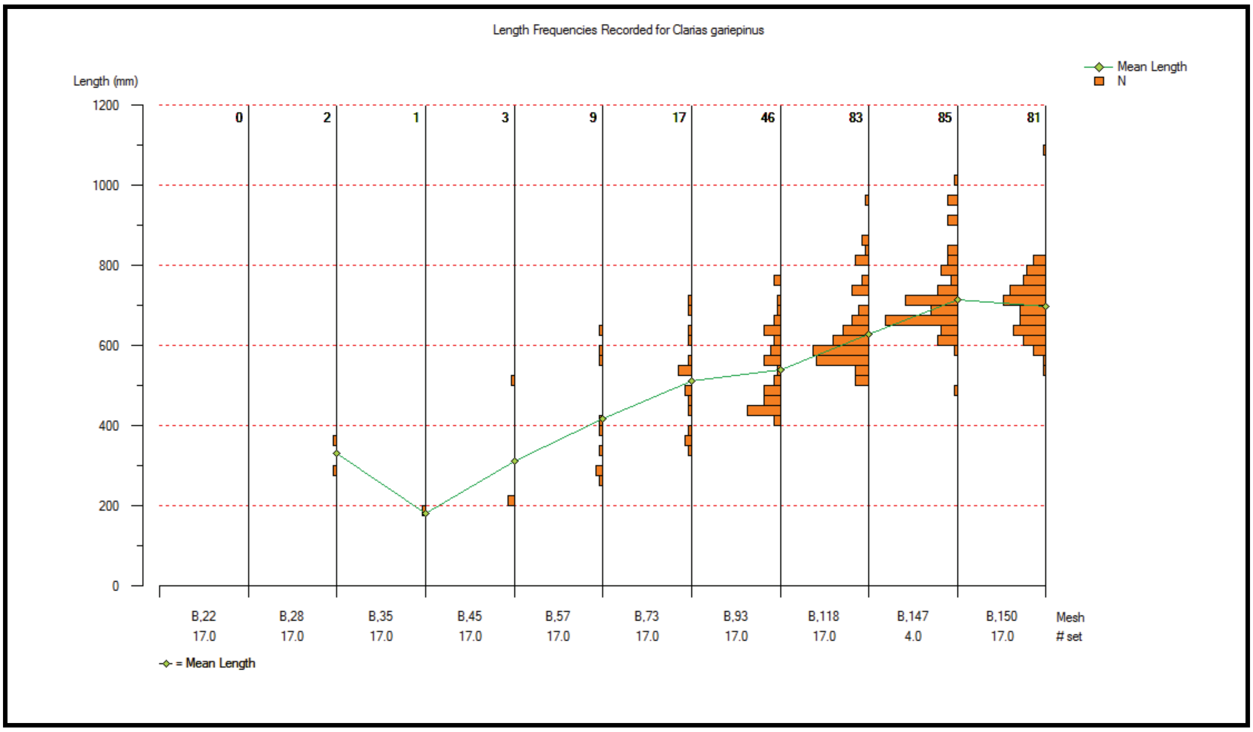

Figure 10.6: Length frequencies recorded for *Clarias gariepinus*.

10.3.3 Gill net selectivity for selected species

Chetia flaviventris:
The probability ranges between 90% and 100% that this species will be sampled with the 35-57 mm gill net meshes (Figure 10.7). Fish in a length range of 10-19 cm are the most likely to be sampled with these meshes.

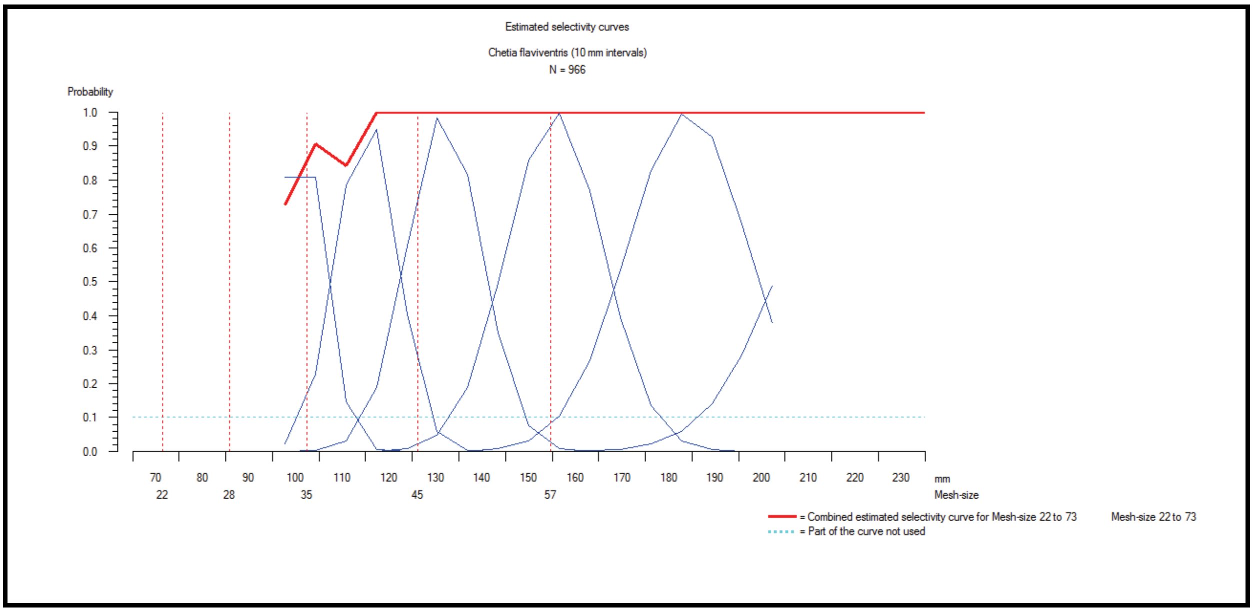

Figure 10.7: Estimated gill net selectivity for *Chetia flaviventris*.

Clarias gariepinus:
The probability is high (100%) for sampling large fish (60-80 cm) in the 118 mm to 150 mm meshes (Figure 10.8).

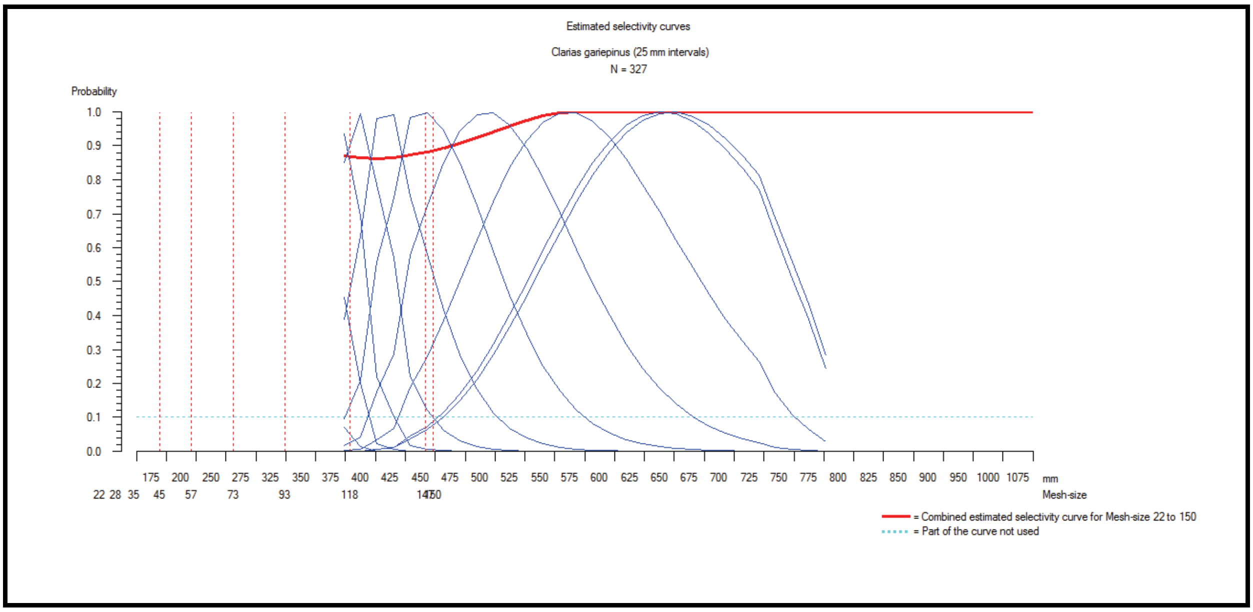

Figure 10.8: Estimated gill net selectivity for *Clarias gariepinus*.

Labeobarbus polylepis:
The probability is high for sampling fish in the 32-56 cm length range with the 73-150 mm gill net meshes (Figure 10.9).

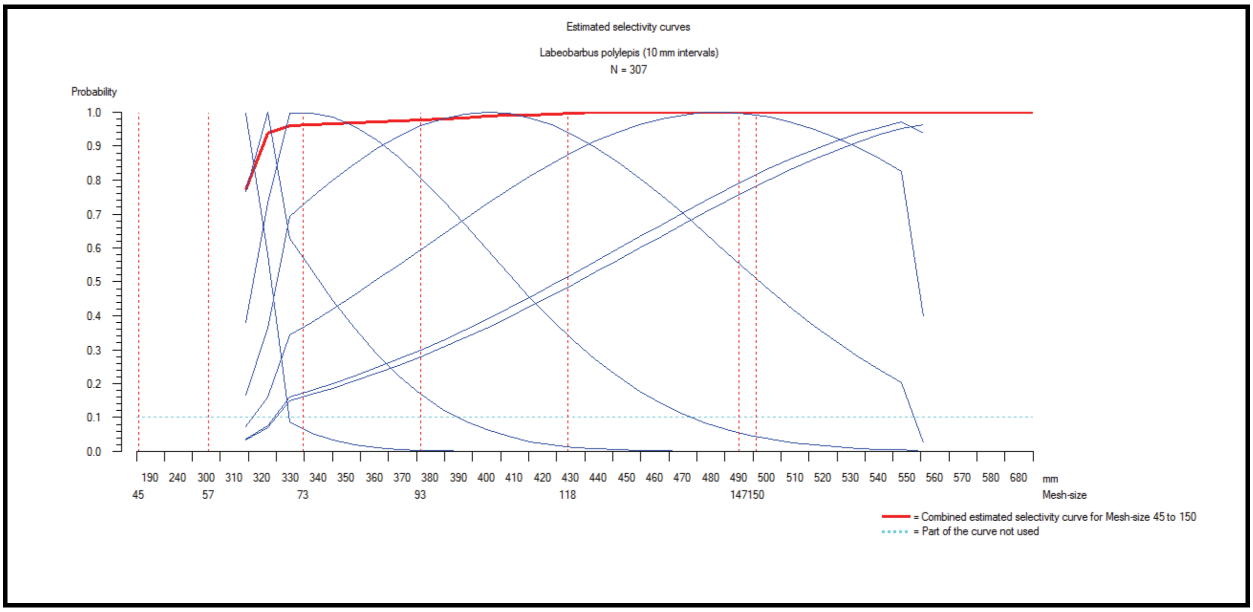

Figure 10.9: Estimated gill net selectivity for *Labeobarbus polylepis*.

Cyprinus carpio:
The probability of sampling fish in the 12-42 cm range with the 93 mm-150 mm meshes is high (85%-100%) (Figure 10.10).

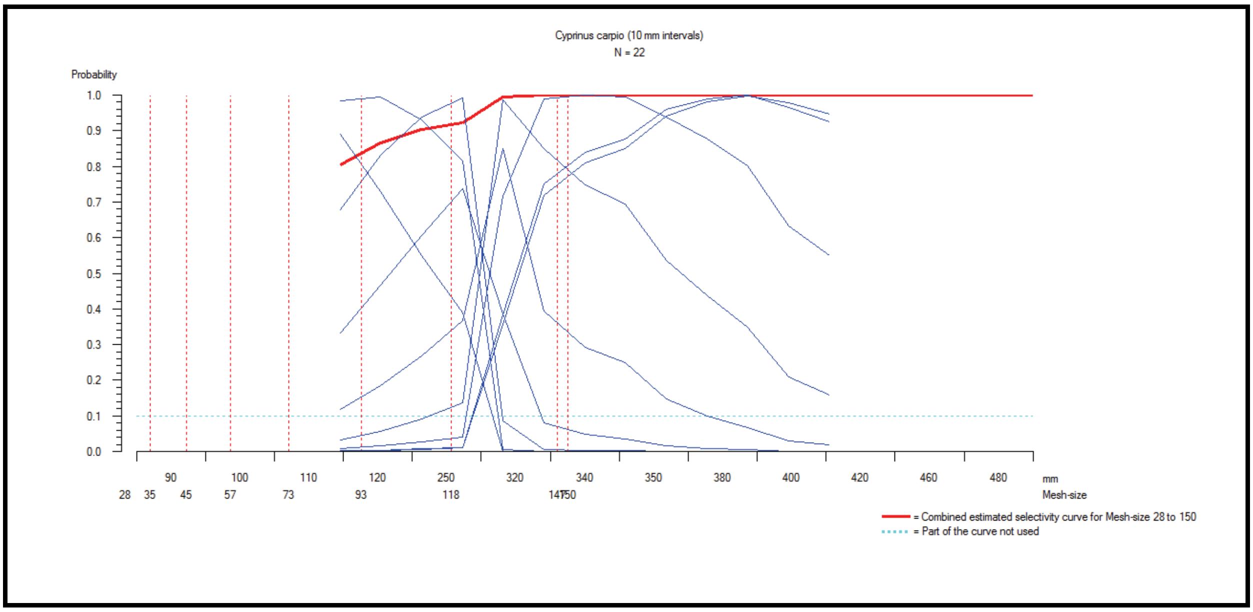

Figure 10.10: Estimated gill net selectivity for *Cyprinus carpio*.

10.3.4 CPUE for the Species Sampled in Rietvlei Dam, 2007-2008

The catch per unit effort (CPUE) was calculated for each of the multifilament gill net meshes and the monofilament gill net at a standard effort. The standard effort for a mesh was 10m² set for 12 hours.

Table 10.5 provides the average CPUE (in numbers – N, and weight – W), for all mesh sizes combined (including the 147 mm mesh) for Rietvlei Dam, 2007-2008. Ten gill net mesh sizes were used to limit selectivity (22, 28, 35, 45, 57, 73, 93, 118, 147, and 150 mm).

The catfish made the largest contribution to the CPUE recorded in weight (3.7 kg per 10m² per setting), followed by the smallscale yellowfish (2.3 kg) (Table 10.5). The other species mostly made their contribution to the CPUE recorded in numbers.

The total CPUE in numbers and weight at the end of Table 10.5 is the average CPUE calculated for the ten meshes combined with a net area of 10m². The CPUE's recorded indicate that 14.8 specimens with a weight of 6.4 kg were sampled in a net area of 10m².

Eight (8) species were caught in the gill nets, and *Clarias gariepinus* made the largest contribution in weight (59%), and *Chetia flaviventris* made the largest contribution to the total numbers (41.7%).

Table 10.5: CPUE for the species sampled in Rietvlei Dam.

Species	NO	% NO	W(kg)	% W	CPUE-N	CPUE-W(kg)
Clarias gariepinus	253	10.9	588.369	59	1.6	3.7
Labeobarbus polylepis	276	11.9	357.512	35.8	1.8	2.3
Chetia flaviventris	966	41.7	27.307	2.7	6.2	0.2
Cyprinus carpio	21	0.9	17.373	1.7	0.1	0.1
Barbus paludinosus	548	23.7	2.614	0.3	3.5	0
Labeobarbus marequensis	1	0	2.3	0.2	0	0
Tilapia sparrmanii	30	1.3	0.952	0.1	0.2	0
Pseudocrenilabrus philander	222	9.6	0.937	0.1	1.4	0
Total	**2316**	**100**	**997.364**	**100**	**14.8**	**6.4**

Graphical display of the CPUE for all species sampled in Rietvlei Dam:
Figure 10.11 gives a graphical representation of the gill net catches in numbers and weight (kg) for each species (CPUE per gill net panel (10m² for 12h), for all mesh sizes combined). *Clarias gariepinus* (catfish) made a large contribution in weight (1st green bar), and *Chetia flaviventris* (canary kurper) made a large contribution in numbers (3rd orange bar). Both species have potential in a fishery.

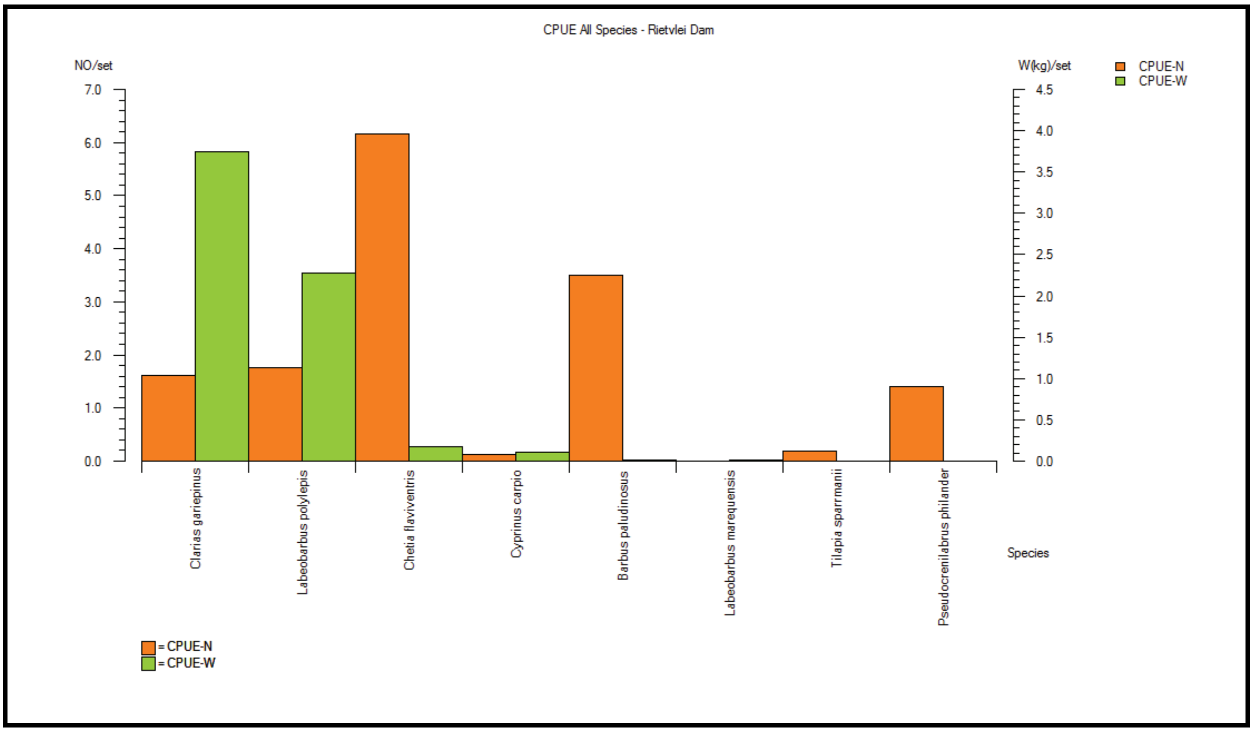

Figure 10.11: CPUE for the species sampled in Rietvlei Dam.

Gill net CPUE-W per station for Rietvlei Dam:
The highest CPUE-W (weight in kg) was recorded at station R3, followed by stations R8 and R1 (Table 10.6 and Figure 10.12). The highest CPUE-N (in numbers) was recorded at station R4, followed by stations R7 and R12.

Table 10.6: CPUE per station for Rietvlei Dam.

Station	CPUE-N	CPUE-W(kg)
R 1	16	7.9
R 2	14.6	5.8
R 3	5.2	10.8
R 4	30.6	7.4
R 5	10.9	7.2
R 6	3	6.7
R 7	24.1	6.9
R 8	3.4	10.5
R 9	8.6	2.9
R 10	9.1	3.8
R 11	3	3.8
R 12	19	7
R 13	13.9	6.8
Total	**14.8**	**6.4**

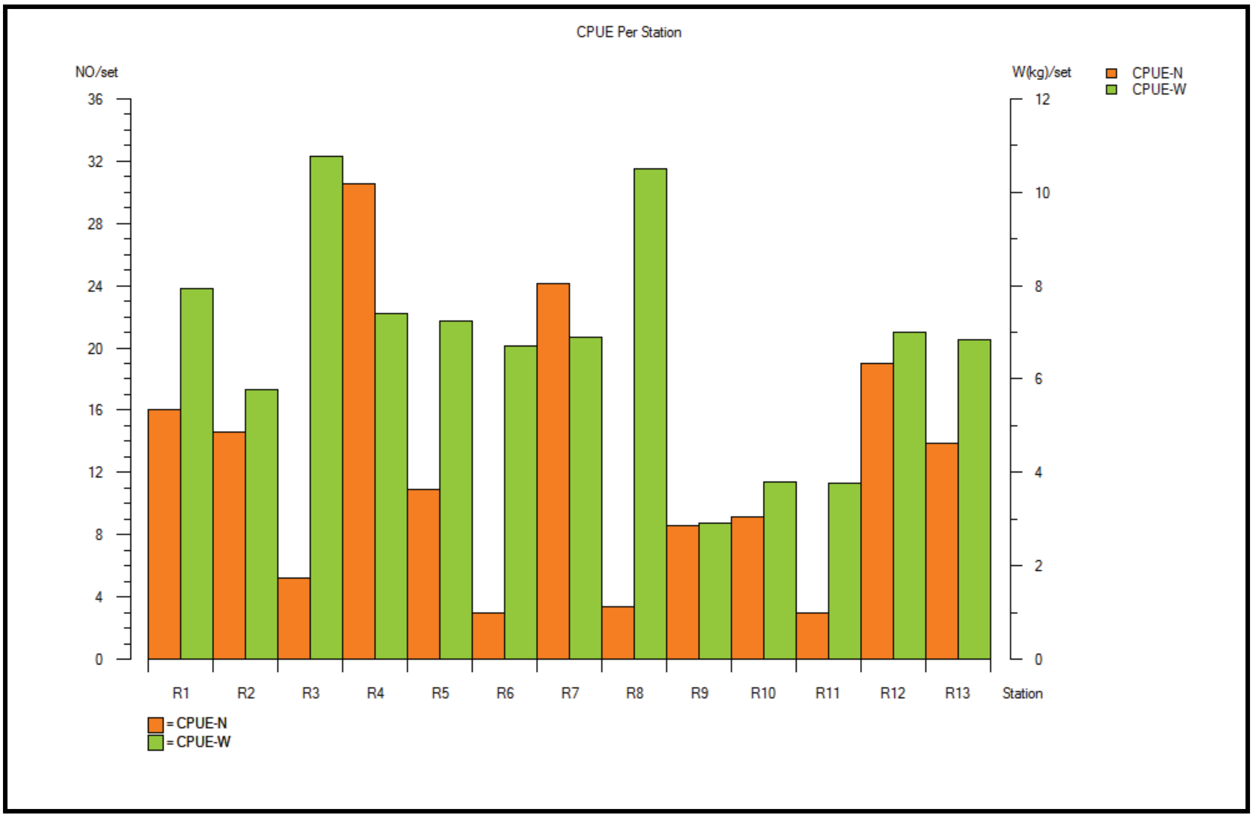

Figure 10.12: CPUE for the stations in Rietvlei Dam.

Gill net CPUE per habitat for Rietvlei Dam:
The areas with deep water and vegetation were the most productive. Large specimens were, however, also sampled in deep-water areas with little or no vegetation (Table 10.7 and Figure 10.13). Shallow water areas were the least productive.

Table 10.7: CPUE per habitat for Rietvlei Dam,.

Setting Type/Code	Habitat Type	CPUE-N	CPUE-W(kg)
30	Deep littoral zone, vegetation	20.1	7.8
40	Deep littoral zone, rocky	10.9	7.2
50	Deep pelagic zone	8.7	5.2
20	Shallow littoral zone, rocky	11	3.2
10	Shallow littoral zone, vegetation, sand	3	3.5
Total		**14.8**	**6.4**

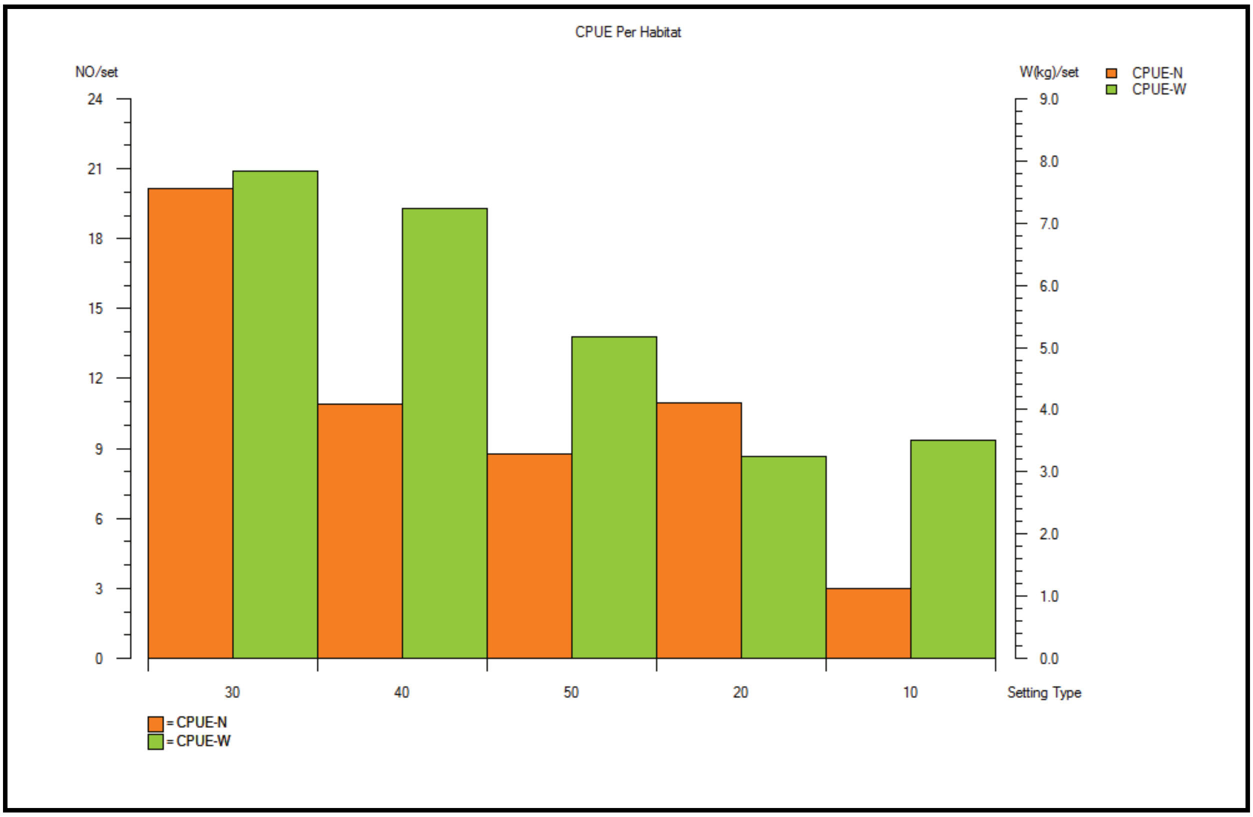

Figure 10.13: CPUE per habitat for Rietvlei Dam.

10.3.5 Biomass and yield estimates for Rietvlei Dam

The estimation of biomass and yield was done with a swept area method (Pauly, 1984):

Rietvlei Dam has a surface area of 2.06km². With the combined catch data from 2007 and 2008 the biomass and yield can be estimated for Rietvlei Dam with a Swept Area Model/Method.

The total fish biomass for Rietvlei Dam was estimated at 131.84 tons, and the total sustainable yield at 43.95 tons per year. This translates to 21.34 t/km²/yr or 213 kg/ha/yr.

Catfish, an undesirable species, made the highest contribution of 59% to the CPUE-W. A potential catfish biomass (yield) of 12.6 t/km²/yr (or 26 tons per year for the whole dam) could, therefore, be removed sustainably. To achieve the desired effects of biomanipulation or food web management up to 80% of the catfish biomass should, however, be removed, and this calculates to 30 t/km², or 62 tons for the whole dam during the start-up phase of such a programme.

Other species to be considered for removal are the canary kurper and carp. Canary kurper was sampled in high numbers, which may have a significant impact on the dam ecology. A potential canary kurper biomass (yield) of 582.5 kg/km²/yr (or 1.2 tons per year for the whole dam) could be removed sustainably.

Carp was sampled in low numbers. A potential carp biomass (yield) of 363 kg/km²/yr (or 747.2 kg per year for the whole dam) could, however, be removed sustainably.

10.4 ROODEPLAAT DAM

10.4.1 Roodeplaat Dam Sampling Sites

Figure 10.14: Roodeplaat Dam sampling sites

Twelve (12) stations were identified and surveyed during both surveys with the aim to obtain data representative of the fish population in the dam (Figure 10.14).

During both surveys the water level of the dam was at approximately 100% of its full supply level. Table 10.8 presents the station statistics, and sampling gears used in the different habitat types during the two surveys.

Table 10.8: Station statistics for Roodeplaat Dam (2007-2008).

Date	St. code	Latitude	Longitude	Gear	Set type
5/11/2007	1	25°38'18.81"S	28°20'13.52"E	Gill net	Lake deep littoral zone, rocky
6/11/2007	2	25°38'27.15"S	28°20'14.92"E	Gill net	Lake deep littoral zone, veg
7/11/2007	3	25°38'24.63"S	28°20'21.75"E	Gill net	Lake deep littoral zone, veg
8/11/2007	4	25°38'29.20"S	28°20'33.97"E	Gill net	Lake deep pelagic
9/11/2007	5	25°37'26.28"S	28°22'07.19"E	Gill net	Lake shallow littoral zone, veg
10/11/2007	6	25°37'22.19"S	28°22'25.12"E	Gill net	Lake deep littoral zone, rocky
11/11/2007	7	25°37'24.01"S	28°22'35.36"E	Gill net	Lake deep littoral zone, veg
12/11/2007	8	25°37'17.78"S	28°22'19.73"E	Gill net	Lake deep pelagic
12/03/2008	6	25°37'22.19"S	28°22'25.12"E	Gill net	Lake deep littoral zone, rocky
13/03/2008	7	25°37'24.01"S	28°22'35.36"E	Gill net	Lake deep littoral zone, veg
14/03/2008	9	25°38'04.55"S	28°22'27.92"E	Gill net	Lake shallow littoral zone, veg
15/03/2008	8	25°37'17.78"S	28°22'19.73"E	Gill net	Lake deep pelagic
16/03/2008	10	25°37'40.27"S	28°21'08.86"E	Gill net	Lake deep littoral zone, rocky
17/03/2008	11	25°37'47.30"S	28°21'07.65"E	Gill net	Lake deep littoral zone, rocky
18/03/2008	12	25°38'13.54"S	28°22'42.09"E	Gill net	Lake shallow littoral zone, veg

Shallow < 1.5m
Deep > 1.5m

10.5 ROODEPLAAT DAM SAMPLING STATISTICS

10.5.1 IRI for Roodeplaat Dam

An **Index of Relative Importance** (IRI) as described by Kolding (1989) was used to indicate the contribution each fish species made to the catch composition.

IRI for the Gill Nets Used in Roodeplaat Dam (2007-2008):
Eleven (11) species were sampled in Roodeplaat Dam (Table 10.9). *Clarias gariepinus* received the highest IRI score overall of 50.5%, followed by *Labeobarbus marequensis* with 20.8%, and *Oreochromis mossambicus* with 15.8%. *Clarias gariepinus* received the highest IRI score due to its contribution in weight (63%) to the total catch. *Labeobarbus marequensis* and *Oreochromis mossambicus* both made considerable contributions in numbers and weight to the total catch; *Labeobarbus marequensis* with a 16.3% contribution in numbers and a 16% contribution to the total weight recorded, and *Oreochromis mossambicus* with a 10.6% and a 15.5% contribution to the total numbers and weight respectively.

The first six species in Table 10.9 were all sampled in high numbers, and *Barbus unitaeniatus* made the highest contribution to the total numbers sampled.

The first three species (catfish, largescale yellowfish, and Mozambique tilapia) were all sampled in high numbers and large specimens of all three species were sampled (Table 10.9). *Clarias gariepinus* which is an undesirable fish species is a definite candidate for a fish species to be exploited in a fisheries project. Roodeplaat Dam has a *Microcystis* problem, and the removal of catfish may help to alleviate the problem and help to shift the fish population towards *Oreochromis mossambicus.*

A total of 2389 fish were sampled during the study, of which *Barbus unitaeniatus* was the most abundant species (36.1%), followed by *Labeobarbus marequensis* (16.3%) (Table 10.9).

A total weight of 1070 kg was recorded during the study, of which *Clarias gariepinus* (63.4%) was the major contributor (Table 10.9).

Table 10.9: IRI for Roodeplaat Dam, 2007-2008.

Species	NO	% NO	W(kg)	% W	FRQ	% FRQ	IRI	% IRI
Clarias gariepinus	279	11.7	674.2	63	66	48.9	3652	50.5
Labeobarbus marequensis	390	16.3	170.8	16	63	46.7	1507	20.8
Oreochromis mossambicus	253	10.6	165.8	15.5	59	43.7	1140	15.8
Barbus unitaeniatus	862	36.1	3.0	0.3	16	11.9	431	6
Chetia flaviventris	228	9.5	6.9	0.6	38	28.1	287	4
Barbus paludinosus	299	12.5	1.3	0.1	15	11.1	140	1.9
Cyprinus carpio	38	1.6	37.8	3.5	17	12.6	65	0.9
Labeobarbus polylepis	12	0.5	5.2	0.5	10	7.4	7	0.1
Tilapia sparrmanii	16	0.7	1.1	0.1	8	5.9	5	0.1
Micropterus salmoides	10	0.4	3.5	0.3	8	5.9	4	0.1
Pseudocrenilabrus philander	2	0.1	0.01	0	2	1.5	0	0
Total	**2389**	**100**	**1069.7**	**100**	**-**	**-**	**7239**	**100**

%IRI = Percentage of Total of IRI values calculated for each species in area
%N = Contribution in Percentage to Total Numbers sampled
%W = Contribution in Percentage to Total Weight sampled
%F = Frequency of Occurrence

Roodeplaat Dam experiences excessive algal growth problem or algal blooms. Water hyacinth (Eichhornia crassipes) is also abundant and a problem for the dam.

Figure 10.15 indicates the large contribution in weight that *Clarias gariepinus* (species 1 in graph) made to the total catch, and the relatively large contributions that *Labeobarbus marequensis* (species 2 in graph) and *Oreochromis mossambicus* (species 3 in graph) made to the total numbers and weight recorded.

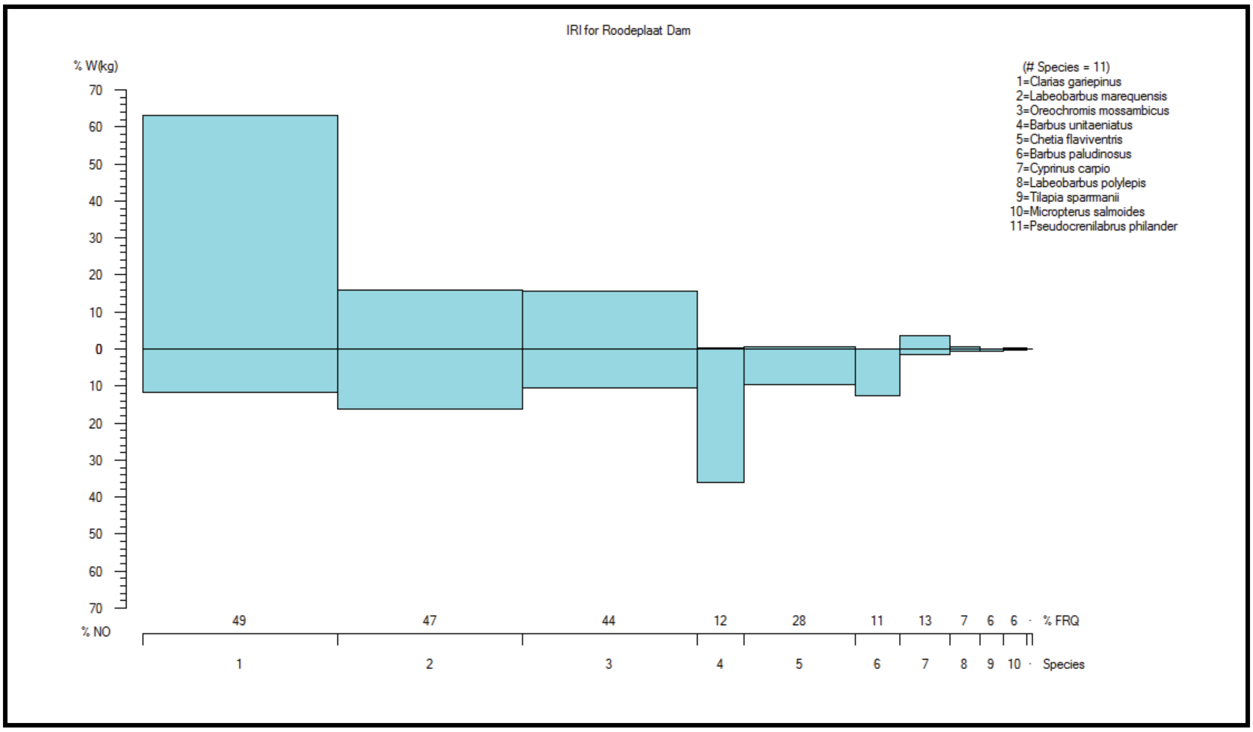

Figure 10.15: IRI for Roodeplaat Dam, 2007-2008.

10.5.2 <u>Catch Statistics for the Gill Nets in Roodeplaat Dam, 2007-2008</u>

Table 10.10 indicates the number of each species sampled in each mesh size (upper section of table). Two specimens of *Pseudocrenilabrus philander* were sampled in the 22 and 28 mm mesh sized gill nets each. *Chetia flaviventris* was sampled in the 22-57 mm meshes, and the most effective being the 22 mm mesh gill net for *Chetia flaviventris*. Nine mesh sized gill nets were used in Roodeplaat Dam. The multifilament gill net range (22-150 mm) was used, with the exception of the 147 mm monofilament gill net. The 147 mm catches are, however, similar to the 150 mm multifilament net.

Clarias gariepinus and *Cyprinus carpio* was sampled in a wide range of mesh sizes, the larger meshes being the most effective for *Clarias gariepinus* (73-150 mm) (Table 10.10). Relatively low numbers of *Cyprinus carpio* were recorded, but the 150 mm mesh seems to be the most effective for catching this species. Most or all of the carp were sampled in the area of Hengelaars Friend towards the eastern leg of Roodeplaat Dam where low gradient slopes and sandy bays are more abundant than in the rest of the dam, where steep rocky slopes are dominant.

The 45-93 mm meshes were also effective in sampling *Labeobarbus marequensis,* but the 57 mm and 73 mm meshes were the most effective (Table 10.10). *Barbus paludinosus* and *Barbus unitaeniatus* were sampled in high numbers (285 and 779 respectively) in the 22 mm mesh.

For fish removal the 118 mm and 150 mm gill nets seem to be the most effective for targeting *Clarias gariepinus* and *Cyprinus carpio* (Table 10.10). *Labeobarbus marequensis* is also targeted with these nets, but in low numbers, and their catch can be reduced by strategically placing the nets in the correct habitats (close to banks away from open water as the yellowfish seem to frequent open water).

The second section (lower section) of Table 10.10 indicates the total number of fish sampled in each of the gill nets, the contribution in percentage each mesh made to the total number recorded, the number of settings for each mesh, the average number of fish sampled in each mesh, and the mean lengths and weight sampled in each mesh.

Table 10.10: Catch Statistics for the Gill Nets in Roodeplaat Dam, 2007-2008.

Species	Gill Net Mesh Size (MM)									Total
	22	28	35	45	57	73	93	118	150	
Pseudocrenilabrus philander	1	1								2
Chetia flaviventris	110	15	28	49	26					228
Clarias gariepinus			2	5	18	38	44	93	79	279
Cyprinus carpio		5		3	3	6	1	5	15	38
Labeobarbus polylepis	1			1	6	1	2	1		12
Labeobarbus marequensis		3	7	36	134	130	62	17	1	390
Barbus paludinosus	285	8	1		5					299
Tilapia sparrmanii			4	4	5	3				16
Barbus unitaeniatus	779	83								862
Oreochromis mossambicus	8	8	14	6	3	12	46	125	31	253
Micropterus salmoides			1	1	3	3	2			10
Total	1184	123	57	105	203	193	157	241	126	2389
% NO	49.6	5.1	2.4	4.4	8.5	8.1	6.6	10.1	5.3	100
No of settings for each mesh	15	15	15	15	15	15	15	15	15	135
AV NO/Mesh	78.9	8.2	3.8	7	13.5	12.9	10.5	16.1	8.4	17.7
ML(mm)/Mesh	82.1	114.2	152.4	197.8	252.7	341.6	404.7	471	640	215.8
MW(g)/Mesh	4	51	103	158	306	644	1013	1382	2838	448

MW = Mean Weight in grams
ML = Mean Length in mm

10.5.3 Species Statistics for the Gill Nets in Roodeplaat Dam, 2007-2008

Table 10.11 provides the total number of each species sampled, their average weight and length, and the biomass (g) contribution each species made to the gill net series (or range, from 22 mm to 150 mm, all meshes included) per setting. The biomass contribution was calculated for each mesh with an area of $10m^2$. *Clarias gariepinus* and *Labeobarbus marequensis,* and *Oreochromis mossambicus* made the largest contribution to the biomass recorded. *Clarias gariepinus* was sampled with a mean weight of 2416 g (2.4 kg) and a mean length of 648 mm (64.8 cm).

Table 10.11: Species Statistics for the Gill Nets in Roodeplaat Dam, 2007-2008.

Species	Total	% NO	MW(g)	ML(mm)	Biomass(g)/set
Pseudocrenilabrus philander	2	0.1	5.5	76	0
Chetia flaviventris	228	9.5	30.4	120	51
Clarias gariepinus	279	11.7	2416.3	648	4994
Cyprinus carpio	38	1.6	995.1	343	280
Labeobarbus polylepis	12	0.5	430	279	38
Labeobarbus marequensis	390	16.3	438	277	1265
Barbus paludinosus	299	12.5	4.4	76	10
Tilapia sparrmanii	16	0.7	66.6	148	8
Barbus unitaeniatus	862	36.1	3.5	87	22
Oreochromis mossambicus	253	10.6	655.5	316	1228
Micropterus salmoides	10	0.4	353.8	274	26
Total	**2389**	**100**	**447.7**	**216**	**7923**

MW = Mean Weight in grams
ML = Mean Length in mm

10.6 SPECIES SELECTION FOR A FISHERY IN ROODEPLAAT DAM

This section aims to identify and select the most appropriate species, which are likely to succeed in terms of a fisheries exploitation project. The species selected all have potential for exploitation in a fisheries project, however, some more than others.

Gill net selectivity was explored for the species. A multifilament gill net range of nine (9) meshes were used during the survey, which included a 22 mm, 28 mm, 35m, 45 mm, 57 mm, 73 mm, 93 mm, 118 mm and a 150 mm mesh. Each of these meshes has a net area of $10m^2$.

The fish retained in a gear is usually only an unknown proportion of the various size classes available in the fished population. Selectivity is a quantitative expression of this proportion and represented as a probability of capture of a certain size of fish in a certain size of mesh. The mesh selectivity was indirectly estimated with methods as described by Kolding, 1998.

10.6.1 Species selection

Five species may be considered for selection as species with potential for utilisation in a fisheries project. The IRI was used as a guideline, as it highlights the important species in terms of their contribution to weight and numbers (section 10.5.1). The species, which may be considered, are *Chetia flaviventris, Clarias gariepinus, Labeobarbus marequensis, Oreochromis mossambicus* and *Cyprinus carpio. Cyprinus carpio* did not make large contributions to the total numbers and weight recorded; however, it is an undesirable alien (introduced) species with negative impacts on the environment and habitat of other species, as it is a habitat altering species (as described by Kleynhans, 1999 and 2001)

All the identified species are well represented in the Roodeplaat Dam. Undesirable species, such as catfish, carp and the canary kurper, could be exploited to lessen pressure on the zooplankton population, which in turn may positively affect water quality.

Clarias gariepinus and *Cyprinus carpio* produce high numbers of offspring due to their high fecundity. High numbers of juvenile fish after the spawning season may have a significant impact on the zooplankton population due to predation, and the exploitation of the breeding stock of these species, may benefit the zooplankton population.

The feeding habits of carp and catfish may also negatively influence water quality, as they tend to re-suspend organic materials and small sediment particles back into the water column (through constant churning of bottom sediments in search of food), which makes it available for use by other organisms, such as algae.

By exploiting carp, catfish, and the canary kurper the fish population may shift towards *Oreochromis mossambicus* and *Labeobarbus marequensis* which are more desirable fish species in terms of ecology, fisheries, and recreational activities.

10.6.2 <u>Length frequencies recorded for selected species</u>

CPUE was calculated for each of the meshes at a standard effort. The standard effort for a mesh was 10m² net area set for 12 hours.

Chetia flaviventris:
Chetia flaviventris was effectively sampled within its length range with the 22 mm to 57 mm mesh sized gill nets (Figure 10.16). The highest number (110) of fish was recorded in the 22 mm mesh gill net with a mean weight of 6 g. This species was sampled in a length range of 7 cm to 21 cm.

Figure 10.16 graphically displays the length frequencies recorded for *Chetia flaviventris* in the different gill nets, as well as the mean length (green line) for each mesh size. *Chetia flaviventris* is a small species, and it was therefore not sampled in the larger mesh sizes (73-150 mm meshes).

The length frequencies recorded (Figure 10.16) gives an indication of length cohorts, in the 7-8 cm, 10-11 cm, 13-14 cm, 15-17 cm and 18-21 cm ranges, representative of age classes, and successful breeding and recruitment during previous seasons. Large specimens of this species were sampled.

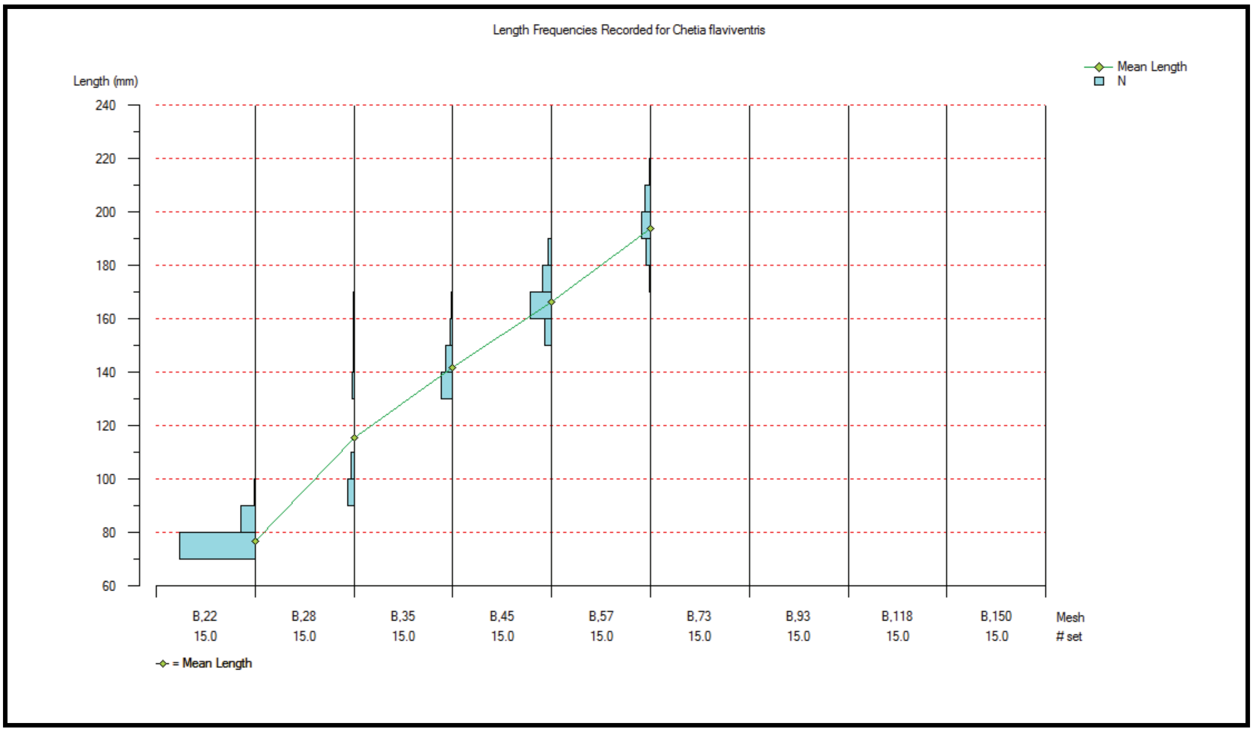

Figure 10.16: Length frequencies recorded for *Chetia flaviventris*.

