Okavango River Basin Transboundary Diagnostic Analysis Technical Report

OKACOM

The Permanent Okavango River Basin Water Commission

Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module Specialist Report Country: Botswana Discipline: Fish

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June 2009

Environmental protection and sustainable management of the Okavango River Basin

EPSMO

BIOPHYSICAL SERIES

Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module

Specialist Report

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EXECUTIVE SUMMARY

This EFA was done using existing fisheries data from the Delta and literature from various sources. The data used in this study was collected from two rapid assessments fo the Delta's fishery at low and high flood periods. Another data set used is based on an ongoing long term monitoring of the Delta' fishery from three sites in the Delta's panhandle, one site in the lower delta around Chief's island, one site in Moremi at Xakanaxa and three sites in the Boteti River. These experiemental fishing data were/ are collected using various fishing gear such as seine nets, two main kinds of research nets (mono-filament, nylon multi-panel nets; multi-filament, cotton, multi-panel nets). Furthermore, several studies have also been done on the socio-economic value of the fishery to the Delta's communities. All these data, biological/ ecological and socio-economic data, then form the basis for the formulation of a fisheries management plan for the Okavango Delta that is currently ongoing. Most of the literature used in this study was based on comprehensive research done on the ecology/ biology of the Delta's fishery in the early 1980's. It was on the basis of these literature (and data) sources that six fish guilds were developed for the Okavango Delta to use them as indicators for this EFA.

The major findings made in this study indicate that the Delta's seasonal flood pulse is the major driver of ecological/ biological change in the Delta's fish populations. The timing of migrations for breeding and feeding, the timing for actual spawning and generally most of the life history strategies of the Delta's fish species are controlled by the flood regime. The best example of these is the annual catfish run in the Delta which occurs annualy between August and October where catfish (especially *Clarias gariepinus* and *C. ngamensis*) form hunting packs that migrate slowly downstream and feed voraciously on *Marcusenius macrolepidotus* that are back-migrating into the main channel from the slowly drying out floodplains. Another major result observed is the seasonal changes in feeding ecology of most fish species where their diet varies between terrestrial and aquatic food sources depending on the flood regime. This suggests that at certain times of the year, there is direct energy flow into the fish community from terrestrial sources that are trapped by the newly arrived floods. A good example of this observation is the high proportion of termites in the diet of *Schilbe intermedius* when the floods arrive in the lower Delta. Another major observation is that due to the nature of the Delta, with its high inter and intra variability, the Delta's fish species are generally resilient to changes in the hydrological regime as long as they fall within the natural variations. This based on the observation of some species that mouthbrood their eggs (such as *Oreochromis andersonii*, etc)which enhances the survial of their young even under adverse conditions. Species such as *Hepsetus odoe* make oxygen enriched bubble nests where they lay their eggs and this protects the eggs from low oxygen conditiosn that may be caused by variations in the flow regime. Other species such as the catfishes (especially the Clarias group) have vestigial lungs that enbale them to breathe atmospheric oxygen when also helps them to survive under adverse conditions.

Expert knowledge was used to produce response curves on how these indicator species would react to variations in the Delta's flow regime caused by water development under several scenarios. This knowledge was a consolidation of ideas from experts from Angola, Botswana and Namibia which was then used to develop the response curves. As expected, minor decreases were observed in fish abundance caused by low and medium water development scenarios in the Basin. However, a high water development scenario showed that there will sharp decreases in fish abundance at the three study sites in Botswana, with the most darstic changes occuring in the Boteti River. While these results were expected based on the information available, there were gaps in knowledge which resulted in a low confidence in some of the results obtained. Clearly, the knowledge that exists in the

Okavango Delta allows for a preliminary study of this nature, but there is need to conduct more directed research to ioncrease the confidence of some of the osbervations and hence better prediction models based on the various water development scenarios. Furthermore, it is understood that this prediction model is preliminary on account of the fact that it does not yet inlcude aspects of climate change in it. Certainly incorporating climate change effects into this prediction model may highten the anticipated effects of these development scenarios on fish stocks in the Okavango Delta, and indeed in the entire basin. Nonetheless, the model worked as expected and the results it produced were plausible, which indicates that the model is appropriate for this kind of dynamic and complex system.

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ABBREVIATIONS

ABBREVIATION	MEANING
DTM	Digital Terrain Model
HOORC	Harry Oppenheimer Okavango Research Centre

ACKNOWLEDGEMENTS

The major part of this work involved intensive literature research from the library and great appreciation is extended to the HOORC library staff who really went out of their way to assist me. Specifically, I wish to extend my greatest gratitude to Ms Monica Morrison who was always so ready and helpful whenever I need material from the HOORC library. Mrs. Daisy Mafanetsa was always ready and willing to assist me with literature needs and she dealt with inter-library loans on my behalf and did some photo-copying. Thank you all for your kind assistance. I also wish to extend my warmest regards to my two colleagues from Angola (Mr M. Morais) and Namibia (Dr. B. van der Waal) who were always ready to share their knowledge and expertise with me.

INTRODUCTION

1.1 Background

An Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) Project is being implemented under the auspices of the **Food and Agriculture Organization** of the United Nations (UN-FAO). One of the activities is to complete a transboundary diagnostic assessment (TDA) for the purpose of developing a Strategic Action Plan for the basin. The TDA is an analysis of current and future possible causes of transboundary issues between the three countries of the basin: Angola, Namibia and Botswana. The Okavango Basin Steering Committee (OBSC) of the Okavango River Basin Water Commission (OKACOM) noted during a March 2008 meeting in Windhoek, Namibia, that future transboundary issues within the Okavango River basin are likely to occur due to developments that would modify flow regimes. The OBSC also noted that there was inadequate information about the physico-chemical, ecological and socioeconomic effects of such possible developments. OBSC recommended at this meeting that an Environmental Flow Assessment (EFA) be carried out to predict possible development-driven changes in the flow regime of the Okavango River system, the related ecosystem changes, and the consequent impacts on people using the river's resources.

The EFA is a joint project of EPSMO and the Biokavango Project. One part of the EFA is a series of country-specific specialist studies, of which this is the Fish Report for Botswana

1.2 Okavango River Basin EFA Objectives and Workplan

1.2.1 Project objectives

The goals of the EFA are:

To summarise all relevant information on the Okavango River system and its users, and collect new data as appropriate within the constraints of the EFA

to use these to provide scenarios of possible development pathways into the future for consideration by decision makers, enabling them to discuss and negotiate on sustainable development of the Okavango River Basin;

to include in each scenario the major positive and negative ecological, resource-economic and social impacts of the relevant developments;

to complete this suite of activities as a pilot EFA, due to time constraints, as input to the TDA and to a future comprehensive EFA.

The specific objectives are:

to ascertain at different points along the Okavango River system, including the Delta, the existing relationships between the flow regime and the ecological nature and functioning of the river ecosystem;

to ascertain the existing relationships between the river ecosystem and peoples' livelihoods;

to predict possible development-driven changes to the flow regime and thus to the river ecosystem;

to predict the impacts of such river ecosystem changes on people's livelihoods.

To use the EFA outputs to enhance biodiversity management of the Delta.

To develop skills for conducting EFAs in Angola, Botswana, and Namibia.

1.3 Layout of this report

Chapter 1 gives an introduction of this study/ project followed by Chapter 2 which provides a description of the study area. Chapter 3 then outlines the fish indicators developed in this study which are then discussed in detail in a literature review given in Chapter 4. Chapter 5 summarizes predicted responses of the indicators to various flooding scenarios, Chapter 6 lists references used in this report while Appendix A gives a full description of the indicators used in the report.

STUDY AREA

1.1 Description of the Okavango Basin

The Okavango River Basin consists of the areas drained by the Cubango, Cutato, Cuchi, Cuelei, Cuebe, and Cuito rivers in Angola, the Okavango River in Namibia and Botswana, and the Okavango Delta (Figure 0.1). This basin topographically includes the area that was drained by the now fossil Omatako River in Namibia. Outflows from the Okavango Delta are drained through the Thamalakane and then Boteti Rivers, the latter eventually joining the Makgadikgadi Pans. The Nata River, which drains the western part of Zimbabwe, also joins the Makgadikgadi Pans. On the basis of topography, the Okavango River Basin thus includes the Makgadikgadi Pans and Nata River Basin (Figure 0.2). This study, however, focuses on the parts of the basin in Angola and Namibia, and the Panhandle/Delta/Boteti River complex in Botswana. The Makgadikgadi Pans and Nata River are not included.