Labeobarbus marequensis
This species was most effectively sampled with the 45 mm to 93 mm mesh sized gill nets (Figure 10.17), and it was sampled in a length range of 13-47 cm. The highest numbers were recorded in the 57 and 73 mm meshes.

Figure 10.17 gives an indication of the length frequencies sampled in the meshes. Relatively large specimens were sampled in the 36-45 cm length range. Length cohorts can be seen in Figure 10.17, which indicates to successful breeding during previous seasons. *Labeobarbus marequensis* was not sampled in the 22 mm gill nets, small specimens were, however, sampled in low numbers in the larger nets, indicating to successful recruitment. A healthy population exists in the dam.

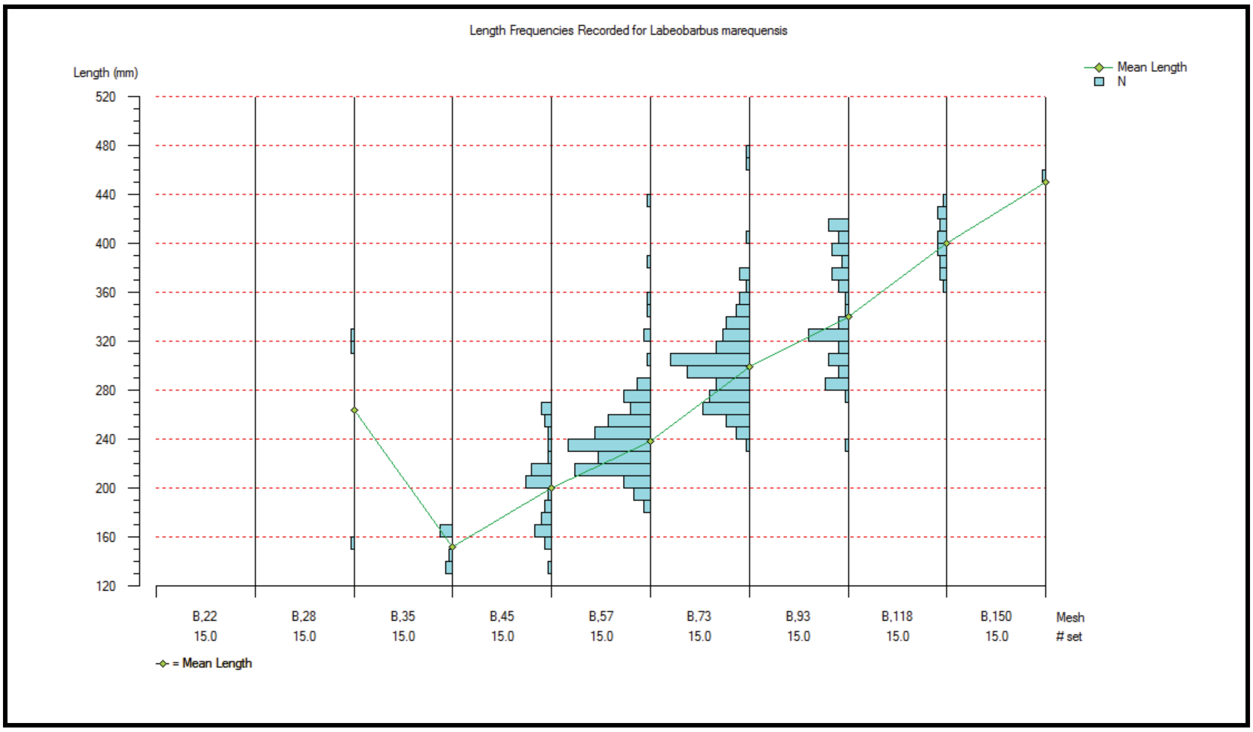

Figure 10.17: Length frequencies recorded for *Labeobarbus marequensis*.

Cyprinus carpio:
Specimens were sampled in a length range of 17-56 cm in the gill nets (Figure 10.18). The highest number of fish was recorded in the 150 mm mesh. Large specimens (N=15) were sampled in the 150 mm mesh.

Cyprinus carpio was sampled in relatively low numbers, but several length cohorts were recorded, indicating successful breeding during previous seasons (Figure 10.18).

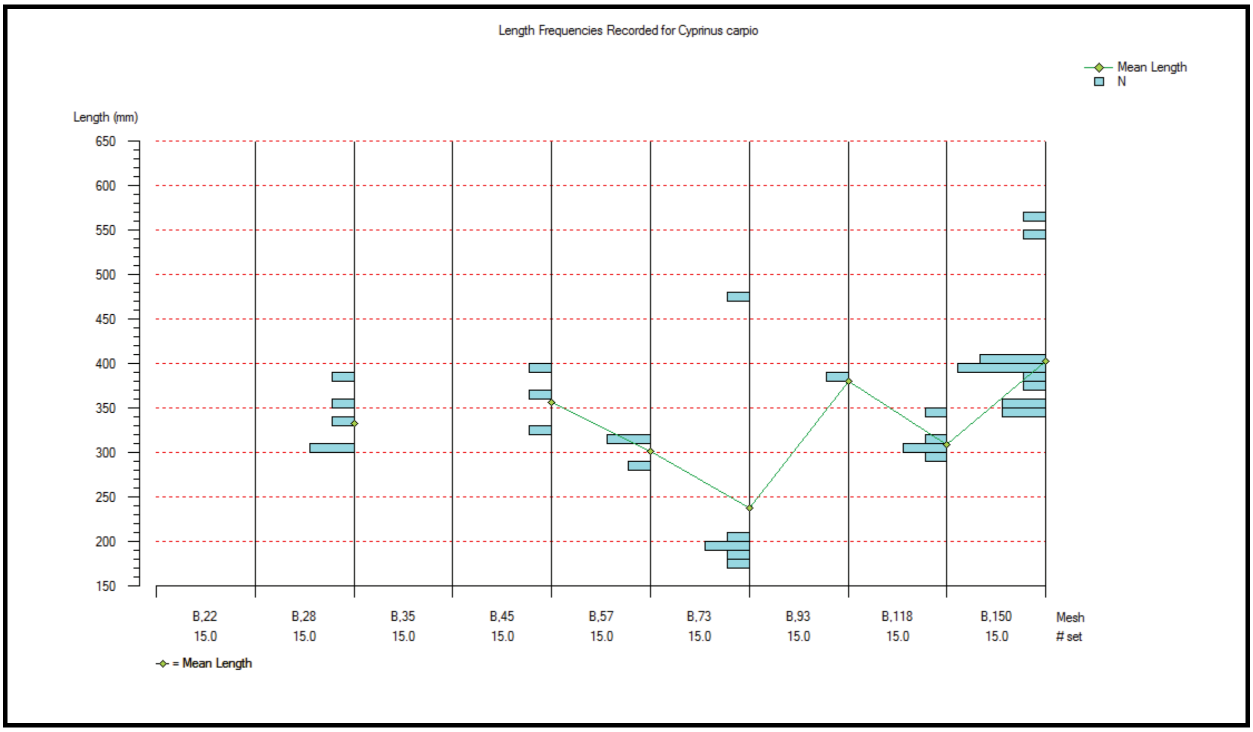

Figure 10.18: Length frequencies recorded for *Cyprinus carpio*.

Clarias gariepinus:

A total number of 279 specimens in a length rage of 20 cm-1m were sampled in the 35-150 mm mesh gill nets (Figure 10.19). The 118-150 mm meshes were the most effective in sampling large specimens. There seems to be a healthy breeding population, as several length cohorts were recorded. Large specimens are present in the system. The 150 mm mesh gill net (as well as the 147 mm monofilament gill net, however, not used, but with the similar potential) has potential as target gear as mature specimens were sampled in this net.

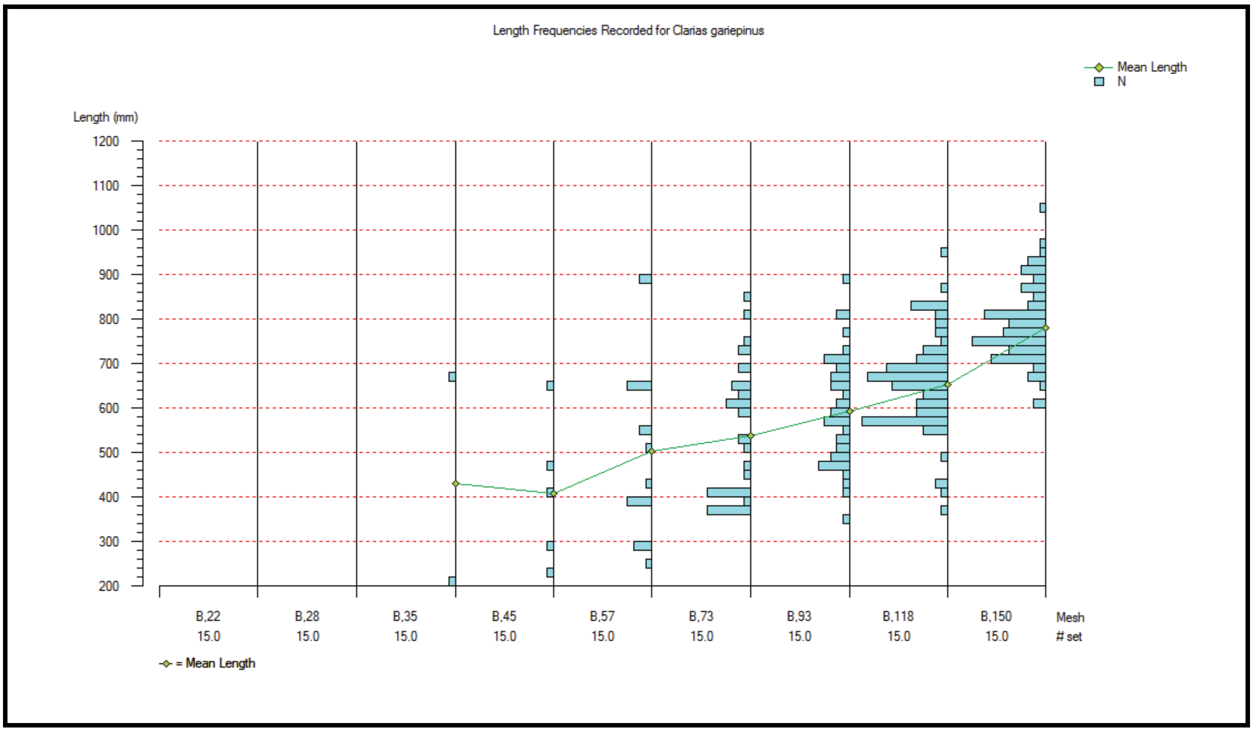

Figure 10.19: Length frequencies recorded for *Clarias gariepinus*.

Oreochromis mossambicus:

Oreochromis mossambicus was sampled within its length range with the 22 mm to 150 mm mesh sized gill nets (Figure 10.20). The highest number (125) of fish was recorded in the 118 mm mesh gill net with a mean weight of 785 g. This species was sampled in a length range of 6 cm to 43 cm. The population is in good condition.

Figure 10.20 graphically displays the length frequencies recorded for *Oreochromis mossambicus* in the different gill nets, as well as the mean length for each mesh size. *Oreochromis mossambicus* was sampled in all the mesh sizes (22-150 mm meshes).

The length frequencies recorded (Figure 10.20) give an indication of a variety of length cohorts present, representative of different age classes, and successful breeding and recruitment during previous seasons. Large specimens of this species were sampled, and the population is in good health.

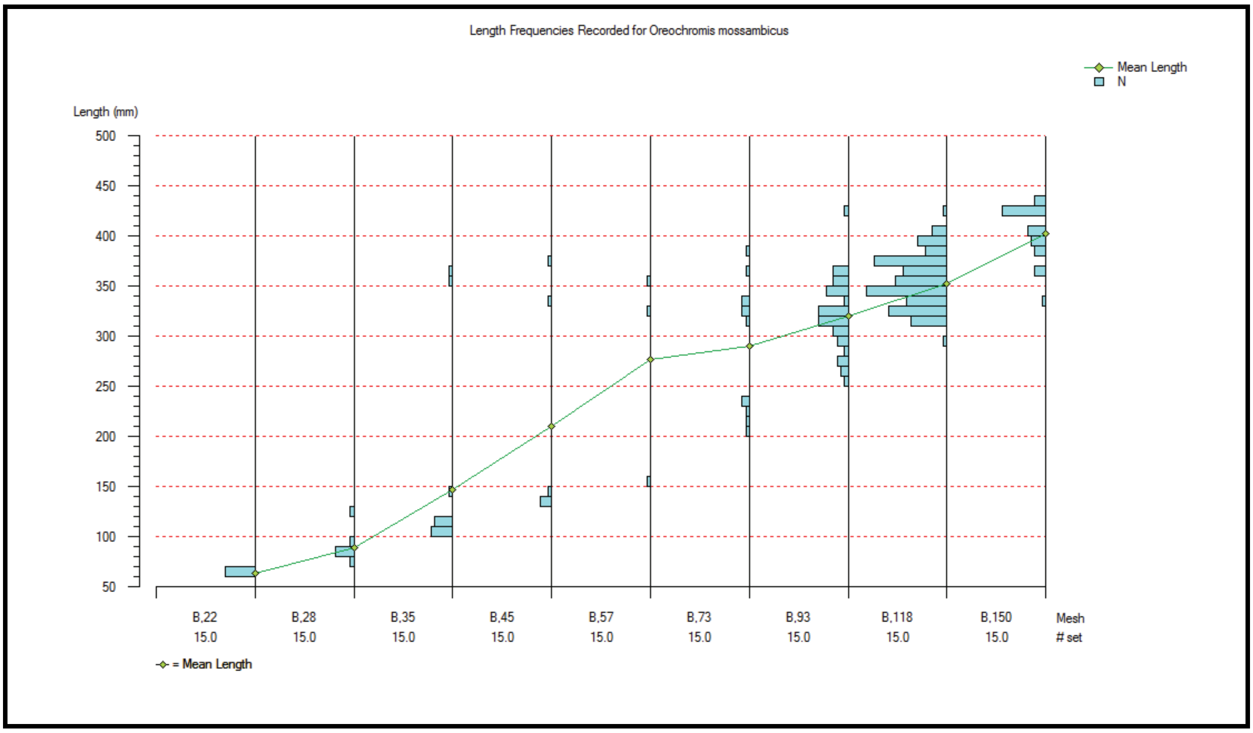

Figure 10.20: Length frequencies recorded for *Oreochromis mossambicus*.

10.6.3 Gill net selectivity for selected species

Chetia flaviventris:
The probability ranges between 80% and 100% that this species will be sampled with the 35-57 mm gill net meshes (Figure 10.21). Fish in a length range of 10-19 cm are the most likely to be sampled with these meshes.

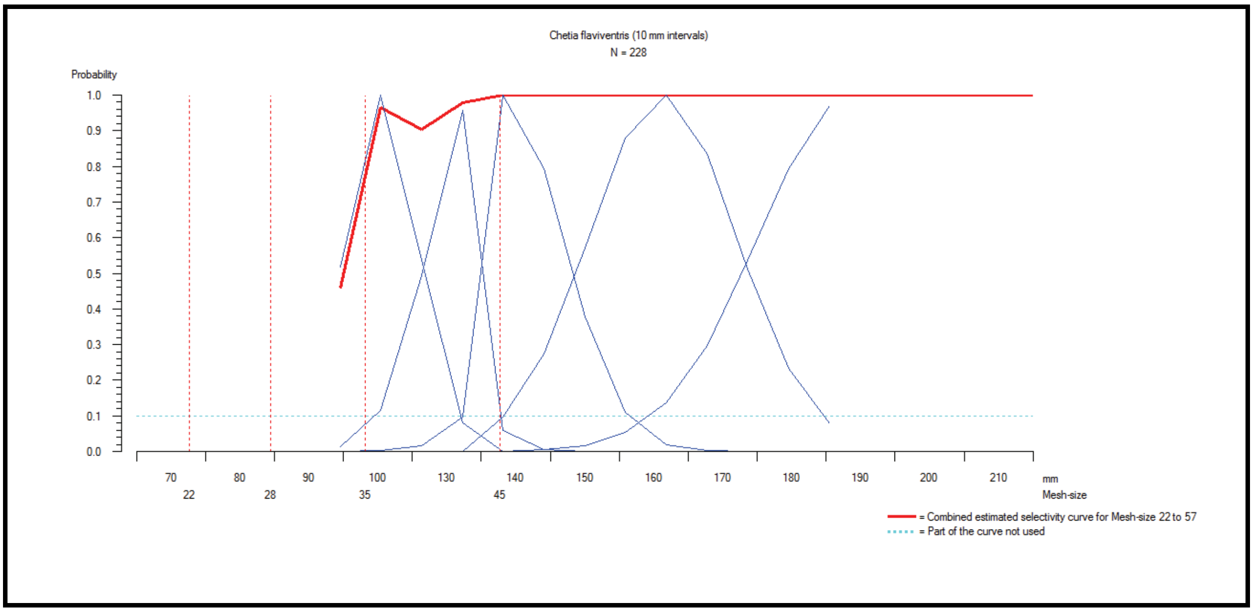

Figure 10.21: Estimated gill net selectivity for *Chetia flaviventris*.

Clarias gariepinus:
The probability is high (100%) for sampling large fish (43-75 cm) in the 73 mm to 150 mm meshes (Figure 10.22).

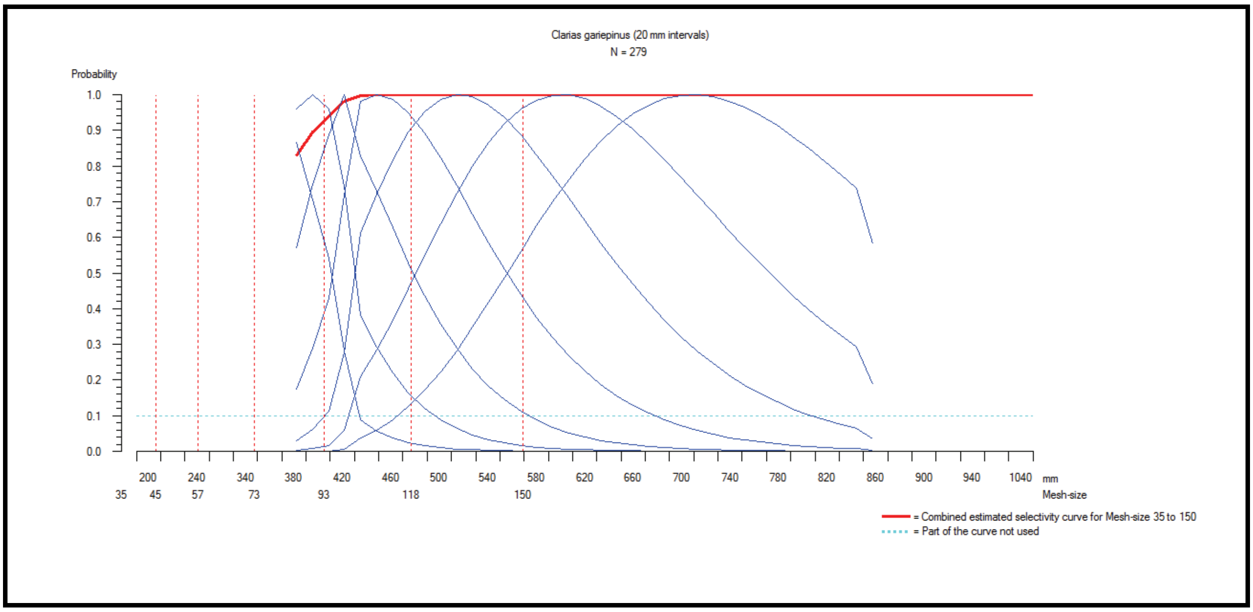

Figure 10.22: Estimated gill net selectivity for *Clarias gariepinus*.

Labeobarbus marequensis:
The probability is high for sampling fish in the 17-42 cm length range with the 28-150 mm gill net meshes (Figure 10.23).

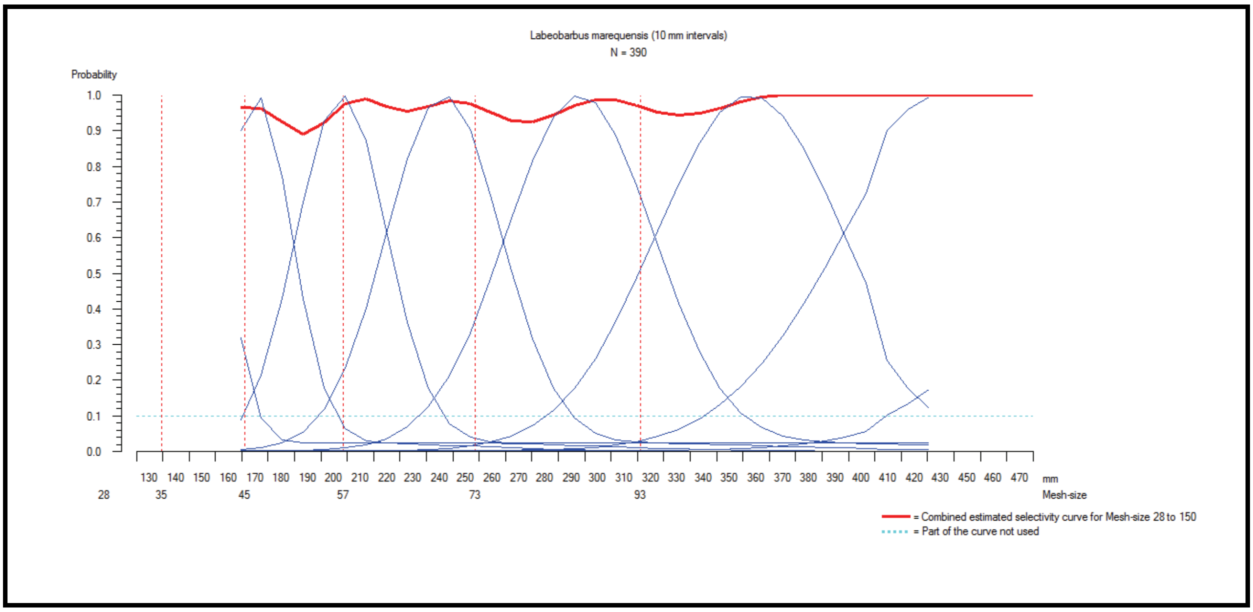

Figure 10.23: Estimated gill net selectivity for *Labeobarbus marequensis*.

Cyprinus carpio:
The probability of sampling fish in the 19-40 cm range with the 73 mm-150 mm meshes is high (100%) (Figure 10.24).

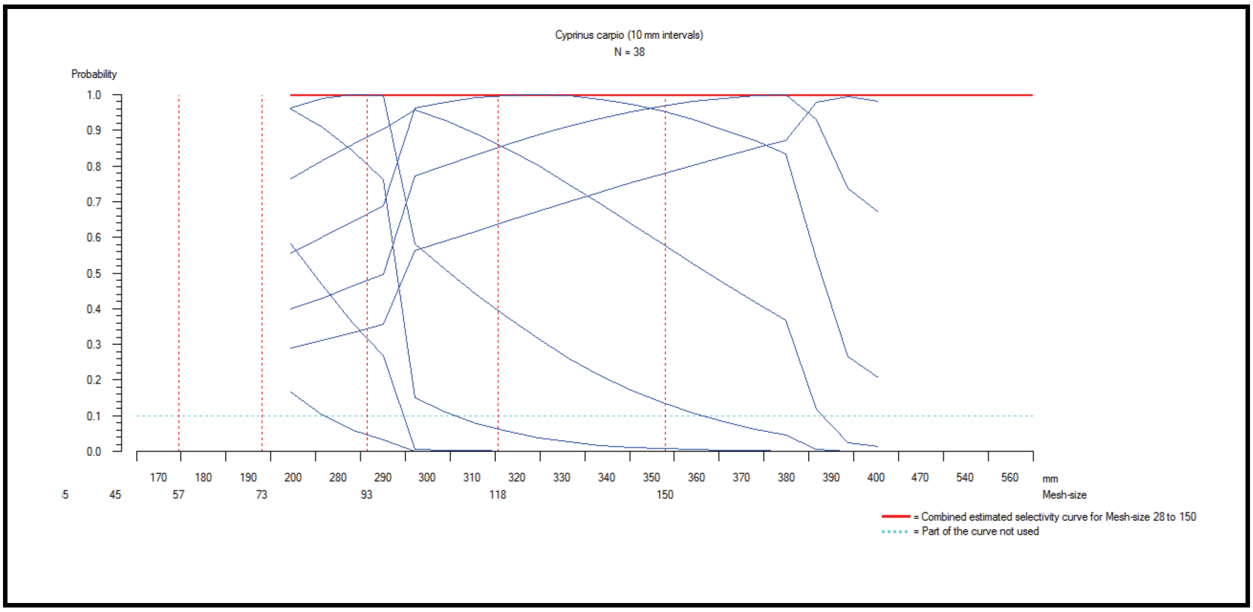

Figure 10.24: Estimated gill net selectivity for *Cyprinus carpio*.

Oreochromis mossambicus:

The probability of sampling fish in the 11-38 cm range with the 45 mm-150 mm meshes is high (95%-100%) (Figure 10.25).

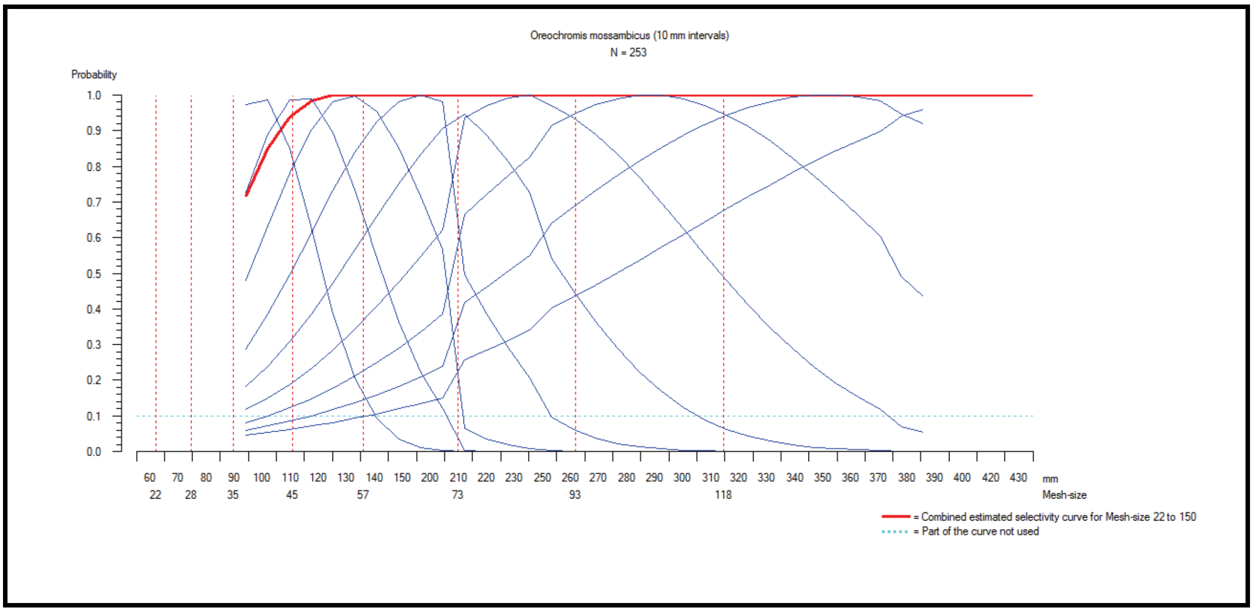

Figure 10.25: Estimated gill net selectivity for *Oreochromis mossambicus*.

10.6.4 CPUE for the Species Sampled in Roodeplaat Dam, 2007-2008

The catch per unit effort (CPUE) was calculated for each of the multifilament gill net meshes at a standard effort. The standard effort for a mesh was 10m² set for 12 hours.

Table 10.12 provides the average CPUE (in numbers – N, and weight – W), for all mesh sizes combined for Roodeplaat Dam, 2007-2008. Nine gill net mesh sizes were used to limit selectivity (22, 28, 35, 45, 57, 73, 93, 118, and 150 mm).

The catfish made the largest contribution to the CPUE recorded in weight (5 kg per 10m² per setting), followed by the largescale yellowfish (1.3 kg) and the Mozambique tilapia (1.2 kg) (Table 10.12). The other species mostly made their contribution to the CPUE recorded in numbers.

The total CPUE in numbers and weight at the end of Table 10.12 is the average CPUE calculated for the nine meshes combined with a net area of 10m². The CPUE's recorded indicate that 17.7 specimens with a weight of 7.9 kg were sampled in a net area of 10m². Counted specimens (i.e. damaged or rotten) were not taken into account in the calculations.

Eleven (11) species were caught in the gill nets, and *Clarias gariepinus* made the largest contribution in weight (63%) followed by *Labeobarbus marequensis* (16%) and *Oreochromis mossambicus* (15.5%), and *Barbus unitaeniatus* made the largest contribution to the total numbers (36.1%) (Table 10.12).

Table 10.12: CPUE for the species sampled in Roodeplaat Dam.

Species	NO	% NO	W(kg)	% W	CPUE-N	CPUE-W(kg)
Clarias gariepinus	279	11.7	674	63	2.1	5
Labeobarbus marequensis	390	16.3	171	16	2.9	1.3
Oreochromis mossambicus	253	10.6	166	15.5	1.9	1.2
Cyprinus carpio	38	1.6	37.8	3.5	0.3	0.3
Chetia flaviventris	228	9.5	6.9	0.6	1.7	0.1
Labeobarbus polylepis	12	0.5	5.2	0.5	0.1	0
Micropterus salmoides	10	0.4	3.5	0.3	0.1	0
Barbus unitaeniatus	862	36.1	3.0	0.3	6.4	0
Barbus paludinosus	299	12.5	1.3	0.1	2.2	0
Tilapia sparrmanii	16	0.7	1.1	0.1	0.1	0
Pseudocrenilabrus philander	2	0.1	0.01	0	0	0
Total	**2389**	**100**	**1070**	**100**	**17.7**	**7.9**

Graphical display of the CPUE for all species sampled in Roodeplaat Dam:
Figure 10.26 gives a graphical representation of the gill net catches in numbers and weight (kg) for each species (CPUE per gill net panel (10m² for 12h), for all mesh sizes combined). *Clarias gariepinus* (catfish) made a large contribution in weight (1st green bar), and *Barbus unitaeniatus* (Longbeard barb) made a large contribution in numbers (8th blue bar).

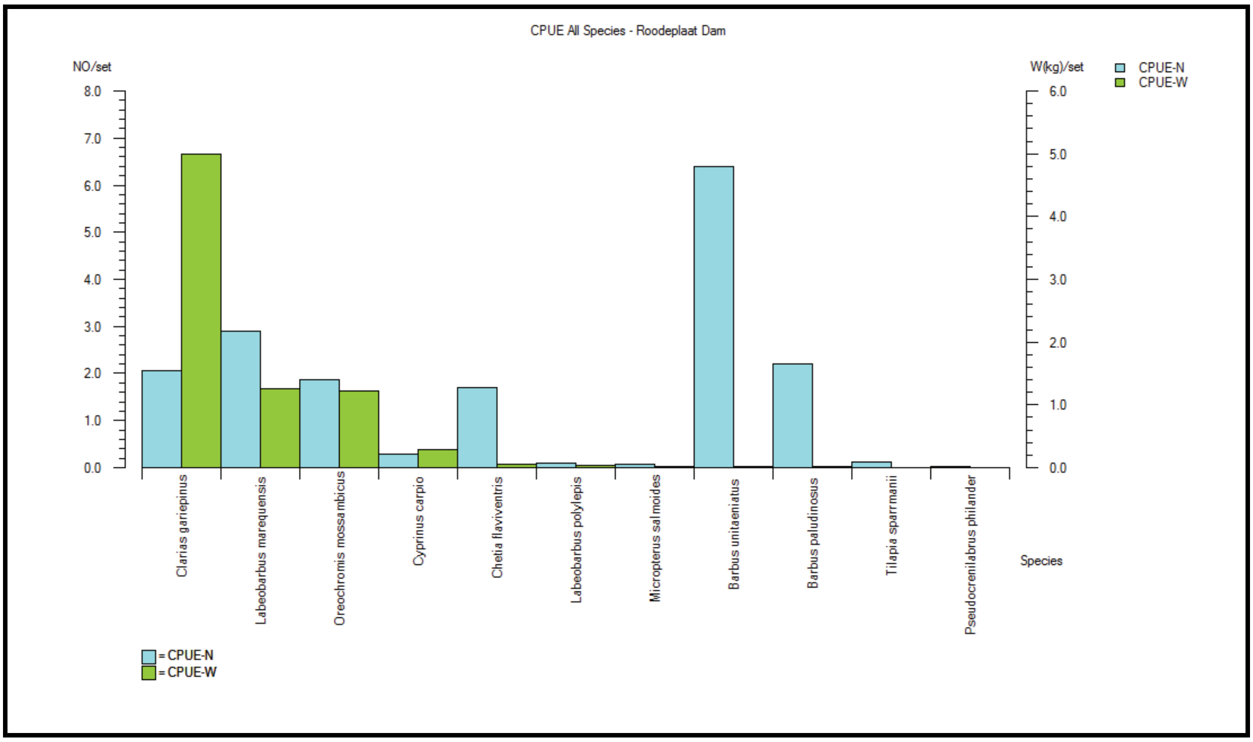

Figure 10.26: CPUE for the species sampled in Roodeplaat Dam.

Gill net CPUE-W per station for Roodeplaat Dam:
The highest CPUE-W (weight in kg) was recorded at station RP2, followed by station RP5 (Table 10.13 and Figure 10.27). The highest CPUE-N (in numbers) was recorded at station RP2, followed by station RP1.

Table 10.13: CPUE per station for Roodeplaat Dam (see Figure 10.14).

Station	CPUE-N	CPUE-W(kg)
RP1	25.6	7.3
RP2	98.9	18.3
RP3	16	6.7
RP4	7.9	5.4
RP5	13.2	16.2
RP6	9.2	7.6
RP7	13	7.7
RP8	10.6	6
RP9	16.2	6.8
RP10	8.9	6.5
RP11	11.7	7.1
RP12	1.6	2.2
Total	**17.7**	**7.9**

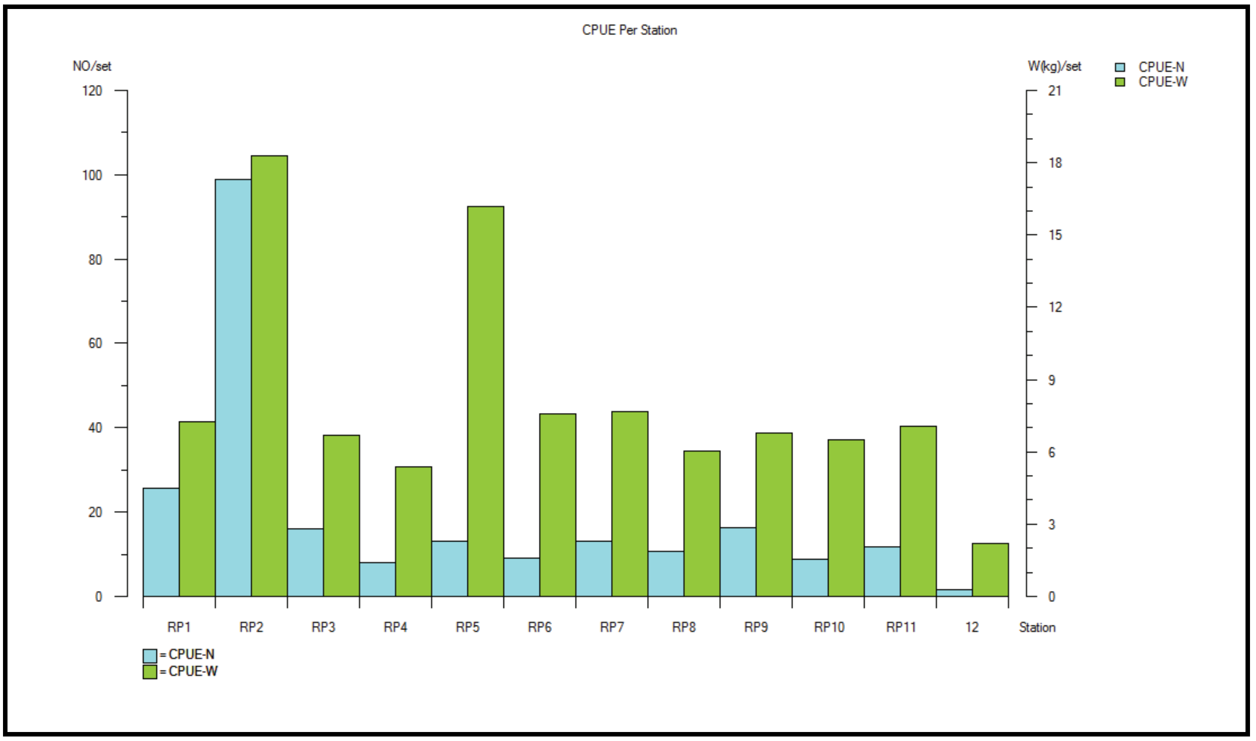

Figure 10.27: CPUE per site for Roodeplaat Dam.

Gill net CPUE per habitat for Roodeplaat Dam:

The areas with deep water and vegetation were the most productive. The other habitats were, however, also relatively productive (Table 10.14 and Figure 10.28). The deep pelagic zones were the least productive.

Table 10.14: CPUE per habitat for Roodeplaat Dam.

Setting Type/Code	Habitat Type	CPUE-N	CPUE-W(kg)
30	Deep littoral zone, vegetation	35.2	10.1
40	Deep littoral zone, rocky	12.9	7.2
10	Shallow littoral zone, vegetation, sand	10.3	8.4
50	Deep pelagic zone	9.7	5.8
Total		**17.7**	**7.9**

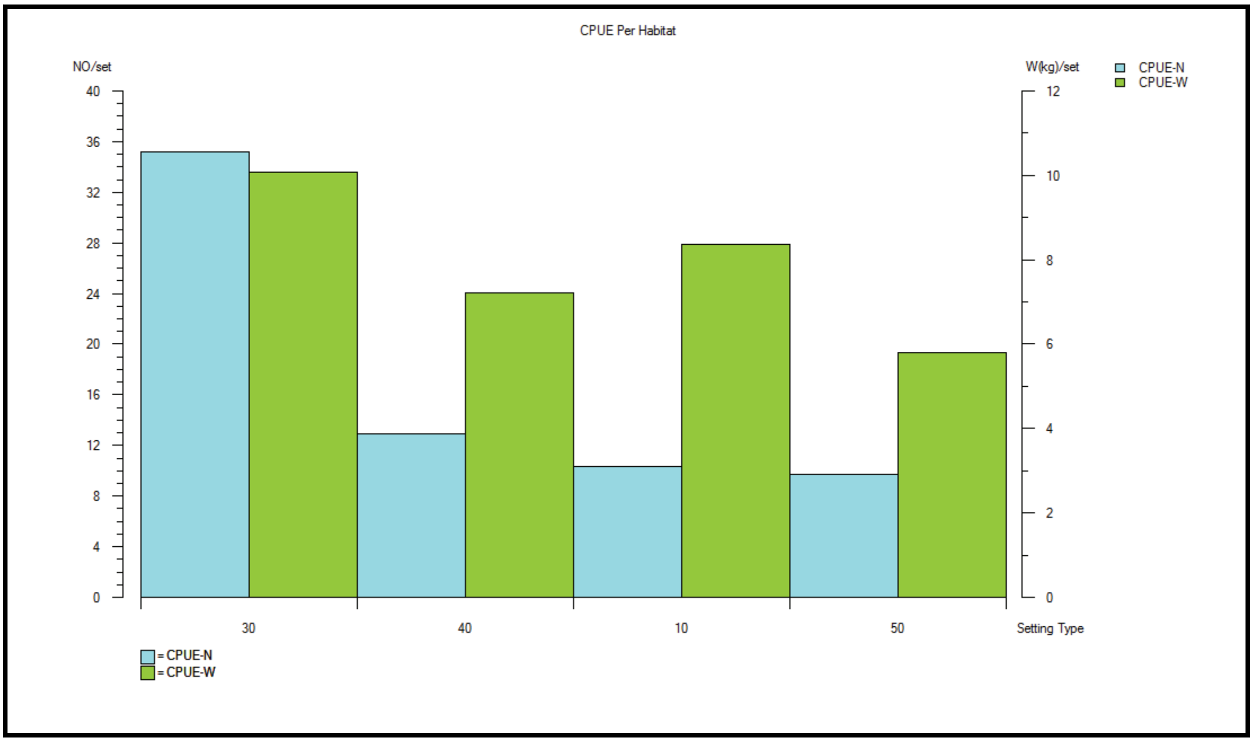

Figure 10.28: CPUE per habitat for Roodeplaat Dam.

10.6.5 Biomass and yield estimates for Roodeplaat Dam

The estimation of biomass and yield was done with a **swept area method** (Pauly, 1984):

Roodeplaat Dam has a surface area of 3.97km². With the combined catch data from 2007 and 2008 the biomass and yield can be estimated for Roodeplaat Dam with a Swept Area Model/Method.

The total fish biomass for Roodeplaat Dam was estimated at 313.63 tons, and the total sustainable yield at 104.54 tons per year. This translates to 26 t/km²/yr or 260 kg/ha/yr.

Catfish, an undesirable species, made the highest contribution of 63% to the CPUE-W. A potential catfish biomass (yield) of 16.59 t/km²/yr (or 65.86 tons per year for the whole dam) could, therefore, be removed sustainably. To achieve the desired effects of bio-manipulation or food web management up to 80% of the catfish biomass should, however, be removed, and this calculates to 39.8 t/km², or 158.1 tons for the whole dam during the start-up phase of such a programme.

Other undesirable species to be considered for removal are the canary kurper and carp. Canary kurper was sampled in relatively high numbers, which may have a significant impact on the dam ecology. A potential canary kurper biomass (yield) of 158 kg/km²/yr (or 627 kg per year for the whole dam) could be removed sustainably.

Carp was sampled in low numbers, but a potential carp biomass (yield) of 919.4 kg/km²/yr (or 3.65 tons per year for the whole dam) could, however, be removed sustainably.

Mozambique tilapia was sampled in high numbers, and a potential Mozambique tilapia biomass (yield) of 4.08 t/km²/yr (or 16.2 tons per year for the whole dam) could be removed sustainably.

Largescale yellowfish may also be considered for exploitation as it was sampled in high numbers, and a potential largescale yellowfish biomass (yield) of 4.2 t/km²/yr (or 16.7 tons per year for the whole dam) could be removed sustainably.

10.7 BON ACCORD DAM

10.7.1 Bon Accord Dam Sampling Sites

Figure 10.29: Bon Accord Dam sampling sites

Eight (8) stations were identified and surveyed during both surveys with the aim to obtain data representative of the fish population in the dam (Figure 10.29).

During both surveys the water level of the dam was at approximately 100% of its full supply level. Table 10.15 presents the station statistics, and sampling gears used in the different habitat types during the two surveys.

Table 10.15: Station statistics for Bon Accord Dam (2007-2008).

Date	St. code	Latitude	Longitude	Gear	Set type
25/11/2007	1	25°37'21.00"S	28°11'24.89"E	Gill net	Lake deep littoral zone, rocky
26/11/2007	2	25°37'24.32"S	28°11'8.13"E	Gill net	Lake deep littoral zone, rocky
27/11/2007	3	25°37'55.87"S	28°11'29.09"E	Gill net	Lake shallow littoral zone, veg
28/11/2007	4	25°37'49.89"S	28°11'29.97"E	Gill net	Lake deep pelagic
29/11/2007	5	25°37'55.79"S	28°11'17.42"E	Gill net	Lake shallow littoral zone, veg
30/11/2007	6	25°37'49.81"S	28°11'14.77"E	Gill net	Lake deep littoral zone, veg
25/02/2008	3	25°37'55.87"S	28°11'29.09"E	Gill net	Lake shallow littoral zone, veg
26/02/2008	4	25°37'49.89"S	28°11'29.97"E	Gill net	Lake deep littoral zone, veg
27/02/2008	7	25°37'21.81"S	28°11'5.95"E	Gill net	Lake deep littoral zone, rocky
28/02/2008	1	25°37'21.00"S	28°11'24.89"E	Gill net	Lake deep pelagic
29/02/2008	8	25°37'36.42"S	28°11'36.16"E	Gill net	Lake deep littoral zone, rocky

Shallow < 1.5m
Deep > 1.5m

10.8 BON ACCORD DAM SAMPLING STATISTICS

10.8.1 IRI for Bon Accord Dam

An **Index of Relative Importance** (IRI) as described by Kolding (1989) was used to indicate the contribution each fish species made to the catch compositions (see section 9.1).

IRI for the Gill Nets Used in Bon Accord Dam (2007-2008):
Nine (9) species were sampled in Bon Accord Dam (Table 10.16). *Clarias gariepinus* received the highest IRI score overall of 50.5%, followed by *Cyprinus carpio* with 24.4%, and *Oreochromis mossambicus* with 18.7%. *Clarias gariepinus* received the highest IRI score due to its contribution in weight (61.2%) to the total catch. *Cyprinus carpio* also made a considerable contribution in weight (30.6%), and *Oreochromis mossambicus* made a large contribution to the total numbers sampled (35.4%).

Clarias gariepinus and *Cyprinus carpio* are both undesirable fish species and they are definite candidates for a fisheries removal project. Bon Accord Dam has a turbidity and hyacinth problem, and the removal of catfish and carp may help to alleviate this problem and help to shift the fish population towards *Oreochromis mossambicus. Oreochromis mossambicus* was sampled in high numbers, but large specimens were not sampled often or in high numbers. This dam is also prone to large cyanobacterial and dinoflagellate blooms – which may be attenuated by fishery management.

A total of 650 fish were sampled during the study, of which *Oreochromis mossambicus* was the most abundant species (35.4%), followed by *Clarias gariepinus* (24%), and *Cyprinus carpio* (15.2%) (Table 10.16). *Labeo molybdinus* also made a considerable contribution to the total catch in terms of numbers (10.9%) and weight (5.5%).

A total weight of 405 kg was recorded during the study, of which *Clarias gariepinus* (61.2%), and *Cyprinus carpio* (30.6%) were the major contributors (Table 10.16).

Table 10.16: IRI for Bon Accord Dam, 2007-2008.

Species	NO	% NO	W(kg)	% W	FRQ	% FRQ	IRI	% IRI
Clarias gariepinus	156	24	247.85	61.2	48	48.5	4131	50.5
Cyprinus carpio	99	15.2	124.008	30.6	43	43.4	1991	24.4
Oreochromis mossambicus	230	35.4	10.029	2.5	40	40.4	1530	18.7
Labeo molybdinus	71	10.9	22.441	5.5	25	25.3	416	5.1
Barbus paludinosus	59	9.1	0.298	0.1	9	9.1	83	1
Barbus unitaeniatus	20	3.1	0.124	0	4	4	13	0.2
Labeobarbus marequensis	6	0.9	0.239	0.1	5	5.1	5	0.1
Pseudocrenilabrus philander	6	0.9	0.02	0	4	4	4	0
Barbus trimaculatus	3	0.5	0.02	0	1	1	0	0
Total	**650**	**100**	**405.029**	**100**	**-**	**-**	**8172**	**100**

%IRI = Percentage of Total of IRI values calculated for each species in area
%N = Contribution in Percentage to Total Numbers sampled
%W = Contribution in Percentage to Total Weight sampled
%F = Frequency of Occurrence

Figure 10.30 indicates the large contribution in weight that *Clarias gariepinus* (species 1 in graph), and *Cyprinus carpio* (species 2 in graph) made to the total catch, and the large contribution that *Oreochromis mossambicus* (species 3 in graph) made to the total numbers recorded.

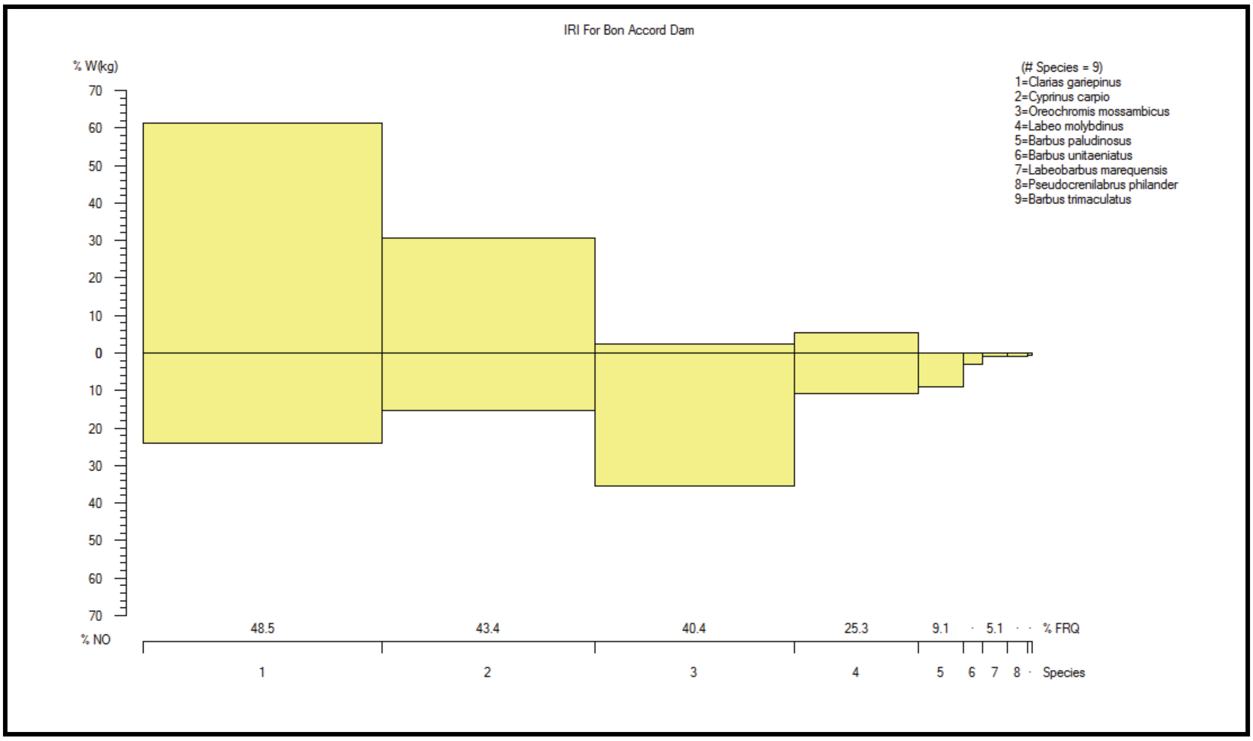

Figure 10.30: IRI for Bon Accord Dam, 2007-2008.

10.8.2 Catch Statistics for the Gill Nets in Bon Accord Dam, 2007-2008

Table 10.17 indicates the number of each species sampled in each mesh size (upper section of table). Six specimens of *Pseudocrenilabrus philander* were sampled in the 22 mm mesh sized gill net. *Clarias gariepinus* was sampled in the 45-150 mm meshes, and the most effective being the 73-150 mm meshes for this species. Nine mesh sized gill nets were used in Bon Accord Dam. A multifilament gill net range (22-150 mm) was used, with the exception of the 147 mm monofilament gill net, the catches of which are similar to the 150 mm mesh gill net.

Clarias gariepinus and *Cyprinus carpio* were sampled in a wide range of mesh sizes, the larger meshes being the most effective for *Clarias gariepinus* (73-150 mm) (Table 10.17). *Cyprinus carpio* was sampled in all the mesh sizes, but the 150 mm mesh seems to be the most effective for catching this species. Bon Accord Dam is a relatively shallow dam, and carp seemed to be abundant in shallow muddy to sandy areas (eastern end of dam).

The 28-45 mm meshes were effective in sampling *Oreochromis mossambicus,* (Table 10.17). *Barbus paludinosus* and *Barbus unitaeniatus* was sampled in the 22 mm mesh.

For fish removal the 73 mm to 150 mm gill nets seem to be the most effective for targeting *Clarias gariepinus* and *Cyprinus carpio* (Table 10.17). Large specimens of *Oreochromis mossambicus* were not sampled in high numbers, and the population may be stunted due to an over population of fish (especially carp and catfish).

The second section (lower section) of Table 10.17 indicates the total number of fish sampled in each of the gill nets, the contribution in percentage each mesh made to the total number recorded, the number of settings for each mesh, the average number of fish sampled in each mesh, and the mean lengths and weight sampled in each mesh.

Table 10.17: Catch Statistics for the Gill Nets in Bon Accord Dam, 2007-2008.

Species	Gill Net Mesh Size (MM)									Total
	22	28	35	45	57	73	93	118	150	
Pseudocrenilabrus philander	6									6
Clarias gariepinus				3	7	25	46	50	25	156
Cyprinus carpio	16	4	1	11	11	8	10	7	31	99
Labeobarbus marequensis	2	1	2	1						6
Barbus paludinosus	58				1					59
Barbus unitaeniatus	20									20
Oreochromis mossambicus	17	45	73	75	8	9	2		1	230
Barbus trimaculatus	3									3
Labeo molybdinus			2	20	14	26	9			71
Total	122	50	78	110	41	68	67	57	57	650
% NO	18.8	7.7	12	16.9	6.3	10.5	10.3	8.8	8.8	100
No of settings for each mesh	11	11	11	11	11	11	11	11	11	99
AV NO/Mesh	11.1	4.5	7.1	10	3.7	6.2	6.1	5.2	5.2	6.6
ML(mm)/Mesh	71.6	96.9	113.5	177.1	315.4	358.5	471.8	614.1	613.9	278.2
MW(g)/Mesh	5	55	22	173	755	653	992	1762	2432	623

MW = Mean Weight in grams
ML = Mean Length in mm

10.8.3 Species Statistics for the Gill Nets in Bon Accord Dam, 2007-2008

Table 10.18 provides the total number of each species sampled, their average weight and length, and the biomass (g) contribution each species made to the gill net series (or range, from 22 mm to 150 mm, all meshes included) per setting. The biomass contribution was calculated for each mesh with a length of 10m. *Clarias gariepinus* and *Cyprinus carpio* made the largest contribution to the biomass recorded. *Clarias gariepinus* was sampled with a mean weight of 2504 g (2.5 kg) and a mean length of 594 mm (59.4 cm). *Cyprinus carpio* was sampled with a mean weight of 1254 g (1.25 kg) and a mean length of 353 mm (35.3 cm).

Table 10.18: Species Statistics for the Gill Nets in Bon Accord Dam, 2007-2008.

Species	Total	% NO	MW(g)	ML(mm)	Biomass(g)/set
Pseudocrenilabrus philander	6	0.9	3.3	65	0
Clarias gariepinus	156	24	1588.8	594	2504
Cyprinus carpio	99	15.2	1252.6	353	1253
Labeobarbus marequensis	6	0.9	39.8	124	2
Barbus paludinosus	59	9.1	5.1	72	3
Barbus unitaeniatus	20	3.1	6.2	83	1
Oreochromis mossambicus	230	35.4	43.6	121	101
Barbus trimaculatus	3	0.5	6.7	79	0
Labeo molybdinus	71	10.9	316.1	255	227
Total	**650**	**100**	**623.1**	**278**	**4091**

MW = Mean Weight in grams
ML = Mean Length in mm

10.9 SPECIES SELECTION FOR A FISHERY IN BON ACCORD DAM

This section aims to identify and select the most appropriate species, which are likely to succeed in terms of a fisheries exploitation project. The species selected all have potential for exploitation in a fisheries project, however, some more than others.

Gill net selectivity was explored for the species. A multifilament gill net range of nine (9) meshes were used during the survey, which included a 22 mm, 28 mm, 35m, 45 mm, 57 mm, 73 mm, 93 mm, 118 mm and a 150 mm mesh. Each of these meshes has a length of ten metres.

The fish retained in a gear is usually only an unknown proportion of the various size classes available in the fished population. Selectivity is a quantitative expression of this proportion and represented as a probability of capture of a certain size of fish in a certain size of mesh. The mesh selectivity was indirectly estimated with methods as described by Kolding, 1998.

10.9.1 Species selection

Two species may be considered for selection as species with potential for utilisation in a fisheries project. The IRI was used as a guideline, as it highlights the important species in terms of their contribution to weight and numbers (section 10.8.1). The species, which may be considered, are *Clarias gariepinus,* and *Cyprinus carpio. Cyprinus carpio* is an undesirable alien (introduced) species with negative impacts on the environment and habitat of other species, as it is a habitat altering species (as described by Kleynhans, 1999 and 2001)

The identified species are well represented in the Bon Accord Dam. Undesirable species, such as catfish and carp could be exploited to lessen pressure on the zooplankton population, which in turn may positively affect water quality. Removal of carp and catfish may also alleviate pressure on other desirable fish species such as *Oreochromis mossambicus* and the smaller species (barbs).

Clarias gariepinus and *Cyprinus carpio* produce high numbers of offspring due to their high fecundity. High numbers of juvenile fish after the spawning season may have a significant impact on the zooplankton population due to predation, and the exploitation of the breeding stock of these species, may benefit the zooplankton population and other aquatic biota.

The feeding habits of carp and catfish may also negatively influence water quality, as they tend to re-suspend organic materials and small sediment particles back into the water column (through its constant churning of bottom sediments in search of food), which makes it available for use by other organisms, such as algae.

By exploiting carp and catfish the fish population may shift towards *Oreochromis mossambicus* which is a more desirable fish species in terms of ecology, fisheries, and recreational activities.

10.9.2 Length frequencies recorded for selected species

CPUE was calculated for each of the meshes at a standard effort. The standard effort for a mesh was 10m² net area set for 12 hours.

Cyprinus carpio:

Specimens were sampled in a length range of 5-56 cm in the gill nets (Figure 10.31). The highest number of fish was recorded in the 150 mm mesh. Large specimens (N=31) with a mean weight of 1.99 kg were sampled in the 150 mm mesh.

Several length cohorts were recorded for *Cyprinus carpio* indicating successful breeding during previous seasons (Figure 10.31).

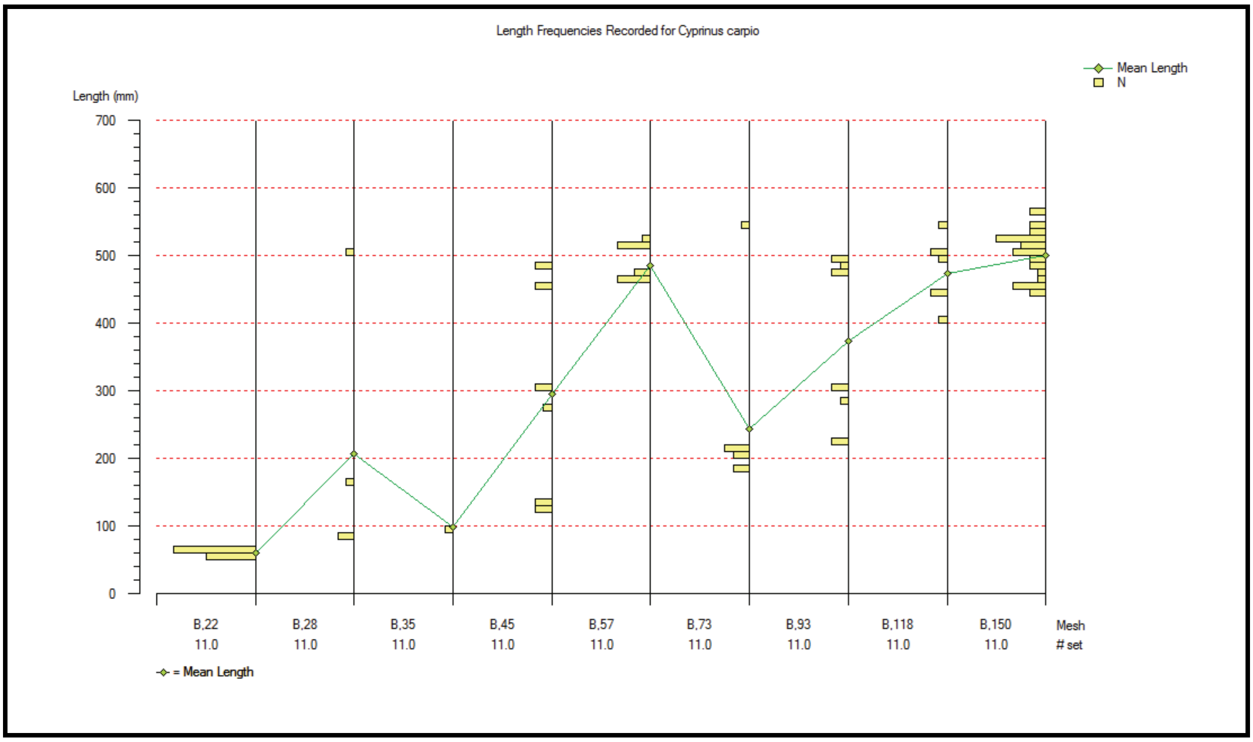

Figure 10.31: Length frequencies recorded for *Cyprinus carpio*.

Clarias gariepinus:
A total number of 156 specimens in a length rage of 26 cm-92 cm were sampled in the 45-150 mm mesh gill nets (Figure 10.32). The 73-150 mm meshes were the most effective in sampling large specimens.

There seems to be a healthy breeding population, as several length cohorts were recorded (Figure 10.32). Large specimens are present in the system. The 93 mm, 118 mm, and 150 mm mesh gill nets (as well as the 147 mm monofilament gill net, however, not used, but with the similar potential as the 150 mm mesh) all have potential as target gears as mature/large specimens were sampled in these nets.

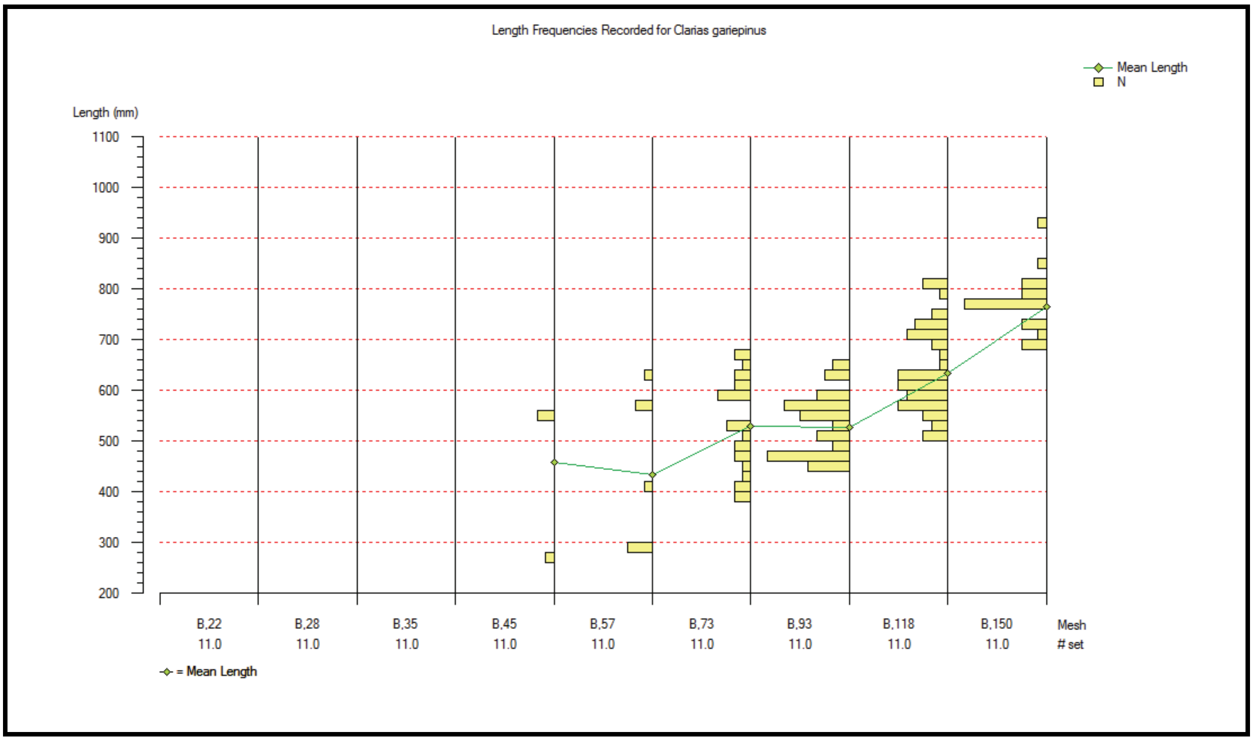

Figure 10.32: Length frequencies recorded for *Clarias gariepinus*.

10.9.3 Gill net selectivity for selected species

Clarias gariepinus:
The probability is high (85%-100%) for sampling large fish (45-74 cm) in the 93 mm to 150 mm meshes (Figure 10.33).

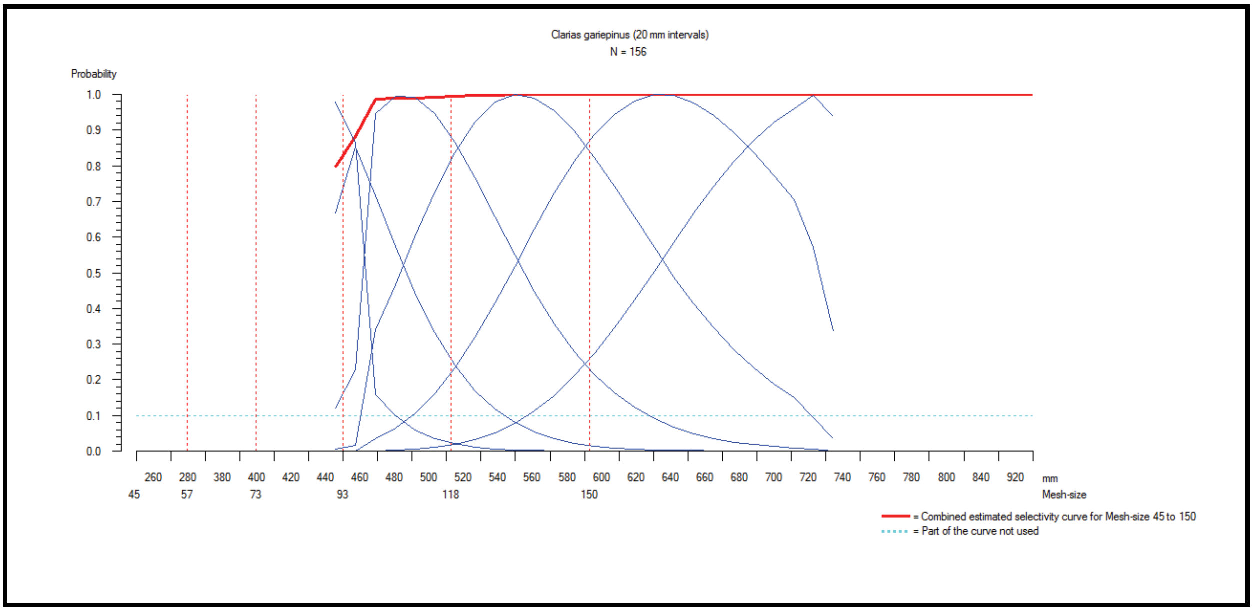

Figure 10.33: Estimated gill net selectivity for *Clarias gariepinus*.

Cyprinus carpio:
The probability of sampling fish in the 16-52 cm range with the 45 mm-150 mm meshes is high (80%-100%) (Figure 10.34).

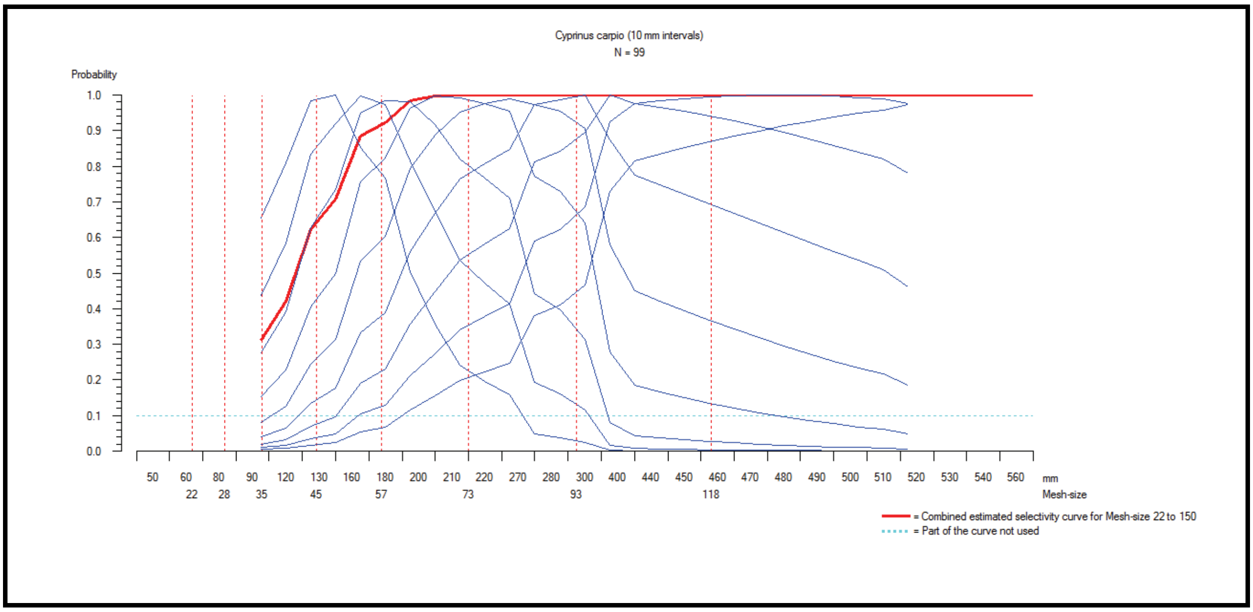

Figure 10.34: Estimated gill net selectivity for *Cyprinus carpio*.

10.9.4 CPUE for the Species Sampled in Bon Accord Dam, 2007-2008

The catch per unit effort (CPUE) was calculated for each of the multifilament gill net meshes at a standard effort. The standard effort for a mesh was $10m^2$ set for 12 hours.

Table 10.19 provides the average CPUE (in numbers – N, and weight – W), for all mesh sizes combined for Bon Accord Dam, 2007-2008. Nine gill net mesh sizes were used to limit selectivity (22, 28, 35, 45, 57, 73, 93, 118, and 150 mm).

The catfish made the largest contribution to the CPUE recorded in weight (2.5 kg per $10m^2$ per setting), followed by the carp (1.3 kg) (Table 10.19). The other species mostly made their contribution to the CPUE recorded in numbers.

The total CPUE in numbers and weight at the end of Table 10.19 is the average CPUE calculated for the nine meshes combined with a net area of $10m^2$. The CPUE's recorded indicate that 6.6 specimens with a weight of 4.1 kg were sampled in a net area of $10m^2$. Counted specimens (i.e. damaged or rotten) were not taken into account in the calculations.

Nine (9) species were caught in the gill nets, and *Clarias gariepinus* made the largest contribution in weight (61.2%) followed by *Cyprinus carpio* (30.6%). *Oreochromis mossambicus* made the largest contribution to the total numbers sampled (35.4%) (Table 10.19).

Table 10.19: CPUE for the species sampled in Bon Accord Dam.

Species	NO	% NO	W(kg)	% W	CPUE-N	CPUE-W(kg)
Clarias gariepinus	156	24	247.85	61.2	1.6	2.5
Cyprinus carpio	99	15.2	124.008	30.6	1	1.3
Labeo molybdinus	71	10.9	22.441	5.5	0.7	0.2
Oreochromis mossambicus	230	35.4	10.029	2.5	2.3	0.1
Barbus paludinosus	59	9.1	0.298	0.1	0.6	0
Labeobarbus marequensis	6	0.9	0.239	0.1	0.1	0
Barbus unitaeniatus	20	3.1	0.124	0	0.2	0
Pseudocrenilabrus philander	6	0.9	0.02	0	0.1	0
Barbus trimaculatus	3	0.5	0.02	0	0	0
Total	**650**	**100**	**405.029**	**100**	**6.6**	**4.1**

Graphical display of the CPUE for all species sampled in Bon Accord Dam:

Figure 10.35 gives a graphical representation of the gill net catches in numbers and weight (kg) for each species (CPUE per gill net panel (10m² for 12h), for all mesh sizes combined). *Clarias gariepinus* (catfish) made a large contribution in weight (1st khaki bar), and *Oreochromis mossambicus* (Mozambique tilapia) made a large contribution in numbers (4th green bar).

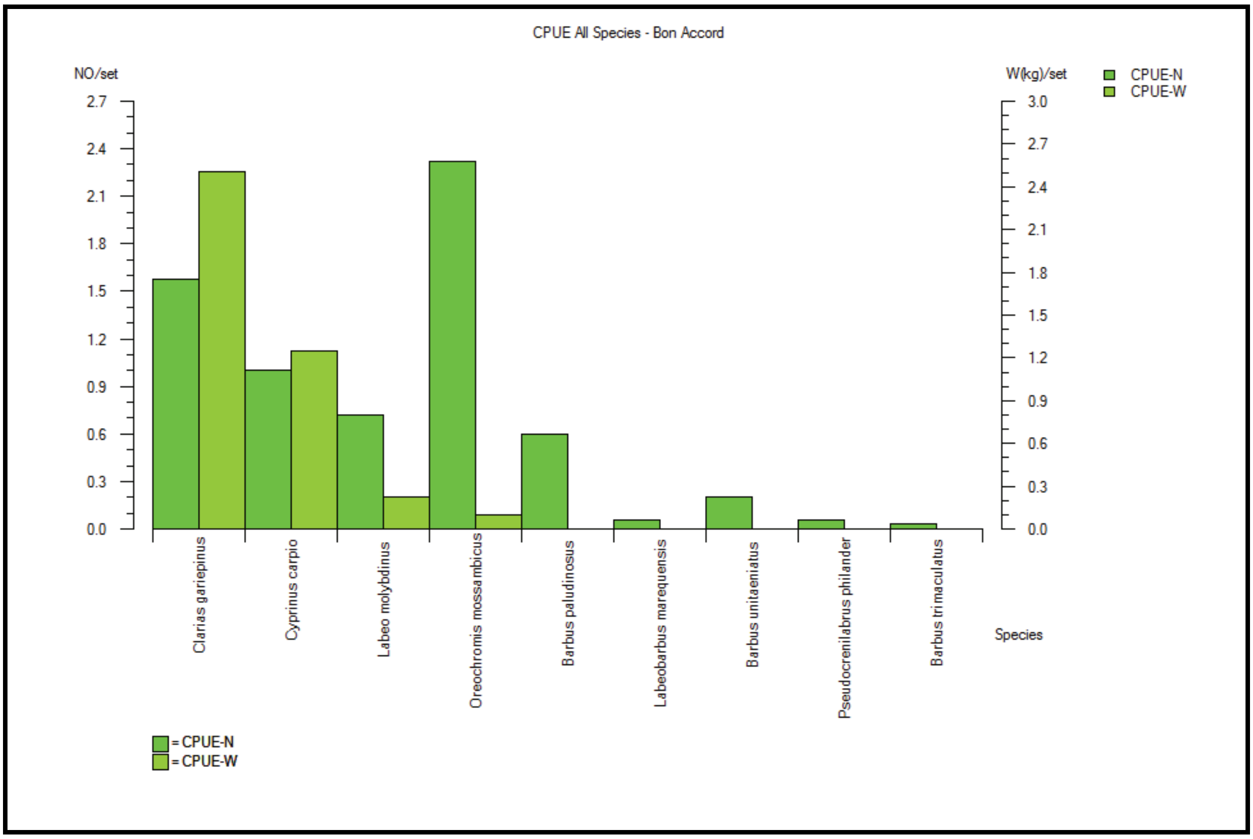

Figure 10.35: CPUE for the species sampled in Bon Accord Dam.

Gill net CPUE-W per station for Bon Accord Dam:
The highest CPUE-W (weight in kg) was recorded at station BA5, followed by station BA6, and BA2 (Table 10.20 and Figure 10.36). The highest CPUE-N (in numbers) was recorded at station BA8.

Table 10.20: CPUE per station for Bon Accord Dam

Station	CPUE-N	CPUE-W(kg)
BA1	4.2	3.0
BA2	7.4	5.4
BA3	7.7	4.6
BA4	5.3	4.2
BA5	7.2	7.0
BA6	4.7	5.6
BA7	6.0	1.7
BA8	12.6	1.7
Total	**6.6**	**4.1**

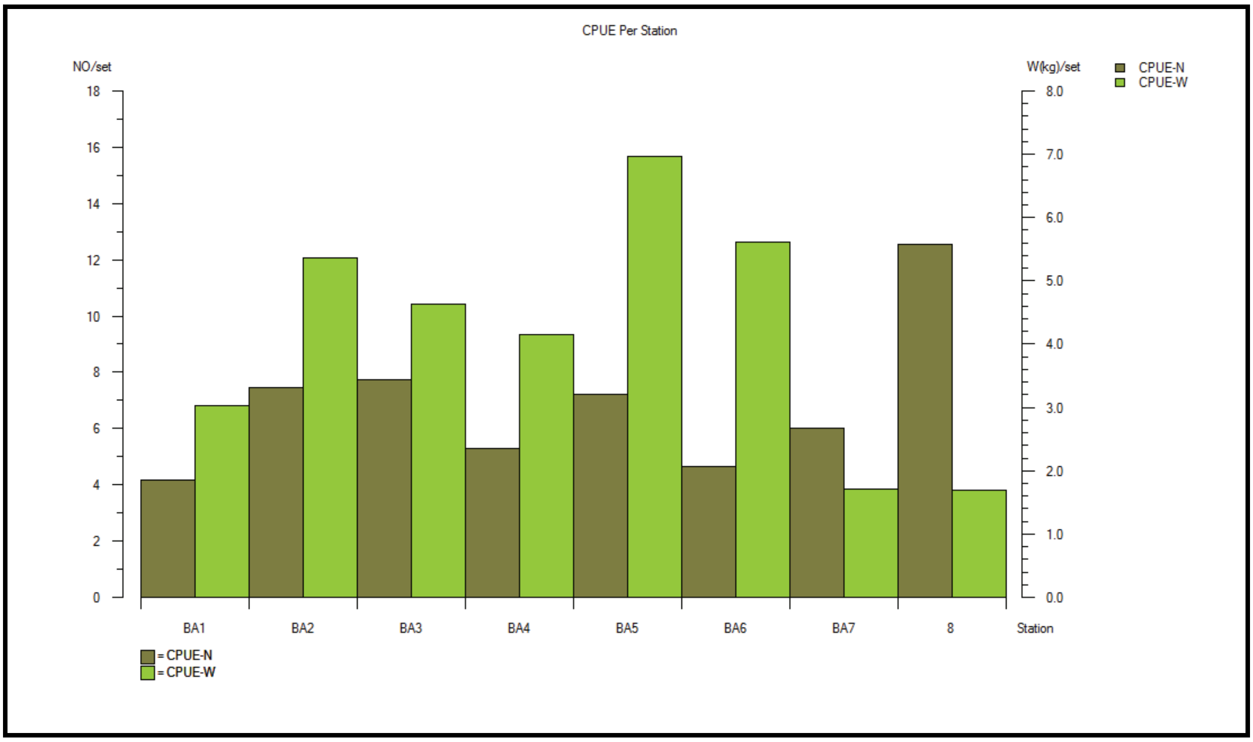

Figure 10.36: CPUE per site for Bon Accord Dam.

Gill net CPUE per habitat for Bon Accord Dam:
Shallow water habitats with vegetation were the most productive. The other habitats were, however, also relatively productive (Table 10.21 and Figure 10.37).

Table 10.21: CPUE per habitat for Bon Accord Dam.

Setting Type/Code	Habitat Type	CPUE-N	CPUE-W(kg)
10	Lake shallow littoral zone, veg	7.6	5.4
40	Lake deep littoral zone, rocky	7.8	3.3
50	Lake deep pelagic	4.1	4.3
30	Lake deep littoral zone, veg	5.9	2.7
Total		**6.6**	**4.1**

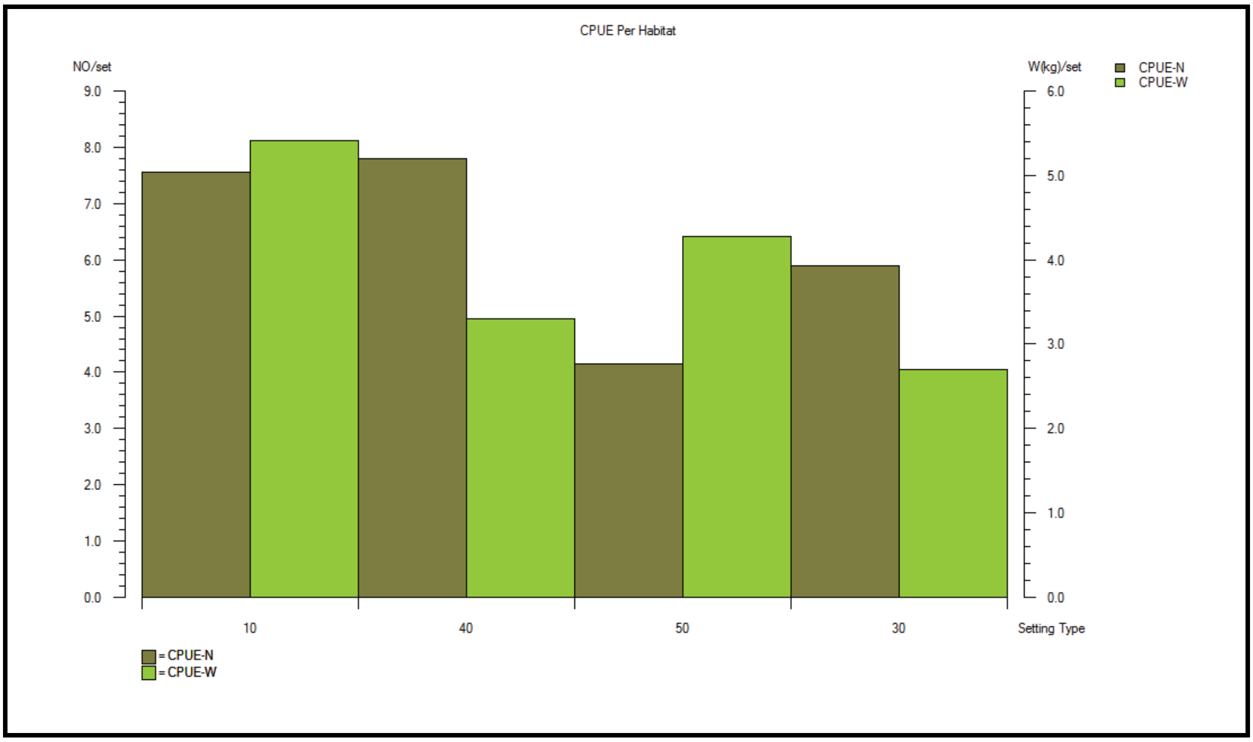

Figure 10.37: CPUE per habitat for Bon Accord Dam.

10.9.5 Biomass and yield estimates for Bon Accord Dam

The estimation of biomass and yield was done with a **swept area method** (Pauly, 1984):

Bon Accord Dam has a surface area of 1.7km². With the combined catch data from 2007 and 2008 the biomass and yield can be estimated for Bon Accord Dam with a Swept Area Model/Method.

The total fish biomass for Bon Accord Dam was estimated at 69.7 tons, and the total sustainable yield at 23.23 tons per year. This translates to 13.664 t/km²/yr or 136.64 kg/ha/yr.

Catfish, an undesirable species, made the highest contribution of 61.2% to the CPUE-W. A potential catfish biomass (yield) of 8.365 t/km²/yr (or 14.22 tons per year for the whole dam) could, therefore, be removed sustainably.

To achieve the desired effects of bio-manipulation or food web management up to 80% of the catfish biomass should, however, be removed, and this calculates to 20 t/km², or 34.125 tons for the whole dam during the start-up phase of such a programme.

Other undesirable species to be considered for removal is the carp. A potential carp biomass (yield) of 4.17 t/km²/yr (or 7.1 tons per year for the whole dam) could be removed sustainably.

10.10 KOSTER RIVER DAM

10.10.1 Koster River Dam Sampling Sites

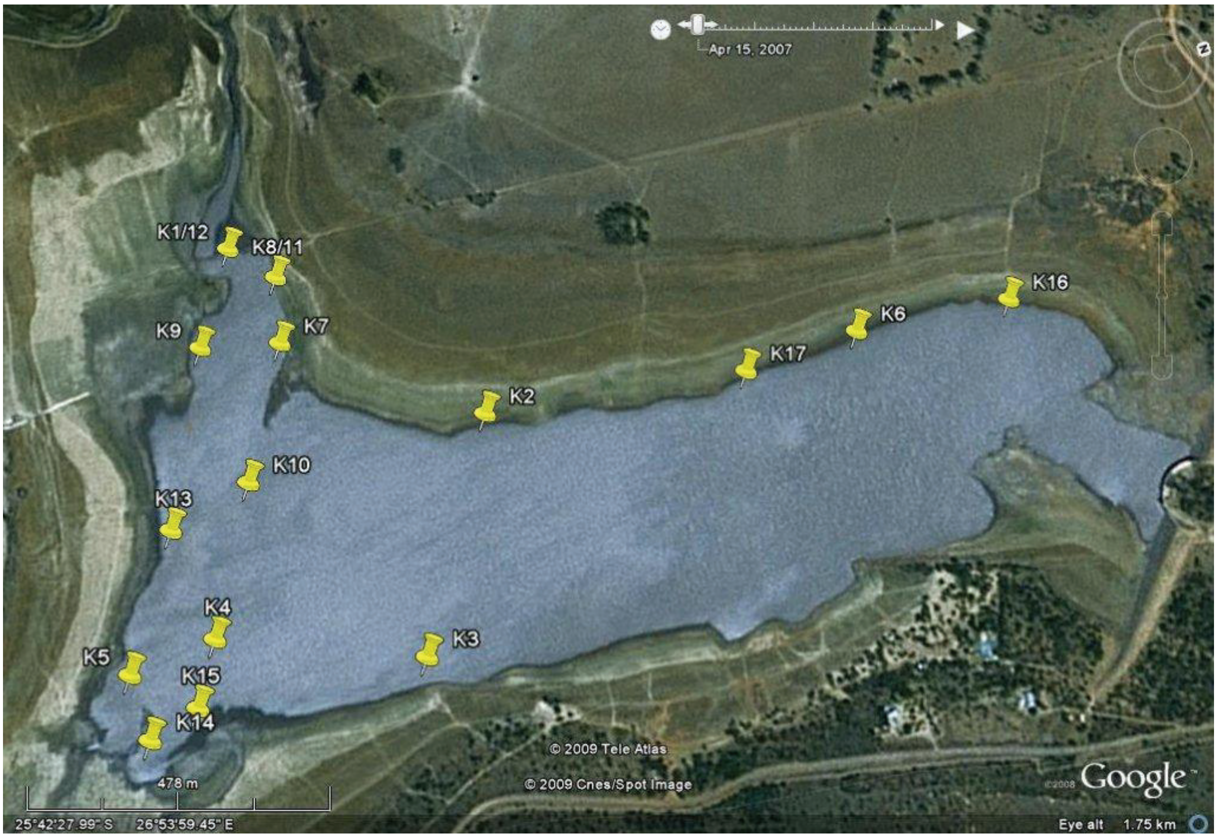

Figure 10.38: Koster River Dam sampling sites

Seventeen (17) stations were identified and surveyed during both surveys with the aim to obtain data representative of the fish population in the dam (Figure 10.38).

During both surveys the water level of the dam was at approximately 100% of its full supply level.

Table 10.22 presents the station statistics, and sampling gears used in the different habitat types during the two surveys.

Table 10.22: Station statistics for Koster River Dam (2008-2009).

Date	St. code	Latitude	Longitude	Gear	Set type
2008/08/26	1/12	25°42'45.73"S	26°53'42.24"E	Gill nets	Lake deep littoral zone, veg
2008/08/27	2	25°42'34.90"S	26°53'57.59"E	Gill nets	Lake deep littoral zone, veg
2008/08/28	3	25°42'41.80"S	26°54'10.30"E	Gill nets	Lake deep littoral zone, rocky
2008/08/28	4	25°42'52.10"S	26°54'5.26"E	147 mm	Lake deep pelagic
2008/08/29	5	25°42'56.80"S	26°54'5.63"E	Gill nets	Lake shallow littoral zone, veg
2008/08/29	6	25°42'13.91"S	26°54'0.14"E	Gill nets	Lake shallow littoral zone, veg
2008/08/30	7	25°42'44.47"S	26°53'49.20"E	147 mm	Lake deep littoral zone, veg
2008/08/30	8/11	25°42'43.64"S	26°53'45.00"E	Gill nets	Lake shallow littoral zone, veg
2008/08/31	9	25°42'48.71"S	26°53'47.90"E	Gill nets	Lake shallow littoral zone, veg
2008/08/31	10	25°42'48.20"S	26°53'56.96"E	147 mm	Lake deep pelagic
2009/01/19	7	25°42'44.47"S	26°53'49.20"E	Gill nets	Lake shallow littoral zone, veg
2009/01/19	2	25°42'34.90"S	26°53'57.59"E	Gill nets	Lake shallow littoral zone, veg
2009/01/19	9	25°42'48.71"S	26°53'47.90"E	147 mm	Lake shallow littoral zone, veg
2009/01/19	13	25°42'52.83"S	26°53'58.22"E	SEINE	Lake shallow littoral zone, veg
2009/01/20	5	25°42'56.80"S	26°54'5.63"E	147 mm	Lake deep littoral zone, veg
2009/01/20	14	25°42'56.63"S	26°54'9.59"E	Gill nets	Lake deep littoral zone, veg
2009/01/20	15	25°42'53.86"S	26°54'8.73"E	Gill nets	Lake deep littoral zone, veg
2009/01/21	16	25°42'5.16"S	26°54'1.33"E	147 mm	Lake deep pelagic
2009/01/21	6	25°42'13.91"S	26°54'0.14"E	Gill nets	Lake shallow littoral zone, veg
2009/01/21	17	25°42'20.52"S	26°54'0.28"E	Gill nets	Lake deep littoral zone, veg
2009/01/22	8/11	25°42'43.64"S	26°53'45.00"E	Gill nets	Lake deep littoral zone, veg
2009/01/22	1/12	25°42'45.73"S	26°53'42.24"E	Gill nets	Lake deep littoral zone, veg

Shallow < 1.5m
Deep > 1.5m

10.11 KOSTER RIVER DAM SAMPLING STATISTICS

10.11.1 IRI for Koster River Dam

An **Index of Relative Importance** (IRI) as described by Kolding (1989) was used to indicate the contribution each fish species made to the catch compositions.

The *percentage commonness* or frequency of occurrence, $\%F$ or %FREQ represents the *percentage probability* of a species occurring in the catch composition of an area if similar sampling methods were used. The $\%F$ for all the species combined does not add up to 100%.

The species were sorted descending in the tables from the highest to the lowest IRI value. The IRI value is a numerical value assigned to each specific species and is given in percentage of the total of the IRI values calculated for the relevant area. The IRI depicts the relative importance of a species in the fish population in terms of its abundance and weight contribution in the relevant catch composition.

A low IRI score does not necessarily mean that a species is less important. The IRI gives an indication of the fish population composition, and the weight each species carries in the population, in terms of its contribution to the total catch.

IRI for the Gill Nets Used in Koster River Dam (2008-2009):
Fish densities were low for Koster River Dam and a total of 428 specimens were caught during the two surveys. Seven species were recorded for the dam (Table 10.23). The catfish received the highest IRI score (69.5%), followed by the smallmouth yellowfish (18.4%). These two species were the most abundant. The catfish made the highest contribution in both numbers (39.5%) and weight (65.5%) to the total catch recorded. The smallmouth yellowfish made a high contribution in numbers (31.5%), and a considerable contribution in weight (10.4%).

Oreochromis mossambicus (Mozambique tilapia) was sampled in low numbers (only one) during the first survey, but was sampled in much higher numbers during the second survey (58) (Table 10.23). This indicates the importance of seasonal differences in distribution and densities.

The Mozambique tilapia made a contribution of 13.6% to the total numbers and 7% to the total weight recorded (Table 10.23). Large specimens were sampled regularly.

The carp made a contribution of 10% to the total numbers and 16% to the total weight recorded (Table 10.23).

Micropterus salmoides (bass), *Barbus paludinosus* (straightfin barb) and *Pseudocrenilabrus philander* (southern mouthbrooder) were sampled in low numbers (Table 10.23). The barb and mouthbrooder are small species, and their numbers may be low due to predation by bass and catfish.

The IRI gives an indication that catfish could be considered for removal in a biomanipulation and food web management programme (Table 10.23). Carp should also be considered.

Koster River Dam is a small mesotrophic dam with turbid water ("coffee" brown). It has abundant aquatic vegetation, ranging from marginal reeds to emergent and submerged aquatic macrophytes. Excessive algae growth does not seem to be a problem, probably due to the turbidity of the water resulting in reduced light penetration.

Table 10.23: IRI for Koster River Dam, 2008-2009.

Species	NO	% NO	W(kg)	% W	FRQ	% FRQ	IRI	% IRI
Clarias gariepinus	169	39.5	225.772	65.5	62	44	4618	69.5
Labeobarbus aeneus	135	31.5	35.752	10.4	41	29.1	1219	18.4
Oreochromis mossambicus	58	13.6	24.079	7	29	20.6	422	6.4
Cyprinus carpio	43	10	55.162	16	19	13.5	351	5.3
Barbus paludinosus	19	4.4	0.085	0	9	6.4	28	0.4
Micropterus salmoides	2	0.5	3.594	1	2	1.4	2	0
Pseudocrenilabrus philander	2	0.5	0.008	0	2	1.4	1	0
Total	**428**	**100**	**344.452**	**100**	**-**	**-**	**6642**	**100**

%IRI = Percentage of Total of IRI values calculated for each species in area
%N = Contribution in Percentage to Total Numbers sampled
%W = Contribution in Percentage to Total Weight sampled
%F = Frequency of Occurrence

The catfish made the largest contribution to the numbers of fish sampled, and this species may tend to dominate systems if conditions are favourable (Table 10.23 and Figure 10.39). The presence of large catfish, sampled in high numbers, may have an effect on the species densities and especially the smaller species such as the barbs and smaller kurper species.

Figure 10.39 provides a graphical display of the contribution each of the fish species sampled made to the total catch. The contribution in weight is indicated above the x-axis, and the contribution in numbers below the x-axis. %F (frequency of occurrence) at the bottom of the graph indicates the percentage probability of obtaining the same catch if similar sampling methods were used.

Figure 10.39 shows the contribution each of the species made to the total catch in terms of numbers and weight. Large carp, catfish and Mozambique tilapia were sampled.

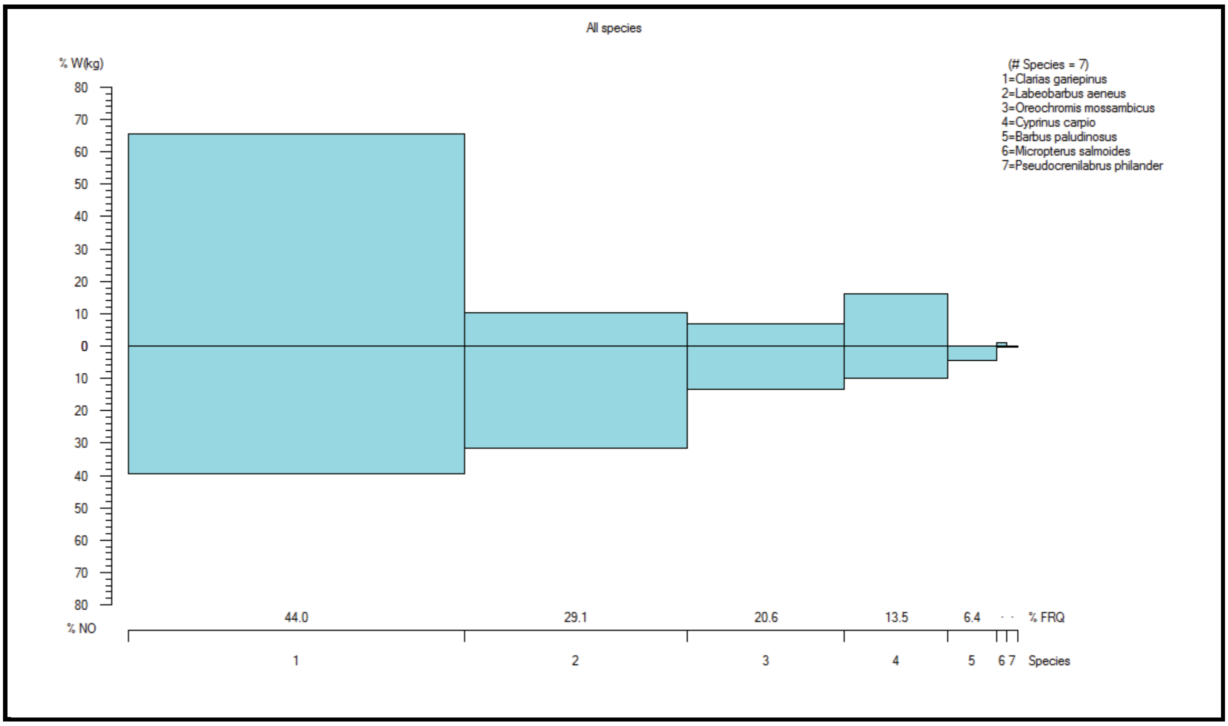

Figure 10.39: IRI for Koster River Dam, 2008-2009.