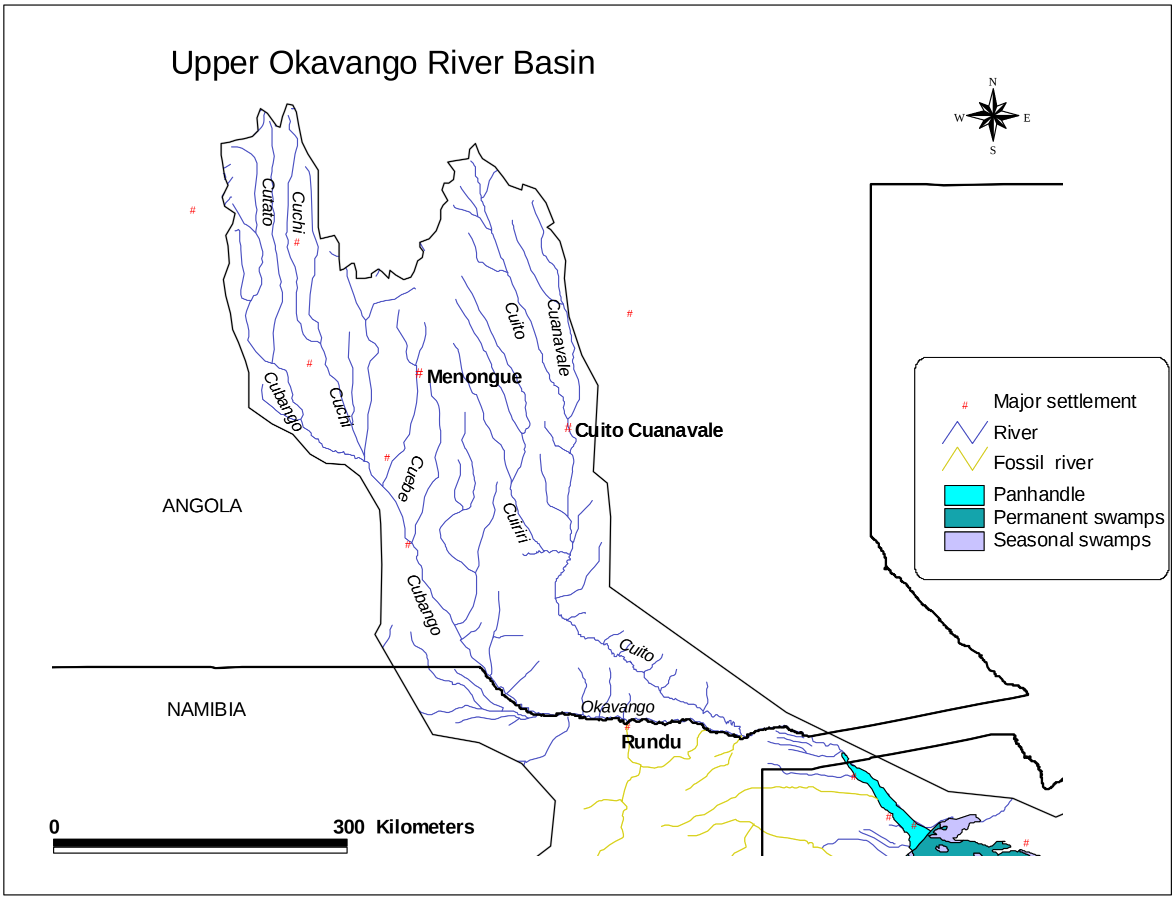

Figure 0.1 Upper Okavango River Basin from sources to the northern end of the Delta

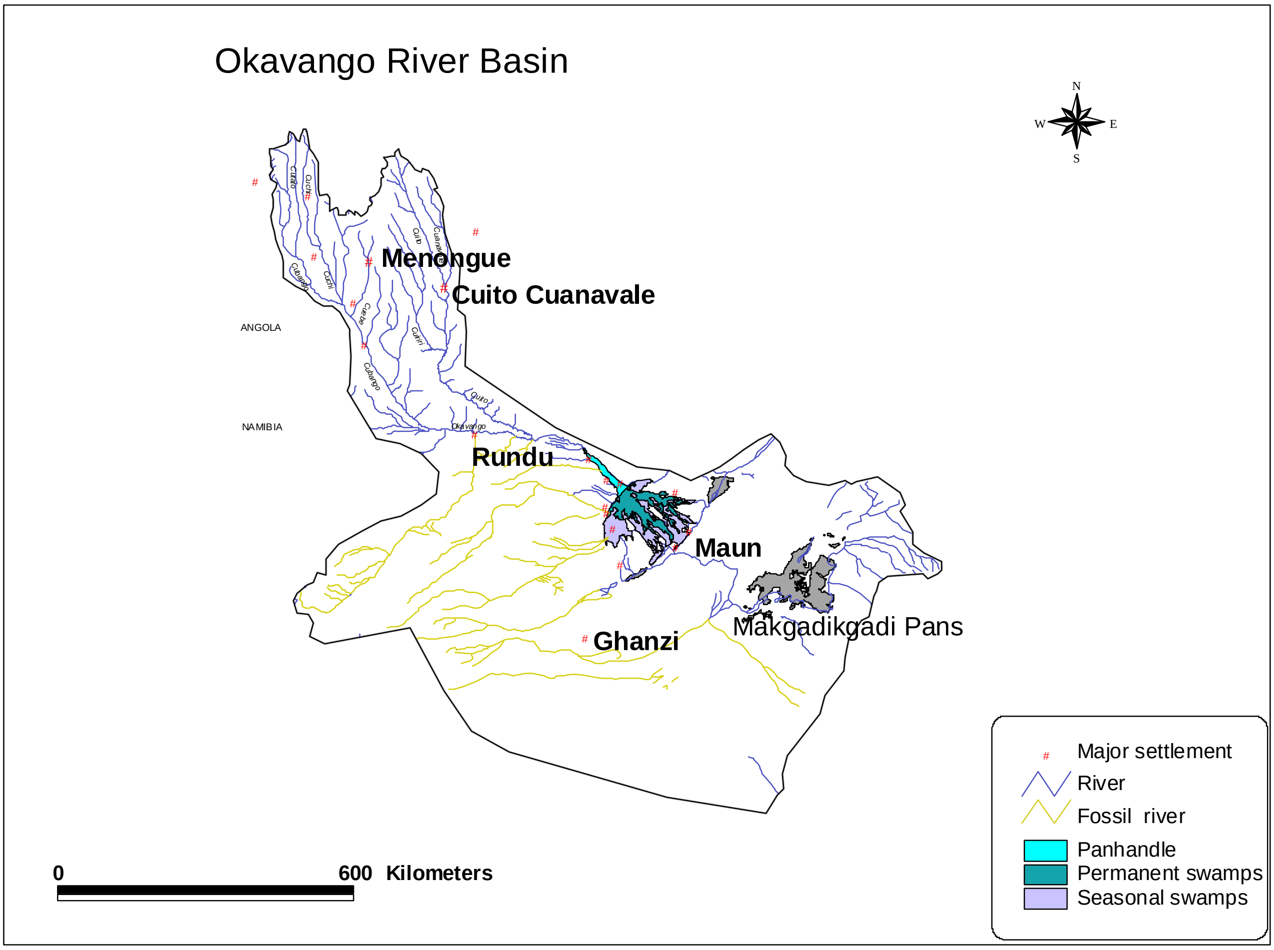

Figure 0.2 The Okavango River Basin, showing drainage into the Okavango Delta and the Makgadikgadi Pans

1.2 Delineation of the Okavango Basin into Integrated Units of Analysis

Within the Okavango River Basin, no study could address every kilometre stretch of the river, or every person living within the area, particularly a pilot study such as this one. Instead, representative areas that are reasonably homogeneous in character may be delineated and used to representative much wider areas, and then one or more representative sites chosen in each as the focus for data-collection activities. The results from each representative site can then be extrapolated over the respective wider areas.

Using this approach, the Basin was delineated into Integrated Units of Analysis (EPSMO/Biokavango Report Number 2; Delineation Report) by:
dividing the river into relatively homogeneous longitudinal zones in terms of:

- hydrology;
- geomorphology;
- water chemistry;
- fish;
- aquatic invertebrates;

vegetation;
harmonising the results from each discipline into one set of biophysical river zones;
dividing the basin into relatively homogeneous areas in terms of social systems;
harmonising the biophysical river zones and the social areas into one set of Integrated Units of Analysis (IUAs).

The 19 recognised IUAs were then considered by each national team as candidates for the location of the allocated number of study sites:
Angola: three sites
Namibia: two sites
Botswana: three sites.

The sites chosen by the national teams are given in Table 0.1.

Table 0.1 Location of the eight EFA sites

EFA Site No	Country	River	Location
1	Angola	Cuebe	Capico
2	Angola	Cubango	Mucundi
3	Angola	Cutio	Cuito Cuanavale
4	Namibia	Okavango	Kapako
5	Namibia	Okavango	Popa Falls
6	Botswana	Okavango	Panhandle at Shakawe
7	Botswana	Khwai	Xakanaka in Delta
8	Botswana	Boteti	Chanoga

IDENTIFICATION OF INDICATORS AND FLOW CATEGORIES

1.1 Indicators

1.1.1 Introduction

Biophysical indicators are discipline-specific attributes of the river system that respond to a change in river flow by changing in their:
abundance;
concentration; or
extent (area).

Social indicators are attributes of the social structures linked to the river that respond to changes in the availability of riverine resources (as described by the biophysical indicators).

The indicators are used to characterise the current situation and changes that could occur with development-driven flow changes.

Within any one biophysical discipline, key attributes can be grouped if they are expected to respond in the same way to the flow regime of the river. By example, fish species that all move on to floodplains at about the same time and for the same kinds of breeding or feeding reasons could be grouped as Fish Guild X.

1.1.2 Indicator list for Fish

In order to cover the major characteristics of the river system and its users many indicators may be deemed necessary. For any one EF site, however, the number of indicators is limited to ten (or fewer) in order to make the process manageable. The full list of indicators was developed collaboratively by the country representatives for the discipline – Dr. Ben van der Waal (Namibia), Miguel Morais (Angola) and Ketlhatlogile. Mosepele (Botswana) - and is provided in Table 0.1. Further details of each indicator, including the representative species of each biological one, are given in Appendix A and discussed fully in Chapter 0.

Table 0.1 List of indicators for fish and those chosen to represent each site

Indicator Number	Indicator name	Sites represented – no more than ten indicators per site							
		1	2	3	4	5	6	7	8
1	Resident channel and lagoon dwellers, which also undergo longitudinal migrations						X	X	X
2	Small species that undertake lateral migrations into seasonally flooded floodplains as major part of their life history strategy						X	X	
3	Large species that undertake lateral migrations into seasonally flooded floodplains as major part of their life history strategy						X	X	
4	Rock dwellers								
5	Marginal vegetation dwellers of the main channel and floodplain lagoons						X	X	X
6	Sandbank specialists (Species that prefer clear, slow-flowing or quiet, well vegetated water in the main channel)						X	X	
7	Shallow, well vegetated backwater habitats						X	X	

1.1.3 Description and location of indicators

Indicator 1

Name: Resident channel and lagoon dwellers, which also undergo longitudinal migrations

Description: These are normally characterized by clear, fast flowing deep water of the main channel or large lagoons that are connected to the main channel.

Representative species: Tiger fish (*Hydrocynus vittatus*)

Other characteristic species: Pink bream (*Serranochromis robustus)*, Nembwe (*S. giardi)*
Flow-related location: *H. vittatus* prefers well oxygenated water in the deep main river channel and large lagoons. Both *S. robustus* and *S. giardi* prefer deep main channel habitats and permanently flooded lagoons. The latter prefers water bodies with sandy bottoms.