10.11.2 Catch Statistics for the Gill Nets in Koster River Dam, 2008-2009

Table 10.24 indicates the number of each species sampled in each mesh size (upper section of table). *Pseudocrenilabrus philander* was sampled in low numbers in the 22 mm mesh sized gill net, and *Chetia flaviventris* was not sampled.

Clarias gariepinus and *Cyprinus carpio* was sampled in a wide range of mesh sizes, the larger meshes being the most effective for *Clarias gariepinus* (57-150 mm) (Table 10.24). The 147 mm mesh Monofilament net seems to be the most effective for catching *Cyprinus carpio*.

Oreochromis mossambicus was sampled in all the nets, with the 73 mm and 93 mm meshes being the most effective (Table 10.24). *Labeobarbus aeneus* was sampled effectively in the 45-73 mm meshes. *Labeobarbus aeneus* was probably trans-located to this dam, as it was not expected to occur due to its natural distribution.

For fish removal the 118, 147, and 150 mm meshes seems to be the most effective for targeting *Clarias gariepinus* and *Cyprinus carpio* with the least effect on other species (Table 10.24). Long lines may also be considered for targeting catfish.

The second section (lower section) of Table 10.24 indicates the total number of fish sampled in each of the gill nets, the contribution in percentage each mesh made to the total number recorded, the number of settings for each mesh, the average number of fish sampled in each mesh, and the mean lengths and weight sampled in each mesh.

Table 10.24: Catch Statistics for the Gill Nets in Koster River Dam, 2008-2009.

Species	Gill Net Mesh Size (MM)										Total
	22	28	35	45	57	73	93	118	147	150	
Pseudocrenilabrus philander	2										2
Oreochromis mossambicus	1	6	4	1	8	12	14	4	6	2	58
Clarias gariepinus				5	12	24	65	45	9	9	169
Cyprinus carpio			1	3	2	3	1	4	25	4	43
Labeobarbus aeneus	2	4	2	34	39	51	3				135
Barbus paludinosus	13	3	3								19
Micropterus salmoides							1			1	2
Total	18	13	10	43	61	90	84	53	40	16	428
% NO	4.2	3	2.3	10	14.3	21	19.6	12.4	9.3	3.7	100
No of settings for each mesh	15	15	15	15	15	15	15	15	6	15	141
AV NO/Mesh	1.2	0.9	0.7	2.9	4.1	6	5.6	3.5	6.7	1.1	3
ML(mm)/Mesh	190	134	137	264	284	352	437	540	486	579	376
MW(g)/Mesh	5	78	114	308	333	625	759	1253	1859	2990	805

MW = Mean Weight in grams
ML = Mean Length in mm

10.11.3 Species Statistics for the Gill Nets in Koster River Dam, 2008-2009

Table 10.25 provides the total number of each species sampled, their average weight and length, and the biomass (g) contribution each species made to the gill net series (or range, from 22 mm to 150 mm, all meshes included) per setting. The biomass contribution was calculated for each mesh with a length of 10m. *Clarias gariepinus* and *Cyprinus carpio* made the largest contribution to the biomass recorded, followed by *Labeobarbus aeneus*. *Clarias gariepinus* was sampled with a mean weight of 1601 g (1.6 kg) and a mean length of 539 mm (53.9 cm).

Table 10.25: Species Statistics for the Gill Nets in Koster River Dam 2008-2009.

Species	Total	% NO	MW(g)	ML(mm)	Biomass(g)/set
Pseudocrenilabrus philander	2	0.5	4	68	0
Oreochromis mossambicus	58	13.6	415.2	234	171
Clarias gariepinus	169	39.5	1335.9	539	1601
Cyprinus carpio	43	10	1282.8	380	391
Labeobarbus aeneus	135	31.5	264.8	263	254
Barbus paludinosus	19	4.4	4.5	180	1
Micropterus salmoides	2	0.5	1797	438	25
Total	**428**	**100**	**804.8**	**376**	**2443**

MW = Mean Weight in grams
ML = Mean Length in mm

10.12 SPECIES SELECTION FOR A FISHERY IN KOSTER RIVER DAM

This section aims to identify and select the most appropriate species, which are likely to succeed in terms of a fisheries exploitation project. The species selected all have potential for exploitation in a fisheries project, however, some more than others.

Gill net selectivity was explored for the species. A multifilament gill net range of nine (9) meshes were used during the survey, which included a 22 mm, 28 mm, 35m, 45 mm, 57 mm, 73 mm, 93 mm, 118 mm and a 150 mm mesh. Each of these meshes has a length of ten metres. A 147 mm mesh monofilament gut gill net was also used, and it has a length of 80 metres. The length of the 147 mm mesh were standardised to 10m during calculations.

The fish retained in a gear is usually only an unknown proportion of the various size classes available in the fished population. Selectivity is a quantitative expression of this proportion and represented as a probability of capture of a certain size of fish in a certain size of mesh. The mesh selectivity was indirectly estimated with methods as described by Kolding, 1998.

10.12.1 Species selection

Four species may be considered for selection as species with potential for utilisation in a fisheries project. The IRI was used as a guideline, as it highlights the important species in terms of their contribution to weight and numbers (section 10.11.1). The species, which may be considered, are *Clarias gariepinus, Labeobarbus aeneus, Oreochromis mossambicus,* and *Cyprinus carpio.*

Cyprinus carpio is an undesirable alien (introduced) species with negative impacts on the environment and habitat of other species, as it is a habitat altering species (as described by Kleynhans, 1999 and 2001). Carp made the second highest contribution to the total weight recorded.

Catfish made the highest contribution to the total numbers and weight recorded. Carp and catfish are both undesirable (coarse fish) species, and should both be considered for removal, especially with bio-remediation in mind.

Clarias gariepinus, Labeobarbus aeneus, Oreochromis mossambicus, and *Cyprinus carpio* are all well represented in Koster River Dam. *Labeobarbus aeneus* and *Oreochromis mossambicus* could be considered for utilisation in a sustainable fisheries project (i.e. where only the annual sustainable yield is removed).

Clarias gariepinus and *Cyprinus carpio* produce high numbers of offspring due to their high fecundity. High numbers of juvenile fish after the spawning season may have a significant impact on the zooplankton population due to predation, and the exploitation of the breeding stock of these species, may benefit the zooplankton population.

The feeding habits of carp and catfish may also negatively influence water quality, as it tends to re-suspend organic materials and small sediment particles back into the water column (through its constant churning of bottom sediments in search of food), which makes it available for use by other organisms, such as algae.

10.12.2 Length frequencies recorded for selected species

CPUE was calculated for each of the meshes at a standard effort. The standard effort for a mesh was 10m² net area set for 12 hours.

Oreochromis mossambicus:

Figure 10.40 graphically displays the length frequencies recorded for *Oreochromis mossambicus* in the different gill nets, as well as the mean length for each mesh size.

Oreochromis mossambicus was sampled within its length range with the 22 mm to 150 mm mesh sized gill nets (Figure 10.40). The highest number (14) of fish was recorded in the 93 mm mesh gill net. This species was sampled in a length range of 8 cm to 42 cm.

The length frequencies recorded (Figure 10.40) gives an indication of different length cohorts, in the 8-11 cm, 14-16 cm, 18-25 cm and 36-42 cm ranges, representative of age classes, and successful breeding and recruitment during previous seasons. Medium to large specimens of this species were also sampled.

This species may be considered for sustainable utilisation only.

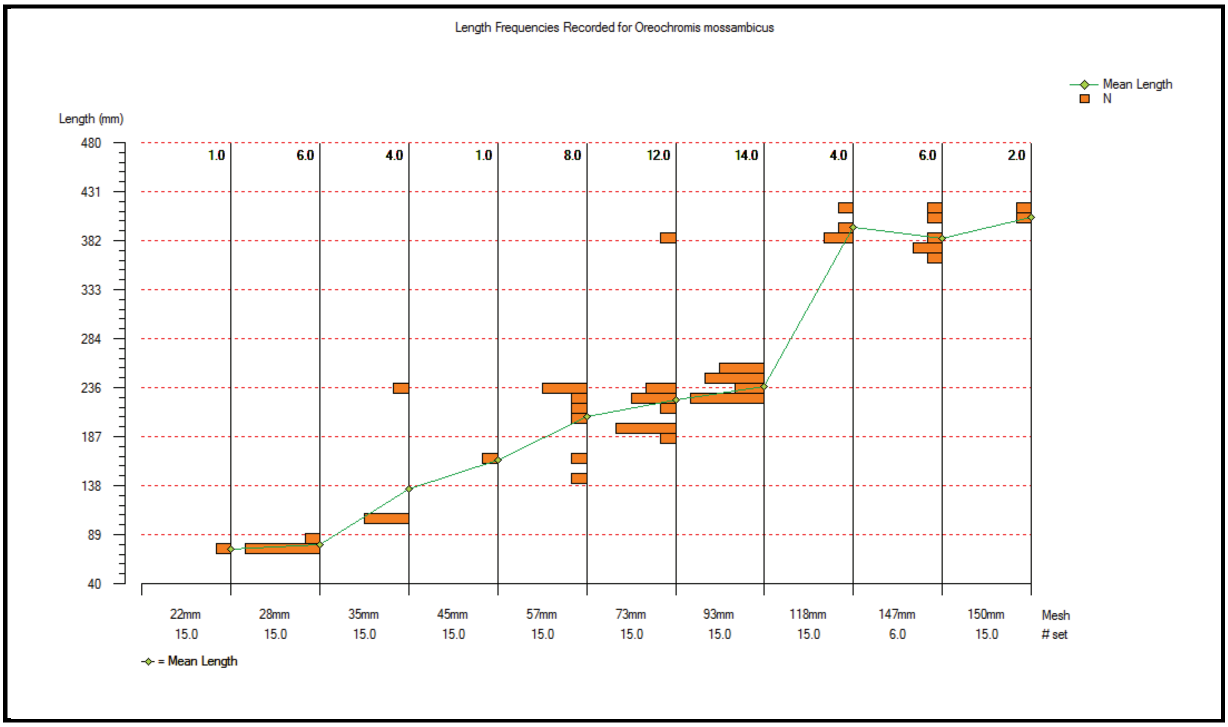

Figure 10.40: Length frequencies recorded for *Oreochromis mossambicus*.

Labeobarbus aeneus:
Figure 10.41 gives an indication of the length frequencies sampled for *Labeobarbus aeneus* in the different meshes. Relatively large specimens were sampled in the 32-38 cm length range. Length cohorts can be seen, which indicates to successful breeding during previous seasons. *Labeobarbus aeneus* is a medium to large species and it was not sampled in the larger mesh gill nets, as can be expected; small specimens were sampled in low numbers.

This species was most effectively sampled with the 45 mm to 73 mm mesh sized gill nets (Figure 10.41), and it was sampled in a length range of 8-38 cm.

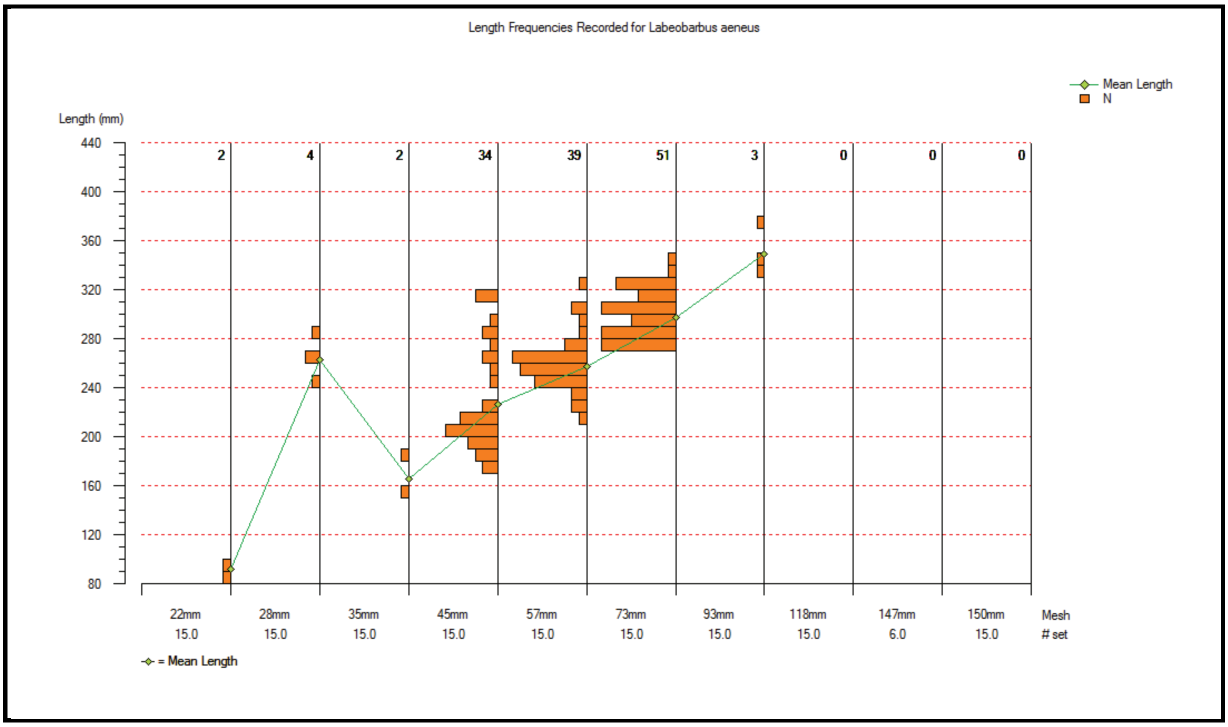

Figure 10.41: Length frequencies recorded for *Labeobarbus aeneus.*

Cyprinus carpio:
Specimens were sampled in a length range of 13-53 cm in the gill nets (Figure 10.42). The highest number of fish was recorded in the 147 mm mesh (monofilament net). Large specimens were sampled in higher numbers.

Cyprinus carpio was sampled in relatively low numbers, but several length cohorts were recorded, indicating successful breeding during previous seasons (Figure 10.42).

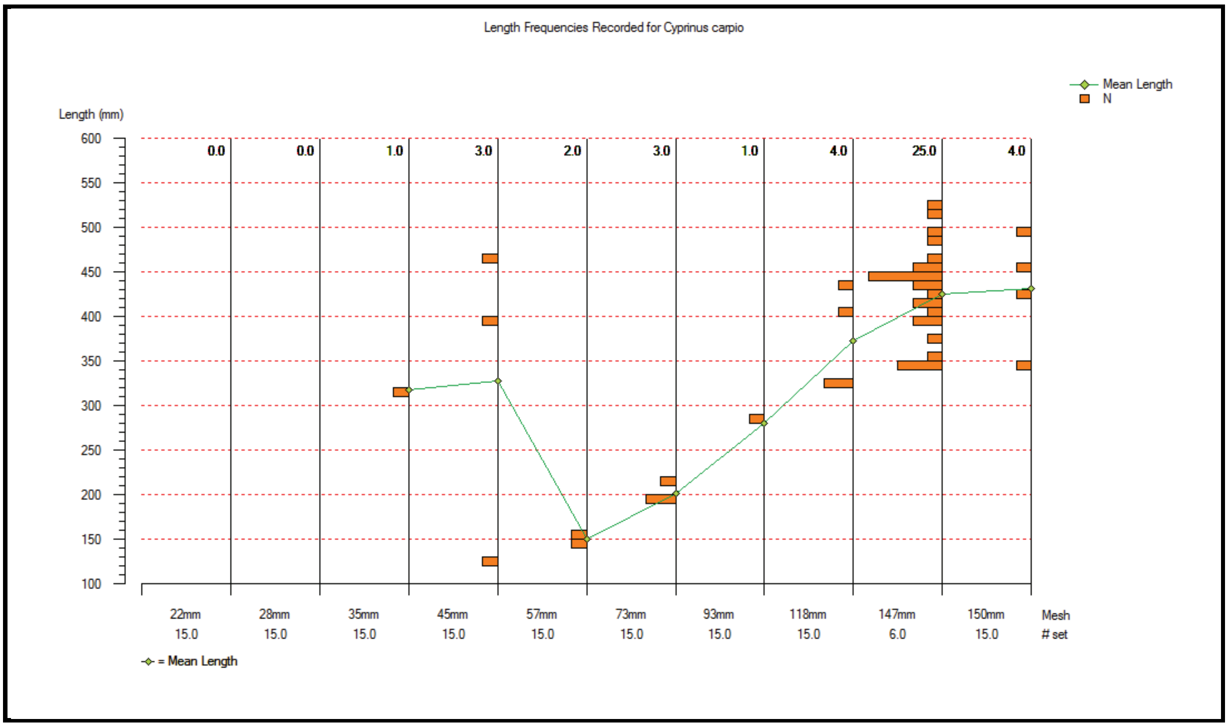

Figure 10.42: Length frequencies recorded for *Cyprinus carpio*.

Clarias gariepinus:

Specimens were sampled in a length range of 25 cm-1.05m in the 45-150 mm mesh gill nets (Figure 10.43). The 93-118 meshes were the most effective in sampling catfish. There seems to be a healthy breeding population, as several length cohorts were recorded (Figure 10.43). Large specimens were sampled.

The 118 mm to 150 mm mesh gill nets have potential as target gear for catfish and carp as mature specimens were sampled in these nets, with the least impact on other species.

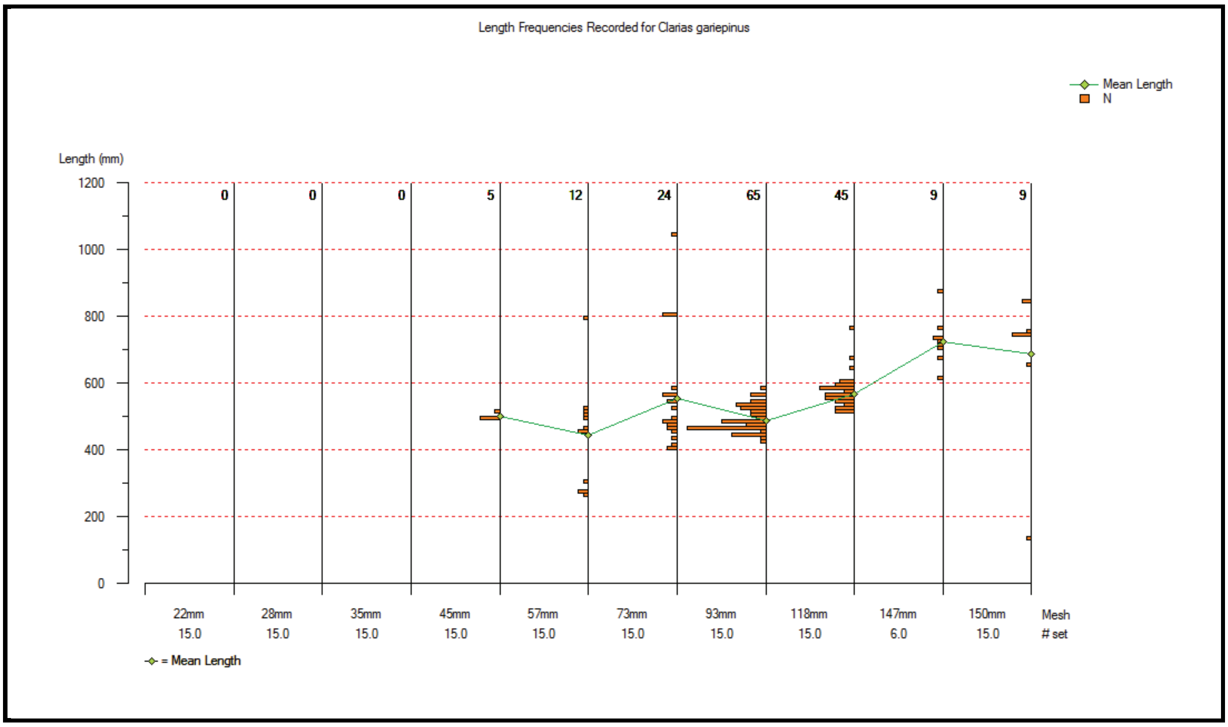

Figure 10.43: Length frequencies recorded for *Clarias gariepinus*.

10.12.3 Gill net selectivity for selected species

Oreochromis mossambicus:
The probability ranges between 70% and 100% that this species will be sampled with the 22-150 mm gill net meshes (Figure 10.44).

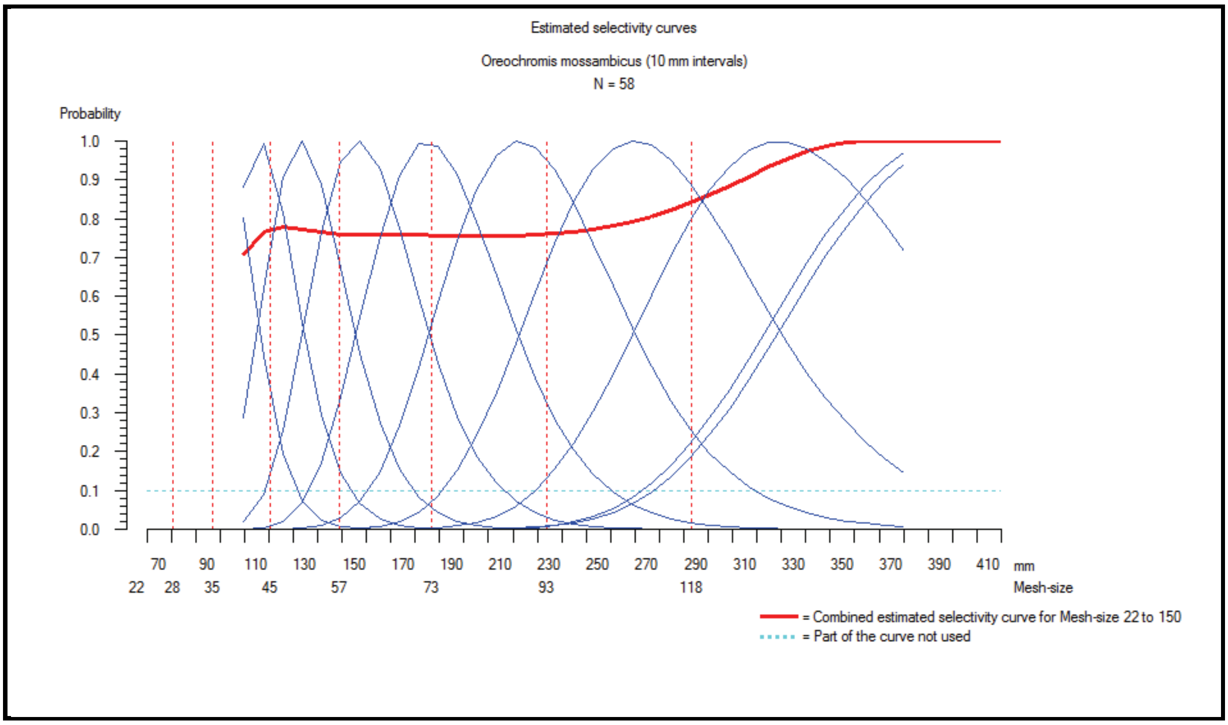

Figure 10.44: Estimated gill net selectivity for *Oreochromis mossambicus*.

Clarias gariepinus:
The probability is high (100%) for sampling large fish (60-100 cm) in the 118 mm to 150 mm meshes (Figure 10.45).

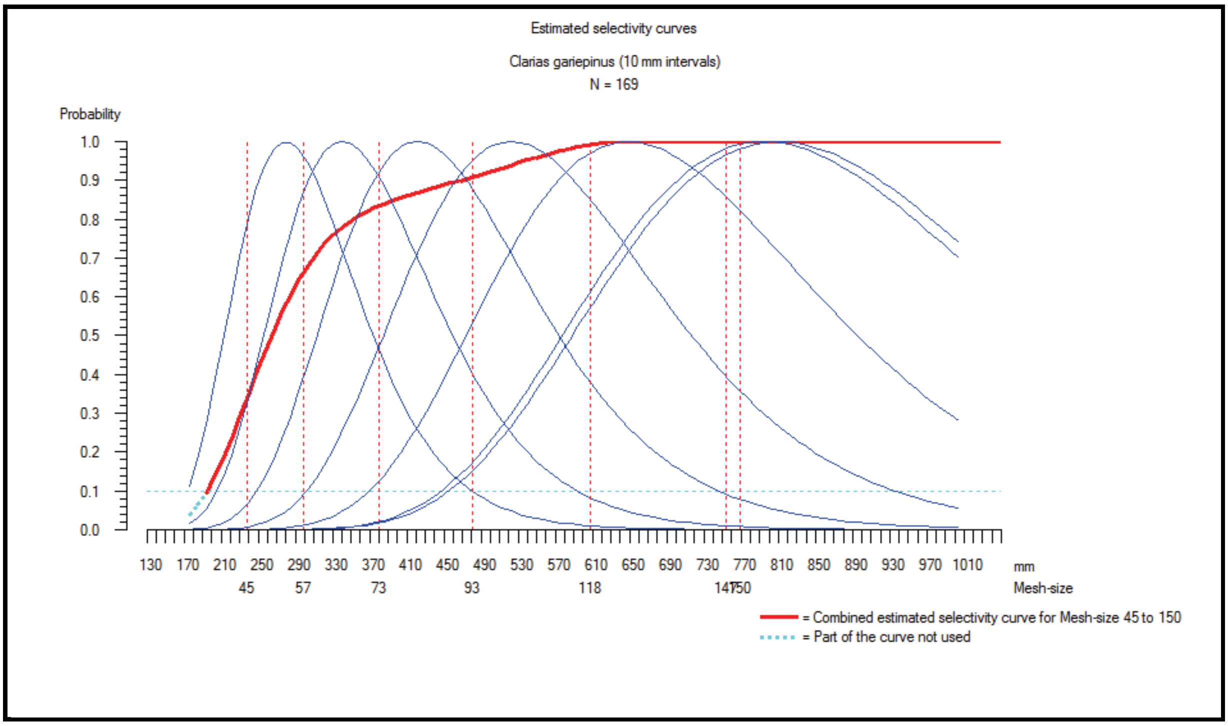

Figure 10.45: Estimated gill net selectivity for *Clarias gariepinus*.

Labeobarbus aeneus:
The probability is high for sampling fish in the 15-34 cm length range with the 28-93 mm gill net meshes (Figure 10.46).

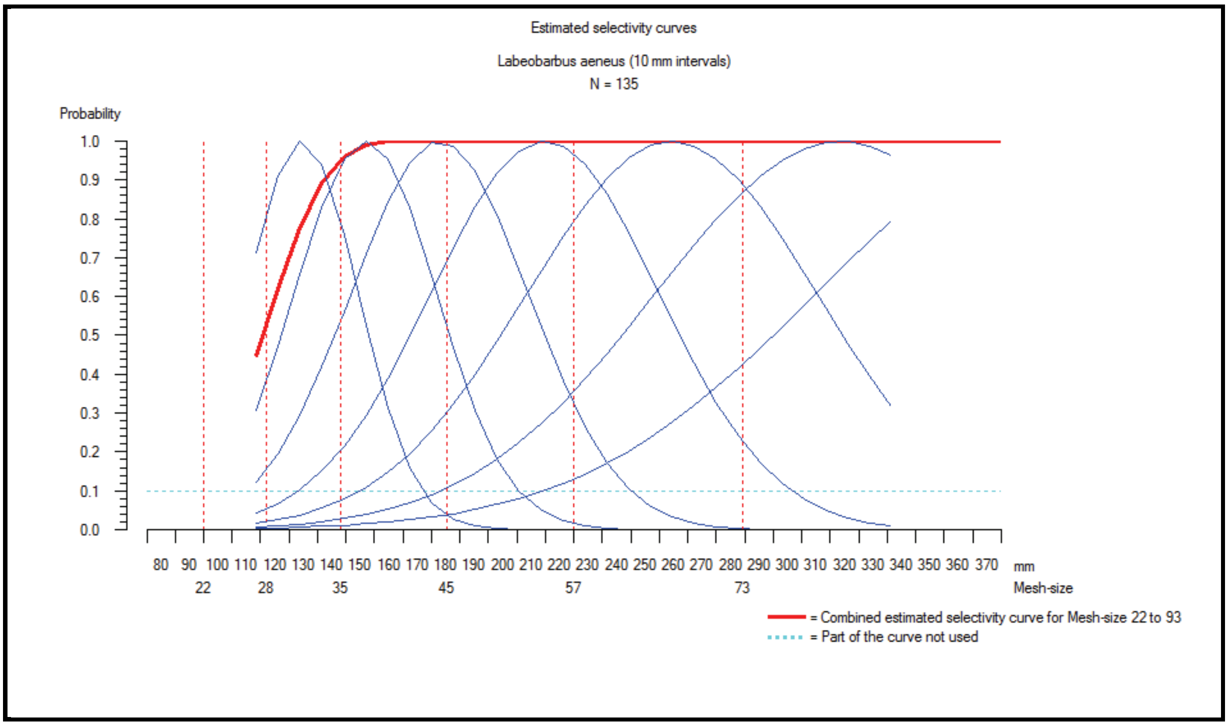

Figure 10.46: Estimated gill net selectivity for *Labeobarbus aeneus*.

Cyprinus carpio:
The probability of sampling fish in the 15-40 cm range with the 45 mm-150 mm meshes ranges between 65%-100% (Figure 10.47). The probability is high 90%-100% for sampling large fish in the 118-150 mm meshes.

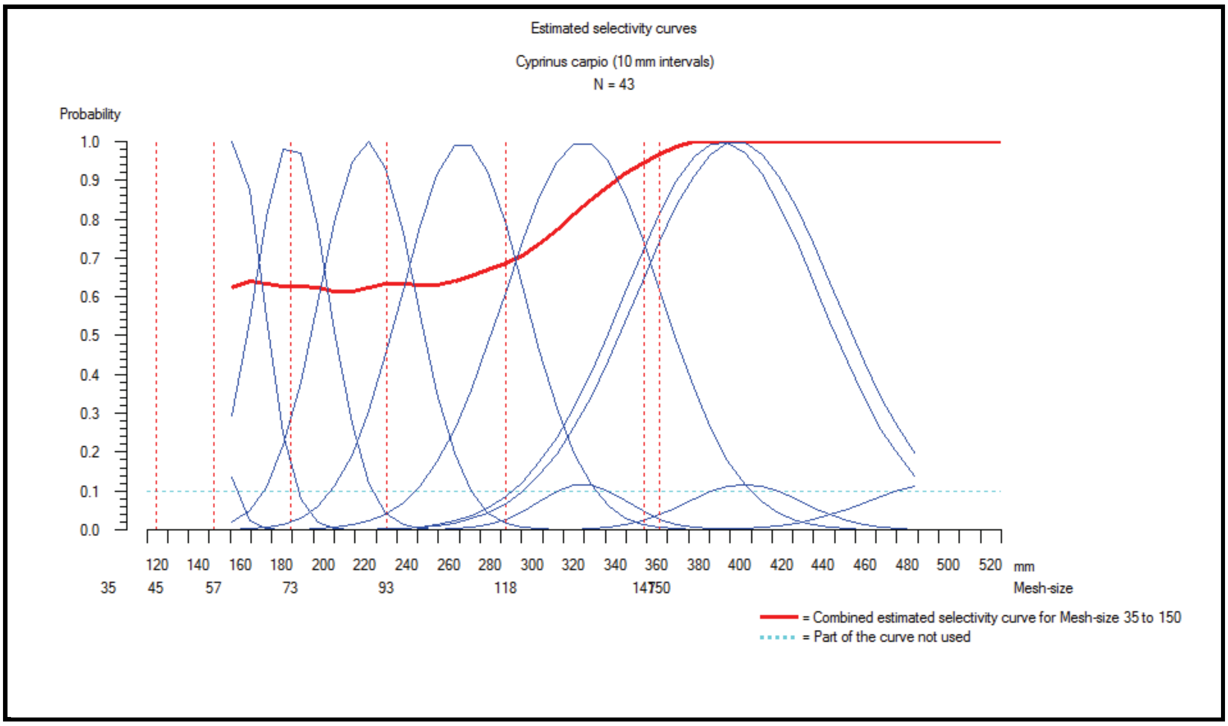

Figure 10.47: Estimated gill net selectivity for *Cyprinus carpio*.

10.12.4 CPUE for the Species Sampled in Koster River Dam, 2008-2009

The catch per unit effort (CPUE) was calculated for each of the multifilament gill net meshes and the monofilament gill net at a standard effort. The standard effort for a mesh was 10m² set for 12 hours.

Table 10.26 provides the average CPUE (in numbers – N, and weight – W), for all mesh sizes combined (including the 147 mm mesh) for Koster River Dam, 2008-2009. Ten gill net mesh sizes were used to limit selectivity (22, 28, 35, 45, 57, 73, 93, 118, 147, and 150 mm).

The catfish made the largest contribution to the CPUE recorded in weight (1.4 kg per 10m² setting), followed by the smallmouth yellowfish (0.3 kg) (Table 10.26). The other species mostly made their contribution to the CPUE recorded in numbers.

The total CPUE in numbers and weight at the end of Table 10.26 is the average CPUE calculated for the ten meshes combined with a net area of 10m². The CPUE's recorded indicate that 2.8 specimens with a weight of 2 kg were sampled in a net area of 10m². Counted specimens (i.e. damaged or rotten) were not taken into account in the calculations.

Seven (7) species were caught in the gill nets, and *Clarias gariepinus* made the largest contribution in weight (72.6%), and the largest contribution to the total numbers (41%) (Table 10.26). *Clarias gariepinus* dominates this dam.

Table 10.26: CPUE for the species sampled in Koster River Dam.

Species	NO	% NO	W(kg)	% W	CPUE-N	CPUE-W(kg)
Clarias gariepinus	161	41	202.839	72.6	1.1	1.4
Labeobarbus aeneus	135	34.4	35.752	12.8	1	0.3
Cyprinus carpio	21	5.4	19.899	7.1	0.1	0.1
Oreochromis mossambicus	53	13.4	17.215	6.2	0.4	0.1
Micropterus salmoides	2	0.5	3.594	1.3	0	0
Barbus paludinosus	19	4.8	0.085	0	0.1	0
Pseudocrenilabrus philander	2	0.5	0.008	0	0	0
Total	**393**	**100**	**279.393**	**100**	**2.8**	**2**

Graphical display of the CPUE for all species sampled in Koster River Dam:

Figure 10.48 gives a graphical representation of the gill net catches in numbers and weight (kg) for each species (CPUE per gill net panel (10m² for 12h), for all mesh sizes combined). *Clarias gariepinus* (catfish) made the largest contribution in weight (1st green bar) and numbers (1st orange bar), and *Labeobarbus aeneus* (smallmouth yellowfish) made a large contribution in numbers (2nd orange bar). *Clarias gariepinus* has the most potential in a fishery, and bio-remediation project, although carp (unwanted alien species) must also be considered. The larger meshes recommended for catfish will also target carp as both are large growing species.

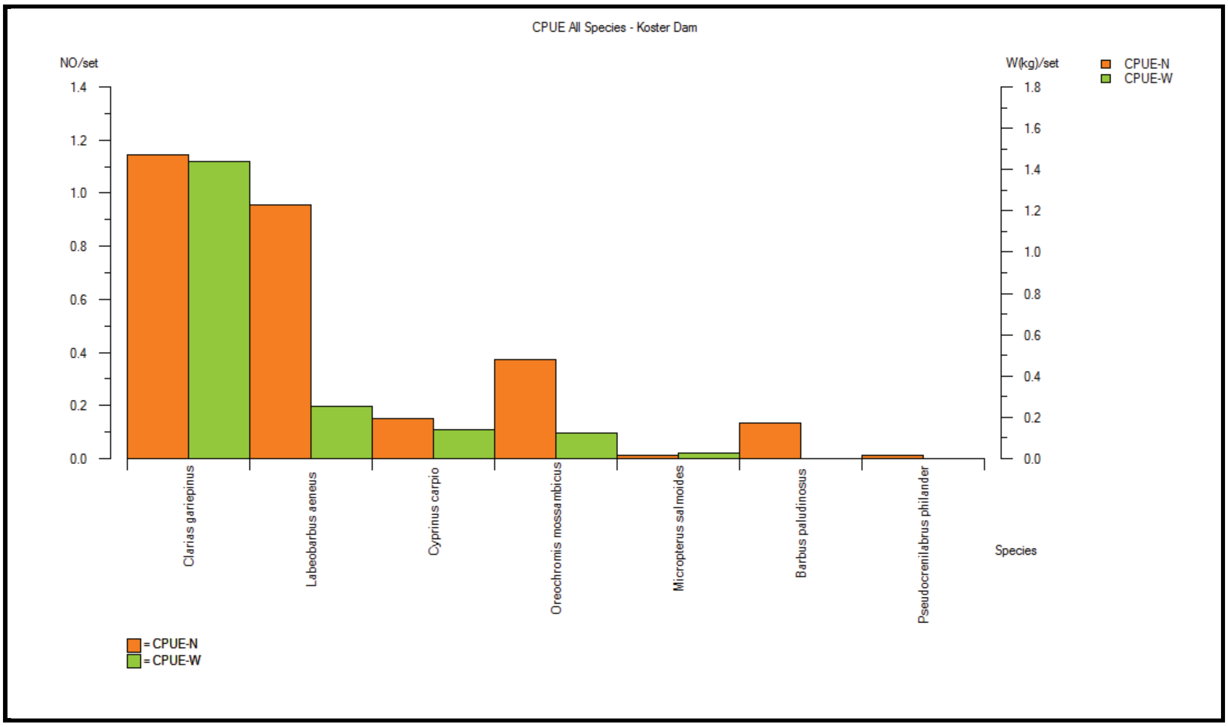

Figure 10.48: CPUE for the species sampled in Koster River Dam.

Gill net CPUE-W per station for Koster River Dam:

The highest CPUE-W (weight in kg) was recorded at station K8, followed by stations K5 and K9 (Table 10.27 and Figure 10.49). The highest CPUE-N (in numbers) was recorded at station K17, followed by stations K6, K14 and K15.

Table 10.27: CPUE per station for Koster River Dam.

Station	CPUE-N	CPUE-W(kg)
K1	2.4	1.8
K2	2.9	2.1
K3	1.8	1.1
K4	0.9	1.4
K5	2.3	2.8
K6	3.8	1.6
K7	1.1	0.4
K8	3.2	3.1
K9	2.3	2.5
K10	0.8	1.2
K14	3.4	2.2
K15	3.4	2.2
K16		
K17	4	1.7
Total	**2.8**	**2**

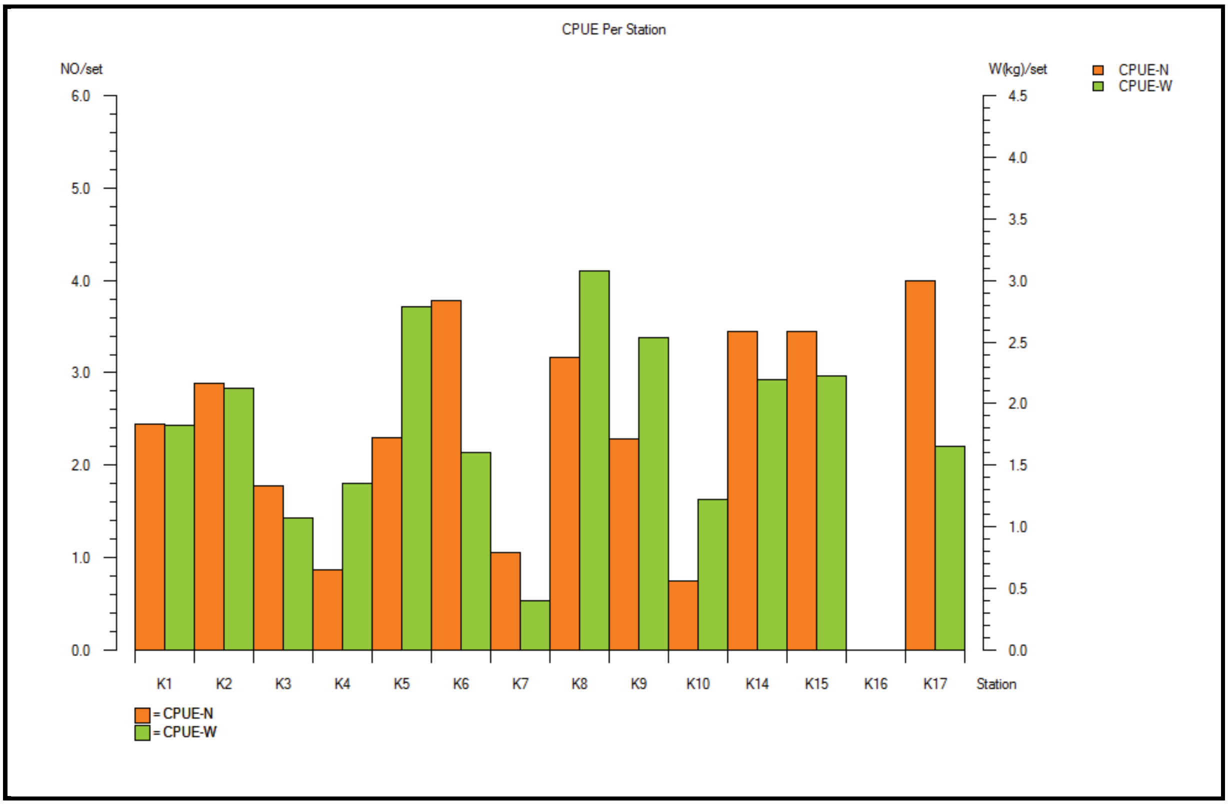

Figure 10.49: CPUE for the stations in Koster River Dam.

Gill net CPUE per habitat for Koster River Dam:

The areas with deep water and vegetation were the most productive. Large specimens were, however, also sampled in shallower vegetated areas (Table 10.28 and Figure 10.50). The deep pelagic zone (open water) was the least productive.

Table 10.28: CPUE per habitat for Koster River Dam.

Setting Type/Code	Habitat Type	CPUE-N	CPUE-W(kg)
30	Deep littoral zone, veg	3.1	2.2
10	Shallow littoral zone, veg	2.7	1.9
40	Deep littoral zone, rocky	1.8	1.1
50	Deep pelagic zone	0.5	0.9
Total		**2.8**	**2**

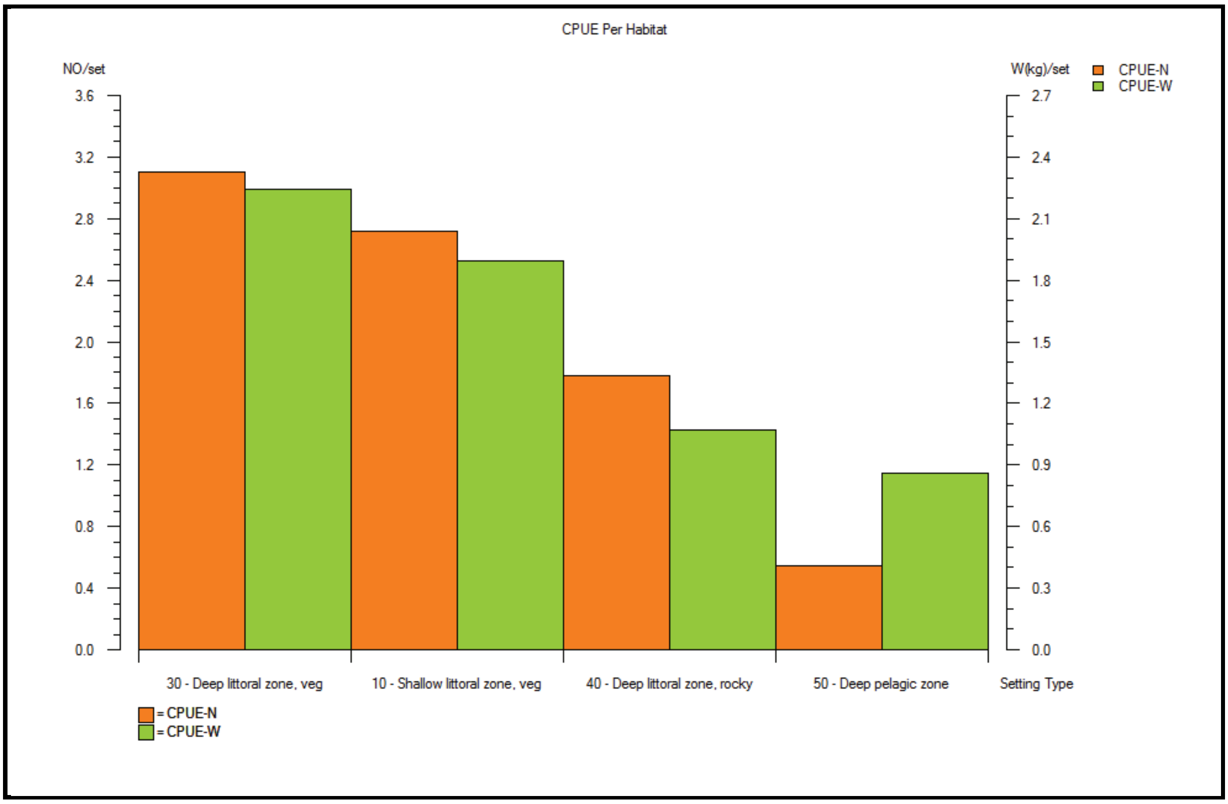

Figure 10.50: CPUE per habitat for Koster River Dam.

10.12.5 Biomass and yield estimates for Koster River Dam

Koster River Dam has a surface area of 2.62km². With the catch data the biomass and yield can be estimated for Koster River Dam with a Swept Area Model/Method.

The total fish biomass for Koster River Dam was estimated at 52.4 tons during the two surveys, and the total sustainable yield at 17.5 tons per year. This translates to a yield of 6.7 t/km²/yr or 67 kg/ha/yr.

Catfish, an undesirable species, made the highest contribution of 72.6% to the CPUE-W. A potential catfish biomass of 4.85 t/km²/yr (or 12.7 tons per year for the whole dam) could, therefore, be removed sustainably. To achieve the desired effects of biomanipulation or food web management up to 80% of the catfish biomass should, however, be removed, and this calculates to 11.6 t/km², or 30.4 tons for the whole dam during the start-up phase of such a programme.

Three tons (3t) of carp (80% of carp biomass) can be removed from Koster River Dam as part of a biomanipulation project. This adds up to a total coarse fish removal of 33.4 tons for the whole dam.