Known water needs: *H. vittatus* undergoes longitudinal migrations to spawn on flooded river banks where newly hatched larvae are transported by receding water to the main channel. It is known to have declined in some systems due to water abstraction, pollution and dams (and weirs) which impeded their migrations. *S. giardi* makes nests within dense vegetation in about 3 m water depth while *S. robustus* nests along vegetated fringes of the main channel in summer.

Indicator 2

Name: Small species that undertake lateral migrations into seasonally flooded floodplains as a major part of their life history

Description: These seasonally flooded habitats are characterized by relatively shallow, but clear water. The habitats normally have sandy bottoms for the nest making species, and have different kinds of submerged and emergent vegetation.

Representative species: Silver catfish (*Schilbe intermedius*), bulldog (*Marcusenius macrolepidotus*), and *Petrocephalus catastoma*

Other characteristic species: Synodontis spp.
Flow-related location: *M. Macrolepidotus* prefers well-vegetated, muddy-bottomed, marginal habitats of river channels while *S. intermedius* is a pelagic species that prefers open water.

Known water needs: *M. macrolepidotus* migrates into the shallow flooded floodplains for breeding in shallow, vegetated water before they back-migrate to the deeper waters. *S. intermedius* is normally found in slow-flowing water with either emergent or submerged vegetation. They also lay eggs on vegetation.

Indicator 3

Name: Large species that undertake lateral migrations into seasonally flooded floodplains as a major part of their life history

Description: These seasonally flooded habitats are characterized by relatively shallow, but clear water. The habitats normally have sandy bottoms for the nest making species, and have different kinds of submerged and emergent vegetation.

Representative species: Red breast tilapia (*Tilapia rendalli*), three-spot tilapia (*Oreochromis andersonii*) and green-head tilapia (*O. macrochir*)

Other characteristic species: Thin-face large-mouth (*Serranochromis angusticeps*), and Catfishes, especially sharp-tooth catfish (*Clarias gariepinus*)

Flow-related location: *T. rendalli* prefers well-vegetated water on river channel and floodplain lagoons margins. *O. andersonii* prefers slow-flowing or standing water in backwaters and floodplain lagoons. *O. macrochir* prefers quiet waters along river margins, backwaters and floodplain habitats. *S. angusticeps* prefers quiet backwater habitats with dense vegetation.

Known water needs: *T. rendalli* undergoes seasonal migrations to seasonally flooded floodplains where it makes nests in shallow water. O. andersonii undergo seasonal migrations into the seasonally flooded floodplains where they breed and feed. Adults then back-migrate to deep open water while juveniles remain among littoral vegetation. *O. macrochir* undergo seasonal migrations into seasonally flooded floodplains where they feed and make nests in shallow water for breeding. *S. angusticeps* makes nests in the flooded floodplains in 1-3 m deep water.

Indicator 4

Name: Marginal vegetation dwellers of the main channel and floodplain lagoons

Description: These habitats are characterized by littoral vegetation on the main channels and lagoons. They generally have deep, slow moving water. The littoral vegetation is normally a mixture of papyrus, reeds and hippo grass.

Representative species: *Sargochromis carlottae, Serranochromis macrocephalus, Hepsetus odoe*

Other characteristic species: *Pollimyrus castelnaui, Synodontis nigromaculatus, C. multispine,*

Flow-related location: *S. carlottae* prefers well vegetated habitats while *S. macrocephalus* occurs more along the littoral vegetation of the floodplain channels and lagoons. *C. multispine, S. nigromaculatus* and *P. castelnaui* occur on marginal vegetation of river channels and floodplain lagoons. Adult *H. odoe* prefer quite, deep water while juveniles of *H. odoe* prefer well-vegetated marginal habitats.

Known water needs: *S. carlottae* prefers deeper water areas with sandy bottoms in floodplain lagoons and river channels; *S. macrocephalus* feeds near the bottom of channels and lagoons and breeds at low water just before the onset of the floods *H. odoe* make bubble nests in the dense vegetation of marginal habitats or the shallow-well vegetated habitats of floodplains.

Indicator 5

Name: Sandbank specialists; species that prefer clear, slow flowing or quiet, well vegetated water along the main channel or side channels off the main channel

Description: These habitats are characterized by sandy banks, normally off the main channels. The water here is normally very clear, is slow moving or quiet, and is sometimes sparsely vegetated.

Representative species: *Brycinus lateralis, Barbus poechii, Leptoglanis rotundiceps*
Other characteristic species:
Flow-related location: *B. lateralis* shoal in clear, slow-flowing or quiet, well vegetated water and these normally occur with *B. poechii*

Known water needs: These species prefer sandy, shallow areas

Indicator 6

Name: Shallow, well vegetated backwater habitats

Description: These habitats are normally found either in the seasonal floodplains or off the main channel in the backwaters. They are characterized by shallow, standing/ quiet, clear and well vegetated water.
Representative species: *Tilapia sparrmanii, Pharyngochromis acuticeps, Aplocheilecthys johnstoni, A. hutereaui, Pseudocrenilabrus philander*

Other characteristic species: *Barbus paludinosus, Hemichromis elongatus, Barbus multilineatus, Aplocheilichthys afrovernayi, Microctenopoma intermedium*

Flow-related location: The Aplocheilichthys spp. prefer inshore, well vegetated water. *H. elongatus* prefers clear, littoral area water, while *T. sparrmanii* prefers quiet/ standing water with either submerged or emergent vegetation. *B. multilineatus* and *A. afrovernayi* both prefer quiet, well vegetated water while *M. Intermedium* occurs in shallow, dense marginal vegetation
Known water needs: Aplocheilichthys spp. prefer shallow water in the seasonal floodplains. *H. elongatus* and *T. sparrmanii* make nests on the substrate. *B. multilineatus* and *A. afrovernayi* prefer shallow water. *M. intermedium* make bubble nests in water among the aquatic vegetation of shallow water habitats.

1.2 Flow categories – river sites

One of the main assumptions underlying the EF process to be used in the TDA is that it is possible to identify parts of the flow regime that are ecologically relevant in different ways and to describe their nature using the historical hydrological record. Thus, one of the first steps in the EFA process, for any river, is to consult with local river ecologists to identify these ecologically most important flow categories. This process was followed at the Preparation Workshop in September 2008 and four flow categories were agreed on for the Okavango Basin river sites:
Dry season
Transitional Season 1

Flood Season
Transitional Season 2.

Tentative seasonal divisions for river Sites 1-5 are shown in Figure 0.1 to Figure 0.5. These seasonal divisions will be formalised by the project hydrological team in the form of hydrological rules in the hydrological model. In the interim they provide useful insights into the flow regime of the river system suggesting a higher within-year flow variability of the Cuebe River and a higher year-on-year variability of the Cubango River.

It is planned to use similar flow seasons for the remaining river sites: 6 and 8.

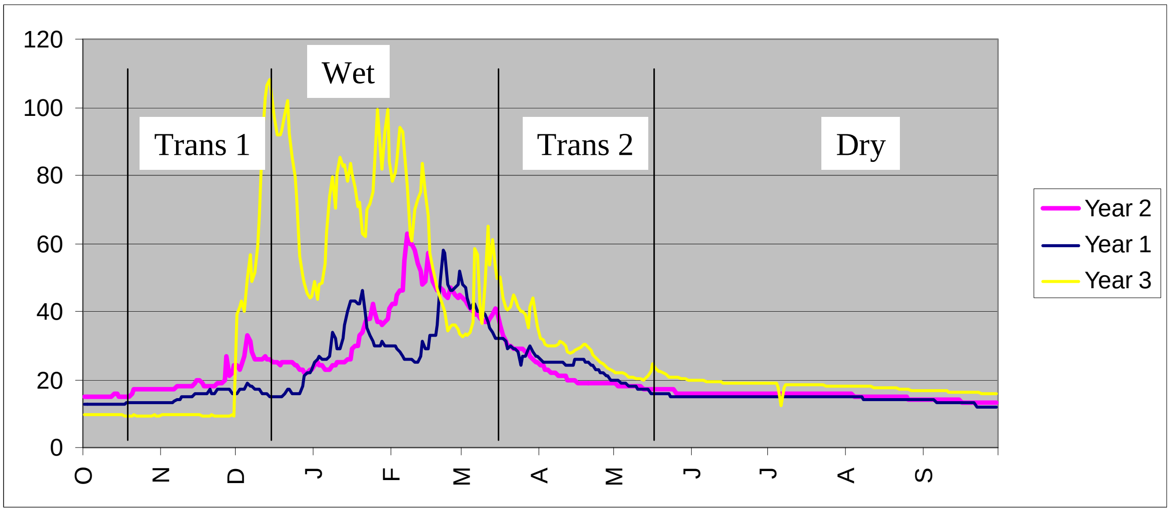

Figure 0.1 Three representative years for Site 1: Cuebe River @ Capico, illustrating the approximate division of the flow regime into four flow seasons

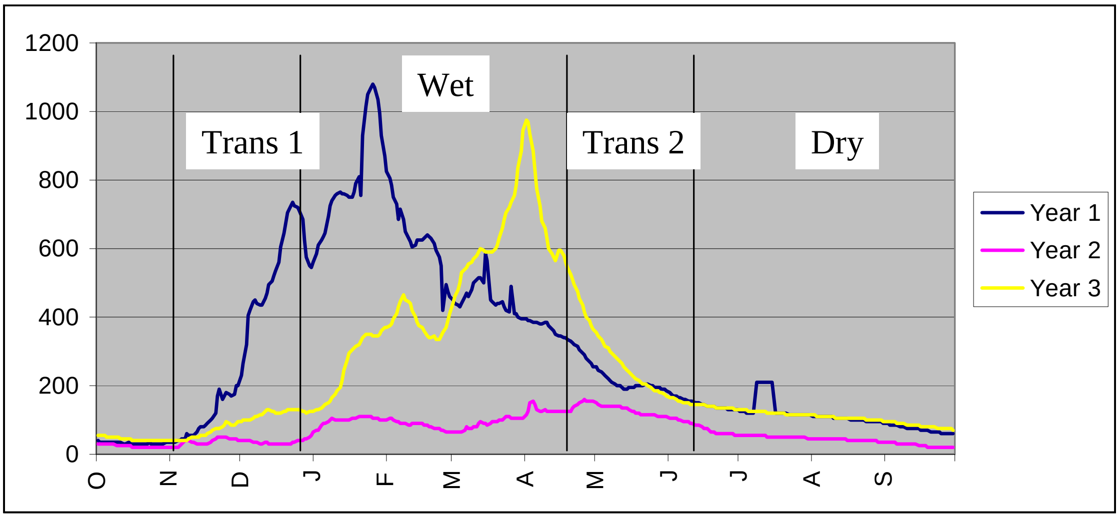

Figure 0.2 Three representative years for Site 2: Cubango River @ Mucindi, illustrating the approximate division of the flow regime into four flow seasons

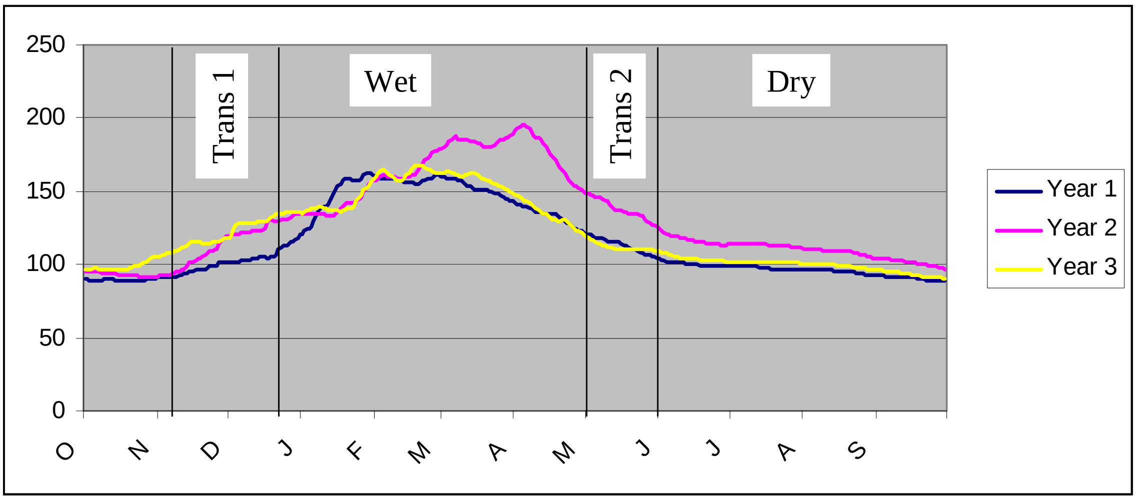

Figure 0.3 **Three representative years for Site 3 Cuito River @ Cuito Cuanavale, illustrating the approximate division of the flow regime into four flow seasons**

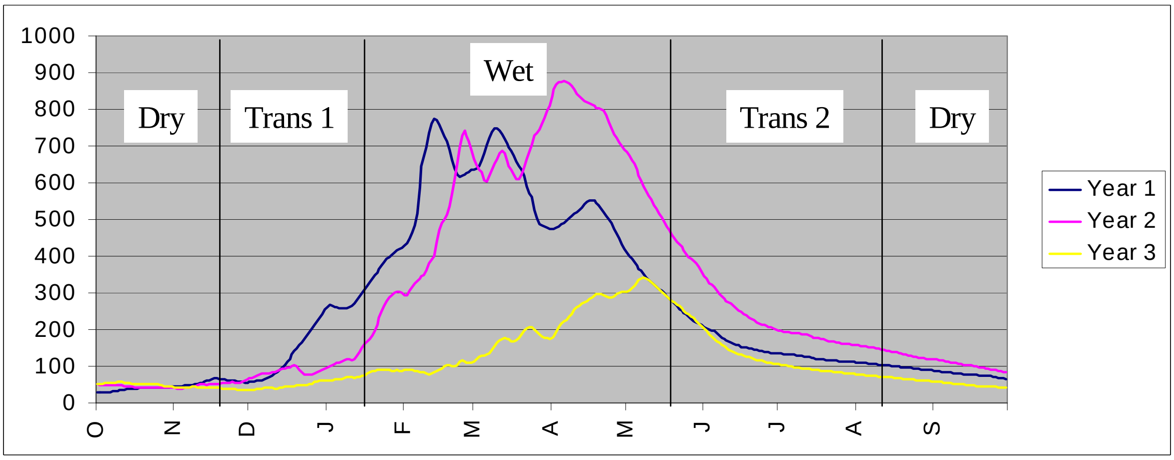

Figure 0.4 **Three representative years for Site 4: Okavango River @ Kapoka (hydrological data from Rundu), illustrating the approximate division of the flow regime into four flow seasons**

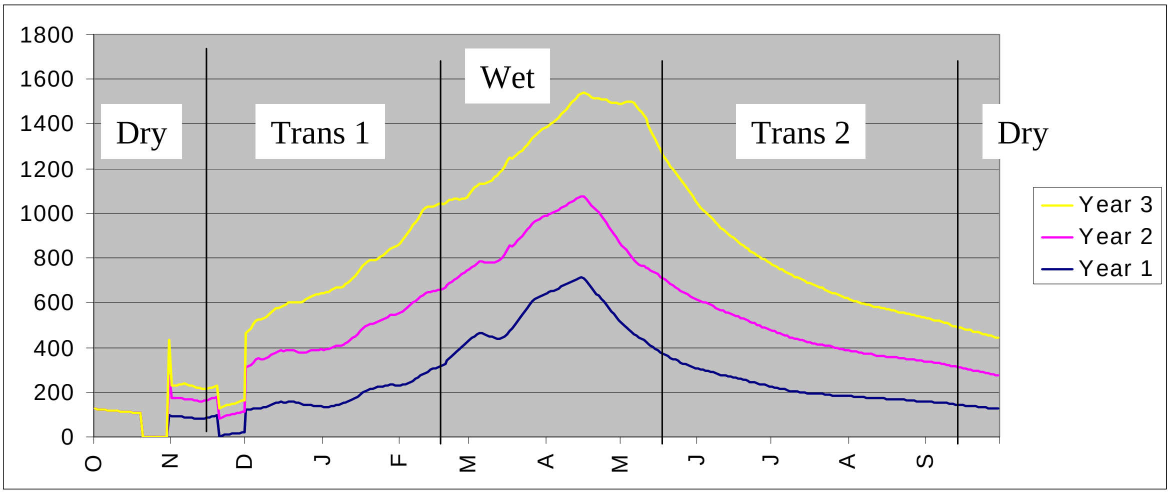

Figure 0.5 Three representative years for Site 5: Okavango River @ Popa (hydrological data from Mukwe), illustrating the approximate division of the flow regime into four flow seasons

The literature review (Chapter 0) and data collection and analysis exercises (Chapter 0) are focused on addressing what is initially expected to be nine main questions related to these flow seasons (Table 0.2).

Table 0.2 Questions to be addressed at the Knowledge Capture Workshop, per indicator per site. In all cases, 'natural' embraces the full range of natural variability

Question number	Season	Response of indicator if:
1	Dry Season	Onset is earlier or later than natural mode/average
2		Water levels are higher or lower than natural mode/average
3		Extends longer than natural mode/average
4	Transition 1	Duration is longer or shorter than natural mode/average - i.e. hydrograph is steeper or shallower
5		Flows are more or less variable than natural mode/average and range
6	Flood season	Onset is earlier or later than natural mode/average – synchronisation with rain may be changed
7		Natural proportion of different types of flood year changed
8	Transition 2	Onset is earlier or later than natural mode/average
9		Duration is longer or shorter than natural mode/average – i.e. hydrograph is steeper or shallower

1.1 Inundation categories – delta sites

The recognised river flow categories are not relevant in the Delta, where inundation is the major driver of ecosystem form and functioning. The main inundation categories recognised by the inundation model developed by the Harry Oppenheimer Okavango Research Centre (HOORC) are used here (Table 0.3).

Table 0.3 Inundation categories for the Okavango Delta as recognised by the HOORC inundation model

Inundation category	Inundation category name	Description
Delta 1	Channel in permanent swamp	
Delta 2	Lagoons in permanent swamp	
Delta 3	Backswamp in permanent swamp	
Delta 4	Seasonal pools in seasonally flooded zones	
Delta 5	Seasonal sedgelands in seasonally flooded zones	
Delta 6	Seasonal grasslands in seasonally flooded zones	
Delta 7	Savannah – dried floodplain in seasonally flooded zones	
Boteti 1	Wet connected	
Boteti 2	Disconnected pools	
Boteti 3	Dry	

LITERATURE REVIEW

Introduction

Both published and grey literature were used to find suitable information for this study. However, while very little literature exists for the Okavango Delta, apart from the extensive work done by Merron and Bruton (1988), most of the available published literature found was for the Zambezi system. Most of this literature, especially old publications, were found in the Peter Smith Collections at the HOORC library. Some internet searches also produced few literature that were also used for this report. Notwithstanding, there is very little literature that exists for the Okavango Delta that explores the relationship between flow and fish biology/ ecology.

The most comprehensive ecological study of the Delta's fish populations was done by Merron and Bruton (1988) and Merron (1991). The general observations made from these key studies indicated that the seasonal flow regime in the Delta is a major drive of change in the Delta's fish communities. Skelton, et al (1985) observed that the annual flood pulse is a major driving force in the Delta fish stocks. This was echoed by Mosepele (2008) who highlighted that, similar to other flood pulsing systems worldwide, the delta's fish stocks are also directly affected by the seasonal flood pulse. This observation concurs with Mosepele et al (2009) who observed that the length of time the water is present in the floodplains and the nature of its flow have a significant effect on the Delta's fish communities. Bell-Cross (1974) observed that the timing, height and duration of annual floods are the main regulatory factors of fish biomass in the neighbouring Zambezi system. Bell-Cross (1974) further observed a positive correlation between fish production and prolonged flooding. According to Bell-Cross (1974), as a consequence of poor rainfall, flood waters will recede from the floodplains and tributaries earlier than usual with several potential effects on the Upper Zambezi fish stocks: (i) increased fishing and natural mortality (i.e. predation pressure) where there will be limited natural cover due to less water availability; (ii) juvenile fish will be forced out of their refuge before they reach adequate size which will make them more vulnerable to predation from a greater size range of predatory species and for a longer period. Moreover, the backwater habitats and lagoons which are normally utilized by sub-adult fish will dry out and be uninhabitable as refuge for juvenile fish; (iii) potentially increased natural mortality (due mainly to predation) of juveniles of some commercial species which spawn in the main channel just before the onset of flooding.