10.13 LINDLEYSPOORT DAM

10.13.1 Lindleyspoort Dam Sampling Sites

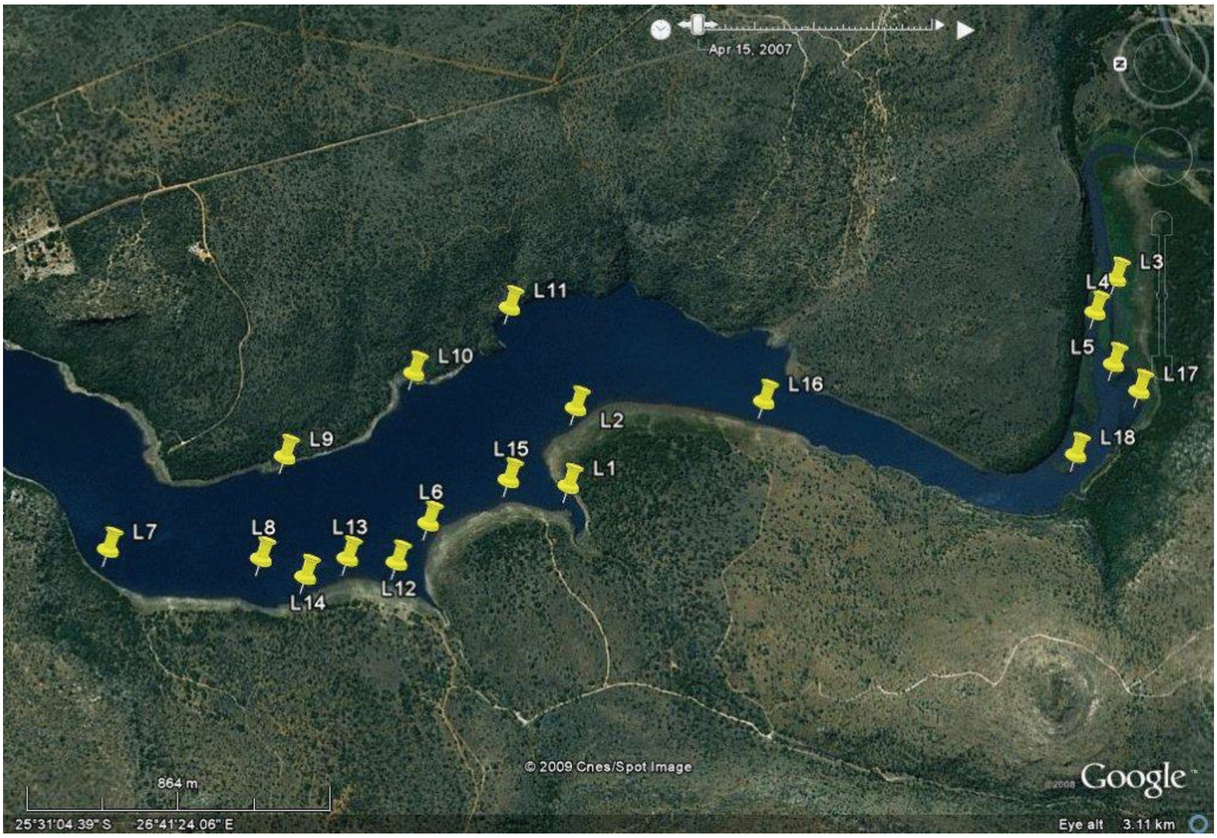

Figure 10.51: Lindleyspoort Dam sampling sites

Eighteen (18) stations were identified and surveyed during both surveys with the aim to obtain data representative of the fish population in the dam (Figure 10.51).

During both surveys the water level of the dam was at approximately 100% of its full supply level.

Table 10.29 presents the station statistics, and sampling gears used in the different habitat types during the two surveys.

Table 10.29: Station statistics for Lindleyspoort Dam (2008-2009).

Date	St. code	Latitude	Longitude	Gear	Set type
2008/09/18	1	25°30'59.81"S	26°41'15.09"E	Gill nets	Lake shallow littoral zone, veg
2008/09/19	2	25°31'0.63"S	26°41'23.40"E	Gill nets	Lake deep littoral zone, veg
2008/09/20	3	25°31'53.79"S	26°41'36.48"E	Gill nets	Lake deep littoral zone, veg
2008/09/20	4	25°31'51.53"S	26°41'32.83"E	Gill nets	Lake deep littoral zone, veg
2008/09/20	5	25°31'52.95"S	26°41'27.06"E	147 mm	Lake deep pelagic
2008/09/21	6	25°30'46.40"S	26°41'11.42"E	Gill nets	Lake deep littoral zone, veg
2008/09/22	7	25°30'15.89"S	26°41'9.32"E	Gill nets	Lake deep littoral zone, veg
2008/09/22	8	25°30'30.46"S	26°41'8.03"E	147 mm	Lake deep pelagic
2008/09/23	9	25°30'32.57"S	26°41'18.78"E	Gill nets	Lake deep littoral zone, rock
2008/09/23	10	25°30'45.00"S	26°41'27.55"E	147 mm	Lake deep pelagic
2008/09/24	11	25°30'54.34"S	26°41'34.58"E	Gill nets	Lake deep littoral zone, rock
2009/02/16	12	25°30'43.37"S	26°41'7.36"E	Gill nets	Lake shallow littoral zone, veg
2009/02/16	13	25°30'38.68"S	26°41'7.90"E	147 mm	Lake shallow littoral zone, veg
2009/02/16	14	25°30'34.69"S	26°41'6.05"E	Gill nets	Lake shallow littoral zone, veg
2009/02/17	1	25°30'59.81"S	26°41'15.09"E	Gill nets	Lake shallow littoral zone, veg
2009/02/17	15	25°30'54.10"S	26°41'15.83"E	147 mm	Lake shallow littoral zone, veg
2009/02/17	6	25°30'46.40"S	26°41'11.42"E	Gill nets	Lake shallow littoral zone, veg
2009/02/18	2	25°31'0.63"S	26°41'23.40"E	Gill nets	Lake deep littoral zone, veg
2009/02/18	16	25°31'18.86"S	26°41'23.73"E	Gill nets	Lake shallow littoral zone, veg
2009/02/18	17	25°31'55.22"S	26°41'24.06"E	147 mm	Lake shallow littoral zone, veg
2009/02/19	3	25°31'53.79"S	26°41'36.48"E	Gill nets	Lake deep littoral zone, veg
2009/02/19	5	25°31'52.95"S	26°41'27.06"E	147 mm	Lake deep littoral zone, veg
2009/02/19	18	25°31'48.67"S	26°41'17.35"E	Gill nets	Lake deep littoral zone, veg

Shallow < 1.5m
Deep > 1.5m

10.14 LINDLEYSPOORT DAM SAMPLING STATISTICS

10.14.1 IRI for Lindleyspoort Dam

The *percentage commonness* or frequency of occurrence, $\%F$ or %FREQ represents the *percentage probability* of a species occurring in the catch composition of an area if similar sampling methods were used. The $\%F$ for all the species combined does not add up to 100%.

The species were sorted descending in the tables from the highest to the lowest IRI value. The IRI value is a numerical value assigned to each specific species and is given in percentage of the total of the IRI values calculated for the relevant area. The IRI depicts the relative importance of a species in the fish population in terms of its abundance and weight contribution in the relevant catch composition.

A low IRI score does not necessarily mean that a species is less important. The IRI gives an indication of the fish population composition, and the weight each species carries in the population, in terms of its contribution to the total catch.

IRI for the Gill Nets Used in Lindleyspoort Dam (2008-2009):
The Index of Relative Importance (Kolding, 1998) gives an indication of the contribution each fish species made in terms of numbers and weight to the total catch (and the fish population). The IRI as recorded for Lindleyspoort Dam during two seasonal surveys is shown in Table 10.30.

A total of 2435 specimens were caught, and 13 species were recorded for the two seasonal surveys for Lindleyspoort Dam (Table 10.30). The catfish received the highest IRI score (43.5%), followed by the papermouth (19.5%), and the Mozambique tilapia (16.7%).

The catfish made the highest contribution in weight (51.4%) to the total catch, as large specimens were mostly sampled (Table 10.30). The papermouth made its contribution in numbers (24%) to the total catch. The Mozambique tilapia made considerable contributions in weight (15.3%) and numbers (18.4%). Large specimens of the Mozambique tilapia were sampled regularly. Large carp was also sampled regularly and it made a considerable contribution to the total weight (21.3%). The carp was sampled in relatively low numbers (4%).

The Threespot barb, small species, made the highest contribution to the total numbers recorded (35.2%), followed by the papermouth (24%), the Mozambique tilapia (18.4%), and the catfish (8.7%) (Table 10.30). The largescale yellowfish made a contribution 5% in numbers and 6% in weight.

The Mozambique tilapia was sampled in low numbers (1.9%) during the first of the two surveys highlighting the importance of the effect of seasonal distribution and densities on the fish population dynamics.

Low numbers of canary kurper sampled may be of note as this species tend to dominate some dams in numbers. The other remaining species were also sampled in low numbers.

Marcusenius macrolepidotus (bulldog) is a relatively scarce species in South Africa, often associated with clear water and marginal vegetation. It is also a prey species of catfish.

Lindleyspoort is a small to medium sized oligotrophic dam. The water was clear at the time of the second survey. Marginal aquatic vegetation is abundant. Excessive algae growth was not observed.

The IRI for Lindleyspoort Dam gives an indication that catfish and carp, as undesirable species, could be considered for removal in a biomanipulation and food web management programme.

Table 10.30: IRI for Lindleyspoort Dam, 2008-2009.

Species	NO	% NO	W(kg)	% W	FRQ	% FRQ	IRI	% IRI
Clarias gariepinus	212	8.7	416.484	51.4	73	48.3	2905	43.5
Barbus mattozi	585	24	36.288	4.5	69	45.7	1302	19.5
Oreochromis mossambicus	449	18.4	124.033	15.3	50	33.1	1117	16.7
Barbus trimaculatus	857	35.2	6.92	0.9	25	16.6	597	8.9
Cyprinus carpio	97	4	172.288	21.3	26	17.2	435	6.5
Labeobarbus marequensis	121	5	48.246	6	40	26.5	289	4.3
Chetia flaviventris	56	2.3	0.943	0.1	17	11.3	27	0.4
Marcusenius macrolepidotus	13	0.5	1.045	0.1	10	6.6	4	0.1
Tilapia sparrmanii	14	0.6	0.316	0	7	4.6	3	0
Barbus paludinosus	18	0.7	0.103	0	3	2	1	0
Pseudocrenilabrus philander	10	0.4	0.038	0	5	3.3	1	0
Micropterus salmoides	2	0.1	3.789	0.5	2	1.3	1	0
Barbus unitaeniatus	1	0	0.004	0	1	0.7	0	0
Total	**2435**	**100**	**810.497**	**100**	**-**	**-**	**6684**	**100**

%IRI = Percentage of Total of IRI values calculated for each species in area
%N = Contribution in Percentage to Total Numbers sampled
%W = Contribution in Percentage to Total Weight sampled
%F = Frequency of Occurrence

Figure 10.52 provides a graphical display of the contribution each of the fish species sampled made to the total catch. The contribution in weight is indicated above the x-axis, and the contribution in numbers below the x-axis. %F (frequency of occurrence) at the bottom of the graph indicates the percentage probability of obtaining the same catch if similar sampling methods were used.

Figure 10.52 shows the contribution each of the first five species made to the total catch in terms of numbers and weight. Species 2, 3 and 4, the *papermouth* (medium to large species), the Mozambique tilapia (medium to large species), and the *threespot barb* (small species), made large contributions to the total number of fish sampled.

The presence of large catfish (with a large weight contribution), also sampled in considerable numbers (species 1 in Figure 10.52), may have an effect on the species densities of especially the smaller species such as the canary kurper, barbs, and smaller kurper species. The threespot barb was, however, sampled in high numbers (35.2%).

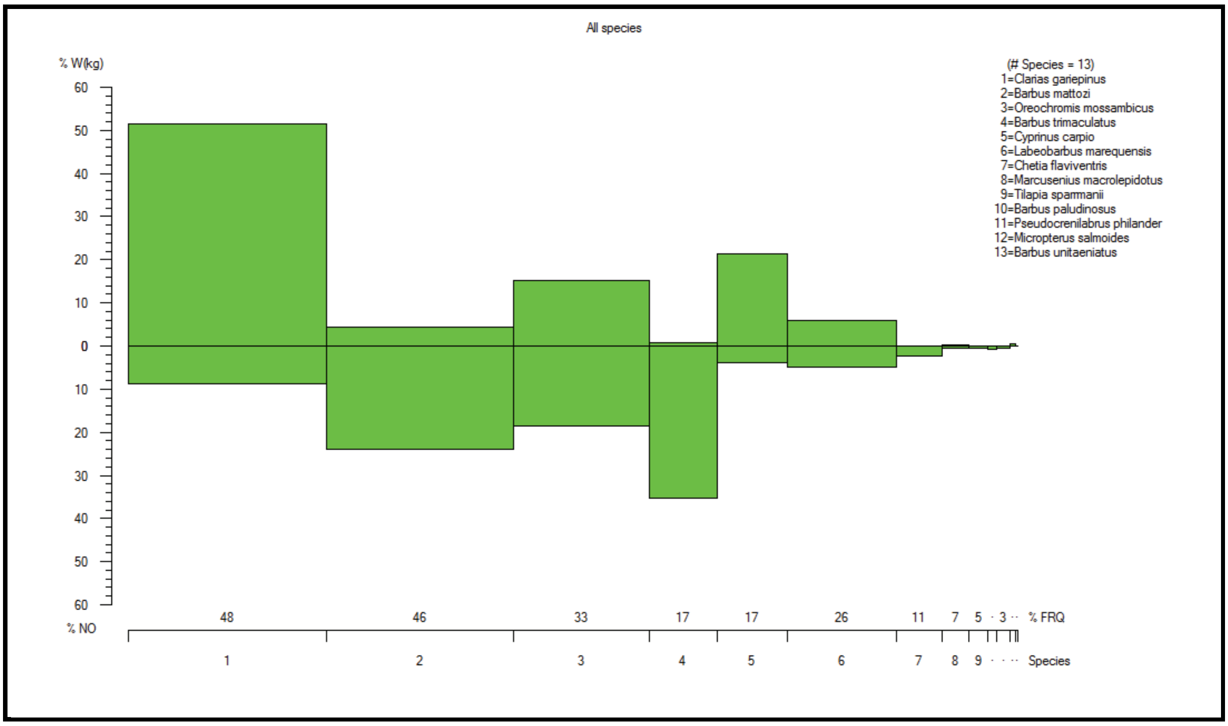

Figure 10.52: IRI for Lindleyspoort Dam, 2008-2009.

10.14.2 Catch Statistics for the Gill Nets in Lindleyspoort Dam, 2008-2009

Table 10.31 indicates the number of each species sampled in each mesh size (upper section of table). *Barbus trimaculatus* and *Barbus mattozi* were effectively sampled in the 22 and 28 mm mesh sized gill nets, and *Oreochromis mossambicus* was effectively sampled in the 35-57 mm meshes, and several large specimens were also sampled in the 147 mm monofilament net.

Clarias gariepinus and *Cyprinus carpio* were sampled in a wide range of mesh sizes, the larger meshes being the most effective (73-150 mm) (Table 10.31). The 118-150 mm meshes seems to be the most effective for the removal of carp and catfish with the least impact on the other species.

The second section (lower section) of Table 10.31 indicates the total number of fish sampled in each of the gill nets, the contribution in percentage each mesh made to the total number recorded, the number of settings for each mesh, the average number of fish sampled in each mesh, and the mean lengths and weight sampled in each mesh.

Table 10.31: Catch Statistics for the Gill Nets in Lindleyspoort Dam, 2008-2009.

Species	Gill Net Mesh Size (MM)										Total
	22	28	35	45	57	73	93	118	147	150	
Pseudocrenilabrus philander	9	1									10
Chetia flaviventris	11	36	5	1	3						56
Oreochromis mossambicus	2	11	134	152	58	12	10	4	45	21	449
Clarias gariepinus			3	6	15	31	33	65	30	29	212
Cyprinus carpio	1		1		2	1	5	14	61	12	97
Labeobarbus marequensis	9	6	3	24	19	34	20	4	2		121
Barbus mattozi	89	307	34	46	87	21	1				585
Barbus trimaculatus	706	150		1							857
Barbus paludinosus	18										18
Barbus unitaeniatus	1										1
Micropterus salmoides						1				1	2

Species	Gill Net Mesh Size (MM)										Total
	22	28	35	45	57	73	93	118	147	150	
Tilapia sparrmanii			10	4							14
Marcusenius macrolepidotus			6	2	5						13
Total	846	511	196	236	189	100	69	87	138	63	2435
% NO	34.7	21	8	9.7	7.8	4.1	2.8	3.6	5.7	2.6	100
No of settings for each mesh	16	16	16	16	16	16	16	16	7	16	151
AV NO/Mesh	52.9	31.9	12.3	14.8	11.8	6.3	4.3	5.4	19.7	3.9	16.1
ML(mm)/Mesh	87.6	108.3	126.3	161.3	226.4	350.4	413.2	558.1	506.3	577.5	186.2
MW(g)/Mesh	9	14	52	81	222	685	898	1782	2028	2514	333

MW = Mean Weight in grams
ML = Mean Length in mm

10.14.3 Species Statistics for the Gill Nets in Lindleyspoort Dam, 2008-2009

Table 10.32 provides the total number of each species sampled, their average weight and length, and the biomass (g) contribution each species made to the gill net series (or range, from 22 mm to 150 mm, all meshes included) per setting. The biomass contribution was calculated for each mesh with a length of 10m. *Clarias gariepinus* and *Cyprinus carpio* made the largest contribution to the biomass recorded, followed by *Oreochromis mossambicus*. *Clarias gariepinus* was sampled with a mean weight of 1964.5 g (1.96 kg) and a mean length of 588 mm (58.8 cm).

Table 10.32: Species Statistics for the Gill Nets in Lindleyspoort Dam 2008-2009.

Species	Total	% NO	MW(g)	ML(mm)	Biomass(g)/set
Pseudocrenilabrus philander	10	0.4	3.8	67	0
Chetia flaviventris	56	2.3	16.8	100	6
Oreochromis mossambicus	449	18.4	276.2	176	821
Clarias gariepinus	212	8.7	1964.5	588	2758
Cyprinus carpio	97	4	1776.2	456	1141
Labeobarbus marequensis	121	5	398.7	252	320
Barbus mattozi	585	24	62	145	240
Barbus trimaculatus	857	35.2	8.1	91	46
Barbus paludinosus	18	0.7	5.7	72	1
Barbus unitaeniatus	1	0	4	80	0
Micropterus salmoides	2	0.1	1894.5	455	25
Tilapia sparrmanii	14	0.6	22.6	113	2
Marcusenius macrolepidotus	13	0.5	80.4	191	7
Total	**2435**	**100**	**332.9**	**186**	**5368**

MW = Mean Weight in grams
ML = Mean Length in mm

10.15 SPECIES SELECTION FOR A FISHERY IN LINDLEYSPOORT DAM

This section aims to identify and select the most appropriate species, which are likely to succeed in terms of a fisheries exploitation project. The species selected all have potential for exploitation in a fisheries project, however, some more than others.

Gill net selectivity was explored for the species. A multifilament gill net range of nine (9) meshes were used during the survey, which included a 22 mm, 28 mm, 35m, 45 mm, 57 mm, 73 mm, 93 mm, 118 mm and a 150 mm mesh. Each of these meshes has a length of ten metres. A 147 mm mesh monofilament gut gill net was also used, and it has a length of 80 metres. The length of the 147 mm mesh were standardised to 10m during calculations.

The fish retained in a gear is usually only an unknown proportion of the various size classes available in the fished population. Selectivity is a quantitative expression of this proportion and represented as a probability of capture of a certain size of fish in a certain size of mesh. The mesh selectivity was indirectly estimated with methods as described by Kolding (1998).

10.15.1 Species selection

Three species (*Clarias gariepinus, Oreochromis mossambicus,* and *Cyprinus carpio*) could be considered for selection as species with potential for utilisation in a fisheries project. The IRI was used as a guideline, as it highlights the important species in terms of their contribution to weight and numbers.

These three species are well represented in the Lindleyspoort Dam, and made considerable contributions in weight.

Clarias gariepinus and *Cyprinus carpio* produce high numbers of offspring due to their high fecundity. High numbers of juvenile fish after the spawning season may have a significant impact on the zooplankton population due to predation, and the exploitation of the breeding stock of these species, may benefit the zooplankton population, and overall health of the dam.

The feeding habits of carp and catfish may also negatively influence water quality, as they tend to re-suspend organic materials and small sediment particles back into the water column (through its constant churning of bottom sediments in search of food), which makes it available for use by other organisms, such as algae. Carp and catfish should be considered for removal as part of a bio-remediation project.

Oreochromis mossambicus should only be considered for a sustainable fish harvesting project.

10.15.2 Length frequencies recorded for selected species

CPUE was calculated for each of the meshes at a standard effort. The standard effort for a mesh was 10m² net area set for 12 hours.

Oreochromis mossambicus:
Figure 10.53 graphically displays the length frequencies recorded for *Oreochromis mossambicus* in the different gill nets, as well as the mean length for each mesh size. *Oreochromis mossambicus* is a medium to large species, and large specimens were sampled.

Oreochromis mossambicus was sampled within its length range with the 22 mm to 150 mm mesh sized gill nets (Figure 10.53). The highest number (152) of fish was recorded in the 45 mm mesh gill net, followed by the 35 mm mesh (134). This species was sampled in a length range of 7 cm to 49 cm.

The length frequencies recorded (Figure 10.53) gives an indication of different length cohorts representative of age classes, and successful breeding and recruitment during previous seasons. Large specimens of this species were sampled.

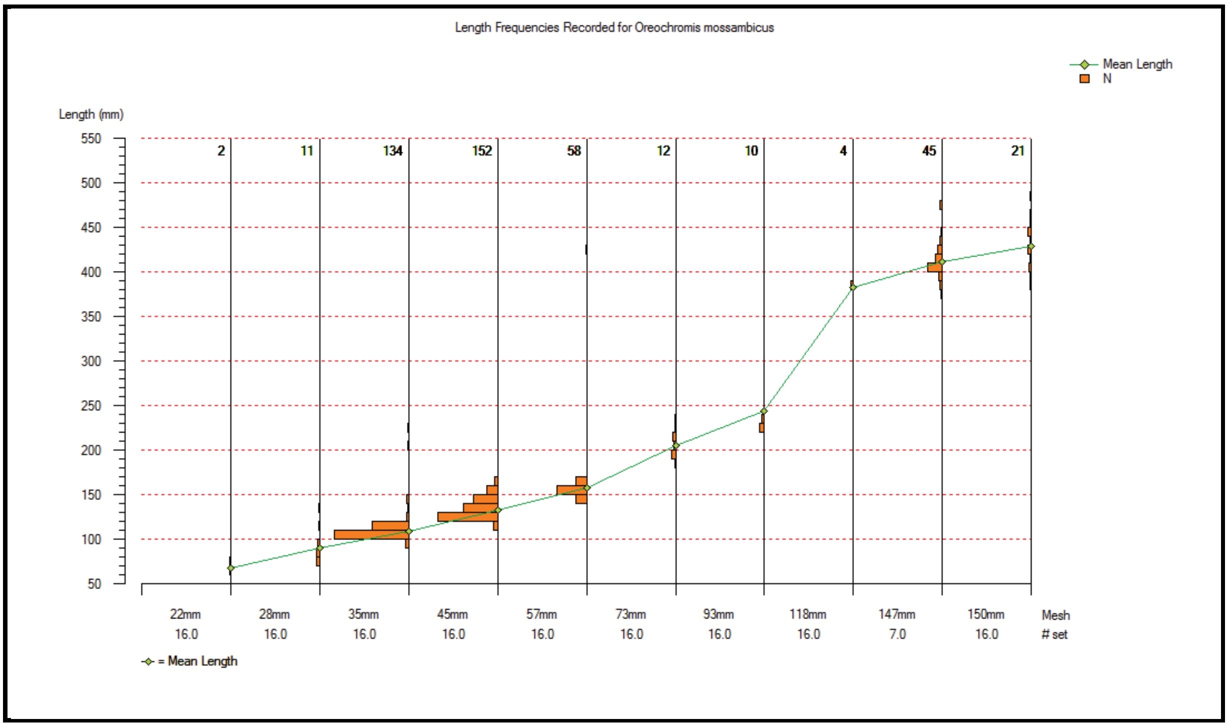

Figure 10.53: Length frequencies recorded for *Oreochromis mossambicus*.

Cyprinus carpio:
Specimens were sampled in a length range of 15-59 cm in the gill nets (Figure 10.54). The highest number of fish was recorded in the 147 mm mesh. Large specimens were sampled effectively in the 118-150 mm meshes.

Several length cohorts were recorded, indicating to successful breeding during previous seasons although smaller specimens were sampled in low numbers (Figure 10.54).

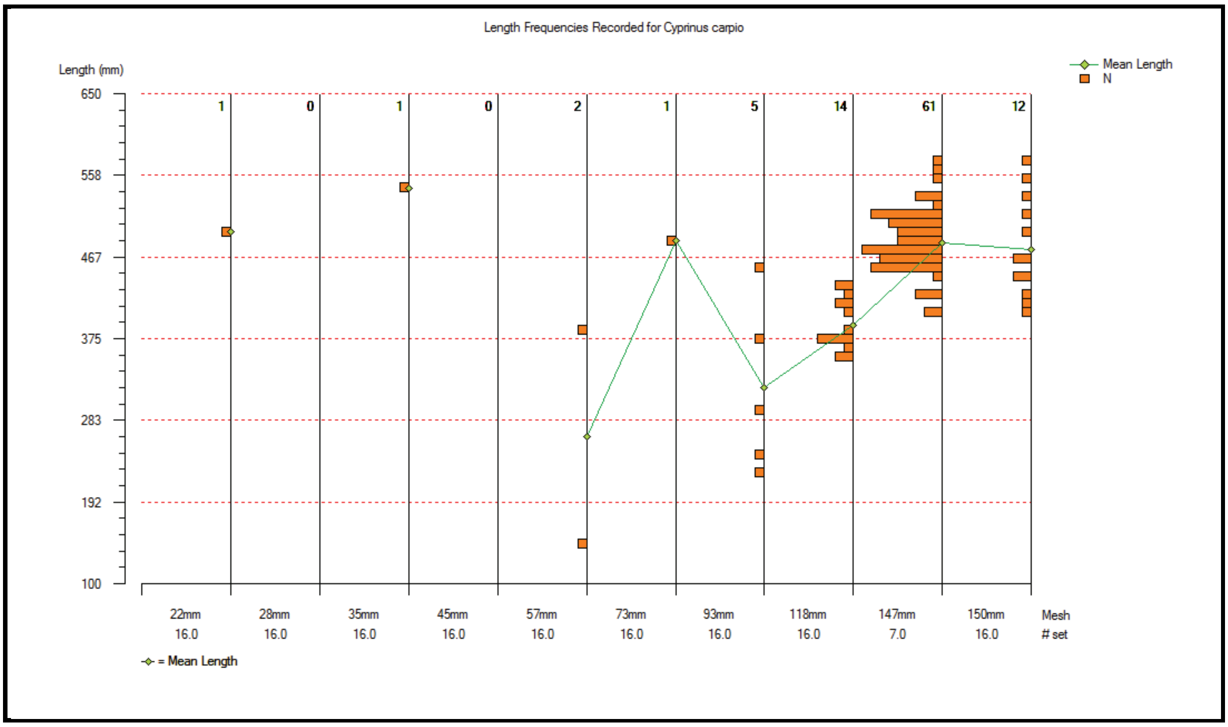

Figure 10.54: Length frequencies recorded for *Cyprinus carpio*.

Clarias gariepinus:

Specimens in a length rage of 15 cm-1.05m were sampled in the 35-150 mm mesh gill nets (Figure 10.55). The 73-150 mm meshes were effective in sampling large specimens, with the 118 mm mesh being the most effective. There seems to be a healthy breeding population, as several length cohorts were recorded. Large specimens are present in the system.

The 73 mm to 150 mm mesh gill nets all have potential as target gear as mature specimens were sampled in these nets (Figure 10.55).

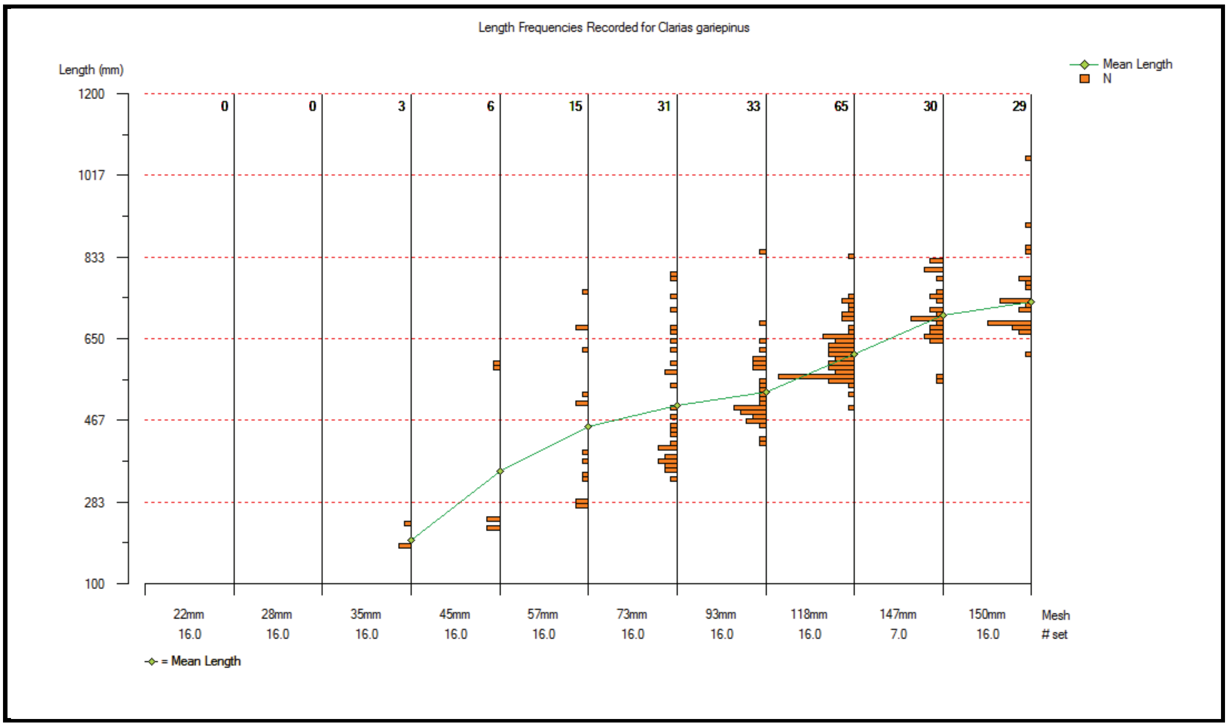

Figure 10.55: Length frequencies recorded for *Clarias gariepinus*.

10.15.3 Gill net selectivity for selected species

Oreochromis mossambicus:
The probability ranges between 65% and 100% that this species will be sampled with the 22-150 mm gill net meshes (Figure 10.56). Fish in a length range of 10-42 cm are the most likely to be sampled with theses meshes. The probability is highest for sampling fish with the larger meshes.

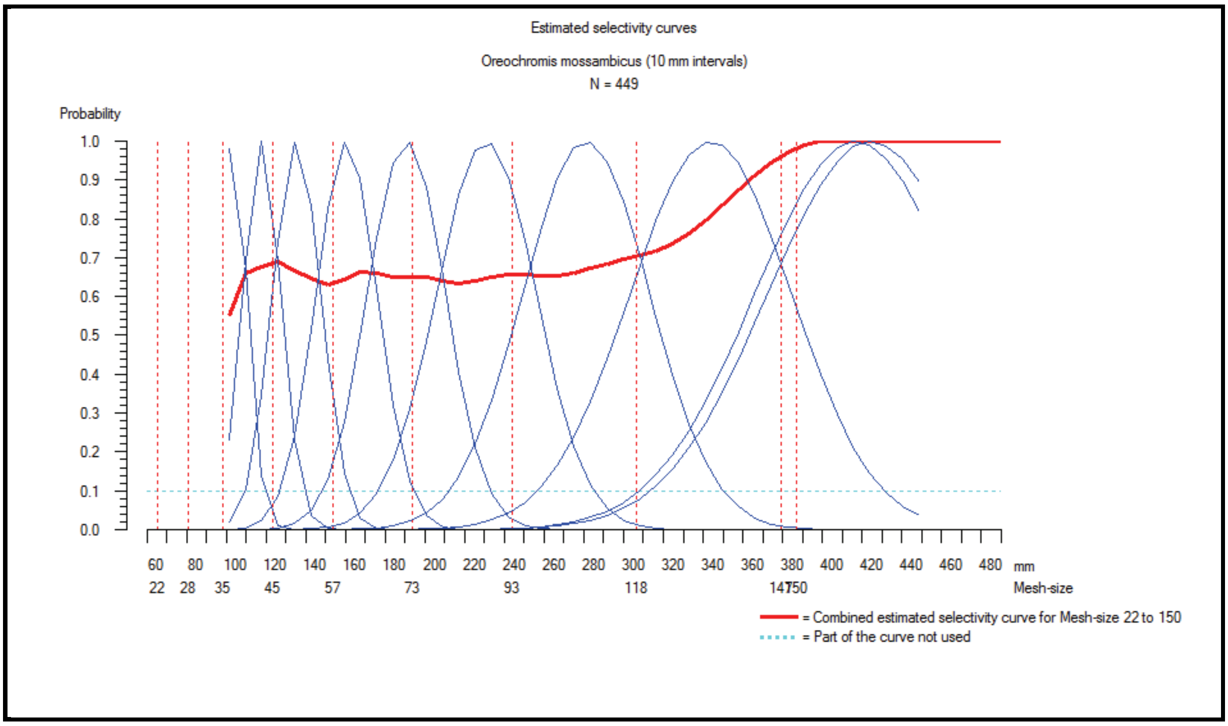

Figure 10.56: Estimated gill net selectivity for *Oreochromis mossambicus*.

Clarias gariepinus:
The probability is high (100%) for sampling large fish (60-80 cm) in the 118 mm to 150 mm meshes (Figure 10.57).

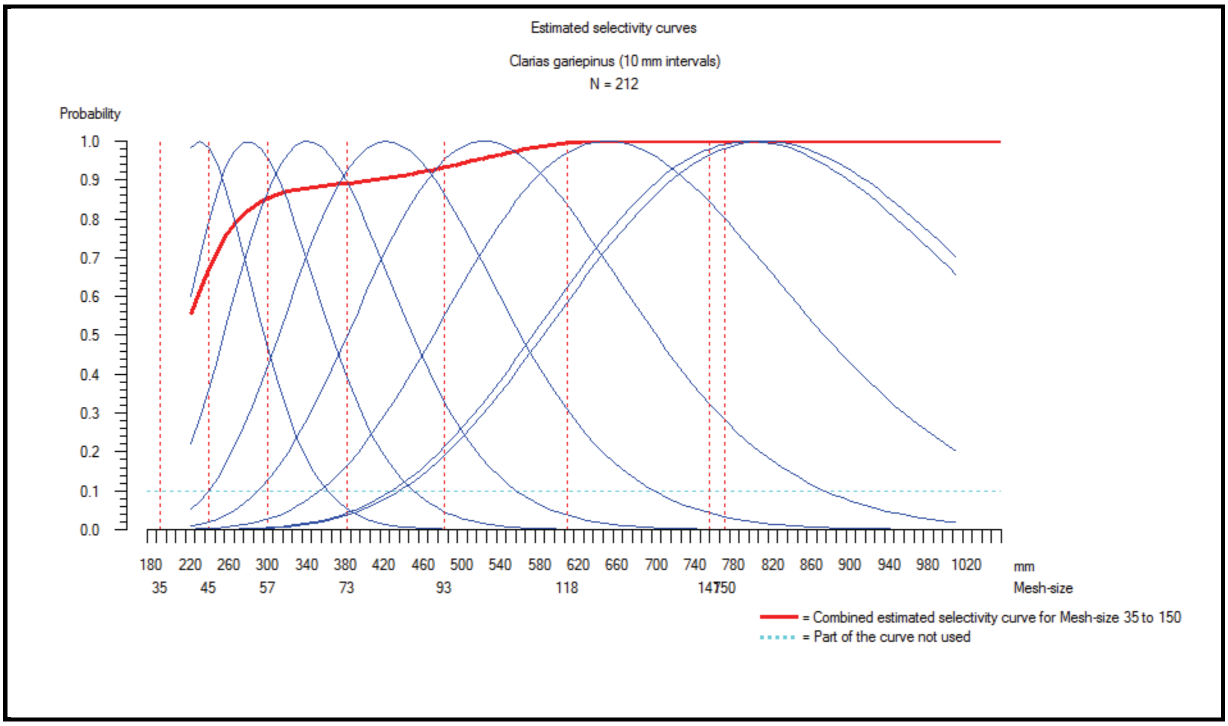

Figure 10.57: Estimated gill net selectivity for *Clarias gariepinus*.

Cyprinus carpio:

The probability of sampling fish in the 18-33 cm range with the 45 mm-93 mm meshes is around 60% (Figure 10.58). The probability becomes higher (80%-100%) for sampling fish in the 39-48 cm length range in the larger meshes (118 mm-150 mm).

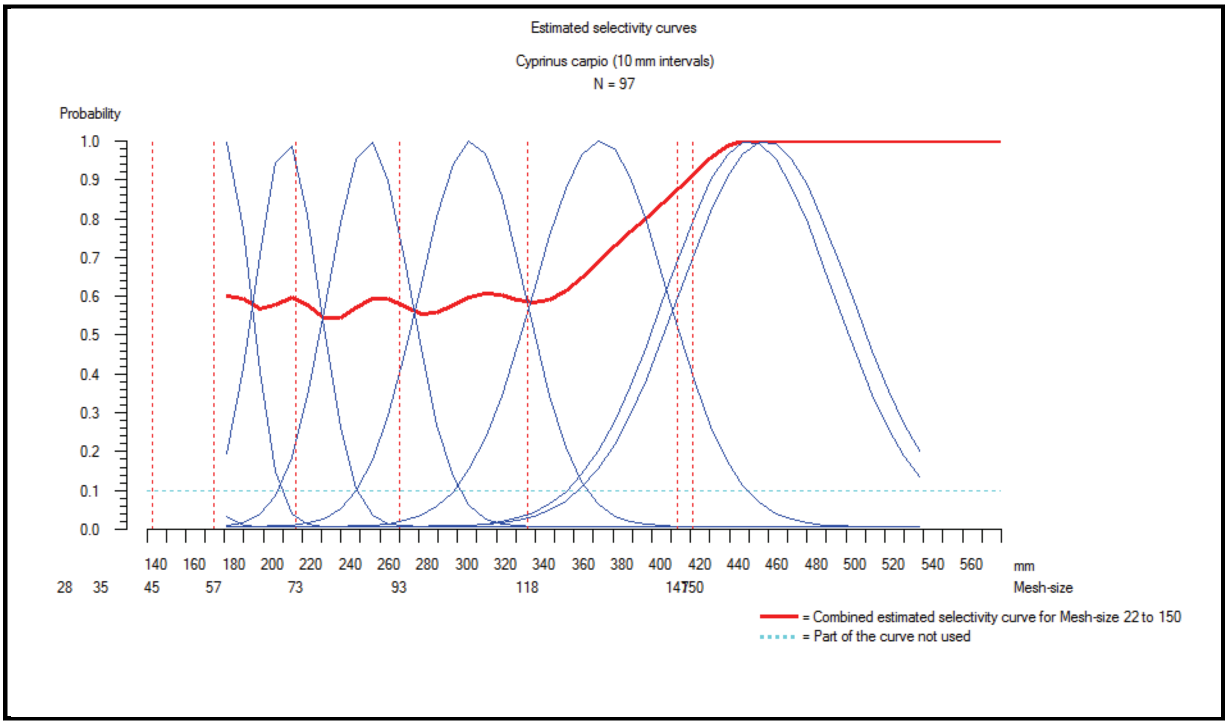

Figure 10.58: Estimated gill net selectivity for *Cyprinus carpio*.

10.15.4 CPUE for the Species Sampled in Lindleyspoort Dam, 2008-2009

The catch per unit effort (CPUE) was calculated for each of the multifilament gill net meshes and the monofilament gill net at a standard effort. The standard effort for a mesh was 10m² set for 12 hours.

Table 10.33 provides the Catch Per Unit Effort (in numbers – N, and weight – W) for the gill nets used in Lindleyspoort Dam, 2008-2009. Ten gill net mesh sizes were used to limit selectivity (22, 28, 35, 45, 57, 73, 93, 118, 147, and 150 mm). The gill net catch effort were standardised to 10m² set for 12 hours.

The catfish made the largest contribution to the CPUE recorded in weight (2.2 kg per 10m² setting), followed by the Mozambique tilapia (0.5 kg) and the carp (0.4 kg) (Table 10.33). The other species mostly made their contribution to the CPUE recorded in numbers.

The total CPUE in numbers and weight at the end of Table 10.33 is the average CPUE calculated for the ten meshes combined with a net area of 10m². The CPUE's recorded indicate that 15.3 specimens with a weight of 3.7 kg were sampled in a net area of 10m².

Table 10.33: CPUE for the species sampled in Lindleyspoort Dam.

Species	NO	% NO	W(kg)	% W	CPUE-N	CPUE-W(kg)
Clarias gariepinus	186	8	337.078	59.6	1.2	2.2
Oreochromis mossambicus	410	17.7	68.737	12.2	2.7	0.5
Cyprinus carpio	44	1.9	65.157	11.5	0.3	0.4
Labeobarbus marequensis	119	5.2	45.184	8	0.8	0.3
Barbus mattozi	585	25.3	36.288	6.4	3.9	0.2
Barbus trimaculatus	857	37	6.92	1.2	5.7	0
Micropterus salmoides	2	0.1	3.789	0.7	0	0
Marcusenius macrolepidotus	13	0.6	1.045	0.2	0.1	0
Chetia flaviventris	56	2.4	0.943	0.2	0.4	0
Tilapia sparrmanii	14	0.6	0.316	0.1	0.1	0
Barbus paludinosus	18	0.8	0.103	0	0.1	0
Pseudocrenilabrus philander	10	0.4	0.038	0	0.1	0
Barbus unitaeniatus	1	0	0.004	0	0	0
Total	**2314**	**100**	**565.601**	**100**	**15.3**	**3.7**

Graphical display of the CPUE for all species sampled in Lindleyspoort Dam:

Figure 10.59 gives a graphical representation of the gill net catches in numbers and weight (kg) for each species (CPUE per gill net panel (10m² for 12h), for all mesh sizes combined). *Clarias gariepinus* (catfish) made a large contribution in weight (1st green bar), and *Barbus trimaculatus* (threespot barb) made a large contribution in numbers (6th orange bar). *Oreochromis mossambicus* made a relative contribution in terms of numbers and weight (2nd species in table). Carp also made a relative contribution in weight (3rd green bar and species in table).

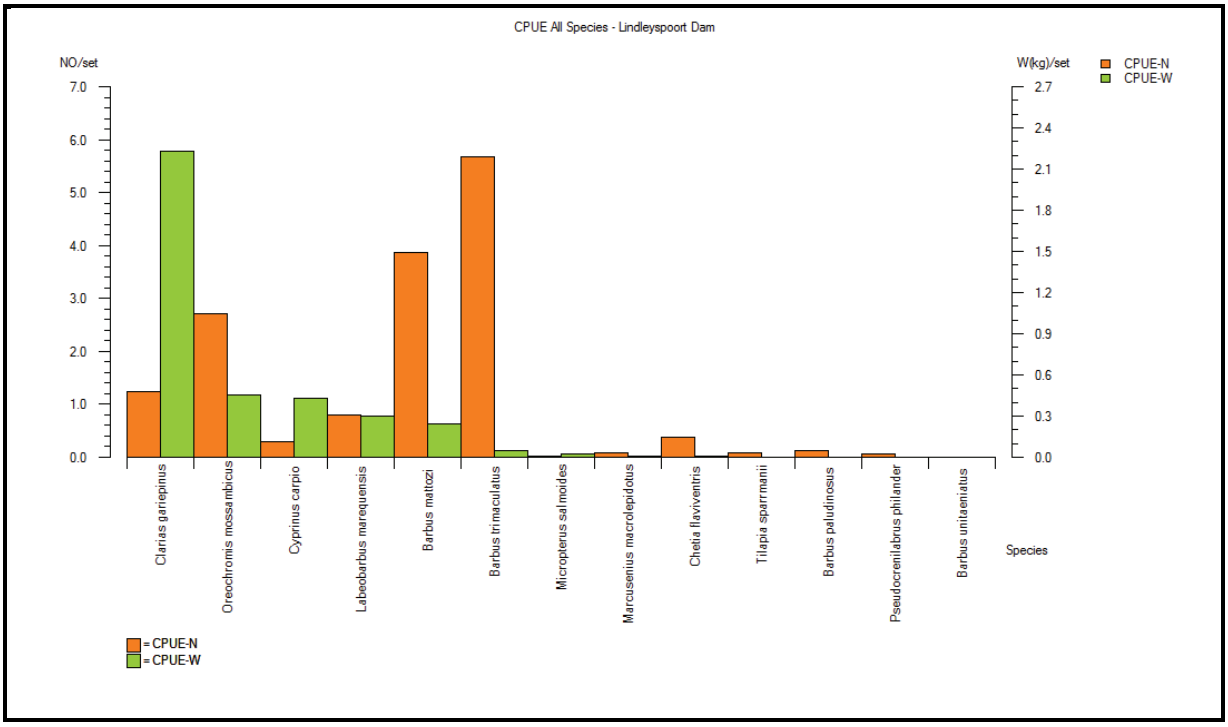

Figure 10.59: CPUE for the species sampled in Lindleyspoort Dam.

Gill net CPUE-W per station for Lindleyspoort Dam:
The highest CPUE-W (weight in kg) was recorded at station L5, followed by stations L4 and L3 (Table 10.34 and Figure 10.60). The highest CPUE-N (in numbers) was recorded at station L12, followed by stations L6 and L14.

Table 10.34: CPUE per station for Lindleyspoort Dam.

Station	CPUE-N	CPUE-W(kg)
L1	15.8	2.8
L2	16.8	4.2
L3	16.6	7.8
L4	13.8	8.2
L5	6.8	13.5
L6	21.2	2.5
L7	14.9	1.1
L8	0.1	0.3
L9	1.4	1.6
L10	0.4	0.9
L11	4.3	2.7
L12	26.8	2
L13	0.3	0.4
L14	20.1	1.9
L15	0.8	1.8
L16	11.8	3.3
L17	2.3	4.7
Total	**15**	**3.8**

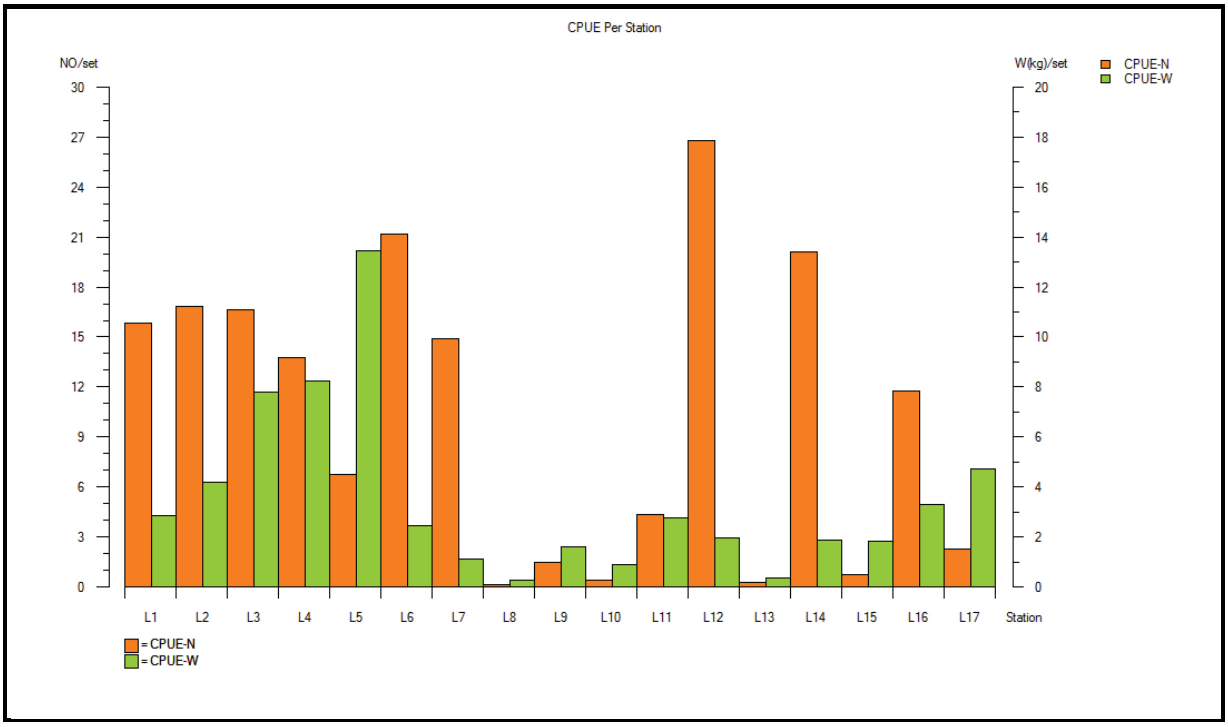

Figure 10.60: CPUE for the stations in Lindleyspoort Dam.

Gill net CPUE per habitat for Lindleyspoort Dam:
The deep pelagic zone or open water was the most productive. Large specimens were, however, also sampled in deep-water with vegetation (Table 10.35 and Figure 10.61). Shallow water areas and rocky habitats were the least productive.

Table 10.35: CPUE per habitat for Lindleyspoort Dam.

Setting Type/Code	Habitat Type	CPUE-N	CPUE-W(kg)
30	Deep littoral zone, veg	17.4	5.1
10	Shallow littoral zone, veg	17.3	2.4
40	Deep littoral zone, rocky	2.9	2.2
50	Deep pelagic zone	2.7	6
Total		**15.3**	**3.7**

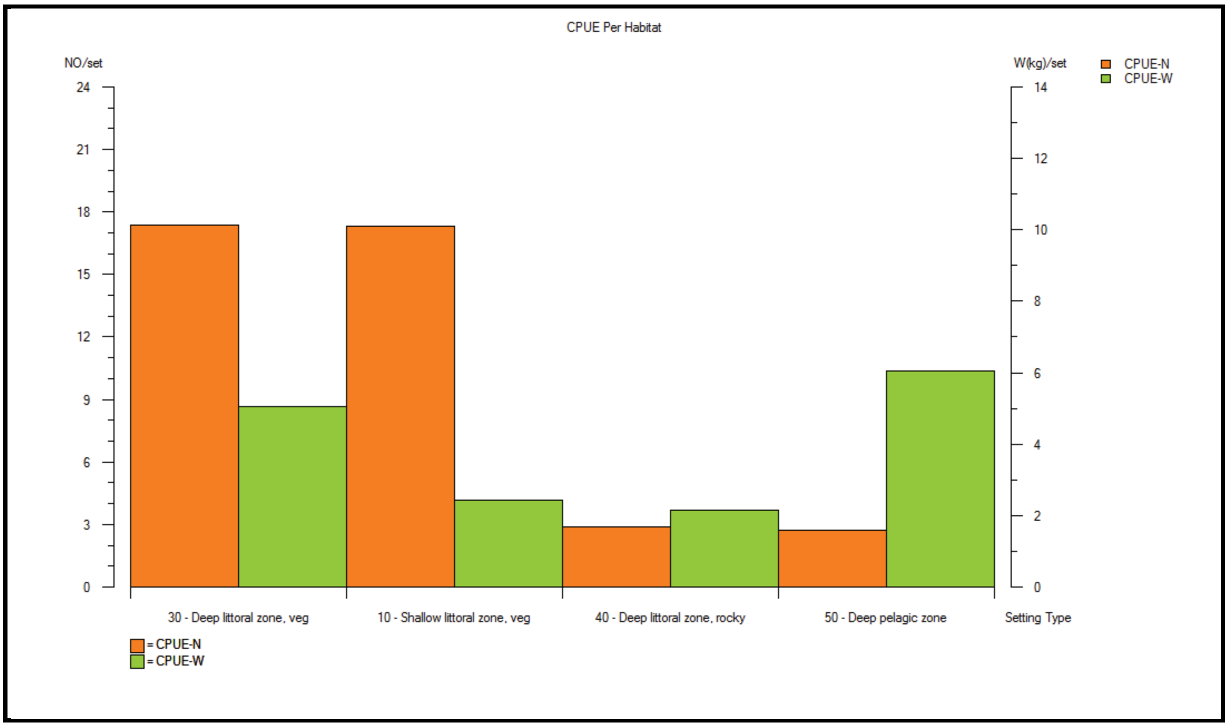

Figure 10.61: CPUE per habitat for Lindleyspoort Dam.

10.15.5 <u>Biomass and yield estimates for Lindleyspoort Dam</u>

The estimation of biomass and yield was done with the **swept area method** (Pauly, 1984):

Lindleyspoort Dam has a surface area of 1.8km². With the catch data the biomass and yield can be estimated for Lindleyspoort Dam with a Swept Area Model/Method.

The total fish biomass for Lindleyspoort Dam was estimated at 66.6 tons, and the total sustainable yield at 22.2 tons per year. This translates to 12.3 t/km²/yr or 123 kg/ha/yr.

Catfish, an undesirable species, made the highest contribution of 59.6% to the CPUE-W for the two surveys combined. A potential catfish biomass of 7.3 t/km²/yr (or 13.4 tons per year for the whole dam) could, therefore, be removed sustainably. To achieve the desired effects of biomanipulation or food web management up to 80% of the catfish biomass should, however, be removed, and this calculates to 17.6 t/km², or 31.76 tons for the whole dam during the start-up phase of such a programme.

As part of a food web management programme it is also estimated that 6.2 tonnes of carp should be removed. This adds up to a coarse fish removal of 37.96 tonnes. (medium to large species).

10.16 RUST DE WINTER DAM

10.16.1 Rust De Winter Dam Sampling Sites

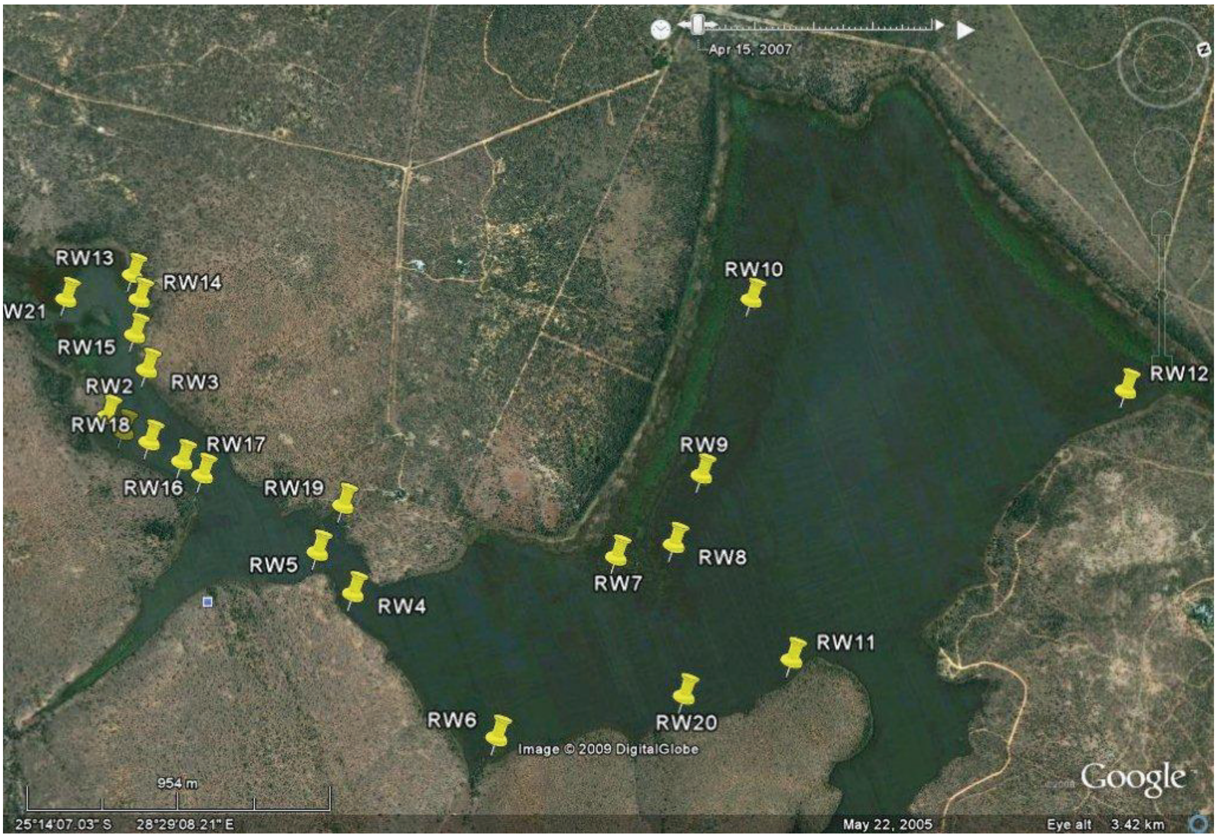

Figure 10.62: Rust De Winter Dam sampling sites

21 stations were identified and surveyed during both surveys with the aim to obtain data representative of the fish population in the dam (Figure 10.62).

During both surveys the water level of the dam was at approximately 100% of its full supply level.

Table 10.36 presents the station statistics, and sampling gears used in the different habitat types during the two surveys.

Table 10.36: Station statistics for Rust De Winter Dam (2008-2009).

Date	St. code	Latitude	Longitude	Gear	Set type
2008/11/18	1	25°14'57.32"S	28°28'53.47"E	Gill nets	Lake deep littoral zone, veg
2008/11/18	2	25°14'58.49"S	28°28'51.17"E	Gill nets	Lake deep littoral zone, veg
2008/11/18	3	25°14'53.12"S	28°28'47.31"E	147 mm	Lake deep pelagic
2008/11/19	4	25°14'39.29"S	28°29'19.89"E	Gill nets	Lake deep littoral zone, veg
2008/11/19	5	25°14'41.57"S	28°29'14.05"E	Gill nets	Lake deep littoral zone, rocky
2008/11/20	6	25°14'29.60"S	28°29'40.63"E	Gill nets	Lake shallow littoral zone, veg
2008/11/20	7	25°14'12.09"S	28°29'25.50"E	Gill nets	Lake shallow littoral zone, veg
2008/11/21	8	25°14'5.93"S	28°29'26.26"E	Gill nets	Lake shallow littoral zone, veg
2008/11/21	9	25°14'0.83"S	28°29'19.71"E	Gill nets	Lake shallow littoral zone, veg
2008/11/22	10	25°13'49.65"S	28°29'1.83"E	147 mm	Lake deep littoral zone, veg
2008/11/22	11	25°13'58.18"S	28°29'43.00"E	Gill nets	Lake shallow littoral zone, veg
2008/11/22	12	25°13'15.20"S	28°29'26.01"E	Gill nets	Lake deep littoral zone, veg
2009/03/16	13	25°14'51.69"S	28°28'35.79"E	Gill nets	Lake shallow littoral zone, veg
2009/03/16	14	25°14'51.76"S	28°28'38.88"E	147 mm	Lake shallow littoral zone, veg
2009/03/16	15	25°14'53.28"S	28°28'42.83"E	Gill nets	Lake shallow littoral zone, veg
2009/03/17	16	25°14'50.68"S	28°29'1.31"E	Gill nets	Lake deep littoral zone, veg
2009/03/17	17	25°14'52.31"S	28°28'59.01"E	147 mm	Lake deep pelagic
2009/03/17	18	25°14'55.00"S	28°28'55.60"E	Gill nets	Lake deep littoral zone, veg
2009/03/18	19	25°14'37.58"S	28°29'9.81"E	Gill nets	Lake shallow littoral zone, veg
2009/03/18	4	25°14'39.29"S	28°29'19.89"E	147 mm	Lake deep littoral zone, veg
2009/03/18	5	25°14'41.57"S	28°29'14.05"E	Gill nets	Lake deep littoral zone, veg
2009/03/19	11	25°13'58.18"S	28°29'43.00"E	Gill nets	Lake shallow littoral zone, veg
2009/03/19	20	25°14'9.97"S	28°29'42.97"E	147 mm	Lake shallow littoral zone, veg
2009/03/19	21	25°14'59.19"S	28°28'36.10"E	Gill nets	Lake deep littoral zone, veg

Shallow < 1.5m
Deep > 1.5m

10.17 RUST DE WINTER DAM SAMPLING STATISTICS

10.17.1 IRI for Rust De Winter Dam

An **Index of Relative Importance** (IRI) as described by Kolding (1989) was used to indicate the contribution each fish species made to the catch compositions.

The *percentage commonness* or frequency of occurrence, $\%F$ or %FREQ represents the *percentage probability* of a species occurring in the catch composition of an area if similar sampling methods were used. The $\%F$ for all the species combined does not add up to 100%.

The species were sorted descending in the tables from the highest to the lowest IRI value. The IRI value is a numerical value assigned to each specific species and is given in percentage of the total of the IRI values calculated for the relevant area. The IRI depicts the relative importance of a species in the fish population in terms of its abundance and weight contribution in the relevant catch composition.

A low IRI score does not necessarily mean that a species is less important. The IRI gives an indication of the fish population composition, and the weight each species carries in the population, in terms of its contribution to the total catch.

IRI for the Gill Nets Used in Rust De Winter Dam (2008-2009):
The Index of Relative Importance (Kolding, 1998) gives an indication of the contribution each fish species made in terms of numbers and weight to the total catch (and the fish population) (Table 10.37).

The IRI as recorded for Rust De Winter Dam during two seasonal surveys is shown in Table 10.37.

Rust De Winter Dam was selected as the control dam for the WRC study (no. 1643). It is a large oligotrophic dam, with good water quality and few impacts. The water of the dam is clear, and the dam lies in a conservation area surrounded by game farms. Aquatic vegetation is abundant.

A total of 1648 specimens were caught, and 12 species were recorded for the two surveys (Table 10.37). The Mozambique tilapia received the highest IRI score (34.2%), followed by the catfish (27.4%), and the bulldog (23.5%).

The Mozambique tilapia made a high contribution in numbers (24.3%) and the highest in weight (44.3%) to the total catch recorded (Table 10.37). The catfish made a contribution of 10.3% in numbers, and 30.9% in weight. The bulldog made the highest contribution in numbers (38.2%). Carp made a contribution of 8.4% to the total weight recorded.

Rust De Winter Dam (the control dam for this study) is the first and only dam where another species feature more prominently than the catfish. Most of the other species are well represented in numbers. The fish population of this dam probably provides a good indication/example of the expected fish population in non-eutrophic conditions.

Table 10.37: IRI for Rust De Winter Dam, 2008-2009.

Species	NO	% NO	W(kg)	% W	FRQ	% FRQ	IRI	% IRI
Oreochromis mossambicus	400	24.3	330.623	44.3	51	30.4	2083	34.2
Clarias gariepinus	169	10.3	230.709	30.9	68	40.5	1668	27.4
Marcusenius macrolepidotus	630	38.2	34.653	4.6	56	33.3	1429	23.5
Micropterus salmoides	98	5.9	40.646	5.5	49	29.2	332	5.5
Barbus mattozi	104	6.3	21.83	2.9	49	29.2	269	4.4
Barbus trimaculatus	132	8	1.683	0.2	22	13.1	108	1.8
Labeobarbus marequensis	55	3.3	19.297	2.6	27	16.1	95	1.6
Cyprinus carpio	32	1.9	62.77	8.4	15	8.9	93	1.5
Chetia flaviventris	24	1.5	1.813	0.2	15	8.9	15	0.2
Labeobarbus polylepis	2	0.1	0.434	0.1	2	1.2	0	0
Labeo molybdinus	1	0.1	1.05	0.1	1	0.6	0	0
Tilapia sparrmanii	1	0.1	0.007	0	1	0.6	0	0
Total	**1648**	**100**	**745.515**	**100**	**-**	**-**	**6093**	**100**

%IRI = Percentage of Total of IRI values calculated for each species in area
%N = Contribution in Percentage to Total Numbers sampled
%W = Contribution in Percentage to Total Weight sampled
%F = Frequency of Occurrence

Figure 10.63 provides a graphical display of the contribution each of the fish species sampled made to the total catch. The contribution in weight is indicated above the x-axis, and the contribution in numbers below the x-axis. %F (frequency of occurrence) at the bottom of the graph indicates the percentage probability of obtaining the same catch if similar sampling methods were used.

Figure 10.63 shows the contribution each of the first three species (Mozambique tilapia, catfish and bulldog) made to the total catch in terms of numbers and/or weight. Most of the other species are relatively well represented in numbers.

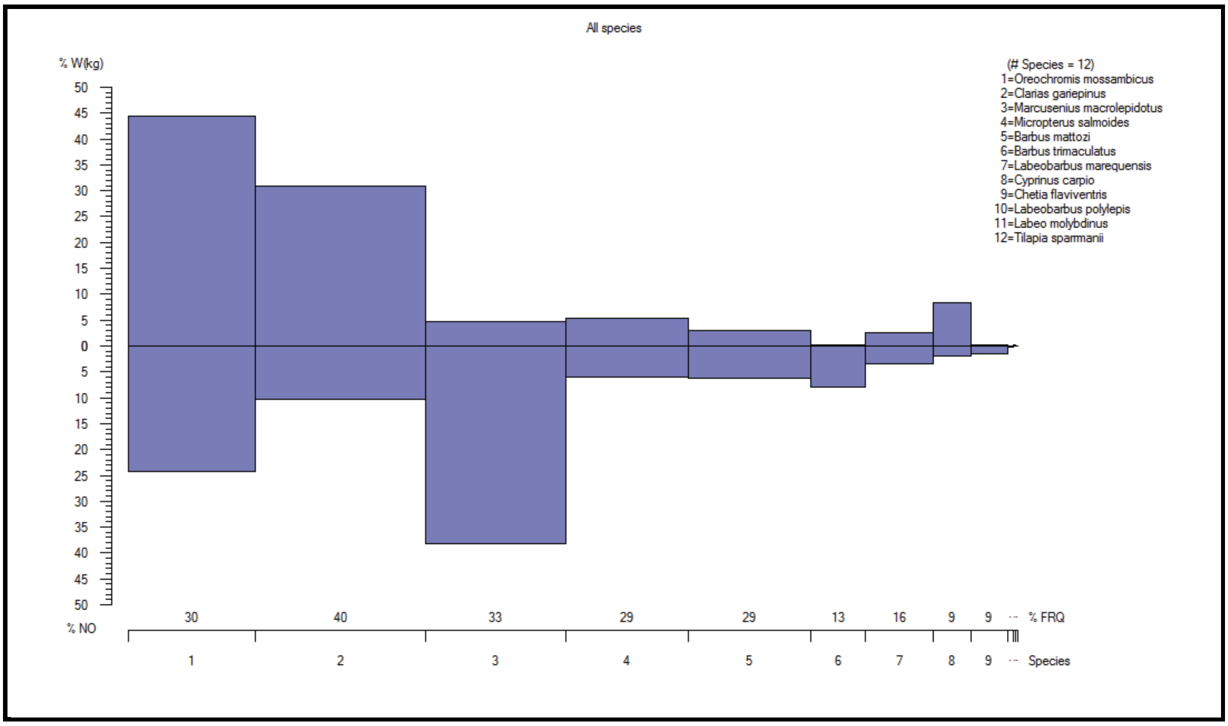

Figure 10.63: IRI for Rust De Winter Dam, 2008-2009.

10.17.2 <u>Catch Statistics for the Gill Nets in Rust De Winter Dam, 2008-2009</u>

Table 10.38 indicates the number of each species sampled in each mesh size (upper section of table). *Chetia flaviventris* was sampled in low numbers, with larger specimens sampled mostly in the 57 mm mesh.

Clarias gariepinus was sampled in a wide range of mesh sizes, with the 57-150 mm meshes being the most effective (Table 10.38). Most catfish were sampled in a medium length range (45 cm-60 cm) in the 93 mm and 118 mm meshes, giving the indication that very large specimens are less abundant.

Low numbers of *Cyprinus carpio* were recorded, but the 147 mm and 150 mm meshes seem to be the most effective for catching this species (Table 10.38).

The larger meshes sampled mostly *Oreochromis mossambicus, Clarias gariepinus,* and *Cyprinus carpio* (Table 10.38). *Labeobarbus polylepis, Tilapia sparrmanii,* and *Labeo molybdinus* were rarely sampled.

The second section (lower section) of Table 10.38 indicates the total number of fish sampled in each of the gill nets, the contribution in percentage each mesh made to the total number recorded, the number of settings for each mesh, the average number of fish sampled in each mesh, and the mean lengths and weight sampled in each mesh.

Table 10.38: Catch Statistics for the Gill Nets in Rust De Winter Dam, 2008-2009.

Species	Gill Net Mesh Size (MM)										Total
	22	28	35	45	57	73	93	118	147	150	
Chetia flaviventris	3		6	2	12	1					24
Oreochromis mossambicus	1		3	9	11	20	31	240	77	8	400
Clarias gariepinus		1	2	6	18	16	51	54	10	11	169
Cyprinus carpio				1	4	1		1	17	8	32
Labeobarbus marequensis		1		13	18	16	6	1			55
Barbus mattozi		1	22	38	16	20	6		1		104
Labeobarbus polylepis					2						2
Barbus trimaculatus	64	65	3								132
Micropterus salmoides				17	25	15	36	5			98
Tilapia sparrmanii		1									1
Marcusenius macrolepidotus	4	25	425	145	31						630
Labeo molybdinus							1				1
Total	72	94	461	231	137	89	131	301	105	27	1648
% NO	4.4	5.7	28	14	8.3	5.4	7.9	18.3	6.4	1.6	100
No of settings for each mesh	18	18	18	18	18	18	18	18	6	18	168
AV NO/Mesh	4	5.2	25.6	12.8	7.6	4.9	7.3	16.7	17.5	1.5	9.8
ML(mm)/Mesh	88.7	111	157	203	251	323	393	396	434	582	262
MW(g)/Mesh	9	22	44	115	231	511	769	999	1427	2514	452

MW = Mean Weight in grams
ML = Mean Length in mm

10.17.3 Species Statistics for the Gill Nets in Rust De Winter Dam, 2008-2009

Table 10.39 provides the total number of each species sampled, their average weight and length, and the biomass (g) contribution each species made to the gill net series (or range, from 22 mm to 150 mm, all meshes included) per setting. The biomass contribution was calculated for each mesh with a length of 10m. *Clarias gariepinus* and *Oreochromis mossambicus* made the largest contributions to the biomass recorded. *Clarias gariepinus* was sampled with a mean weight of 1365 g (1.37 kg) and a mean length of 537 mm (53.7 cm). Carp was sampled with a mean weight of 1.96 kg.

Table 10.39: Species Statistics for the Gill Nets in Rust De Winter Dam 2008-2009.

Species	Total	% NO	W(g)/NO	L(mm)/NO	Biomass(g)/set
Chetia flaviventris	24	1.5	75.5	165	11
Oreochromis mossambicus	400	24.3	826.6	342	1968
Clarias gariepinus	169	10.3	1365.1	537	1373
Cyprinus carpio	32	1.9	1961.6	463	374
Labeobarbus marequensis	55	3.3	350.9	267	115
Barbus mattozi	104	6.3	209.9	230	130
Labeobarbus polylepis	2	0.1	217	241	3
Barbus trimaculatus	132	8	12.8	95	10
Micropterus salmoides	98	5.9	414.8	277	242
Tilapia sparrmanii	1	0.1	7	80	0
Marcusenius macrolepidotus	630	38.2	55	167	206
Labeo molybdinus	1	0.1	1050	390	6
Total	**1648**	**100**	**452.4**	**261**	**4438**

MW = Mean Weight in grams
ML = Mean Length in mm

10.18 SPECIES SELECTION FOR A FISHERY IN RUST DE WINTER DAM

This section aims to identify and select the most appropriate species, which are likely to succeed in terms of a fisheries exploitation project. The species selected all have potential for exploitation in a fisheries project, however, some more than others.

Gill net selectivity was explored for the species. A multifilament gill net range of nine (9) meshes were used during the survey, which included a 22 mm, 28 mm, 35m, 45 mm, 57 mm, 73 mm, 93 mm, 118 mm and a 150 mm mesh. Each of these meshes has a length of ten metres. A 147 mm mesh monofilament gut gill net was also used, and it has a length of 80 metres. The length of the 147 mm mesh were standardised to 10m during calculations.

The fish retained in a gear is usually only an unknown proportion of the various size classes available in the fished population. Selectivity is a quantitative expression of this proportion and represented as a probability of capture of a certain size of fish in a certain size of mesh. The mesh selectivity was indirectly estimated with methods as described by Kolding, 1998.

10.18.1 Species selection

Three species may be considered for selection as species with potential for utilisation in a fisheries project. The IRI was used as a guideline, as it highlights the important species in terms of their contribution to weight and numbers. The species, which may be considered, are *Clarias gariepinus, Cyprinus carpio,* and *Oreochromis mossambicus. Cyprinus carpio* did not make large contributions to the total numbers and weight recorded; however, it is an undesirable alien (introduced) species with negative impacts on the environment and habitat of other species, as it is a habitat altering species (as described by Kleynhans, 1999 and 2001)

The three species are well represented in Rust De Winter Dam, and *Oreochromis mossambicus* occurs in high numbers. This species must only be exploited in a sustainable manner, if a fisheries project is considered.

Clarias gariepinus and *Cyprinus carpio* produce high numbers of offspring due to their high fecundity. High numbers of juvenile fish after the spawning season may have a significant impact on the zooplankton population due to predation, and the exploitation of the breeding stock of these species, may benefit the zooplankton population. The removal of these two species will also alleviate the pressure on the other fish species (i.e. competition for food and habitat, and predation from catfish).

The feeding habits of carp and catfish may also negatively influence water quality, as it tends to re-suspend organic materials and small sediment particles back into the water column (through its constant churning of bottom sediments in search of food), which makes it available for use by other organisms, such as algae.

10.18.2 Length frequencies recorded for selected species

CPUE was calculated for each of the meshes at a standard effort. The standard effort for a mesh was 10m² net area set for 12 hours.

Oreochromis mossambicus:
Figure 10.64 graphically displays the length frequencies recorded for *Oreochromis mossambicus* in the different gill nets, as well as the mean length for each mesh size. *Oreochromis mossambicus* is a medium to large species, and mostly large and mature specimens were sampled in the larger mesh gill nets. A strong breeding population is present in the dam.

Oreochromis mossambicus was sampled within its length range of 8-46 cm with the 22 mm to 150 mm mesh sized gill nets (Figure 10.64). The highest number (240) of fish was recorded in the 118 mm mesh gill net.

The length frequencies recorded (Figure 10.64) gives an indication of different length cohorts representative of age classes, and successful breeding and recruitment during previous seasons, although juvenile and small fish were sampled in low numbers. Large specimens of this species were abundant. Fish in the 33-35 cm length range were the most abundant. Fish in this length range could be sustainably removed with the 118 mm mesh gill net, if a fisheries project is considered.

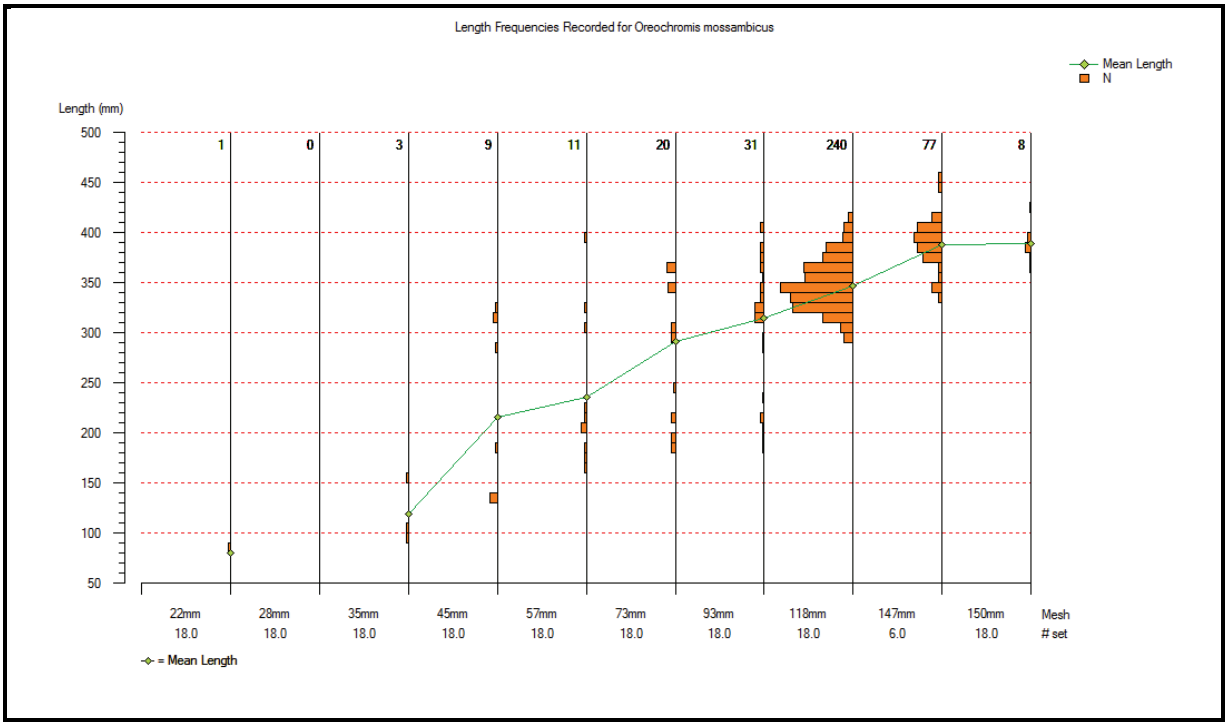

Figure 10.64: Length frequencies recorded for *Oreochromis mossambicus*.

Cyprinus carpio:
Cyprinus carpio was sampled in low numbers, but several length cohorts were recorded, indicating successful breeding during previous seasons (Figure 10.65).

Specimens were sampled in a length range of 14-67 cm in the gill nets (Figure 10.65). Mostly large specimens were sampled in the 147 mm and 150 mm mesh gill nets, and these nets could be used in its removal.

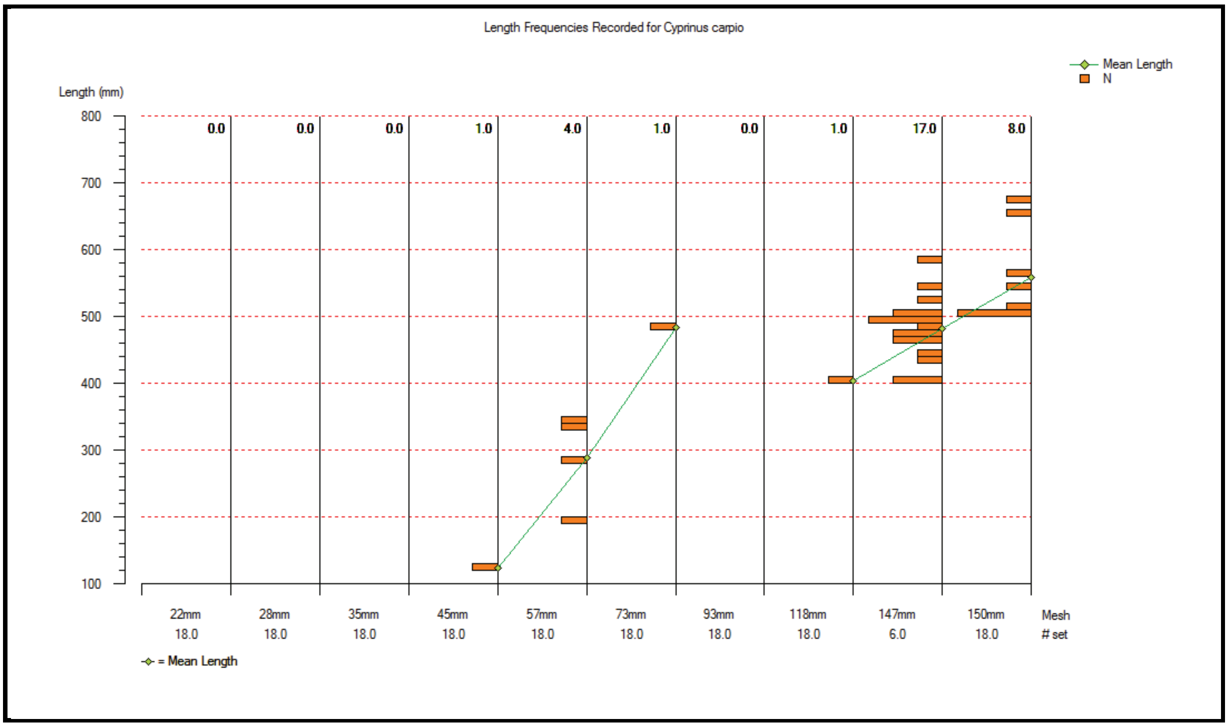

Figure 10.65: Length frequencies recorded for *Cyprinus carpio*.

Clarias gariepinus:
Specimens were sampled in a length rage of 24 cm-92 cm in the 28 mm-150 mm mesh gill nets (Figure 10.66). The 93 mm and 118 mm meshes were the most effective in sampling medium to large specimens. There seems to be a healthy breeding population, as several length cohorts were recorded. Large specimens are present in the system, although the medium sized fish in the 44 cm-60 cm length range seems to be dominant.

The 93 mm to 150 mm mesh gill nets all have potential as target gear for this species. These nets will effectively target the broodstock.

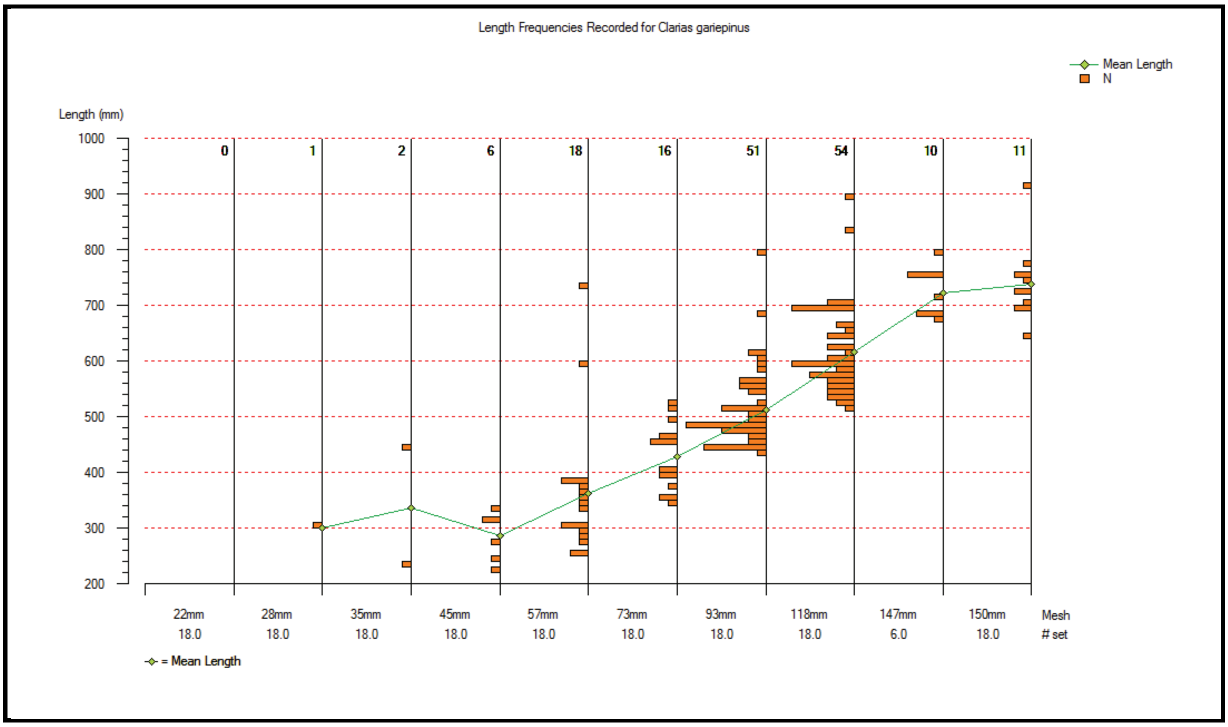

Figure 10.66: Length frequencies recorded for *Clarias gariepinus*.

10.18.3 Gill net selectivity for selected species

Oreochromis mossambicus:
The probability ranges between 95% and 100% that this species will be sampled with the 22-150 mm gill net meshes (Figure 10.67). Fish in a length range of 30-42 cm are the most likely to be sampled with the 93 mm-150 mm mesh gill nets. This species should only be considered for sustainable utilisation.

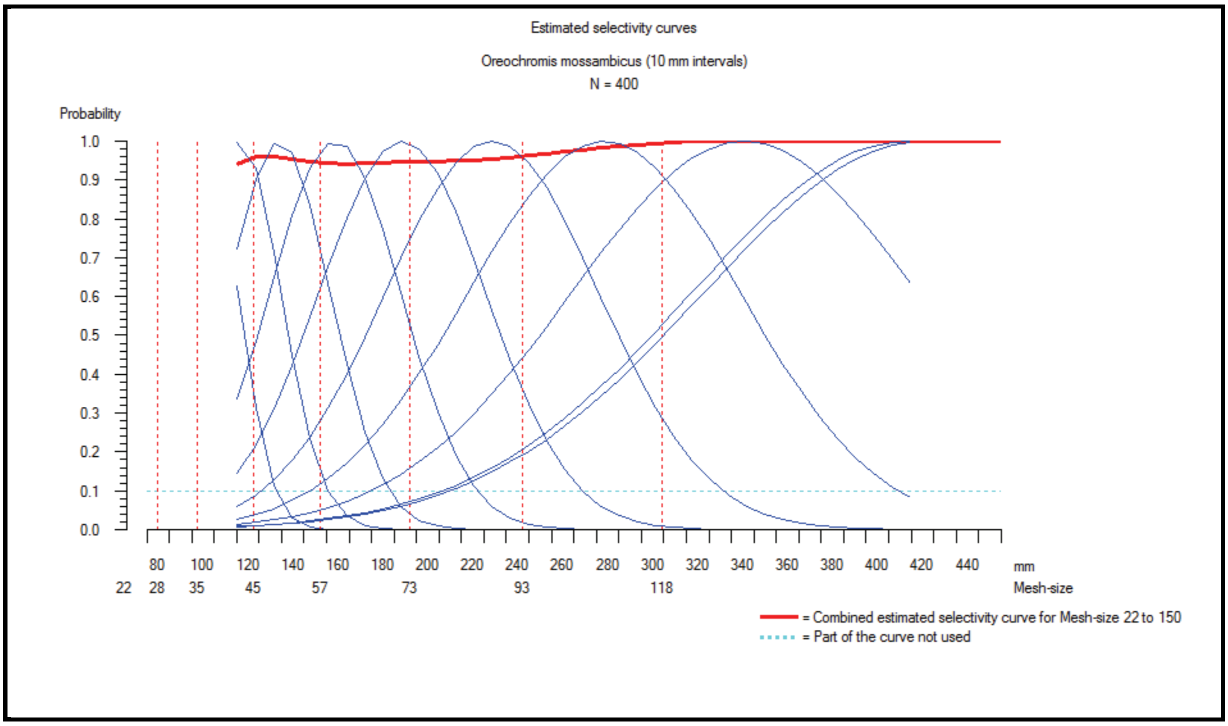

Figure 10.67: Estimated gill net selectivity for *Oreochromis mossambicus*.

Clarias gariepinus:
The probability is high (80%-100%) for sampling large fish (55-80 cm) in the 93 mm to 150 mm meshes (Figure 10.68).

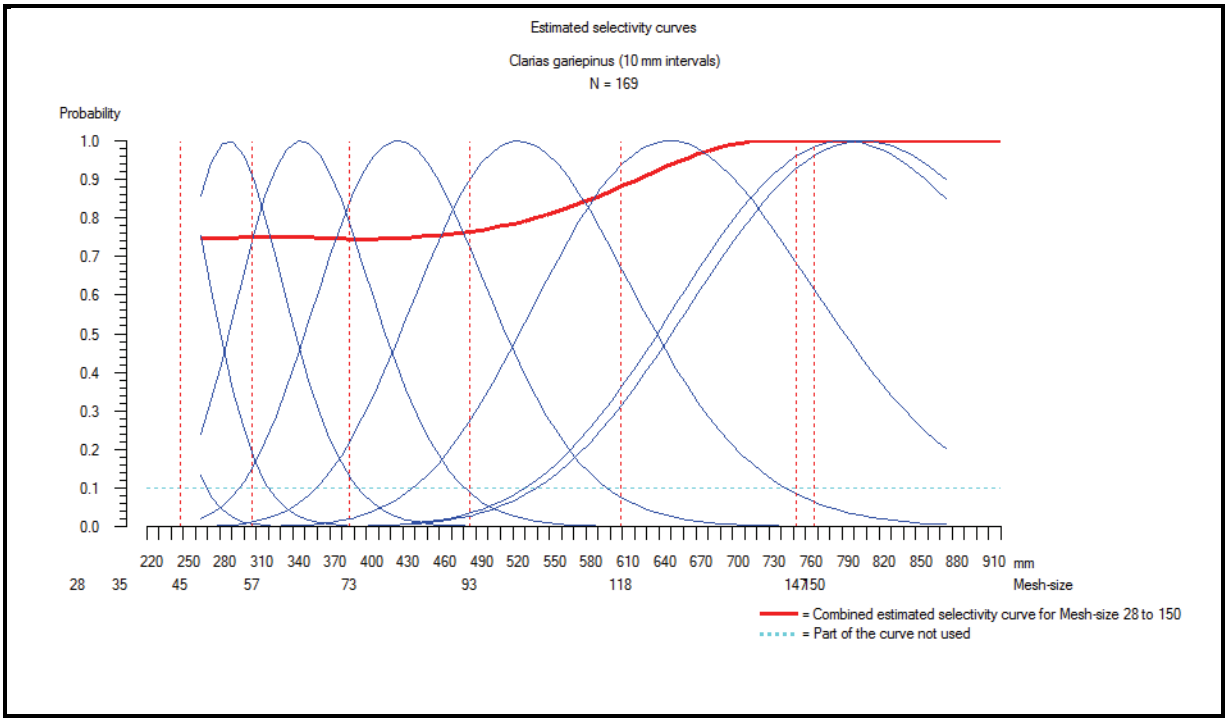

Figure 10.68: Estimated gill net selectivity for *Clarias gariepinus*.

Cyprinus carpio:

The probability of sampling fish in the 18-36 cm length range with the 45 mm-93 mm meshes ranges between 50%-70% (Figure 10.69). The probability becomes higher (100%) for sampling fish in the 44 cm-58 cm length range with the 147 mm and 150 mm mesh gill nets. These nets can be considered in the removal of this species, if bio-manipulation is considered.

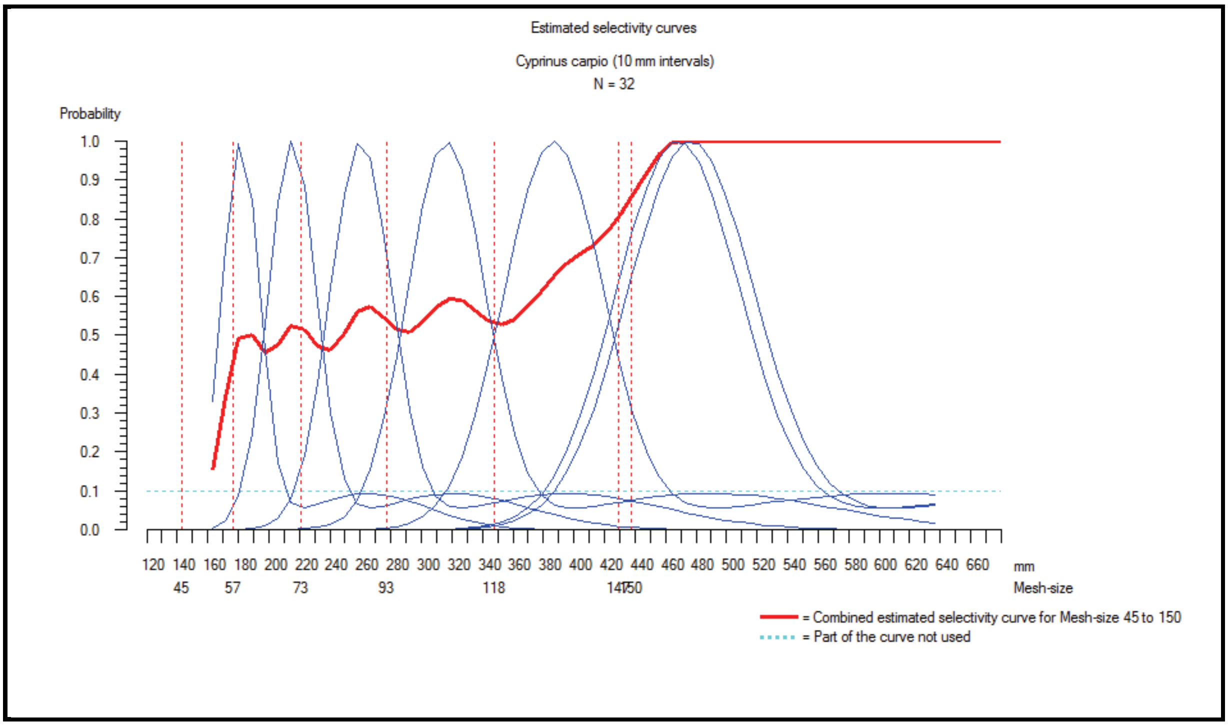

Figure 10.69: Estimated gill net selectivity for *Cyprinus carpio*.

10.18.4 CPUE for the Species Sampled in Rust De Winter Dam, 2008-2009

Table 10.40 provides the Catch Per Unit Effort (in numbers – N, and weight – W) for the gill nets used in Rust De Winter Dam, 2008-2009. Ten gill net mesh sizes were used to limit selectivity (22, 28, 35, 45, 57, 73, 93, 118, 147, and 150 mm). The gill net catch effort were standardised to 10m² set for 12 hours.

The Mozambique tilapia made the largest contribution to the CPUE recorded in weight (1.5 kg per 10m² per setting), followed by the catfish (1.2 kg) (Table 10.40). The other species mostly made their contribution to the CPUE recorded in numbers. The Mozambique tilapia and bulldog made the highest contributions in numbers to the CPUE (N = 2, and N = 3.8 respectively).

The total CPUE in numbers and weight at the end of Table 10.40 is the average CPUE calculated for the ten meshes combined with a net area of 10m². The CPUE's recorded indicate that 9.3 specimens with a weight of 3.7 kg were sampled in a net area of 10m².

Table 10.40: CPUE for the species sampled in Rust De Winter Dam.

Species	NO	% NO	W(kg)	% W	CPUE-N	CPUE-W(kg)
Oreochromis mossambicus	333	21.4	253.747	41.3	2	1.5
Clarias gariepinus	160	10.3	207.359	33.8	1	1.2
Micropterus salmoides	98	6.3	40.646	6.6	0.6	0.2
Marcusenius macrolepidotus	630	40.5	34.653	5.6	3.8	0.2
Cyprinus carpio	17	1.1	32.101	5.2	0.1	0.2
Barbus mattozi	103	6.6	21.581	3.5	0.6	0.1
Labeobarbus marequensis	55	3.5	19.297	3.1	0.3	0.1
Chetia flaviventris	24	1.5	1.813	0.3	0.1	0
Barbus trimaculatus	132	8.5	1.683	0.3	0.8	0
Labeo molybdinus	1	0.1	1.05	0.2	0	0
Labeobarbus polylepis	2	0.1	0.434	0.1	0	0
Tilapia sparrmanii	1	0.1	0.007	0	0	0
Total	**1556**	**100**	**614.371**	**100**	**9.3**	**3.7**

Graphical display of the CPUE for all species sampled in Rust De Winter Dam:
Figure 10.70 gives a graphical representation of the gill net catches in numbers and weight (kg) for each species (CPUE per gill net panel (10m² for 12h), for all mesh sizes combined). *Oreochromis mossambicus* (Mozambique tilapia) made the largest contribution in weight (1st green bar), followed by *Clarias gariepinus* (catfish) (2nd green bar). The bulldog (*Marcusenius macrolepidotus*) made the highest contribution in numbers (4th orange bar).

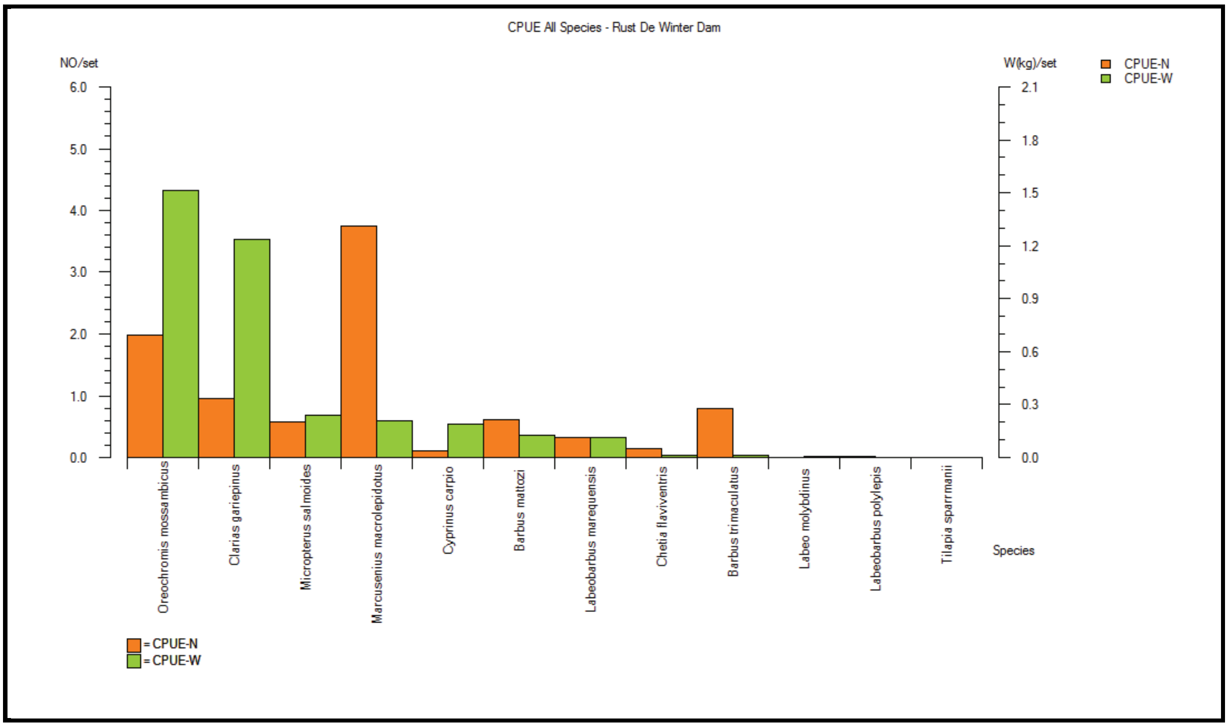

Figure 10.70: CPUE for the species sampled in Rust De Winter Dam.