Chapman and Chapman (1993) observed seasonal variations in fish abundance in the River Sokoto (Nigeria). They concluded that spawning success, migration, habitat partitioning, mortality and other “random trapping of individuals as waters fall” may account for their observations in fluctuating abundance of fish in the Sokoto system. Furthermore, Chapman and Chapman (1993) discussed that spawning success and mortality are affected by the onset and duration of flooding in the Sokoto system. Smaller fish may escape predation pressure in floodplain pools through an earlier rise in water levels where there may be a high concentration of predators by the end of the dry season. Moreover, they also observed that longer duration floods may be beneficial to multiple spawners such as Tilapia spp. and Oreochromis spp. Notwithstanding, Chapman and Chapman (1993) also highlighted that unpredictability in the magnitude and duration of flooding may result in some fish getting trapped in floodplain pools. They observed that a faster rate of flood level decline in the 1956-1957 flooding season resulted in a high proportion of migratory species/ fish getting trapped in floodplain pools in the Sokoto system. However, it is equally important to note that density dependent factors on fish populations will also begin to play a major role on fish stocks in floodplain pools/ lagoons as the dry season progress. According to Chapman and Chapman (1993) they may result in heavy pressure on available food and limited space which will increase both intra and inter specific competition for resources.

Merron and Bruton (1988) concluded that the breeding cycle of most Delta species is directly influenced by the flood regime. Furthermore, they also observed that the seasonal flood pulse opens up new littoral habitat seasonally which acts as nurseries for most fish species. While the Delta might be an unstable system due to the seasonal flood regime, its fish species are highly resilient because they persist in space and time (Merron and Bruton, 1988). According to Bell-Cross (1974), an increase in water velocity is the first trigger of fish migrations in the Upper Zambezi system. After movement has been initiated, then the depth dependency factor becomes important, where lack of “acceptable water depth” regulates any further movements of certain size classes of fish within each species group. Based on this observation, Bell-Cross (1974) highlighted that the first fish species to migrate laterally are small sized species that have a low a depth-dependency factor, and juveniles of some large species which breed before the floods arrive, such as some cichlid species. Bell-Cross (1974) observed that the depth dependency factor might be the major factor regulating fish back-migrations to the main channel. Kapoor and Khanna (2004) observed that freshwater fish undertake migrations either for foraging or breeding purposes. They concluded that water current is used as a major cue for orientation during migrations, where the direction of water flow orients a fish. Therefore, apart from Bell-Cross’s (1974) depth dependency factor, Kapoor and Khanna’s (2004) observations suggested that back-water flow from the drying up floodplains may be the environmental cue for fish species to start back-migrating into more permanent/ deeper water. Notwithstanding, Chapman (1995) observed that depth was a major factor regulating the dispersal of Clarias liocephalus in the Rwembaita Swamp (Uganda). However, Chapman et al (1998) also found a positive relationship between high saturated oxygen levels in floodplain water and peak flood periods. Subsequently, they (Chapman et al., 1998) discussed that dissolved oxygen is limiting during the dry season period. Therefore, low flood periods, while contributing towards density dependent factors regulating fish abundance and production, might also cause low dissolved oxygen which would also be detrimental to fish stocks. Subsequently, Chapman and Liem (1995) had observed that the relative Barbus neumayeri during the dry season in the Rwembaita Swamp was positively correlated to dissolved oxygen levels and not depth.

These pulses in fish migrations, caused by the seasonal flood pulse, cause variations in fish catch rates. This observation agrees with Welcomme (1985) that fish catch rates in floodplain systems are affected by dilution and concentration factors, and this has been established for the Delta (Merron and Bruton, 1988; Mosepele, 2000). Cued by the seasonal flood pulse, species either undergo longitudinal or lateral migrations in the Delta primarily for feeding and breeding purposes (Merron and Bruton, 1988; Merron, 1991). This observation agrees with Chapman (2001) who concluded that fish in the Congo River undergo migrations for feeding and breeding purposes. Chapman and Liem (1995) made similar observations that the seasonal dispersal of Barbus neumayeri in the Rwembaita Swamp is not restricted to spawning individuals only. Moreover, fish growth during the high flood period tends to be faster due to high food availability (Chapman, 2001) compared to low flood periods when density dependent factors are major regulating factors. Moreover, while some species might spawn throughout the year (i.e. multiple spawners), their peak spawning normally coincide with high flooding.

As a counterpoint to lateral and longitudinal migrations caused by the arrival of the flood, Bell-Cross (1974) described dry-season fish migrations of small-sized fish species along the margins of the main channel in water of 1-m or less depth. These small-sized species form shoals which might include (but are not restricted to) Barbus barotseensis, B fasciolatus, B. paludinosus, Hemigramocharax multifasciatus, Aplocheilichthys johnstoni, juvenile Labeo lunatus and Tilapia sparrmanii. Possibly, the stimulus for these upstream migrations is water velocity, because Bell-Cross (1974) observed that these upstream migrations might last for only several weeks when the water velocity is still relatively high in the Zambezi (April - June). Subsequently, these migrations cease completely which is attributed to either a substantial decrease in water velocity or intense predation by species such as H. vittatus. Conversely, Bell-Cross (1974) suggested that larger sized species are more territorial during the dry season period.

Lindholm et al (2007) observed that “seasons of large and long lasting floods cause improved circulation and enhanced reproductive success for fish”. This is based on the observation that low floods constrained fish migrations into the floodplains which severely affected recruitment. Subsequently, Lindholm et al (2007) observed that fish abundance during a high flood was almost double (i.e. 2x) that at low flood levels. This intimate relationship between general fish ecology/ biology (or fish production) and the flood regime is also highlighted by Mosepele et al (2009). They (Mosepele et al 2009) observed that the seasonal flood pulse does not only open new habitat to fish colonization, but that seasonal flooding also drives fish breeding and subsequent recruitment into the Delta fishery which is ultimately utilized by both subsistence, commercial (albeit small scale) and recreational fishers. Furthermore, Mosepele et al (2009) observed that maintaining the Delta’s ecosystem as the mainstay of abundant fish and wildlife resources requires and deep understanding of the Delta’s flow requirements and “then using this understanding to allocate water in the rest of the Okavango watershed”. Subsequently, Mosepele et al (2009) modified the existing WEAP model to incorporate environmental needs (in this case fish and flows). One basic assessment made under this model was that minor hydrologic manipulations upstream would have minimal impact on the Delta’s ecosystem. However, Mosepele et al (2009) concluded that a more holistic and comprehensive approach, that incorporates conflicting water uses, is needed “to fully understand the interactions between upper basin management and ecosystem status in the delta”. Therefore, it is envisaged that this current approach will address most of the concerns raised by Mosepele et al (2009) using their conceptual approach.

1.1 Indicator 1: Main channel/ open water species

1.1.1 Main characteristics of Indicator 1

The fish species in this indicator spend most of their adult life history in the deep, open waters of the main channel and deep, large lagoons and oxbow lakes which are connected to the main channel. According to Merron (1991), water permanency, depth and flow are some of the major ecological factors limiting the distribution of Hydrocynus vittatus in the Okavango Delta. Therefore, H. vittatus occurs in the more hydrologically stable and permanent parts of the Delta (Merron and Bruton, 1988; Merron, 1991). Winemiller and Winemiller (1994) also made a similar observation that adult H. vittatus prefer more riverine habitats and large lagoons and are not found in seasonally flooded floodplains. In the Zambezi system (main channel of Zambezi and Chobe rivers), H. vittatus was found to occur at mid-water depth within the water column, in fast flowing water. According to Winemiller (1991), S. robustus and S. giardi in the Upper Zambezi prefer deep portions of the main channel habitats close to the bottom and near high sand banks. S. robustus prefer moderate to swift flowing water, while S. giardi prefer slow, swirling water currents (Winemiller, 1991). For the upper Zambezi, Winemiller (1991) described S. robustus as a “river-dwelling, epibenthic, diurnal piscivore” while S. giardi as described as a “river-dwelling molluscivore”.

Hydrocynus vittatus, which is a key species in this guild is a key recreational species that sustains the Delta’s recreational fishery. However, S. robustus is also a key recreatioanlly harvested species in the Delta’s fishery (Mosepele et al 2003). Based on data available, Mosepele and Nengu (2003) estimated that the maximum size (i.e. L) that H. vittatus can reach is 68 cm total length (though fork length is normally the preferred length for this species), while they estimated a maximum total length of 56 cm for S. robustus. Nothwithstanding, estimates from the Fishbase database (www.fishbase.org) based on data from Rwanda estimated a total length of 105 cm for H. vittatus. The database indicates that this species has a life span of 11 years, and reaches sexual maturity between 27 and 40 cm .

1.1.2 Life cycle attributes of Indicator 1

Skelton (2001) observed that H. vittatus undergo longitudinal migrations in the main channels in search of suitable spawning/ breeding habitat. According to Merron (1991), H. vittatus breeds in early summer on the shallow littoral areas (along papyrus vegetation) of the main channels and oxbows lagoons. They undergo longitudinal migrations in the main channel on feeding forays and also in search of optimum breeding habitat. Due to the cannibalistic nature of this species (Merron and Bruton, 1988; Merron, 1991; Winemiller and Winemiller, 1994), there is a strict habitat partitioning of the different size classes of H. vittatus, where juvenile/ sub-adult fish are found in slower flowing and more vegetated water while adult fish are found in more open, fast flowing water (Merron and Bruton, 1988). This agrees with Winemiller and Winemiller (1994) who observed habitat partitioning between young-of-the-year and adult H. vittatus in the Zambezi system.