Gill net CPUE-W per station for Rust De Winter Dam:
The highest CPUE-W (weight in kg) was recorded at station R10 and R3, followed by stations R1 and R21 (Table 10.41 and Figure 10.71). The highest CPUE-N (in numbers) was recorded at station R21, followed by stations R1 and R12.

Table 10.41: CPUE per station for Rust De Winter Dam.

Station	CPUE-N	CPUE-W(kg)
R 1	15.3	5.7
R 2	10.4	5.2
R 3	5.1	6.2
R 4	13.8	4.5
R 5	4.7	2
R 6	8.8	4.9
R 7	9.1	2.9
R 8	6.1	4.6
R 9	7.7	4.8
R 10	5	6.2
R 11	8.4	2.9
R 12	15.2	4.9
R 13	8.1	3.3
R 14	1.4	3
R 15	10	2.2
R 16	5.6	2.2
R 17	1	1.9
R 18	2.7	1.6
R 19	7.9	3.8
R 20	0.1	0.4
R 21	23.1	5.4
Total	**9.3**	**3.7**

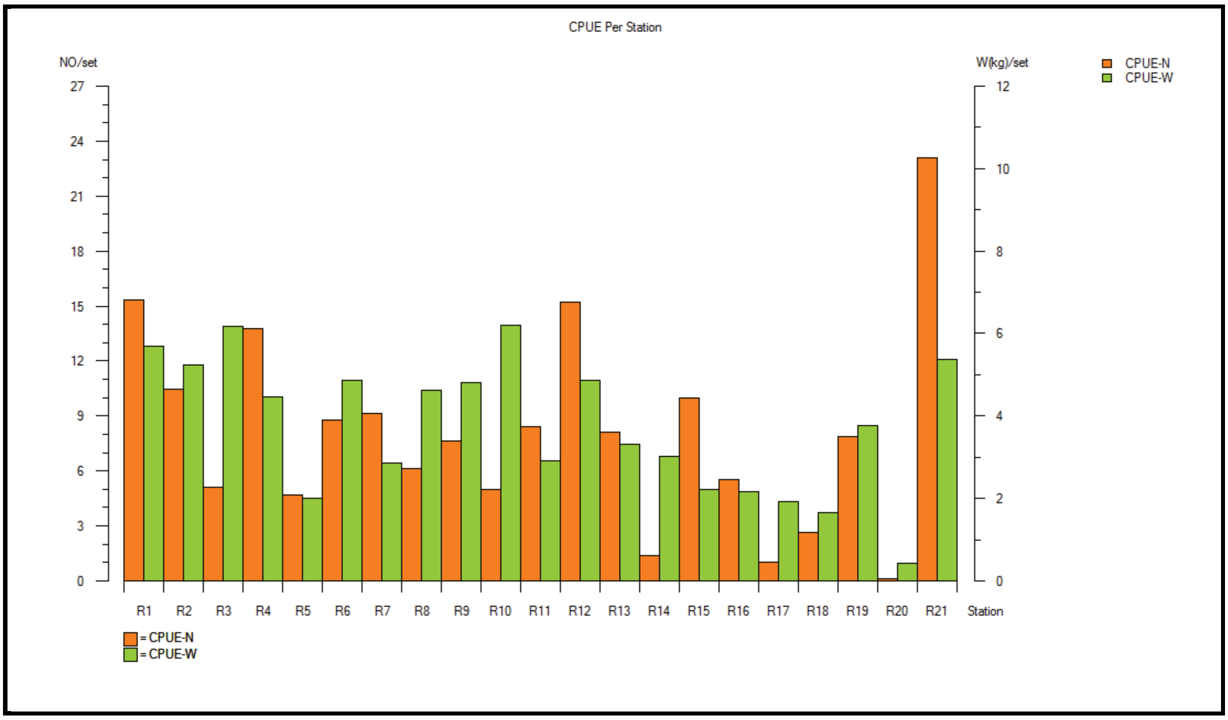

Figure 10.71: CPUE for the stations in Rust De Winter Dam.

Gill net CPUE per habitat for Rust De Winter Dam:
The deep pelagic or open water zone was the most productive in terms of bio-mass caught. The other habitats were, however, also productive (Table 10.42 and Figure 10.72).

Table 10.42: CPUE per habitat for Rust De Winter Dam.

Setting Type/Code	Habitat Type	CPUE-N	CPUE-W(kg)
10	Shallow littoral zone, veg	8.1	3.5
30	Deep littoral zone, veg	11.1	3.8
40	Deep littoral zone, rocky	6.6	3.6
50	Deep pelagic zone	3.1	4.1
Total		**9.3**	**3.7**

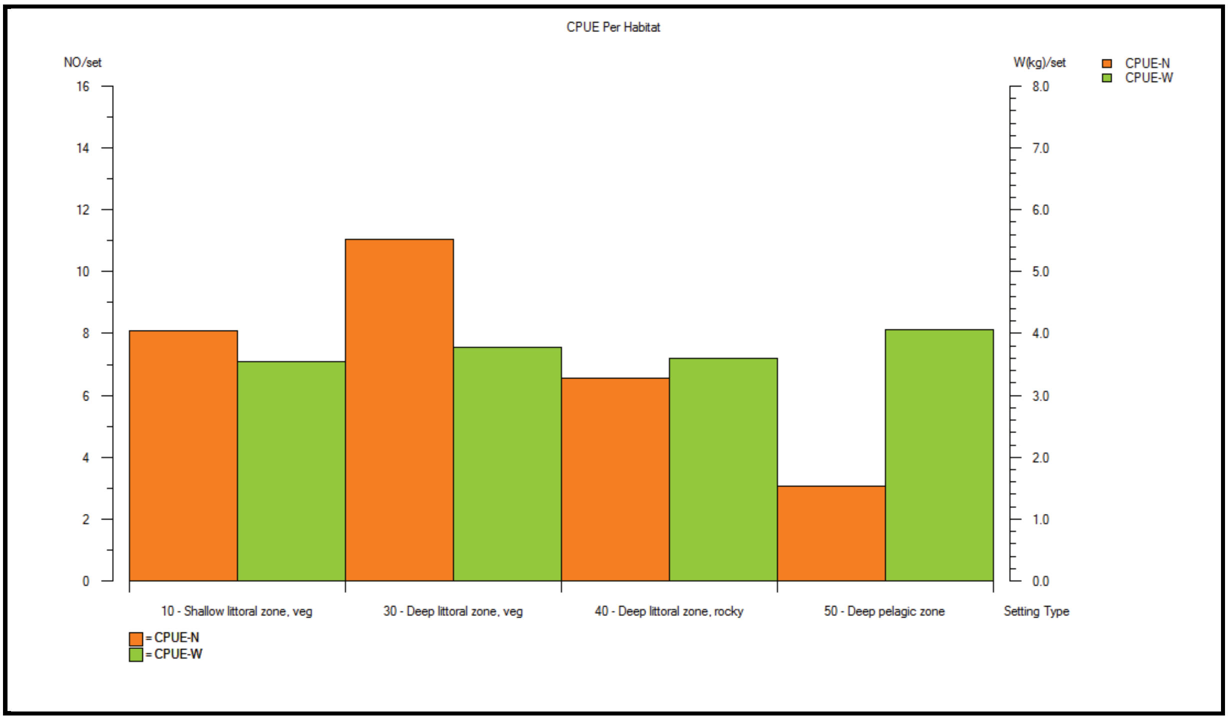

Figure 10.72: CPUE per habitat for Rust De Winter Dam.

10.18.5 Biomass and yield estimates for Rust De Winter Dam

The estimation of biomass and yield was done with the **swept area method** (Pauly, 1984):

Rust De Winter Dam has a surface area of 4.73km^2. With the catch data the biomass and yield can be estimated for Rust De Winter Dam with a Swept Area Model/Method.

The total fish biomass for Rust De Winter Dam for the two surveys combined was estimated at 175 tons, and the total sustainable yield at 58.3 tons per year. This translates to 19.4 t/km^2/yr or 194 kg/ha/yr.

Catfish, an undesirable species, made the second highest contribution of 33.8% to the CPUE-W. A potential catfish biomass of 4.16 t/km^2/yr (or 19.72 tons per year for the whole dam) could, therefore, be removed sustainably.

If bioremediation is considered for this dam, in order to prevent future problems, 80% of the catfish biomass to be removed calculates to 10 t/km^2 or 47.3 tons for the whole dam during the start-up phase of such a programme. The carp biomass to be removed as part of a food web management programme is calculated at 7.3 tons. This adds up to a total coarse fish biomass of 54.62 tons to be removed if food web management is considered.

Currently there seems to be a balance in the fish population and bioremediation does not seem necessary, and the water quality of the dam also seems to be in good condition. A seemingly strong population of crocodiles in the dam may also have an impact on the catfish population in terms of predation and control of catfish numbers.

10.19 POTENTIAL VIABILITY OF BIOMANIPULATION AND COMMUNITY-BASED FISHERIES PROGRAMMES FOR ALL THE DAMS

All the dams in this study have potential for a community based fishery, which may form part of a food web manipulation programme, by eradication of undesirable species in the fish communities of the dams. In Rust De Winter dam food web manipulation would, however, be considered a preventative management strategy to eliminate future problems with the fish population dynamics and the food web.

10.19.1 Species selection for biomanipulation

Species selected for Rietvlei Dam:
Undesirable species: Catfish, carp, and canary kurper.
Desirable, exploitable: Smallscale yellowfish.

Species selected for Roodeplaat Dam:
Undesirable species: Catfish, carp, and canary kurper
Desirable, exploitable: Mozambique tilapia and largescale yellowfish.

Species selected for Bon Accord Dam:
Undesirable species: Catfish and carp.

Species selected for Koster River Dam:
Undesirable species: Catfish and carp
Desirable, exploitable: Mozambique tilapia and smallmouth yellowfish.

Species selected for Lindleyspoort Dam:
Undesirable species: Catfish and carp
Desirable, exploitable: Mozambique tilapia.

Species selected for Rust De Winter Dam:
Undesirable species: Catfish and carp
Desirable, exploitable: Mozambique tilapia.

10.19.2 Discussion of selected species

The catfish is dominant in all the dams (except Rust De Winter Dam) and carp occurs to a lesser extent in most of the dams. Carp is well represented in Bon Accord Dam.

Chetia flaviventris is an extremely efficient carnivorous fish, equivalent to bass, and will have a significant impact on zooplankton colonies, other invertebrates and larval fish. Furthermore, the catfish and carp have very high fecundities. A single large (4 kg) female of each of the carp and catfish can produce in excess of one million larvae per spawning. Based on their feeding behaviour, the larvae of both these species can be classified as zooplanktivorous, and they consume large quantities of zooplankton, thus exerting huge pressure on zooplankton populations. It is obvious that primary production may exceed the grazing potential of zooplankton communities affected by the above species.

As a result of eutrophication, total biomass and species composition of a fish community change – typically fish biomass is positively-correlated with nutrient availability (trophy). This process especially favours benthivorous fish such as carp and catfish. While foraging in the benthic zone and bringing nutrients back into pelagic water, these fish may be of major importance behind the mass development of phytoplankton.

Proposed remediation (food web manipulation) incorporates a restructuring of the coarse fish populations by large-scale catch and removal operations. Coarse fish in this instance refers mainly to catfish as identified by the index of relative importance for each dam, although carp and the canary kurper is also considered. This is intended to offset "top-down" grazing pressures on the zooplankton and macro benthos communities of the reservoirs.

Recent large-scale bio-manipulations (Hansson *et al.*, 1998) have made it possible to update earlier recommendations regarding when, where and how a manipulation programme should be performed: (1) the reduction in the biomass of planktivorous fish should be 75% or more (In this study it is mainly applicable to *Clarias gariepinus,* and to a lesser extent to *Chetia flaviventris*, and *Cyprinus carpio*); (2) the fish reduction should be performed efficiently and rapidly in few years time; (3) efforts should be made to reduce the number of benthic feeding fish (*Clarias gariepinus* and *Cyprinus carpio*); (4) the recruitment of young of the year fish should be reduced (broodstock of high fecundity species *i.e. Clarias gariepinus* and *Cyprinus carpio* will be targeted); (5) the external input of nutrients should be reduced as much as possible before biomanipulation is implemented (the support of DWA, GDARD and NW-DACERD, and other relevant authorities is essential, furthermore these authorities should be involved to streamline the process of establishing a fully functional Water Users Association). The aforementioned feeding modes remain to be confirmed in the study dams.

In order to initiate the restoration of the zooplankton and macro benthos communities, it is essential to implement the restructuring of the fish community, as quickly as possible, if restructuring is deemed necessary. Establishment of mesocosms or floating wetlands to provide suitable habitat for zooplankton and other aquatic biota, precipitation of bonded phosphate and eradication of undesirable fish species, are synergistic actions in the holistic process of food web manipulation and the current standing crop of undesirable fish species needs to be reduced to about 20% of the biomass.

No introductions of other species will be necessary in most of the dams, as the dams contain all the elements of a successful fishery. Restocking of *Oreochromis mossambicus* into Rietvlei Dam may be necessary. Although it has been stocked previously into Rietvlei Dam, this species was not sampled during the study – but it is speculated that the dam may be too cold. The absence of this species from Rietvlei Dam may be due to predation pressure from catfish. Catfish often hunt tilapia schools in "packs", and can effectively eradicate an entire school of prey fish. By targeting the fish species as recommended, the fish communities will naturally shift towards *Oreochromis mossambicus* (Mozambique tilapia or blou kurper) as the most important species. This species has tremendous commercial potential as a high quality table fish. From an ecological perspective this is a highly desirable species as it has an omnivorous feeding behaviour and is also an algal feeder.

10.19.3 Motivation

South Africa is a semi-arid country, with the annual rainfall below the world average, and high evaporation rates (Koekemoer and Steyn, 2003). Seasonal rainfall often occurs as high-intensity storms of short duration and results in runoff that washes silt, organic and inorganic material, which has accumulated in the catchments into the water bodies. Consequently, both the quality and quantity of water are affected by increases in anthropogenic activity. Water quantity and quality are of particular importance in South Africa where water is a limited natural resource.

Any attempt in the sustainable utilisation of freshwater fish in South Africa should therefore seriously address the problems of water quality and quantity in the production and harvesting strategy. One such strategy is to utilise freshwater fish in a bioremediation programme. Such a strategy will, however, be worthless if it is not based on sound economic principles.

The end product or species to be produced and harvested should be of high quality and should be able to sell at a high price. A reliable market with a good price will serve as a motivation to apply a biomanipulation strategy by restructuring the fish community in a bioremediation programme.

A suitable freshwater fish species to be harvested as part of a bioremediation programme is the Mozambique tilapia. Tilapia is the second most important aquaculture species in the world today, and the third most important "seafood" commodity imported into the U.S.A. after marine shrimp and Atlantic salmon (Koekemoer and Steyn, 2003). For the past several years, the world's production of cultured and wild-caught tilapia has reached over 800 000 MT. In the 1980s a study using as the main variables fish colour and size, determined that the potential for massive tilapia consumption in the U.S.A. was essentially unlimited. Tilapia has undoubtedly become one of the most popular seafood products in the U.S.A., and this is evident from the growth rate experienced by imports in the past few years.

The project design therefore includes: a high quality end product; competing for an existing market with a favourable exchange rate; an economically viable operation and the development of technology for the sustainable utilization of our scarce water resource.

The aquaculture output of sub-Saharan Africa has been estimated to be approximately 29474 metric tons (Koekemoer and Steyn, 2003). The most common species farmed in Africa are cichlids (commonly known as Tilapia) and these make up 43% of production.

Tilapia is a genus from the Cichlidae family (cichlids), but cichlids are often commonly referred to as Tilapia. The six most popular cichlids are *Oreochromis. andersonii*, *O. mossambicus, O. niloticus*, *T. rendalli*, *O. macrochir* and *O. aureus*.

Oreochromis mossambicus is widely cultivated throughout the world and particularly in Asia (Koekemoer and Steyn, 2003). Up to almost half of aquaculture production in sub-Saharan Africa is from the culture of cichlids. These species are favoured because of their ease of production, fast growth rate, trophic plasticity and general tolerance of poor water quality conditions.

11 DISCUSSION

The findings of this research project may be summarized as follows

FINDINGS

Dams in the test set

The characteristics of the seven impoundments, including Hartbeespoort Dam, are summarized in **Table 1**:

Table 1: Summarized characteristics for each dam (Data from Harding, 2008; Van Ginkel et al. 2007 and DWAF, 2004 – NEMP). The data are ranked according on the basis of increasing median annual Total Phosphorus (TP). Nutrient and chlorophyll-a data are annual medians.

		Rust de Winter	Lindleyspoort	Koster	Hartbeespoort	Roodeplaat	Bon Accord	Rietvlei
Parameter	Units							
Vol (FSL)	MCM	28	14	12	193	41.2	4.4	12.3
Mean depth	m	5.7	7.4	4.8	9.6	10.6	3.6	6.2
Max depth	m	18	22	13	33	43	7.4	19
HRT	yr	0.3	0.5	-	0.81	1.28	-	0.4
Surface area	km^2	4.9	1.9	2.6	20	3.97	1.7	2.06
Min water temp	deg C	17	13	14	14	15	11	10
Max water temp	deg C	28	28	27	26	28	29	31
Sediment Content	% Volume	4.4	12.3	1.7	16	4.4	33	4.6
Total P	ppb	42	44	68	104	208	285	360
Ortho-P	ppb	20	20	24	55	118	102	223
Chlorophyll-a	ppb	2	4	4	12	33	113	27
Trophy		Mesotrophic	Mesotrophic	Eutrophic	Eutrophic	Hypertrophic	Hypertrophic	Hypertrophic

Fish populations

The fish assemblages found in the seven reservoirs are summarized in **Table 2**. The number of fish species per dam ranged from seven (Kosterrivier) to thirteen (Lindleyspoort), with an average of 10 species per dam. Only three species, common carp (*C. carpio*), sharptooth catfish (*Clarias gariepinus*) and Mozambique tilapia (*Oreochromis mossambicus*) were found in all seven dams. The two biogenically clearwater control dams, Lindleyspoort and Rust de Winter, had the highest species diversity with, respectively, thirteen and twelve species. Kosterrivier Dam, the turbid dam, had seven species, the lowest number in the set of seven dams. Although over a narrow range and with the exception of the highly-turbid Kosterrivier Dam, there was a general progression of declining species number with increasing trophy.

Numerical density per species, as corrected for Catch per Unit Effort (CPUE) and expressed as a percentage of the total survey catch, is shown in **Table 3**, whilst biomass, similarly-corrected, is shown in **Table 4**. Graphical representations of both datasets are provided in **Figures 1 and 2**.

From **Figure 1** it is apparent that there was no trend in numerical dominance across all seven dams. Canary kurper (*Chetia flaviventris*) was dominant in Hartbeespoort and Rietvlei (55% and 42% of total catch, respectively), whereas the sharptooth catfish dominated in the shallower, sediment-rich Bon Accord and Koster River systems (respectively 61% and 41% of total catch). The numbers of these species were considerably less in the two control dams, as well as in Roodeplaat (a hypertrophic system).

A clear inter-reservoir pattern is apparent from the biomass data (**Figure 2**). The sharptooth catfish dominated the biomass in all seven dams, exceeding 50% in all but two (Rust de Winter, 34% and Bon Accord, 24%) and amounting to a maximum of 73% of total biomass in Koster River Dam. By contrast, common carp ranged from 2% in Rietvlei to 15% in Bon Accord. Despite its numerical predominance in Rietvlei and Hartbeespoort Dams, the small size of the canary kurper resulted in this species contributing only 3% and 6% of total biomass in these two reservoirs, respectively. Mozambique tilapia was the dominant in Rust de Winter (41% total biomass), as well as in Bon Accord (35% total biomass).

Fish biomass, expressed per unit area (see **Table 5**), considerably exceeded 20 kg/ha in six of the seven dams assessed, i.e. exceeding the threshold above which algal-dominance is expected to prevail). The seventh dam, the turbid Koster River, had an areal biomass of 202 kg/ha. Areal biomass bore no relationship to trophic state (see Table 5).

Significantly, there was no difference between the ratios of CPUE-derived biomass in the control and test dams. In fact, the fish assemblages of Lindleyspoort (control dam) and Bon Accord were very similar. The proportional representation of species in the remaining dams was the same as for the second control dam, Rust de Winter (see Figure 2).

Table 2: Fish assemblages of the seven reservoirs assessed in this study (ranked as per Table 1).

Species	Common Name	Family	Rust de Winter	Lindleyspoort	Koster	Hartbeespoort	Roodeplaat	Bon Accord	Rietvlei
Barbus mattozi	Papermouth	Cyprinidae	X	X		X			
Barbus paludinosus	Straightfin barb	Cyprinidae		X	X	X	X	X	X
Barbus trimaculatus	Threespot barb	Cyprinidae	X	X		X		X	
Barbus unitaeniatus	Longbeard barb	Cyprinidae		X		X	X	X	
Chetia flaviventris	Canary kurper	Cichlidae	X	X		X	X		X
Clarias gariepinus	Sharptooth catfish	Clariidae	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Cyprinus carpio	Common carp	Cyprinidae	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Labeo molybdinus	Leaden labeo	Cyprinidae	X					X	
Labeobarbus aneus	Smallmouth yellowfish	Cyprinidae			X				
Labeobarbus marequensis	Largescale yellowfish	Cyprinidae	X	X		X	X	X	X
Labeobarbus polylepis	Smallscale yellowfish	Cyprinidae	X			X	X		X
Marcusenius macrolepidotus	Bulldog	Mormyridae	X	X					
Micropterus salmoides	Largemouth bass	Centrarchidae	X	X	X	X	X		
Oreochromis mossambicus	Mozambique (common) tilapia	Cichlidae	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Pseudocrenilabrus philander	Southern mouthbrooder	Cichlidae		X	X	X	X	X	X
Tilapia sparrmanii	Banded tilapia	Cichlidae	X	X		X	X		X
TOTAL SPECIES PER DAM			**12**	**13**	**7**	**13**	**11**	**9**	**9**

Table 3: Numerical dominance, expressed as a percentage of the total survey catch.

Species	Species code	**Rust de Winter**	**Lindleyspoort**	**Koster**	**Hartbeespoort**	**Roodeplaat**	**Bon Accord**	**Rietvlei**
Barbus mattozi	BM	6.6	25.3	0.001	1.1	0.001	0.001	0.001
Barbus paludinosus	BP	0.001	0.8	4.8	0.1	12.5	0.1	23.7
Barbus trimaculatus	BT	8.5	37	0.001	8.3	0.001	0.001	0.001
Barbus unitaeniatus	BU	0.001	0.001	0.001	3.9	36.1	0.001	0.001
Chetia flaviventris	CF	1.5	2.4	0.001	54.6	9.5	0.001	41.7
Clarias gariepinus	CG	10.3	8	41	2.2	11.7	61.2	10.9
Cyprinus carpio	CC	1.1	1.9	5.4	1.9	1.6	30.6	0.9
Labeo molybdinus	LM	0.1	0.001	0.001	0.001	0.001	5.5	0.001
Labeobarbus aneus	LA	0.001	0.001	34.4	0.001	0.001	0.001	0.001
Labeobarbus marequensis	LQ	3.5	5.2	0.001	8.5	16.3	0.1	0.001
Labeobarbus polylepis	LP	0.1	0.001	0.001	0.3	0.5	0.001	11.9
Marcusenius macrolepidotus	MM	40.5	0.6	0.001	0.001	0.001	0.001	0.001
Micropterus salmoides	MS	6.3	0.1	0.5	0.001	0.4	0.001	0.001
Oreochromis mossambicus	OM	21.4	17.7	13.4	18.9	10.6	2.5	0.001
Pseudocrenilabrus philander	PP	0.001	0.4	0.5	0.001	0.1	0.001	9.6
Tilapia sparrmanii	TS	0.1	0.6	0.001	0.001	0.7	0.001	1.3
Total # fish		**1556**	**2314**	**393**	**6390**	**2389**	**405**	**2316**

Figure 1: Graphical representation of fish numbers per dam – as a percentage of total catch (for fish codes please see Table 3).

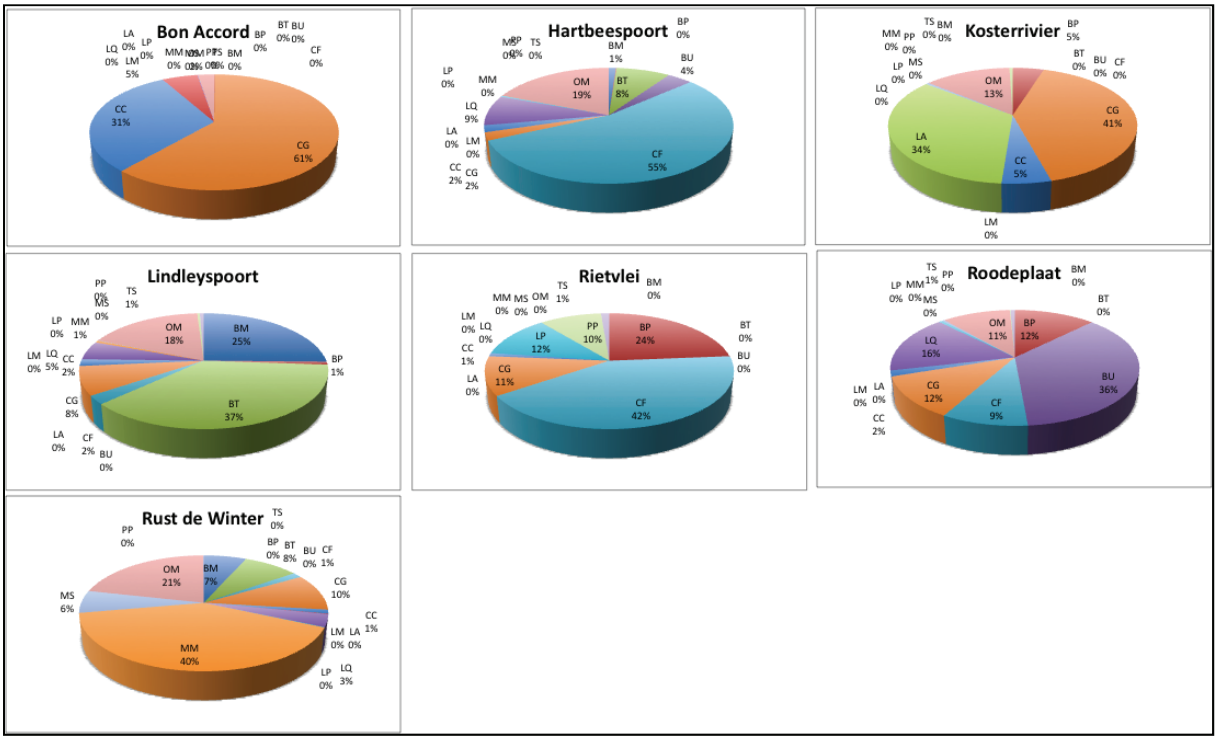

Table 4: Biomass dominance, expressed as a percentage of the total survey catch.

Species	Species code	**Rust de Winter**	**Lindleyspoort**	**Koster**	**Hartbeespoort**	**Roodeplaat**	**Bon Accord**	**Rietvlei**
Barbus mattozi	BM	3.5	6.4	0.001	0.7	0.001	0.001	0.001
Barbus paludinosus	BP	0.001	0.001	0.001	0.001	0.1	9.1	0.3
Barbus trimaculatus	BT	0.3	1.2	0.001	0.8	0.001	0.5	0.001
Barbus unitaeniatus	BU	0.001	0.001	0.001	0.3	0.3	3.1	0.001
Chetia flaviventris	CF	0.1	0.2	0.001	5.6	0.6	0.001	2.7
Clarias gariepinus	CG	33.8	59.6	72.6	53.5	63	24.1	59
Cyprinus carpio	CC	5.2	11.5	7.1	12.6	3.5	15.2	1.7
Labeo molybdinus	LM	0.2	0.001	0.001	0.001	0.001	10.9	0.001
Labeobarbus aneus	LA	0.001	0.001	12.8	0.001	0.001	0.001	0.001
Labeobarbus marequensis	LQ	3.1	8	0.001	13.2	16	0.9	0.2
Labeobarbus polylepis	LP	0.1	0.001	0.001	0.3	0.5	0.001	35.8
Marcusenius macrolepidotus	MM	5.6	0.2	0.001	0.001	0.001	0.001	0.001
Micropterus salmoides	MS	6.6	0.7	1.3	0.3	0.3	0.001	0.001
Oreochromis mossambicus	OM	41.3	12.2	6.2	12.7	15.5	35.4	0.001
Pseudocrenilabrus philander	PP	0.001	0.001	0.001	0.001	0.001	0.9	0.1
Tilapia sparrmanii	TS	0.001	0.1	0.001	0.001	0.1	0.001	0.1
Total biomass (kg caught)		**614**	**566**	**279**	**606**	**1070**	**650**	**997**

Figure 2: Graphical representation of fish biomass per dam – as a percentage of total catch (for fish codes please see Table 3).

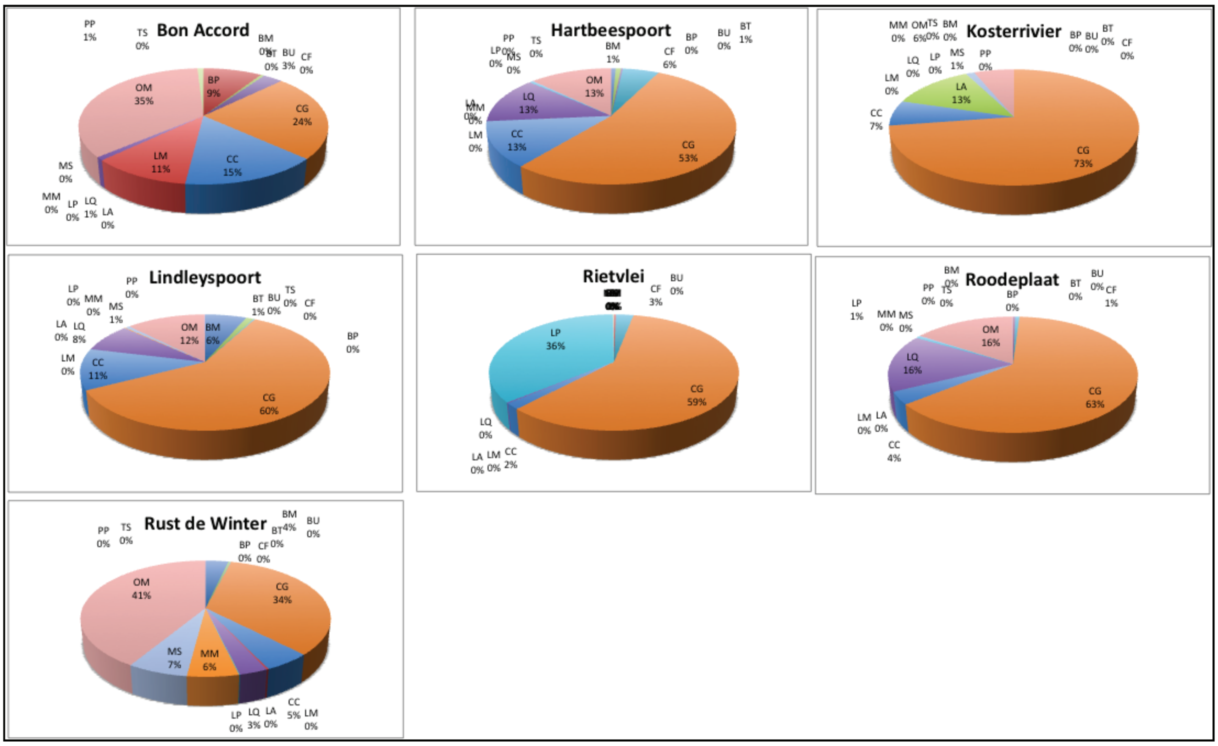

Table 5: Areal fish biomass (kg/ha) for each of the seven dams (dams ranked as before).

Rust de Winter	Lindleyspoort	Koster	Hartbeespoort	Roodeplaat	Bon Accord	Rietvlei
357	350	202	300	791	412	641

Identified problem (coarse) species

The catfish is dominant in all of the dams, with the exception of Rust De Winter, with carp present, at a lesser extent, in most of the dams. The catfish (all dams) and carp (especially for Bon Accord Dam) are dominant species and have very high fecundities. A single large (4 kg) female of each of the carp and catfish can produce in excess of one million larvae per spawning. *Chetia flaviventris* is an extremely efficient carnivorous fish, equivalent to bass, and will have a significant impact on invertebrates and larval fish – and possibly zooplankton. It has been surmised that the larval stages of carp and catfish may tend towards obligate zooplanktivory. Empirical evidence for this, however, appears to be lacking and is not supported by the extremely successful dominance of zooplankton-poor river systems by *Clarias gariepinus*. Additionally, foodweb-based work being conducted in Rietvlei has revealed no evidence of zooplankton grazing by fish (Harding and Hart, WRC Project 1918).

By targeting the above mentioned fish species, the fish community will naturally shift towards *Oreochromis mossambicus* (Mozambique tilapia or blou kurper) as the most important species. From an ecological perspective this is a highly desirable species as it has an omnivorous feeding behaviour and is also an algal feeder.

Potential yields of fish per dam

This project has determined the possible tonnages of fish that could be harvested on a sustainable annual basis from each dam. These data are summarized in **Table 6**. It should be noted that the initial, bulk-removal tonnages required to re-set the fish population, are not shown but are included in the relevant section of this report. Where available, tonnages per species are shown.

Table 6: Biomass and yield characteristics, per dam.

	Biomass, tonnes (t)	Kg/ha	Yield, t/a	Catfish	Carp	Chetia	Tilapia	Yellowfish
Rietvlei	132	640	44	26	0.75	1.2		
Roodeplaat	314	790	104	66	3.7	0.6	4.1	17
Bon Accord	70	410	23	14	4.2			
Koster	52	200	18	13	3.3			
Lindleyspoort	67	370	22	13	6.2			
Rust deWinter	175	370	58	20	7.3			
Hartbeespoort	750	375	250					

Species selection for biomanipulation

All of dams examined in this project appear to provide a basis for biomanipulation linked to a community-based fishery. The latter would underpin an ongoing foodweb manipulation programme necessary to maintain target levels of problematical species. While the fish population of Rust de Winter Dam appears to be balanced, there is scope for harvesting of carp as a proactive management approach.

Target species for biomanipulation, as well as those species showing potential for sustainable utilization, are shown in **Table 7**.

Table 7: Target species for biomanipulation per dam

	Undesirable species	Desirable species
Bon Accord Dam	Sharptooth catfish, common carp	
Hartbeespoort Dam	Sharptooth catfish, common carp, canary kurper	
Koster River Dam	Sharptooth catfish, common carp	Smallmouth yellowfish, Mozambique tilapia
Lindleyspoort Dam	Sharptooth catfish, common carp	Mozambique tilapia
Rietvlei Dam	Sharptooth catfish, common carp, canary kurper	Smallscale yellowfish
Roodeplaat Dam	Sharptooth catfish, common carp, canary kurper	Largescale yellowfish
Rust de Winter Dam	Sharptooth catfish, common carp	Mozambique tilapia

Edibility of fish from Roodeplaat Dam

Samples of tissue from common carp and sharptooth catfish collected from Roodeplaat Dam were tested for the presence of endocrine disruptors and trace metals. The PCBs found in muscle of some of the fish from both species were just above the recommended guideline of 0.3 mg/kg in the edible portion of the fish. This indicates that the fish are not safe for human consumption. By contrast, the edible parts of the fish were deemed safe to eat based on the DDT, DDD and DDE levels, according to the guidelines set by the FDA and EPA. There are no guidelines for HCH and endosulfan, but the concentrations detected in the muscle were higher than the guidelines recommended in water.

There are no guidelines available for the metals tested for in the muscle of both fish species. However, the possible effects of the detected metals are discussed in brief, bearing in mind that the intake and the availability of the metals were not calculated according to a risk formulation for humans consuming wild fish.

In conclusion, if the fish are consumed over a long-term basis, adverse health effects are expected. However if consumption of fish is lower than that considered to be a “reasonable” exposure, these risks are considerably reduced. The risk assessment is a first-tier or screening exercise and indicates that more information is needed to make an informed decision.

POSSIBLE SUCCESS OF BIOMANIPULATION

A considerable amount of literature (see accompanying Literature Summary) has reported in the successes and failures of fish-directed biomanipulation of lakes. Reported successes have revealed that the following criteria predispose towards successful biomanipulation (Sierp et al., 2009):

- Small lakes, < 4 ha;
- Shallow lakes, < 3 m mean depth;
- In-lake phosphorus level of between 80-150 µg ℓ^{-1};
- Initial fish removal must ≥ 75% standing stock;
- Timing should coincide with the normal temporal development of large cladoceran zooplankters – i.e. removal complete by late winter, early spring.

Equally, a number of constraints to the success of biomanipulation have been identified (Sierp et al., 2009):

- Total fish biomass < 50-100 kg ha^{-1};
- Initial fish removal < 75%;
- Insufficient piscivores;
- Unsuitable sediments (for macrophyte establishment), alternatively large interannual fluctuations in lake water levels preventing establishment of littoral zone vegetation;
- High level of wind-induced mixing;
- Logistical difficulties in removing fish from large lakes;
- Very high nutrient levels;
- Extreme densities of cyanobacteria;
- Appearance of invertebrate predators (chaoborids);
- *Ceratium hirundinella* blooms.

All of the above aspects have been laregly derived from studies of shallow environments in north-temperate regions. Accordingly, an additional constraint would be the unknowns associated with warmer climates in the southern hemisphere.

The foregoing can be used to examine the likelihood of biomanipulation success in the set of dams assessed in this project (see Table 8).

All of the dams are much larger than 4 ha and all deeper than 3 m. However, the three shallowest (Rust de Winter, Koster and Bon Accord) have large areas shallower than 3 m. The nutrient levels of three dams (Roodeplaat, Bon Accord and Rietvlei) all exceed the deemed range above which success is unlikely to be achievable.

Trials at Hartbeespoort Dam have proven that the administration and logistics of bulk fish removal pose a major constraint for multi-functional reservoir lakes. Such waters also impose the additional limitation of fixed catch areas – with the result that fish have unrestricted access to most of the dam and can modify their behaviour to avoid the designated catch area. These issues constrain the ability to remove at least 75% immediately.

All of the dams tested had fish biomass levels that exceed published values above which success is more likely. However, there was no relationship between trophic state and fish biomass, and with the control dams having biomass levels higher than dams with a higher trophic state. In this regard it is conceded that other aspects limiting or augmenting fish development in each dam have not been considered.

The issue of piscivores as a natural control measure does not apply. By contrast, in these dams we have coarse fish who are piscivorous, namely canary kurper and sharptooth catfish.

The issue of sediments relates to two aspects: firstly the ability of the sediments to support the establishment of macrophytes and, secondly, the ease with which the sediments may be disrupted by wind and wave (wind- or mechanical disturbance induced) action. In the main, South African dams are characterized by steep, regularly-exposed shorelines that are entirely unsuitable for macrophyte establishment. With the exception of shallows bays and inlets, this precludes the development of significant areas of submerged, rooted macrophytes. These problems are less evident in Bon Accord and Koster Dams, as well as the littoral of Rietvlei – which develops dense stands of pondweeds during the summer.

The success of any food- or economic-security linked defishing of South African dams is directly-related to whether or not the fish are indeed edible. This will largely be determined by the nature of any effluents being discharged to individual dams and/or residual agricultural impacts (organochlorine pesticides). Recent assessments linked to this project have shown that the organochlorine content of carp and catfish from Roodeplaat and Rietvlei Dams poses a consumption risk. Additionally, work performed in African lakes has independently shown the accumulation of cyanobacterial hepatotoxins to levels which, based on WHO guidelines, may exceed safe daily consumption limits (A. Poste, U. Waterloo, Canada, pers. comm). Accordingly, consumption of fish from these waters would need to be approached with caution.

Table 8: Analysis of biomanipulation success for South African dams (this set)

Criteria for biomanipulation success	RdW	LPrt	KostR	HBPD	RdP	BA	RVlei
Area < 4 ha	X	X	X	X	X	X	X
Depth < 3 m	(✓)	X	(✓)	X	X	(✓)	X
In-lake P 80-150 µg ℓ^{-1}	✓	✓	✓	✓	X	X	X
Initial removal > 75%	X	X	X	X	X	X	X
Timing	✓	✓	✓	✓	✓	✓	✓
Fish biomass > 100 kg ha^{-1}	✓	✓	✓	✓	✓	✓	✓
Piscivores	X	X	X	X	X	X	X
Sediments	✓	✓	X	X	(✓)	X	✓
Wind action	?	?	?	?	?	?	?
Logistics	X	X	X	X	X	X	X
Edibility	?	?	?	(✓)	X	?	X
OVERALL	(✓)	X	(✓)	X	X	(✓)	X

Key: ✓ = Meets requirement; (✓) = possibly meets requirement; X = does not meet requirement; ? = unknown or undetermined.

The overall assessment indicates that biomanipulation may derive ecosystem-health benefits in the shallowest dams in the set (Rust de Winter, Koster and Bon Accord), but is unlikely to do so in the deeper and/or more polluted reservoirs. For the latter the main focus remains the attenuation of nutrient loading at source.

CONCLUSIONS

The fish biomass in all of the dams, including the controls, was dominated by sharptooth catfish. By contrast, the contribution made by common carp was considerably less than expected. The canary kurper was numerically-dominant in only two dams, Hartbeespoort and Rietvlei. In a parallel investigation at Rietvlei, it is apparent that limited removal of zooplankton by fish is occurring – a finding that contradicts the hypothesis that top-down control is prevalent in the presence of this fish species (Harding and Hart, WRC Project 1918).

All of the dams supported fish populations that exceed areal biomass levels commonly-associated with a swing towards algal dominance. As the control dams in this set also exceeded this level, further studies will be necessary to determine biomass levels peculiar to South African dams.

All of the dominant, coarse species are known to impart a variety of bottom-up negative stresses on the aquatic environments in which they are present. Accordingly, their deliberate management, through a process of fish-directed biomanipulation, should provide a measure of relief of these impacts and allow populations of desirable species to resurge. By contrast, it is deemed unlikely that any significant measure of top-down control will be achieved deliberate biomanipulation. The likelihood of success is further negated by the absence of a macrophyte-dominated stable state in any of the assessed reservoir lakes.

This study estimates that a harvestable potential of coarse fish (carp, catfish) exists in all of the dams examined, including the controls. Additionally, there is a potential for harvesting higher value species from five of the seven dams reviewed. This finding supports the original contention that efforts to reduce coarse fish pressure on these waters, in the process augmenting ecosystem health, may be underpinned by sustainable economic and food security incentives

This study concludes that there are sufficient grounds to support further research into the implementation of fishery-based interventions in nutrient-enriched South African dams as a means of providing in-lake relief from eutrophication pressure. This work will require a closer examination of the feeding pathways and mechanisms. The application of biomanipulation may offer a novel approach for in-lake treatment in dams where the catchment is dominated by dry-land agriculture (i.e. few options for catchment-level nutrient or pollutant attenuation, see Harding, 2008).

Presumptions regarding food-types eaten by the different species requires empirical confirmation, for example using Stable Isotope Analysis (SIA), supported by some gut content analysis (at least for the 3 coarse species) in several of the study dams. In parallel, zooplankton:phytoplankton biomass ratios need explicit determination in a wider suite of dams, along with assessments of zooplankton composition (large vs. small-bodied taxa). Additionally, the health risks associated with the consumption of fish harvested from these eutrophic waters will require additional investigation.

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13 APPENDIX A: LITERATURE OVERVIEW

This review comprises two components: (a) an overview of key issues that underpinned the rationale for this project and (b) a CD containing a year-by-year catalogued set of published papers relevant to this topic spanning the period 1988-2010.

All of the papers referred to in the overview are included in the catalogued set.

BACKGROUND

The process of storing (impounding) water in dams (reservoirs) embodies the unintended consequence of adversely-altering the physico-chemical and biological conditions over time. This process is variously accelerated and exacerbated by a variety of anthropogenic pressures, commonly typified by increased pollutant loading – with nutrients being most problematical – and occurrence of invasive or opportunistic plant and animal species. Some of these non-native or invasive species can exert substantial impacts on native species and/or ecosystem processes, resulting in a progressive decline in water quality and ecosystem health. Well-known illustrative examples of such changes are Lake Victoria (Central African Great Lakes Region), where the introduction of Nile perch (*Lates niloticus*) has altered the entire foodweb structure of the lake as a consequence of reduced phytoplanktivore grazing, or Hartbeespoort and Roodeplaat Dams (South Africa), where sustained eutrophication as a consequence of urban effluent disposal, has created sustained conditions of extreme hypertrophy. Typical outcomes are a plagioclimactic biotic condition, dominated by an increased frequency of noxious algal blooms – caused by cyanobacteria – and dominance of the fishery – by ecosystem-modifying species – that exert high predation pressures on zooplankton or elevate bioturbation of sediments – resulting in increased nutrient recycling, increased turbidity, depleted benthos fauna and reduced establishment of rooted macrophytes in shallow and littoral zones.

Elevated levels of eutrophication-related impacts are now commonplace in several inland reservoirs serving the economic heartland of South Africa, i.e. reservoirs for which effluent flows form a recognized and substantial fraction of the annual water balance. Currently, in excess of 30 reservoirs, with a combined storage amounting to 35% of the total national storage, are classified as eutrophic to hyper-eutrophic. Many more exist in an incipient-eutrophic condition and the problem continues to increase. In the Crocodile-West Marico Water Management Area, 65% of the total bulk storage is classified as hyper-eutrophic. Substantial and increasing ecological and economic costs go hand-in-hand with these negative changes.

For most of the eutrophic/hypertrophic reservoirs, the levels of nutrient reduction required to ensure return to a mesotrophic condition, this quite apart from addressing foodweb disruptions or internal loading, are extremely high. Harding (2008)[1] has shown for a set of thirteen reservoirs that reductions of between 25 and 96% over extant will be necessary – with eight of the thirteen waters requiring reductions greater than 50%. In most cases the bulk loads of nutrients emanate from either wastewater disposal or arise from dryland landuse activities – i.e. nutrient sources unlikely to be meaningfully attenuated in the short to medium term (5-15 years). This places a considerably greater emphasis on being able to provide some measure of relief at the "in-lake" level – while waiting for catchment-based interventions to be put in place.

[1] Harding WR (2008) The Determination of Annual Phosphorus Loading Limits for South African Dams. WRC Report 1687/1/08.

The nett result of these eutrophication changes (stressors) is an altered balance within the aquatic ecosystem foodweb. International experiences have shown that the impacts of this imbalance project throughout the ecosystem via a variety of cause and effect pathways. The concept of 'balance' is central to this theme. In unaltered ecosystems – in the case of dams newly or recently-impounded waters, it may be assumed that high levels of biodiversity, in balanced proportion, increases the intensity of competition and precludes invasion by undesirable species – i.e. competition underpins ecosystem health and balance (e.g. Bulleri, 2008)[2]. The changes that occur post-impoundment and in anthropogenically-altered reservoirs (*inter alia* nutrient enrichment, alien species introductions, unmanaged fisheries, sediment accumulation), distort the balance in favour of species that amplify both top-down (grazing) as well as bottom-up (bioturbation & fish nutrient recycling) impacts. Sustained eutrophication reduces the resilience of indigenous or desirable taxa to outcompete introduced or opportunistic species.