1.1.3 Links to flow

<u>H. vittatus</u>

While Winemiller and Winemiller (1994) observed that breeding of H. vittatus may be positively correlated to the duration of the annual flood, Merron and Bruton (1988) observed that H. vittatus spawns in early summer in the Delta (before the onset of the annual floods).

This agrees with Kenmuir's (1973) observation from Lake Kariba that the duration of breeding of H. vittatus is tied to the duration of river flow. It is on this basis that Kenmuir (1973) observes that the presence of atrophied female H. vittatus gonads in the Mwenda area could be attributed to female fish waiting for too long for “the river to start flooding sufficiently.” flood properly. Kenmuir (1973) also observed that the atrophied gonads could also have been caused by the river stopping flowing before female fish had reached a “fully ripe laying condition.”

Merron and Bruton (1988) observed that H. vittatus spawns in the papyrus fringe of the main channel and ox-bow lakes. According to Merron (1991), H. vittatus is predominantly found in the main channel habitat, characterized by high water retention, with a mean depth of 2.5 m and relatively fast flowing water (i.e. a water flow rate of approximately 2-7 m/ sec). H. vittatus prefers a sandy substrate, with abundant emergent vegetation, some fairly common submerged vegetation, and some floating vegetation. Furthermore, Winemiller and Winemiller (1994) observed that water depth is possibly one of the major limiting factors for the distribution of H. vittatus. According to some past research (Merron and Bruton, 1988; Merron, 1991), juvenile H. vittatus (age 1) stay in the shallow, well vegetated areas in the littoral areas of the main channel and large lagoons (and ox-bow lakes/lagoons) connected to the main channel. Sub-adult H. vittatus (age 2) inhabit tributary channels off the main channel while adult fish (age 3+) inhabit the deeper and open water habitats of the main channel and large lagoons (and ox-bow lakes/ lagoons).

H. vittatus has an ontogenetic feeding behaviour, where juvenile fish are primarily insectivorous while adults are mainly piscivorous (Merron and Bruton, 1988; Skelton, 2001). Notwithstanding, Kenmuir (1973) observed that H. vittatus fry in Lake Kariba graze zooplankton heavily, perhaps on account of their preferred habitat at this age (shallow, well vegetated habitats with slow flowing water) Winemiller and Winemiller (1994) observed a seasonal shift in the diet of H. vittatus in the upper Zambezi. At high flood levels, its top three prey items were Hepsetus odoe, cichlids (unidentified) and haplochromine cichlids respectively. Conversely, the top three prey items for H. vittatus at low flood levels were Synodontis sp., haplochromine cichlids and momyrids respectively. According to Merron and Bruton (1988) adult H. vittatus congregate at outlets of floodplain channels at receding floods and prey heavily on Barbus sp which are back-migrating into the main channel due to drying out floodplains. This observation agrees with Kenmuir's (1973) observation that H. vittatus feeding activity increased with decreasing lake levels in Kariba.

Serranochromis robustus* and *Sargochromis giardi

Winemiller (1991) observed that S. robustus and S. giardi in the Upper Zambezi appear to spawn just prior to flooding. This observation on S. giardi agrees with Bell-Cross (1975) who observed that S giardi's breeding season coincides with the rainy season, which occurs between October and February in the Upper Zambezi.

While their sample size was extremely small (15 fish) and the time series too short to make any conclusive statements(6 months), Okland et al (2002) observed that S. robustus prefers water depths of around 3.7 m in the Zambezi River. Okland et al (2002) also observed that S. robustus prefers water with sandy substrates. Notwithstanding, Winemiller (1991) observed seasonal shifts in the population structure of S. robustus in the Upper Zambezi. There was a higher abundance of smaller/ younger fish during falling water levels while the population was dominated by larger/ older fish at low floods. The higher proportion of younger/ smaller S. robustus at falling floods was attributed to spawning that occurred just prior to or during the peak flooding. Subsequently, the higher proportion of older/larger S. robustus at low floods was attributed to increased predation on juvenile fish and “growth in the absence of spawning activity that would add new recruits to the smallest size classes” (Winemiller, 1991).

S. giardi in the Upper Zambezi has an ontogenetic feeding pattern where younger fish fed mostly on aquatic invertebrates, while older fish fed primarily on bivalve molluscs and Trichoptera larvae off the sandy substrate. S. robustus also showed an ontogenetic feeding pattern where younger fish preyed more on Barbus sp and less on juvenile Synodontis sp while older fish preyed on juvenile Synodontis sp and less on Barbus sp (Winemiller, 1991).

1.1 Indicator 2: Small species that undertake lateral migrations into the shallow, seasonally flooded floodplains

1.1.1 Main characteristics of Indicator 2

These are small sized species which migrate into the flooded floodplains seasonally with the arrival of the annual flood. Generally, floodplain species, especially small sized individuals such as in this guild, are characretrised by fast and seasonal growth patterns as a consequence of seasonality in flooding (MRAG, 1994), which sugests that they have a high degree of relience to environmental variability. According to Mosepele and Nengu (2003), M. Macrolepidotus, which is a key species in this guild, can reach a maximum size (i.e. L) of approximately 20 cm total length. Based on Fishbase (www.fishbase.org), M. macrolepidotus lays 6000 eggs, reaches sexual maturity between 11 and 15 cm, and spawns during teh rainy season. According to the Fishbase database (www.fishbase.org), S. intermedius lays approximately 18 000 eggs, is a non-guarder, spawns throughout the year, lives to about 5 years and reaches sexual maturity between 11 and 16 cm total length. Furthermore, while larger sized M. macrolepidotus might prefer large floodplain lagoon habitats, smaller sized M. macrolepidotus undertake seasonal migrations to the main channel at receding flood levels where they are subsequently preyed upon by C. gariepinus. According to Kramer (1999), C. gariepinus preys more heavily on male M. macrolepidotus than females primarily because the male’s produce an electric discharge. This high preference for M. macrolepidotus is perhaps based on Hanika and Kramer’s (2000) observation that C. gariepinus is electro-receptive and may home in onto electric discharges of M. macrolepidotus. S. intermedius is one of the most abundant and ubiquitous species in the Okavango Delta (Merron and Bruton, 1988; Mosepele et al, 2005) and is normally a shoaling species found in slow flowing water (Merron and Bruton, 1988).
According to Mosepele et al (2003), these species are harvested by subsistence fishers using a variety of fishing gears (e.g. fishing baskets, fishing weir, traditional hook and line, etc). Notwithstanding, the small sized species in this guild are all important subssitence fishery species and are key sources of food security during times of food scarcity (Mosepele et al 2006). Furthermore, subsistence fishing (for these species) is an important social safety net in the Delta that acts as a buffer for households against HIV/AIDS related stressors and chronic poverty (Ngwenya and Mosepele, 2007). Notwithstanding all these, availability of these species to exploitation (and that of floodplain species in general (Welcomme, 1985)) is subject to concentration and dilution effects because of the hydrological regime (Mosepele, 2000; Mmopelwa et al 2009). However, subssistence fishers have developed differeht coping mechanisms to exploit these species optimally despite the observed spatio-temporal varaitions in availability (Mmopelwa, et al 2009). Moreover, the spatio-temporally diffused nature of the fishery (Mosepele and Mosepele, 2005) controlled by a flood pulse (Mosepele, 2008) pose daunting fisheries management challenges.

1.1.2 Life cycle attributes of Indicator 2

<u>S. intermedius</u>

According to Mosepele et al (2005), S. intermedius is an opportunistic predator with an ontogentic feeding behaviour which makes it a successful predator in the Delta. Because of its feeding ecology, this species feeds on a wide variety of species ranging from aquatic and terrestrial invertebrates by younger/ juvenile fish to being piscivorous as the fish grow older (Merron and Bruton, 1988; Merron, 1991; Mosepele et al, 2005). Furthermore, S. intermedius is known to prey heavily on termites that normally appear just after the summer rains (Merron and Bruton, 1988; Mosepele et al, 2005). Merron and Bruton (1988) observed that S. intermedius' breeding cycle is closely tied to the arrival of annual flood waters in the Okavango Delta

1.1.3 Links to flow

<u>M. macrolepidotus</u>

Merron (1993) observed that large populations of smaller-sized M macrolepidotus (i.e. <140 mm) start back-migrating from the floodplains into the main channel of the Delta at receding flood levels (i.e. starting from around August in the Upper Delta). According to Merron (1993), this is possibly a dispersal mechanism which is caused by limited space in floodplain lagoons, where the larger M macrolepidotus remain and breed throughout the summer months as observed by Merron and Bruton (1988).

1.2 Indicator 3: Large species that undertake lateral migrations into the shallow, seasonally flooded floodplains

1.3 Main characteristics of Indicator 3

These are large sized species that undergo seasonal lateral migrations as a consequence of the seasonal flood regime. According to Mosepele and Nengu (2003), specis such as O. andersonni can reach a maximum size (i.e. L) of 53 cm total length, T. rendalli can reach a maximum size of 47 cm while O. macrochir can reach a maximum size of 40 cm, making it the smallest of these cichlids. Nonetheless, it has been observed that similar individuals of same species from upper and lower Delta habitats have different growth rates. Generally upper Delta individuals appear to growth slowly and reach bigger sizes while lower Delta individuals grow faster and reach smaller sizes (Tweddle et al 2003; Mosepele et al, 2005). Adult O. andersoni spend most of their time in the main channel (s) of the Delta while O. macrochir is found mostly in slow flowing channels and lagoons and some well-vegetated backwater lagoons (Merron and Bruton, 1988). Furthermore, while C. gariepinus is generally ubiquitous in the Delta, its major inclusion in this indicator is based on its strong seasonal behaviour where it congregates in hunting packs and preys heavily on smaller sized species that back-migrate to the main channel at receding flood levels from the floodplains. Notwithstanding, these three cichlid species (i.e. O andersoni, O. Macrochir and T. rendalli) are key commercially harvested species in the Delta (Mosepele, 2000; Mosepele and Kolding, 2003; Mosepele et al, 2003) and have sustained a commercially viable and vibrant small scale commercial fishery in the Delta (Mmopelwa et al, 2005). Commercial fishers employ indigenous traditional knowledge to selectively harvest these species in the Delta (Mosepele et al 2007). Despite consistent concerns about commercial over-exploitation of these key species that has resulted in various forms of conflict (Kolding, 1996; Mosepele 2000; Tweddle et al 2003), assessments of the fishery using various indicators such as a classical length based assessment (Mosepele and Kolding, 2003), trends in catch per unit of effort (i.e. cpue expressed as kg/fisher/ year) by Kgathi et al (2005), trends in mean length over time and reaction time of this fishery (i.e. cichlids) to the flood regime (Ntsima, 2008), there has been no indications of biological over-fishing observed. The greatest management challenge facing this fishery, and floodplain fisheries in general, is to not only implement policies based on classical fisheries management approaches that have failed elsewhere (Mosepele, 2008), but to also find the balance between traditional user rights and modern management approaches (Mosepele et al 2007) based on a co-management approach (Jul-Larsen et al 2003).

1.3.1 Life cycle attributes of Indicator 3

Oreochromis andersoni* and *O. macrochir

While O. macrochir in the Upper Zambezi commence breeding in the early summer months before the onset of the floods, they also breed during the high flood period in the floodplains (after undergoing lateral migration). Juvenile O. macrochir then remain in floodplain lagoons and backwaters until they are large enough to co-exist with H. vittatus in the main channel habitat (Bell-Cross, 1974).

C. gariepinus

In the Zambezi, C. gariepinus commence breeding during the middle of the rainy season when adults undergo lateral migrations to spawn on the shallow, newly inundated grassy floodplains (Bell-Cross, 1974). C gariepinus spawns in shallow floodplains and slow flowing river channels where the eggs hatch after 24 hours and the fish fry/ larvae are free-swimming start feeding/ foraging around 80 hours (2-3 days) after being hatched (Merron and Bruton, 1988; Skelton, 2001). According to Skelton (2001), the larvae remain under vegetation cover in littoral areas, presumably to hide from predators. While growth is rapid, it is affected by local conditions but they may grow to about 200 mm (SL) within the first year (Skelton, 2001).

1.3.2 Links to flow

Oreochromis andersoni, O. macrochir* and *Tilapia rendalli

According to Bell-Cross (1974), periphyton is the most important diet of juvenile fish of commercially important species like Oreochromis andersoni and O. macrochir, which are normally found in the quiet, slow flowing waters of seasonally flooded floodplains. While T rendalli is primarily a herbivore, it also feeds on detritus, aquatic and terrestrial insects. It makes nests in shallow water of not more than 2-m depth in floodplains (Bell-Cross, 1974). On the other hand, Merron and Bruton (1988) observed that O. andersoni make nests on a sandy substrate in water of between 0.2 – 2 m depth. Merron and Bruton (1988) highlighted that one month after the eggs are hatched, the fish fry move into very shallow littoral habitats in floodplains where they maximise growth due to the relatively high temperatures.

Bell-Cross (1974) observed that there was intense predation on young cichlids (juveniles and sub-adults) during years of poor rainfall in the Zambezi because the fish are then restricted to the permanent channels only. Merron and Bruton (1988) observed an extended and large scale breeding/spawning for O. andersoni in the Delta which they associated with the high floods of 1984 that had maintained high water levels and created extensive flooded areas. Conversely, they (Merron and Bruton, 1988) also observed a significant decrease/ decline in the proportion of spawning/ breeding female fish in 1985, which was a year of poor floods and high water temperatures.

According to Merron and Bruton (1988), T. rendalli spawn between September and March, where upper Delta populations have an extended spawning/ breeding season compared to the lower Delta populations. They also observed that T. rendalli spawn on cleared substrate and the parents guard the eggs until they hatch. The hatched larvae are then transferred to nest holes where they are guarded by the parents until they start to swim freely and become independent off their parents (Lowe-McConnell, 1975).

C. gariepinus

According to Merron and Bruton (1988), spawning for C. gariepinus varies based on location. In the upper panhandle, C. gariepinus spawns during February and March at the peak of the flooding season (measured at Mohembo) where they migrate to seasonally flooded grassy floodplains, where their eggs are attached to aquatic vegetation. Notwithstanding, Merron (1993) observed an increase in the reproductive condition of C. gariepinus with pack-hunting in the upper Delta. While only 20% of the sampled pack-hunting C. gariepinus were ripe running at the start of their annual feeding migrations in October, a higher proportion (70%) of ripe running females was observed at the end of the pack-hunting feeding migrations in mid-December. In the lower Delta, C. gariepinus spawns between September and December.

Depending on the timing, duration and magnitude of the annual flood season, C. gariepinus form pack-hunting shoals between August and mid-December annually (Merron and Bruton, 1988; Merron, 1991, 1993). During this time, they prey heavily on momyrids (specifically on M. macrolepidotus and P. catastoma) (Merron and Bruton, 1988; Merron, 1991, 1993; Hanika and Kramer, 2000) and to a lesser extent on other fish species such as Schilbe intermedius, T. sparrmanii and Barbus sp (Merron and Bruton, 1988; Merron, 1991, 1993). According to Merron (1993), average water depth where C. gariepinus feed during this time (between August - December) is approximately 0.5 m and the shoals normally extend about 20 m into the papyrus fringe. A similar pack-hunting behaviour was observed by Bell-Cross (1974) in the Zambezi where C. gariepinus prey heavily on smaller fish back-migrating from the drying up floodplains. Merron (1993) further highlighted that pack-hunting C. gariepinus is a predictable response of predators to changes in the Delta's flood levels.

1.4 Indicator 4: marginal vegetation dwellers of the main channel and floodplain lagoons

1.4.1 Main characteristics of Indicator 4

Winemiller (1991) observed that large S. altus prefer mid-depth water habitats or near surface areas beneath or adjacent to dense stands of aquatic marginal vegetation usually at the interface between swift downstream current and slower back eddies of the main channel of the upper Zambezi. This observation agrees with Skelton (2001) who highlighted that S. altus is found inshore from well vegetated river banks. H. odoe builds nets in the shallow, seasonally flooded floodplain habitats as part of its life history.. Furthermore, H. odoe is a top predator in the lower Delta (in the absence of H. vittatus) as observed by Merron and Bruton (1988) and it subsequently has a regulatory impact on the fish community of the lower Delta. H. odoe is also an important subsistence fishery species (Mosepele al, 2003).

1.4.2 Life cycle attributes of Indicator 4

H. Odoe

H. odoe spawns between September and March in both the upper and lower portions of the Okavango Delta (Merron and Bruton, 1988) where it lays bubble/ foam nests among aquatic vegetation of seasonally flooded floodplains or even on the aquatic vegetation on the margins of main channel habitats in the lower Delta (Merron and Bruton, 1988).

1.4.3 Links to flow

H. odoe

Winemiller and Winemiller (1994) observed seasonal changes in the diet of H. odoe in the Upper Zambezi. At low flood levels, Haplochromine cichlids constituted the highest proportion (30.3%) of the diet of H. odoe, followed by momyrids and other H. odoe respectively. Conversely, while Haplochromine cichlids still constituted the highest proportion of the H. odoe diet at high floods, this proportion was much higher than at low floods (i.e. 49% vs. 30.3%), followed by momyrids and some Tilapia sp. This observation suggests that H. odoe is more cannibalistic at low floods, possibly due to increased intra-specific competition caused by reduced space.

1.5 Indicator 5: sandbank specialists: Species that prefer clear, slow flowing or quiet well vegetated water in the main channel

1.5.1 Main characteristics of Indicator 5

This indicator refers primarily to species that either prefer sandy banks of the main channel, or species that prefer slow flowing, clear water of the main channel and large lagoons. Some species in this indicator (Leptoglanis) spend most of their time covered in the clean, white sand substrate, while other species (Brycinus lateralis and Barbus poechii) spend most of their time feeding either from the water surface for terrestrial insects or feeding among the aquatic vegetation for aquatic macro-invertebrates.

1.5.2 Life cycle attributes of Indicator 5

While very little is known about the biology of Leptoglanis rotundiceps, this species is known to bury itself in sand and snap/ grab at passing food particles/ prey. This species is also known to be an early summer spawner (Merron and Bruton, 1988).

1.5.3 Links to flow

B. lateralis has an omnivorous diet comprising of both plant material and aquatic macro-invertebrates (e.g. gastropods, bivalves, crustaceans, etc). Merron and Bruton (1988) observed that plant material; especially seeds and fruits from marginal and submerged plants like Nymphea sp constitute a significant proportion of the diet of this species. In this case, B. lateralis is an important conduit of energy from the terrestrial to the aquatic habitats.

1.6 Indicator 6: Shallow, well vegetated backwater habitats

1.6.1 Main characteristics of Indicator 6

This indicator refers to species which spend most of their time in the shallow, well vegetated backwater habitats off the main channel or seasonal floodplain habitats. These species are normally found in slow flowing water among aquatic vegetation, while some species such as the A johnstoni can also be found in the fast flowing waters of the channel habitats at low flood periods.
Most of the small sized cichlids that are found in this guild (i.e. T. Sparrmanii, H. elongatus, P. philander, etc) are harvested by the subsistence fishery using fishing baskets by women predominantly (Mosepele et al 2003) and constitute a major buffer during lean periods (Mosepele et al, 2006).

1.6.2 Life cycle attributes of Indicator 6

Chapman and Liem (1995) observed that the reproductive activity of a cyprinid, Barbus neumayeri, increased during seasonal flooding, which agrees with Merron and Bruton's (1988) observation that the reproductive activity of most cyprinids in the Delta is regulated by the seasonal flood regime

1.6.3 Links to flow

C. multispine
This species is not common in the fast flowing waters of the upper Delta and is found more in the slower flowing shallow floodplain habitats in the lower Delta (Merron and Bruton, 1988). According to Merron and Bruton (1988), C. multispine is sometimes found in rain pools shortly after heavy rains because of its ability to crawl over wet ground to other habitats. Furthermore, Skelton (2001) observed that C. multispine also preys on small fish and aquatic macro-invertebrates.