The most appropriate means of remediating eutrophication, with inherent time-lagged responses, remains attenuation of nutrient loading to acceptable levels. However, nutrient reductions are difficult to achieve and, in the absence of opportunities to meaningfully address the problem at the catchment level in the short to medium term (10-20 years), resort to in-lake remedial options for reservoirs provides relatively few practical, cost-effective opportunities. In recent years, however, there has been a growing body of evidence that suggests that re-structuring of imbalanced fishery assemblages can impart a profound and beneficial effect on ecosystem condition. This approach addresses the facilitated re-establishment of positive species interactions within a disturbed environment.

Although the restoration of lakes and reservoirs via the release of biotically-induced top-down (grazing pressure) and bottom-up (bioturbation) impacts is rapidly gaining precedence and increasingly support by scientific study, the approach is new to South Africa. There are a range of factors by which southern African, warm-water, reservoir lakes differ from their northern hemisphere counterparts, or from lakes *per se*, as opposed to the more artificial conditions prevailing in impounded waters. These remain to be described (see Hart, 2006[3]: Hart and Hart, 2006)[4].

Completed and on-going investigations at Hartbeespoort and other dams within the same drainage region, have clearly indicated the local potential for foodweb restoration, via the reservoir fisheries. These findings were based on carefully modeled carrying capacity and fish assemblage responses to the proposed harvesting of target species – an approach that embodies sustainable economic benefits. The conclusions drawn from this work are, however, as yet unsupported by quantitative descriptions of the extant trophic structure of the affected waters.

Although restructuring of the Hartbeespoort Dam fishery has already commenced during early 2008, it is unsupported by an appropriate level of monitoring and evaluation. Currently, the coarse-level monitoring being undertaken at Hartbeespoort and other dams does not have the level of sophistication necessary to track responses to the imposed interventions. This is not an isolated case. The limnologically-informed management of reservoirs in South Africa is fundamentally unsupported by both a lack of skills and appropriate understanding of ecosystem functioning, based on abiotic/biotic interactions, species level responses and

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[2] Bulleri, F, Bruno, JF and L Benedetti-Cecchi (2008) PLoS Biology 6(6):1136-1140.

[3] Hart, RC (2006) Food web (bio-)manipulation of South African reservoirs – viable eutrophication management prospect or illusory pipe dream? A reflective commentary and position paper. Water SA 32:567-575.

[4] Hart, R and RC Hart (2006) Reservoirs and Their Management: A Review of the Literature since 1990. WRC Report KV 173/06.

functioning occurring in individual reservoirs (see WRC 2000)[5]. This proposal, i.e. Phase II of WRC1643, describes an approach to identify, describe and track foodweb interactions, energy flows and trophic structure in response to applied fishery restoration. It has the added and not insignificant benefit in that the nature of the proposed monitoring will strongly develop an integrated understanding of reservoir limnology in the studied waters.

RATIONALE FOR INVESTIGATION

Experimental studies have indicated that the release of "top-down" pressures on aquatic foodwebs, effected by restructuring of the fishery, benefits lakes and reservoirs for a variety of reasons, *inter alia*:

- The presence of fish increases the relative retention of P in the water column, with concentrations of particulate carbon, nitrogen and phosphorus positively correlated with fish biomass (Vanni et al., 1997)[6]. Conversely, fish biomass is positively correlated with the ambient concentrations of total phosphorus (TP) – i.e. fish biomass is a function of lake or reservoir trophy (Jeppesen et al., 2005)[7];
- Zooplanktivorous fish, such as cyprinids, reduce the abundance and body size of large zooplankters, with a concomitant increase in phytoplankton biomass (Vanni, ibid);
- Zooplanktivorous fish strongly influence the abundance of algal biomass by changing zooplankton grazing regimes, zooplankton nutrient recycling and directly, by recycling of nutrients (fish excretion) to phytoplankton (Matveev et al., 2002[8]; Hunt et al., 2003[9]; Fernandez-Alaez et al., 2004[10]; Romo et al., 2004[11]; Vaikkilainen et al., 2004[12]). The nature and level of this impact is likely to vary across different fish species;
- Systems with low levels of fish, or without fish, tend to be characterized by large populations of *Daphnia, Ceriodaphnia* and calanoid copepods – with low levels of phytoplankton and increasing dominance by chlorophytes over cyanobacteria (Hunt et al., 2003[13]; Romo et al., 2004[14]). Sudden, large-scale removal of fish has been observed to be followed immediately by a resurgence of large-bodied daphnids (Harding and Wright, 1999[15]; Harding et al., 2005 – Paardevlei[16]). Recent work in

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5 Walmsley, RD (2000) Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. WRC Report KV129/00.
6 Vanni, M, Layne, C and S Arnott (1997) "top-down" trophic interactions in lakes: effects of fish on nutrient dynamics. Ecology 78(1):1-20.
7 Jeppesen et al. (2005) Lake responses to reduced nutrient loading- an analysis of contemporary long-term data from 35 case studies. Freshwater Biology 50:1747-1771.
8 Matveev, V, Closs, G, Lieschke, JA and MJ Shirley (2002) Are pelagic fish important in the foodwebs of Australian reservoirs? Verh. Int. Verein. Limnol 28:1-4.
9 Hunt, R, Matveev, V, Jones, G and K Warburton (2003). Structuring of the cyanobacterial community by pelagic fish in subtropical reservoirs: experimental evidence from Australia. Freshwater Biology 48:1482-1495.
10 Fernandez-Alaez et al (2004). A 2-year experimental study on nutrient and predator influences on foodweb constituents in a shallow lake of north-west Spain. Freshwater Biology 49:1574-1592.
11 Romo, S et al (2004). Mesocosm experiments on nutrient and fish effects on shallow lake foodwebs in a Mediterranean climate. Freshwater Biology 49:1593-1607.
12 Vakkilainen, K et al. (2004). Response of zooplankton to nutrient enrichment and fish in shallow lakes: a pan-european mesocosm experiment. Freshwater Biology 49:1619-1632.
13 Hunt R et al (2003) *ibid*.
14 Romo S et al (2004) *ibid*
15 Harding, WR and S Wright (1999) Initial findings regarding changes in phyto- and zooplankton composition and abundance following the temporary drawdown and

Australia has shown that removal of 50% of the carp population in a 20 ha lake resulted in an immediate 8-fold reduction in total phytoplankton biovolume (Matveev, 2008, personal communication). The complete eradication of carp from a shallow, western Cape coastal lake resulted in an order of magnitude reduction in water column phosphorus (Harding et al., 2005[17]);

- Research in Australia has indicated that nutrient limitation, zooplankton grazing and the positive effects of fish (balanced fishery structure) are important controls of phytoplankton biomass in reservoirs (dams) (e.g. Matveev, 2003[18]);
- Nutrient enrichment and high fish biomass (> 20 g fresh mass per sq m) have been shown to promote turbid, algal-dominated waters – with zooplankton dominated by rotifers that exert only very limited algal control potential (e.g. Hietala, 2004[19]);
- The conditions (nutrient levels, algal biomass, algal and zooplankton community structure and successional stage) prevailing at the outset of any restoration intervention will strongly influence the nature of the outcome; (= ecosystem resilience, described by Jeppesen et al. (2005[20]) as "chemically and biologically-conditioned resistance" (Stephen et al., 2004[21]). The longer sustained eutrophication and an hydraulically-regulated (impounded) biophysical environment have been in place, the harder it will be to reverse the conditions towards a more acceptable trophic condition;
- Reduction (improvements) in nutrient loading, other than the extreme of re-oligotrophication, are less likely to have a marked effect on the zooplankton while the fishery remains unbalanced – as zooplanktivorous grazing will continue to over-control the large crustacean grazers (e.g. Vakkilainen et al., 2004[22]);
- There is a need to develop an informed understanding of the mechanistic manner in which the plankton of a dam responds to biomanipulation (alternatively termed 'foodweb management'). Food chain theory cannot generically explain the finer level changes within the primary and secondary production levels that are likely to differ at a variety of spatial scales – spanning local, regional and intercontinental transects;
- While phytoplankton and fish are likely to decline in response to nutrient reductions that are in excess of the thresholds for excessive growth, the magnitude of the required reductions – in some cases amounting to in excess of 80% of extant annual loadings (Harding, 2008[23], see above) – are unlikely to be achieved in the short to

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refilling of a shallow hypertrophic South African coastal lake. Journal of Lake and Reservoir Management 15:47-53.

[16] Harding, WR, Steyn, G and J Koekemoer (2005). Rotenone-based eradication of fish from a shallow coastal lake prior to rehabilitation. (unpublished consultancy report).

[17] Harding, WR, Steyn, G and J Koekemoer (2005). *Ibid*.

[18] Matveev, V (2003) Testing predictions of the lake foodweb theory on pelagic communities of Australian reservoirs. Oikos 100:149-161.

[19] Hietala, J, Vakkilaienen, K and T Kairesalo (2004). Community resistance and change to nutrient enrichment and fish manipulation in a vegetated lake littoral. Freshwater Biology 49:1525-1537.

[20] Jeppesen E et al (2005) Lake responses to reduced nutrient loading- an analysis of contemporary long-term data from 35 case studies. Freshwater Biology 50:1747-1771.

[21] Stephen, D et al. (2004) Continental-scale patterns of nutrient and fish effects on shallow lakes: introduction to a pan-European mesocosm experiment. Freshwater Biology 49:1517-1524.

[22] Vakkilainen, K et al. (2004). Response of zooplankton to nutrient enrichment and fish in shallow lakes: a pan-european mesocosm experiment. Freshwater Biology 49:1619-1632.

[23] Harding, WR (2008) The determination of annual phosphorus loading limits for South African dams. WRC Report 1687/1/08.

medium term. This places greater emphasis on the need for practical and pragmatic in-lake options that will provide effective ecosystem health enhancements;

- The impact of fish on lake foodwebs has been shown to be greater in the sub-tropics than at temperate latitudes (e.g. Jeppesen et al., 2007[24]). The nature of the interactions remains to be fully-determined and described for South African conditions;
- While zooplanktivory has been found to be greater in vegetated, clear-water sub-tropical lakes – as opposed to their temperate counterparts (Iglesias, 2007[25]) – South African reservoirs lack any indigenous obligate zooplanktivorous fishes (Hart, 2006[26]). This suggests that, in reservoirs not dominated by opportunistic zooplanktivores (carp, *Chetia*), restored or augmented littoral or wetland zones will contribute to higher abundances of large-bodied zooplankters occurring in South African reservoirs;
- Restoration of balanced foodwebs contributes to ecosystem-beneficial levels of inter-species competition and ecosystem stability (e.g. Bulleri et al., 2008[27]).

[24] Iglesias, C et al (2007) Horizontal dynamics of zooplankton in subtropical Lake Bianca (Uruguay) hosting multiple zooplankton predators and aquatic plant refuges. Hydrobiologia (2007) 584:179-189.
[25] Iglesias, C et al (2007) *Ibid*.
[26] Hart, RC Hart (2006) *Ibid*.
[27] Bulleri, F, Bruno, JF and L Benedetti-Cecchi (2008) PLoS Biology 6(6):1136-1140.

14 APPENDIX B: EDIBILITY OF FISH FROM ROODEPLAAT DAM

This report forms part of a mini-dissertation entitled: A histology-based fish health assessment to determine the health status and edibility of fish from the Roodeplaat Dam. Marchand MJ. The analytical portion of this work was funded from WRC K5/1643.

14.1 METHODOLOGY

20 *Clarias gariepinus* and 18 *Oreochromis mossambicus* were taken from the catch effort by EcoDynamics at the Roodeplaat Dam. Skeletal muscle samples were collected from each fish for target chemical analyses. These samples were individually wrapped in aluminium foil (Endocrine disrupting chemical (EDC) analyses) and plastic bags (metal analyses) and stored at -20° C until analyses. The samples were analysed by FDA- and Waterlab (PTY) Ltd. Laboratories (Pretoria, South Africa) using Gas Chromatograph – Mass Spectrometry (GC-MS) and Inductively Coupled Plasma – (ICP- OES) quantitative analysis.

14.2 *ENDOCRINE DISRUPTING CHEMICALS (EDCS)*

The EDCs included the organochlorine pesticides (OCs), and qualitative analyses of alkylphenols (AP). The OCs include: alpha (α) -hexachlorocyclohexane (HCH), gamma (γ) -HCH (lindane), heptachlor, aldrin, dieldrin, beta (β) -HCH, delta (Δ) -HCH, heptachlor epoxide, endosulfan I, endosulfan II, endosulfan sulphate, alpha-chlordane, gamma-chlordane, the six 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane (DDT) isomers (o*,p'*- and *p,p'*-DDT, – 1,1-dihloro-2,2-bis(*p*-chlorophenyl)ethane (DDD) and – 1,1-dihloro-2,2-bis(*p*-chlorophenyl)ethylene (DDE), endrin, endrin aldehyde, endrin ketone, methoxychlor and polychlorinated biphenyl (PCB) 153. The APs included nonylphenol (*p*-NP) and octylphenol (OP).

14.2.1 Metals

The metals, metalloids and non-metals quantitatively analyzed for included: aluminium (Al), arsenic (As), boron (B), Barium (Ba), Beryllium (Be), bismuth (Bi), Calcium (Ca), cadmium (Cd), Cobalt (Co), chromium (Cr), Copper (Cu), Iron (Fe), potassium (K), Lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), antimony (Sb), selenium (Se), silicon (Si), tin (Sn), strontium (Sr), titanium (Ti), vanadium (V), tungsten (W), zinc (Zn) and sirconium (Zr).

14.3 HUMAN RISK ANALYSES

Human health risk assessment resulting from exposure to fish

The presentation of risk assessment methods in this section are well established methods and follow the format of the risk assessment process recommended by EPA for cancer and non-cancer toxicity:

- Hazard identification
- Dose-response assessment
- Exposure assessment
- Risk characterization (U.S. EPA, 1986 a,b; IRIS, 1999).

The US EPA methods were first described and developed in the National Academy of Sciences (NAS) report entitled *Risk Assessment in the Federal Government: Managing the Process* (NAS, 1983).

Screening health risk assessment

This risk assessment provides a first level screening assessment only to indicate whether a potential health risk exists as a result of consumption of fish resulting from exposure to those chemicals examined and the mean concentrations detected. In addition other chemicals such as metals were detected but not included in the estimate. This risk assessment only examines the potential risks based on pesticides detected in fish.

Subsistence Fishers

Subsistence fishers consume fish as a major staple of their diet. These fishers rely on fish to meet nutritional needs, as an inexpensive food source, and, in some cases, because of their cultural traditions. Subsistence fishers often have higher consumption rates than other fisher groups; however, consumption rates vary considerably among subsistence fishers. Consequently, generalizations should not be made about this fisher group. If studies contained in this section are used to estimate exposure patterns for a subsistence population of concern, care should be taken to match the dietary and population characteristics of the two populations as closely as possible.

Subsistence fishers include a wide variety of people who differ in many respects. Subsistence fishers may consume different types or portions of fish than sport fishers (e.g., organs, whole fish), although individual tastes will vary. Their consumption patterns in this regard may result in greater exposure to contaminants.

14.4 RESULTS

14.4.1 Endocrine disrupting chemicals (EDCs)

Table 1 and Table 2 represent the EDC levels measured in the muscle (edible part) of *O. mossambicus* and *C. gariepinus* respectively.

14.4.2 Metal, metalloids and non-metals

Tables 3 and 4 represent the metal, metalloids and non-metals detected in the muscle of *O. mossambicus* and *C. gariepinus* respectively.

Table 1: The EDC concentrations in muscle samples from *O. mossambicus* (µg/kg; * = <50µg/kg; ** = <75µg/kg).

Fish	γ-Lindane	Δ-Lindane	Heptachlor	Aldrin	Endosulfan	*p,p'*-DDE	Endrin	PCB 153	Endrin aldehyde	*p,p'*-DDT	Dieldrin
1	**	*	*	*	**	*	*	*	*	**	*
2	**	*	*	*	**	*	*	*	*	**	*
3	**	*	*	*	260.9	*	*	*	*	**	*
4	**	*	*	*	**	*	*	*	*	**	*
5	**	*	*	*	141.7	*	*	*	*	**	*
6	**	*	*	*	295.9	*	*	*	*	**	*
7	**	*	*	*	158.2	*	*	*	*	**	*
8	**	*	*	*	218.3	*	*	*	*	**	*
9	**	*	*	*	174.9	*	134.9	*	*	**	*
10	**	*	*	*	170.6	*	*	*	*	**	*
11	**	99.8	*	*	174.3	*	*	*	*	**	*
12	**	159.2	*	*	116.5	*	*	*	*	**	*
13	**	*	*	*	**	*	148.4	*	*	149.2	*
14	178.4	*	*	*	**	216.5	*	*	105.7	**	324.8
15	257.2	*	98.7	*	158	122.5	*	57.2	*	**	178.4
16	220.7	*	*	81.4	299.1	*	119.3	*	*	**	161
17	184.4	*	*	*	**	*	*	*	*	**	276.6
18	**	102.3	*	*	245.6	244.4	*	*	*	**	*
Mean	**210.175**	**120.4**			**201.2**	**194.5**	**134.2**				**235.2**
SD	**36.5**	**33.6**			**61.2**	**63.9**	**14.6**				**78.5**
Median	**202.6**	**102.3**			**174.6**	**216.5**	**134.9**				**227.5**

The EPA and FDA guidelines for:

(Edible portion of fish)

- PCB's – 2.0 mg/kg (ppm/µg/g)
- Aldrin and dieldrin – 0.3 mg/kg.
- DDT, TDE and DDE – 5.0 mg/kg.
- Heptachlor and heptachlor epoxide – 0.3 mg.kg.

Table 2: The EDC concentrations in muscle samples from *C. gariepinus* (µg/kg; * = <50µg/kg; ** = <75µg/kg).

Fish	α-Lindane	γ-Lindane	Δ-Lindane	Heptachlor	Aldrin	Endosulfan	*p,p'*-DDE	11. Endrin	*o,p'*-DDT	PCB 153	*p,p'*-DDD	Endrin aldehyde	*p,p'*-DDT	Methoxychlor	Dieldrin
1	*	111.4	145.8	*	*	**	*	*	*	*	*	*	**	*	*
2	*	**	*	*	*	141.4	107.6	*	*	*	*	197.4	**	*	297.6
3	*	108.4	*	*	*	**	*	*	*	*	*	*	168.4	*	*
4	*	162.8	*	*	*	**	350.8	*	*	*	*	*	**	*	*
5	*	**	*	*	*	**	77.7	*	*	*	*	*	**	*	*
6	*	135.9	*	*	*	**	*	*	*	*	*	*	**	*	*
7	*	**	120.1	*	*	516.2	112.8	*	*	*	*	*	**	*	*
8	*	118.8	*	*	91.2	**	112.3	*	*	*	*	*	**	*	*
9	*	256	*	*	*	**	89	133.2	*	*	*	123.9	**	*	218.6
10	*	166.5	*	288.6	81.7	**	*	126	113.4	86.1	113.1	*	**	106	*
11	*	**	*	*	*	**	112.6	*	*	*	*	*	**	*	*
12	*	157.4	*	*	*	206.2	*	*	*	*	*	*	**	*	128.5
13	*	514.8	*	*	*	225.5	*	150.7	*	*	*	*	**	*	314.5
14	*	**	*	*	*	**	*	*	*	60.8	*	*	**	*	*
15	201.6	117.8	*	*	*	175	*	*	*	*	*	*	**	*	*
16	375.9	119.7	*	*	*	325.1	*	*	*	*	*	*	**	*	*
17	*	**	*	*	*	216	*	*	*	*	*	*	**	*	*
18	*	**	*	*	*	**	*	*	*	*	*	*	**	*	*
19	*	**	*	*	*	152.4	*	*	*	*	*	*	**	*	*
20	*	**	*	*	*	**	*	*	*	*	*	*	**	*	*
Mean	**288.75**	**179.0**	**133.0**		**86.45**	**244.7**	**137.5**	**136.6**		**73.5**		**160.7**			**239.8**
SD	123.2	119.1	18.2		6.7	123.6	95.0	12.7		17.9		52.0			85.2
Median	**288.8**	**135.9**	**133.0**		**86.5**	**211.1**	**112.3**	**133.2**		**73.5**		**160.7**			**258.1**

Table 3: The metal, metalloids and non-metals detected in the muscle of *O. mossambicus* (mg/kg).

Fish	Al	Ba	Bi	Cr	Cu	Fe	Mn	Ni	S	Sb	Se	Si	Sn	V	W	Zn	Zr
1	8	18	0	1	0	402	2	1	7243	2	7	22	2	0	3	29	0
2	37	18	1	3	1	645	10	6	7638	2	7	396	3	0	7	35	1
3	13	18	0	1	0	884	4	2	6246	1	7	22	1	0	2	25	0
4	8	18	0	1	0	370	2	1	7814	1	8	26	2	0	1	36	0
5	9	18	0	0	0	307	1	1	8119	2	7	25	2	0	1	26	1
6	7	25	1	1	0	355	2	1	7616	1	6	27	2	1	10	27	1
7	18	19	0	1	1	930	4	3	8080	2	7	22	2	0	2	35	1
8	10	20	0	2	0	808	4	2	7225	1	5	20	2	587	1	44	0
9	21	17	0	2	0	908	5	3	8048	1	8	21	2	1	0	27	0
10	22	16	0	1	1	1234	6	3	8882	1	8	24	3	1	0	37	0
11	30	18	0	1	0	781	3	1	7256	1	7	30	1	0	0	27	0
12	8	17	0	1	1	1673	8	3	8930	1	6	27	2	0	0	27	0
13	29	17	0	5	1	1212	6	3	7194	2	7	27	2	0	1	50	0
14	16	15	0	2	0	1079	4	3	6939	1	6	20	1	0	0	32	0
15	20	23	0	1	2	453	3	2	8257	1	45	28	2	0	3	40	1
16	9	19	0	0	0	538	3	2	5759	1	21	25	1	1	1	29	0
17	15	18	0	2	0	725	3	2	6245	1	13	26	1	0	0	31	0
18	130	19	0	6	3	2736	13	7	8931	2	12	34	4	0	0	51	2
Mean	**23**	**18**	**0**	**2**	**0**	**891**	**4**	**3**	**7579**	**1**	**11**	**46**	**2**	**33**	**2**	**34**	**1**
SD	28	2	0	2	1	586	3	2	921	0	9	87	1	138	3	8	0
Median	**16**	**18**	**0**	**1**	**0**	**794**	**4**	**2**	**7627**	**1**	**7**	**25**	**2**	**0**	**1**	**32**	**0**

Table 4: The metal, metalloids and non-metals detected in the muscle of *C. gariepinus* (mg/kg).

Fish	Al	B	Ba	Cr	Cu	Fe	Mn	Ni	S	Sb	Se	Si	Sn	W	Zn
1	10	283	12	0	1	437	3	1	4378	3	10	26	4	64	52
2	8	282	14	1	0	759	4	1	4237	2	11	22	4	25	17
3	36	257	15	1	1	775	4	2	5113	0	10	22	3	13	44
4	8	240	14	1	0	777	3	2	4421	2	9	18	2	10	15
5	22	217	14	2	1	1112	5	2	5115	2	10	26	1	7	27
6	17	194	15	0	0	627	2	1	3127	1	9	23	1	4	16
7	10	195	15	0	0	578	3	1	4276	1	11	19	3	9	19
8	14	233	17	1	0	562	3	2	4823	1	11	24	3	12	28
9	12	148	15	1	0	676	3	1	4757	1	10	21	1	4	18
10	52	113	16	2	2	1294	6	6	4232	2	11	24	2	3	28
11	13	69	15	0	0	476	2	1	4214	2	10	22	3	7	38
12	16	35	15	2	2	758	3	2	4912	1	10	22	1	5	56
13	26	11	16	1	0	1020	4	1	3348	1	9	21	1	2	31
14	20	-15	16	1	0	578	2	3	3538	2	9	17	0	2	20
15	9	-21	16	1	0	1014	4	2	3815	1	8	22	3	7	51
16	7	-21	16	0	0	546	2	1	3104	1	7	17	2	4	16
17	8	-21	17	5	0	493	3	3	5471	2	7	21	3	10	80
18	19	-21	17	2	0	750	3	2	6075	1	9	25	3	3	56
19	15	-21	19	1	0	334	2	1	3312	2	6	24	1	2	26
20	16	-21	18	3	0	876	4	2	5023	1	7	20	2	6	46
Mean	**17**	**107**	**16**	**1**	**0**	**722**	**3**	**2**	**4365**	**1**	**9**	**22**	**2**	**10**	**34**
SD	11	121	2	1	1	245	1	1	817	1	1	3	1	14	18
Median	14	91	16	1	0	713	3	2	4327	1	10	22	2	7	28

14.5 HUMAN RISK ANALYSES

Table 5: Chemical concentrations in fish (µg/kg) used in the health risk calculations.

CAS#	Chemical Name	Concentration in Fish µg/kg
60-57-1	Dieldrin	230
58-89-9	Lindane	200
72-20-8	Endrin	130
76-44-8	Heptachlor	99
50-29-3	DDT	149
309-00-2	Aldrin	80
115-29-7	Endosulfan	175
72-55-9	DDE	200
336-36-3	PCBs	70

Exposure Scenarios – Ingestion of Fish

Oral ingestion of fish with the specific chemical concentrations used derived from median values of each of the 20 + 18 fish samples from the sample site. An assessment that incorporates other exposures or that does not incorporate all of the exposures described in this analysis will yield different results. This list presents the exposure scenarios evaluated for each contaminated medium considered in this assessment.

The dose and concentration estimates in this assessment, refer only to the specific exposures that have been described. This description consists of:

Table 6: General population parameters used for the exposure assessment.

Population: Assuming subsistence fisherman	
Body Weight:	70 kg
Lifetime	70 years
Exposure Period	10 years
Event Frequency	350 events per year
Amount ingested	0.05 kg per event [28]
Fraction contaminated 100% this assessments assumes that the only fish ingested is that collected locally.	

To take into account the variation in fish ingestion, a Monte Carlo simulation was carried out to examine the probability distribution of the ingestion volumes based on literature from the USA EPA, Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories

[28] See probability distribution of fish ingested

Volume 2: Risk Assessment and Fish Consumption Limits Third Edition, (US EPA, 2000). The results of this Monet Carlo are demonstrated below.

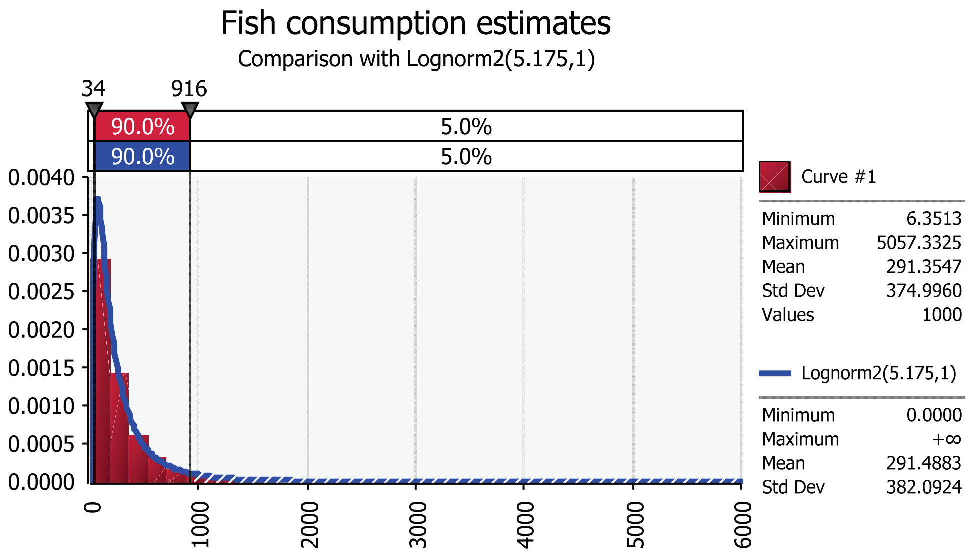

Figure 73: Monte Carlo Probability distribution of fish ingestion amounts.

These ingestions are based on a weekly ingestion amount and this was converted to a mean daily amount ingested.

Average Daily Dose (ADD) or Exposure Concentration

When evaluating the risk of chronic non-cancer health effects from oral or dermal exposures, EPA employs the Average Daily Dose (ADD) received during the period of exposure. These are compared to Reference Doses (RfDs).

ADD = Average Daily Dose (during exposure period).
in milligrams per kilogram of body weight per day.

Table 7: Exposure concentrations – Oral average daily dose.

CAS#	Chemical	Oral ADD mg/kg/d
60-57-1	Dieldrin	0.000158
58-89-9	Lindane	0.000137
72-20-8	Endrin	0.000068
76-44-8	Heptachlor	0.000068
50-29-3	DDT	0.000102
309-00-2	Aldrin	0.000055
115-29-7	Endosulfan	0.000120
72-55-9	DDE	0.000137
1336-36-3	PCBs	0.000052

Lifetime Average Daily Dose (LADD)

When evaluating carcinogenic risks from exposures that last less than a lifetime, the ADD or exposure concentration is adjusted to a dose or concentration that would yield an equivalent exposure if exposure continued for the entire lifetime.

Table 8: Lifetime average daily dose calculated based on exposure assumptions described.

LADD = ADD * (exposure period in years / lifetime in years)	
Chemical	**Oral LADD mg/kg/d**
Dieldrin	0.000023
Lindane	0.000020
Endrin	0.000010
Heptachlor	0.000010
DDT	0.000015
Aldrin	0.000008
Endosulfan	0.000017
DDE	0.000020
PCBs	0.000052

Carcinogenic Risk

For chemicals that may cause cancer if ingested, risk is calculated as a function of oral Slope Factor and Dose:

$$\text{Risk} = 1 - e^{-(\text{Oral Slope Factor} * \text{Lifetime Average Daily Dose})}$$

These estimates represent the risk over background cancer incidence of developing cancer. For example, if the calculated risk is 1 in 1,000,000 (or 1 e-006), this suggests that a person would have a one-in-a-million chance of getting cancer because of the specified chemical exposure, in addition to her/his chance of getting cancer from other causes. It is important to keep the predicted risks in this perspective as the general risk of developing cancer is 0.25 or a 1 in 4 chance) Ref from the South African National Cancer Association.

Oral Slope of a chemical is described as 1/(milligram of chemical per kilogram of body weight per day). They are generally estimated as the 95th percentile confidence limits using the linearized multistage model, and are conservative estimates of toxic hazard.

The EPA classifies carcinogens according to the strength of evidence of the supporting data with the following used to describe this weight of evidence.

A = Known human carcinogen.
B1 = Probable human carcinogen, limited human data.
B2 = Probable human carcinogen, inadequate or no human data.
C = Possible human carcinogen.
D = Not classifiable as human carcinogen.
E = Evidence that not carcinogenic in humans.

Table 9: Cancer risks based on exposure assumptions described.

Chemical	Weight of Evidence &	slope factor 1/(mg/kg/d)	Risk from specified exposure
Dieldrin	B2	16	1 in 1,000 (1e-03)
Lindane	No Slope	-	-
Endrin	No Slope	-	-
Heptachlor	B2 (mg/kg/d):	4.5	4 in 100,000 (4e-05)
DDT	B2 (mg/kg/d):	0.34	5 in 1,000,000 (5e-06)
Aldrin	B2 (mg/kg/d):	17	1 in 10,000 (1e-04)
Endosulfan	No Slope	-	-
DDE	B2 (mg/kg/d):	0.34	7 in 1,000,000 (7e-06)
PCBs	B2	7.7	4 in 10,000 (4e-04)
Total			2 in 1,000 (2e-03)

As a result of the large uncertainties associated with all risk estimates, they should always be interpreted as general indicators, rather than precise estimates. (EPA generally considers risks below 1 in a 1,000,000 (1e-6) to be low and 1 in 10,000 as unacceptable)

This is represented in the following figure.

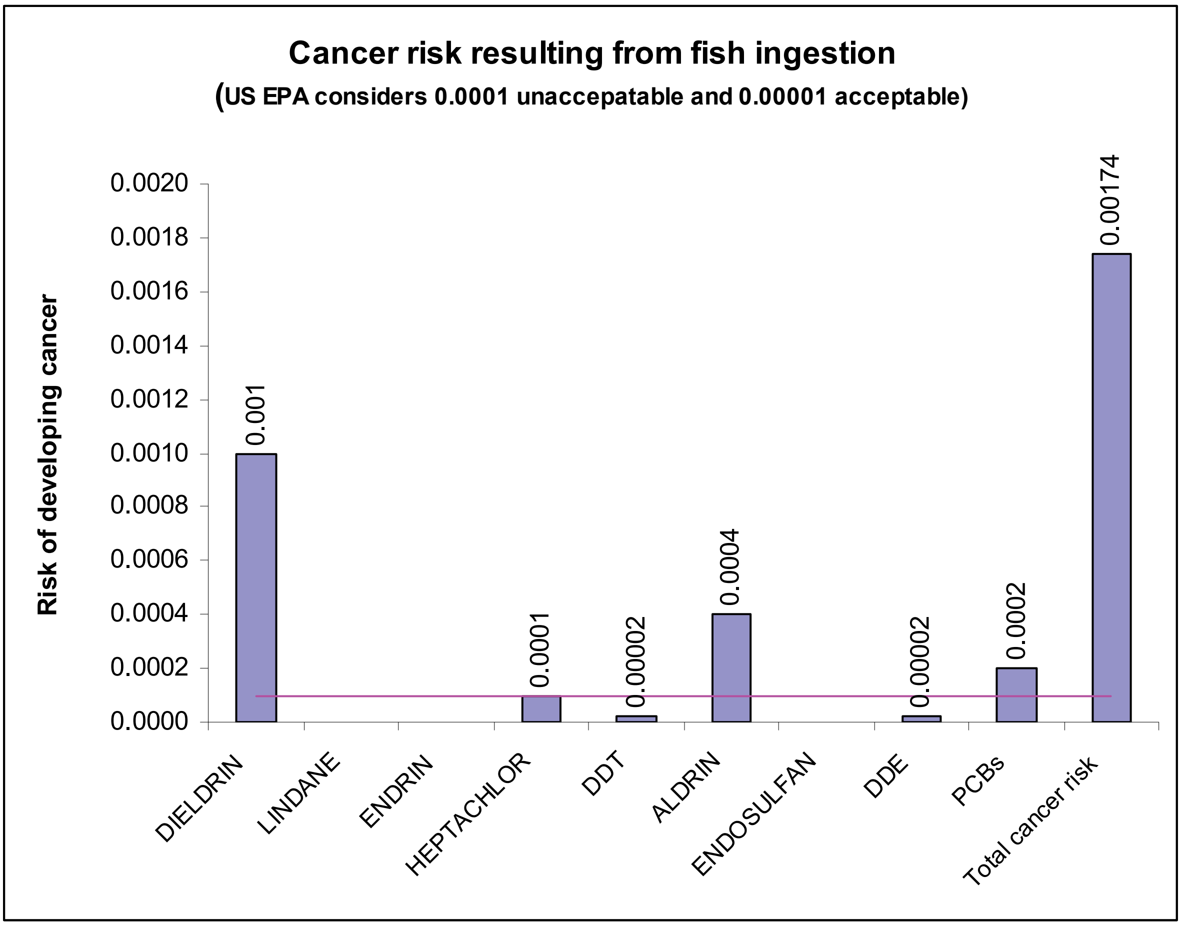

Figure 74: Cancer risks resulting from fish ingestion.

Non carcinogenic risk – Hazard quotient

For agents that cause non-cancer toxic effects, a Hazard Quotient (H.Q.) is calculated, which compares the expected exposure to the agent to an exposure that is assumed not to be associated with toxic effects. For oral or dermal exposures, the Average Daily Dose (ADD) is compared to a Reference Dose (RfD) and is calculated using the following equation.

H.Q. = Average Daily Dose / Reference Dose

Reference Doses are a conservative estimate of non-cancer toxic hazards with differences in sensitivity to toxic effects within and between species, and differences in toxic effects between chronic and sub-chronic exposures taken into account. Units are milligrams of contaminant per kilogram of body weight per day.

Table 9: Hazard Quotients due to ingestion of contaminated fish.

Hazard Quotient or Ratio of Average Dose to 'Safe' Daily Dose			
Chemical	RfD (mg/kg/d)	Source	Hazard Index
Dieldrin	0.00005	IRIS(05/30/95)	3.4
Lindane	0.0003	“”	0.49
Endrin	0.0003	“ “	0.33
Heptachlor	0.0005	IRIS(05/30/95)	0.147
DDT	0.0005	IRIS(05/30/95)	0.22
Aldrin	0.00003	IRIS(05/30/95)	1.97
Endosulfan	No RfD		-
DDE	No RfD		-
PCBs	No RfD		-
Total			6.57

These results are shown for all chemicals in the figure below.

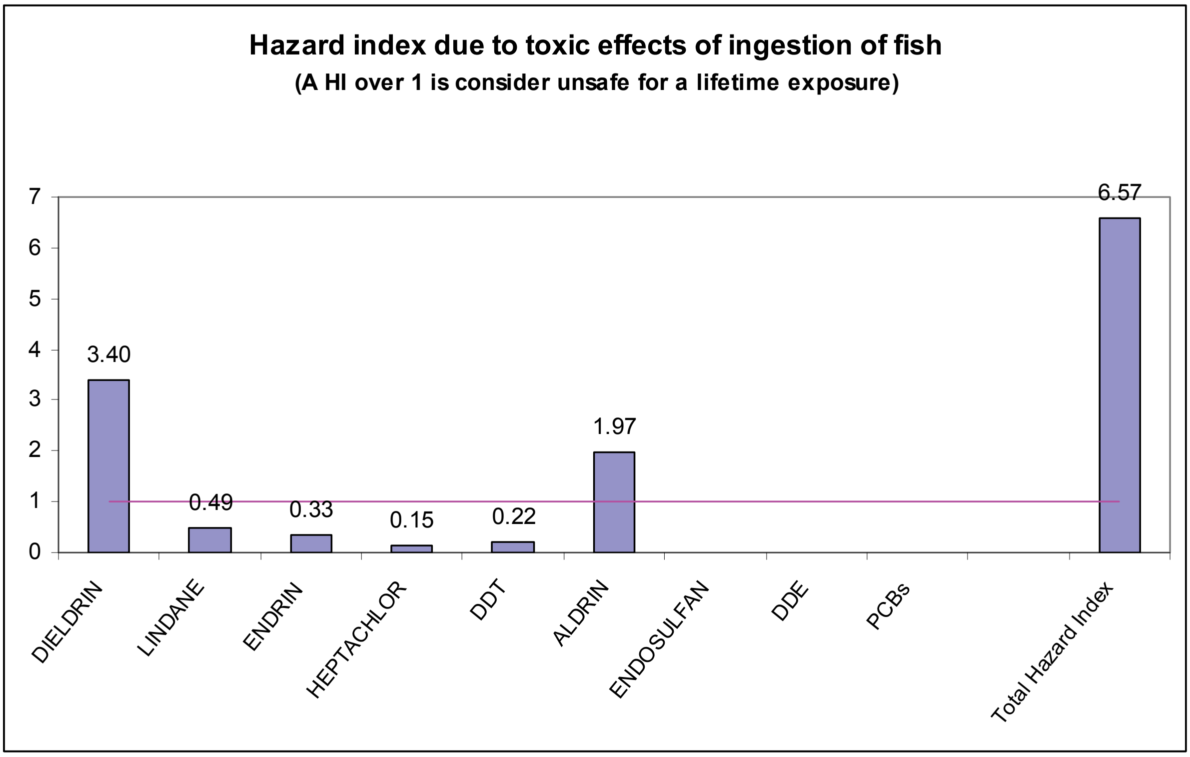

Figure 75: Hazard Index as a result of fish ingestion.

It is generally assumed that non-cancer toxic effects have some threshold. That is, up to some finite level of exposure, physiological defence mechanisms ensure that no toxic effect will occur. Accordingly, hazard assessments for non-carcinogenic effects involve estimating an exposure that is less than this threshold level. This is done by applying "uncertainty factors" to exposures that appear to be near this threshold in laboratory toxicology studies. This yields a Reference Dose (RfD) for oral exposures,

14.6 DISCUSSION

14.6.1 EDCs

The available recommended guideline line for all fish species (edible portion) by the US EPA and FDA (2001) for EDCs are listed below. The edible portion of fish excludes head, scales, viscera, and inedible bones. For:

- PCB's – 2.0 mg/kg (ppm/µg/g)
- Aldrin and dieldrin – 0.3 mg/kg.
- DDT, TDE and DDE – 5.0 mg/kg.
- Heptachlor and heptachlor epoxide – 0.3 mg/kg.

For both species the concentration of PCBs found in muscle (0.0572-, 0.0861- and 0.0608 mg/kg) were well below the recommended guideline of 2.0 mg/kg. One fish from each species collected had dieldrin levels (0.325- and 0.315 mg/kg) that is just above the recommended guideline of 0.3 mg/kg in the edible portion of the fish.

The edible part of the fish also seems safe to eat concerning the DDT, DDD and DDE levels according to the guidelines set by the FDA and EPA.

Although HCH is banned or restricted in many countries including SA, it is also a ubiquitous contaminant in the environment (Willett et al., 1998). Like OCs, HCH (lindane), the gamma-HCH (γ-HCH) isomer of HCH or benzene hexachloride (BHC) is used as insecticide on fruit, vegetables, forest crops, animals and –premises (Agency for Toxic Substances and Disease Registry (ATSDR), 2005). There are no available Δ- and β- Lindane guidelines regarding the safe consumption of contaminated fish. However, the mean level of γ-Lindane in *O.mossambicus* 210µg/kg (n= 4) and *C. gariepinus* 179µg/kg (n = 11) detected in fish, was higher than the value recommended (7µg/kg) for the fat of meat products (Environmental Protection Agency (EPA), 2003).

Endosulfan, is an insecticide, while acaricide, is a pesticide used by many subsistence farmers in African countries (Darko et al., 2008). Although there are no guidelines available concerning safe levels in fish tissue for human consumption, the levels found in muscle from *O. mossambicus* (min: 158 µg/kg; max: 299.1 µg/kg, n = 12) and *C. gariepinus* (min: 141.4 µg/kg, max: 516.2 µg/kg, n = 8) were higher the guidelines recommended by the EPA for ambient water quality criteria for protection of human health for α- and β-endosulfan and endosulfan sulphate of 110µg/L (EPA, 1999). Endosulfan is also listed as an endocrine disruptor (Park et al., 2001) and both the EPA and the ATSDR consider endosulfan to be a potential endocrine disruptor. Numerous *in vitro* studies have documented its potential to disrupt hormones and animal studies have demonstrated its reproductive and developmental toxicity, especially among males (ATSDR, 2000).

14.6.2 Metals

There are no distinctive guidelines available for permissible metal values in fish tissues regarding safe human consumption. Micronutrients including Cr, Cu, Fe, Si and Zn are regarded as essential elements that help with normal metabolic functions in the body. They are also form part of the chemical structure of hormones, vitamins and enzymes (Szefer and Nriagu, 2006). None of the so called endocrine disrupting metals (EDMs), As, Cd and Pb were detected in the muscle of both species. Due to the lack of guidelines the rest of the discussion

Most metals have an estimate of exposure levels posing minimal risk to humans or MRL value. This value is characterized as an estimate of daily human exposure to a substance that is likely to be without a considerable risk of undesirable effects (non-carcinogenic) over a specified duration of exposure (ATSDR, 2008). According to ATSDR (2008) the MRL for Al is 1 mg Al/kg/day. Levels in processed fish consumed in the UK are estimated at 5.5 mg/kg. 52

and 130 mg/kg (maximum) was found in muscle from *O. mossambicus* and *C. gariepinus* respectively caught in the Roodeplaat Dam. The Al guideline for drinking water is 0.2 mg/L (WHO, 2004). The daily intake of Al ranges in the published literature from 1.53 to 160 mg/person/day (Sorensen et al., 1974). Al has not been regarded as a toxic substance to humans for over a decade and the first illness connected with Al has been discovered in 1974 (Flaten et al., 1996). Excess Al in the body has been implicated as a poisonous driving force in the aetiology of Alzheimer's disease, Guamiam amyotrophic lateral sclerosis, and parkinsonism-dementia (Hewitt et al*.,* 1990). Furthermore, carcinogenicity, reproductive and developmental toxicity, neurotoxicity, and acute toxicity have been included (ATSDR, 2008).

Humans usually get exposed to Ba via food especially Brazil nuts, seaweed and fish (ATSDR, 2007b). It is also known to bioconcentrate in marine animals. The health effects of Ba are also determined by the dose, duration and route of exposure. For Ba the ATSDR (2007b) have no acute value but an intermediate and chronic MRL of 0.2 mg/kg/day through oral exposure.

Boron (B) was detected in the muscle of *C. gariepinus.* For humans, B has recently been characterized as a nutritional supplement that enhances the body's ability to use calcium, magnesium and vitamin D. It also aid in brain function, reduces the symptoms of arthritis and lessens menstrual pain (www.geva.co.za/html/minerals_trace_elements.html#boron). The MRL for B set by ATSDR (2007) for oral ingestion is 0.2 mg/kg/day for acute and intermediate exposure. There is no recommended dietary (RDA) allowance for B, but up to 10 mg/day is recommended as safe and therefore the meat of the *C. gariepinus* seems not to be safe for human consumption (B = min: 11 mg/kg and max: 293 mg/kg). However, high B intake has shown no toxic effects.

Fe and Zn are essential elements to most organisms. Fe is however regulated in mammals partly because of the high potential for biological toxicity. Humans consume Fe through their dietary intake which includes fish. The tolerable upper intake level (UL) for adults is stipulated as 45 mg/day and for children under fourteen the level is 40 mg/day (Spanierman, 2007). However there is no guideline for Fe or Zn for safe human consumption of freshwater fish.

Except for vanadium in the muscle of *O. mossambicus*, all the other metals (Bi, Cr, Cu, Mn, Ni, Sb, Se, Sn, Si, W and Zr) were present in lower concentrations. Vanadium is known to accumulate in fish (lenntech.com) and experiments using animals it can have neurological defects, breathing disorders, paralyses and negative effects on the liver and kidneys (ATSDR, 1992). There are no guidelines, MRL or RDA's for V concerning edibility.

14.7 HUMAN RISK ANALYSES

From the results it can be seen that the chemicals responsible for the maximum cancer risk are Dieldrin, Aldrin and PCBs, with possible toxic effects due to Dieldrin and Aldrin. This risk assessment provides an indication of possible risks only and is subject to many uncertainties. These uncertainties are touched on below.

Chemical concentrations detected in fish are a major source of uncertainty due to the limits in detection levels of pesticides and quantification methods used. The detection methods may not be precise due to equipment limitations and sample size used to assess these.

Intake rates of fish are subject to uncertainties. In the risk assessment it is assumed that the amount of fish intake is constant and representative of the exposed population. This assumption may under- or overestimate the intake rates of fish. If one assumes a consumption half of that described in the assessment, the total risk of developing cancer is reduced from 0.00174 (or approximately 2 in 1000) to 0.000555 (or approximately 5 in 10000). This demonstrates the effect of the assumption regarding consumption values of fish. The assumptions regarding the period of exposure may not be representative of the actual exposure situation. This assumption may also under- or overestimate the intake rate of fish.

Cancer Slope factors used in the risk calculation are based on an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a chemical. Each of the chemicals involved in this risk assessment are classified as a B2 Probable carcinogen, based on inadequate data. This classification may either over- or underestimates cancer risks. In addition risks at low exposure levels are difficult to measure directly, either by animal experiments or by epidemiological studies. The development of a cancer slope factor generally entails applying a model to the available data set and using the model to extrapolate from the relatively high doses administered to experimental animals (or the exposures noted in epidemiological studies) to lower exposure levels expected for human contact in the environment.

Model uncertainty is associated with all models used in all phases of a risk assessment, particularly animal models used as surrogates for testing human carcinogenicity, and the dose-response models used in extrapolations.

14.8 CONCLUSION

The PCBs found in muscle of some of the fish from both species were just above the recommended guideline of 0.3 mg/kg in the edible portion of the fish. Therefore should render the fish not safe for human consumption. However the edible part of the fish also seemed safe to eat concerning the DDT, DDD and DDE levels according to the guidelines set by the FDA and EPA. There are no guidelines for HCH and endosulfan but the concentration detected in the muscle were higher than the guidelines recommended in water.

There are also no available guidelines for the metals tested for in the muscle of both fish species. However, the possible effects of the detected metals are discussed in brief. This discussion is not a certainty as the intake and the availability of the metals are not calculated according to a risk formulation to humans consuming wild fish.

In conclusion according to the risk assessment, if the fish is consumed over a long term basis, adverse health effects are expected. However if consumption of fish is lower than that considered to be a "reasonable" exposure, these risks are considerably reduced. The risk assessment is a first tier or screening exercise and indicates that more information is needed to make an informed decision.

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