1.7 Summary

As already indicated, floodplain fish have fast growth rates and variable growth patterns on account of the seasonal flood regime. Moreover, because of the nature of the environment they live in, they have relatively elastic life history strategies which allows them to adapt to different macro and micro ecosystems that are found within the Delta. Therefore, while six guild/ indicators were developed for the Delta based on their habitat preferences, these indicators still need to be refined further with more basic research to establish some of the observations and associations that were made in this chapter. Species such as C. gariepinus and S. intermedius are fairly ubiquitous in the Delta and is found in any particular habitat. O. andersoni is a pioneer species that has found been found in either drying out isolated pools in the seasonal floodplains or was observed colonizing a recently inundated sump lake in the Delta (i.e. Lake Ngami). Even more interesting was that while O. andersoni is recorded in published literature as a detritivore, it was feeding voraciously on cyprinids in Lake Ngami. Therefore, there is need for more basic research to establish quantitative relationships between flow variability, habitat partitioning and fish population dynamics in the Delta.

DATA COLLECTION AND ANALYSIS

No new data were collected for this study.

1.8 Methods for data collection and analysis

Data collected on long term monitoring projects was used in this study and none was collected specifically for this project.

1.9 Results

No new data

1.10 A summary of present understanding of the predicted responses of all fish indicators to potential changes in the flow regime

The following tables summarize predicted response of the fish indicators developed in this study due to changes in the flow regime of the Delta and the Boteti River.

5 DATA COLLECTION AND ANALYSIS

Methods for data collection and analysis

This report is based on fieldwork on birds conducted during the period 2000 to the present, and not on any specific work for this project. Previous fieldwork is summarized below:
Extensive aerial surveys of the whole Delta censusing Wattled Cranes, during 2001, 2002 and 2003. This was supported by groundwork monitoring breeding success of nesting pairs
Fieldwork gathering data for a baseline study of the Slaty Egret during 2004 and 2005.
AquaRap 2003 – birds were surveyed at two of the sites relevant to this project (viz. Shakawe and Xakanaxa) as well as at other sites, which provided the basis for selecting the indicator species at these sites.
African Waterbird Census data – these waterbird counts are conducted biannually (mid-winter and mid-summer) throughout the Okavango Delta and provide detailed information on the numbers and distribution of waterbirds which can be related to water flow levels. The three sites for this project have been regularly surveyed in the past – for some sites the dataset spans almost two complete decades.

A summary of present understanding of the predicted responses of all bird indicators to potential changes in the flow regime

The following tables summarise general responses of the indicator species to dry season variables, flood season variables and the transition between flood and dry seasons. It must be emphasised that these are general reponses as they are not area specific.

4.11.1 Fish Indicator 1 – Resident in river

Table 0.1 Predicted response to possible changes in the flow regime of fish resident in river in the Okavango River ecosystem

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	Relatively negligible if later because it might result in a prolonged spawning season which is good Negative if earlier because then it shortens breeding season which might affect recruitment	High
2		Water levels are higher or lower than natural	Higher water levels might have a positive effect Lower water levels might have a negative effect because it might affect spawning/ breeding	High
3		Extends longer than natural	Negative because it might affect spawning/ breeding and feeding	High
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	A steep rise in water levels will have negative effects A longer rise will have relatively positive effects	medium
5		Flows are more or less variable than natural	The effects might be negligible - Nil	low
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	The effects may be negligible if synchronisation with rain is changed. Earlier onset might be positive while later may be negative	medium
7		Natural proportion of different types of flood year changed	Higher floods than normal are always good for general floodplain fish production Lower floods than normal are always negative for general floodplain fish production	medium
8	Transition 2	Onset is earlier or later than natural	Earlier decrease may affect fish recruitment negatively Late decrease may affect fish recruitment positively	high
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	A steep hydrograph might have a negative effect on larval fish back-migrations into main channel A shallower hydrograph might be beneficial to larval fish growth and eventual recruitment	medium

4.11.2 Fish Indicator 2 – Small fish migrating to floodplains

Table 0.2 Predicted response to possible changes in the flow regime of small fish migrating to floodplains in the Okavango River ecosystem

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	Might be beneficial if later because it might result in a prolonged spawning season hence facilitating increased fish production Negative if earlier because then it shortens breeding season which might affect fish production	High
2		Water levels are higher or lower than natural	Higher water levels might have a positive effect on fish production Lower water levels might have a negative effect because it might affect spawning/ breeding	medium
3		Extends longer than natural	Negative because it might affect spawning/ breeding and feeding. However, catfishes might not be as severely affected as other species in this guild	high
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	A steep rise in water levels will have negative effects because juvenile fish might get trapped in the floodplains which will negatively affect recruitment A longer rise will have relatively positive effects because juvenile fish will have more time to grow and hence increase year class strength	high
5		Flows are more or less variable than natural	Nil- the effects might be negligible because these are relatively small species which have relatively faster growth rates and extremely high turnover rates.	medium
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	The effects may be negligible if synchronisation with rain is changed. However, the effects will be highly detrimental to silver catfish whose feeding ecology is closely tied to the rainy season where they feed voraciously on termites in the seasonally flooded floodplains Earlier onset might be positive while later may be negative	high
7		Natural proportion of different types of flood year changed	Higher floods for these floodplain fish might result in stronger year-class strength (and more than one cohort per season) Lower floods will have a negative effect on fish production due to limited spawning/ breeding habitat	high
8	Transition 2	Onset is earlier or later than natural	Earlier onset may affect recruitment and will hence be negative to fish production Later onset will be beneficial to fish production because of a prolonged growing season	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	A steep hydrograph might have a negative effect on larval fish back-migrations into main channel A shallower hydrograph might be beneficial to larval fish growth and eventual recruitment	high

5.3.3 Fish Indicator 3 – Large fish migrating to floodplains

Table 0.3 Predicted response to possible changes in the flow regime of large fish migrating to floodplains in the Okavango River ecosystem

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	Might be beneficial if later because it might result in a prolonged spawning season hence facilitating increased fish production Negative if earlier because then it shortens breeding season which might affect fish production	High
2		Water levels are higher or lower than natural	Higher water levels might have a positive effect on fish production Lower water levels might have a negative effect because it might affect spawning/ breeding	Medium
3		Extends longer than natural	Negative because it might affect spawning/ breeding and feeding	medium
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	A steep rise in water levels will have negative effects because juvenile fish might get trapped in the floodplains A longer rise will have relatively positive effects because juvenile fish will have more time to grow and hence increase year class strength	high
5		Flows are more or less variable than natural	If the flows are highly variable, then this will have a negative effect on fish in this guild because they take longer to respond to environmental variability which makes them more vulnerable to high variability	low
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	The effects may be negligible if synchronisation with rain is changed. Earlier onset might be positive while later may be negative	medium
7		Natural proportion of different types of flood year changed	Higher floods for these floodplain fish might result in stronger year-class strength (and more than one cohort per season) Lower floods will have a negative effect on fish production due to limited spawning/ breeding habitat	medium
8	Transition 2	Onset is earlier or later than natural	Earlier onset may affect recruitment and will hence be negative to fish production Later onset will be beneficial to fish production because of a prolonged growing season	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	A steep hydrograph might have a negative effect on larval fish back-migrations into main channel A shallower hydrograph might be beneficial to larval fish growth and eventual recruitment	high

5.3.4 Indicator 4 – Sandbank dwellers

Table 0.4 Predicted response to possible changes in the flow regime of sandbank dwellers in the Okavango River ecosystem

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	Might be beneficial if later because it might result in a prolonged spawning season hence facilitating increased fish production Negative if earlier because then it shortens breeding season which might affect fish production	medium
2		Water levels are higher or lower than natural	Higher water levels might be negative because they might erode habitat quality Lower water levels might have a negative effect because it might affect spawning/ breeding	Medium
3		Extends longer than natural	Negative because it might affect spawning/ breeding and feeding	medium
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	A steep rise in water levels will erode sandbanks and hence have a negative impact on habitat quality A longer rise will have relatively positive effects because juvenile fish will have more time to grow and hence increase year class strength	medium
5		Flows are more or less variable than natural	More variable flows than normal will have a negative impact on habitat quality which might affect fish production	low
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	The effects may be nil if synchronisation with rain is changed. Earlier onset might be positive while later may be negative	medium
7		Natural proportion of different types of flood year changed	Higher floods may affect development of sandbank which will have a negative impact on fish production while lower floods than normal may also affect habitat integrity and hence fish production	medium
8	Transition 2	Onset is earlier or later than natural	Earlier onset may affect recruitment and will hence be negative to fish production Later onset will be beneficial to fish production because of a prolonged growing season	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	A steep hydrograph might have a negative effect on sandbank habitats A shallower hydrograph might be beneficial to larval fish growth and eventual recruitment	high

5.3.5 Indicator 5 – Marginal vegetation dwellers

Table 0.5 Predicted response to possible changes in the flow regime of sandbank dwellers in the Okavango River ecosystem

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	Relatively negligible if later because it might result in a prolonged spawning season which is good Negative if earlier because then it shortens breeding season which might affect recruitment	High
2		Water levels are higher or lower than natural	Higher water levels might have a negative effect because it will affect habitat integrity Lower water levels might have a negative effect because it might affect spawning/ breeding	medium
3		Extends longer than natural	Negative because it might affect spawning/ breeding and feeding	High
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	A steep rise in water levels will have negative effects A shallower rise will have relatively positive effects	medium
5		Flows are more or less variable than natural	The effects might be negligible - Nil	low
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	Nil- The effects may be negligible if synchronisation with rain is changed. Earlier onset might be positive while later may be negative	medium
7		Natural proportion of different types of flood year changed	Higher floods than normal might be negative because this will affect habitat integrity Lower floods than normal might also affect habitat integrity negatively	medium
8	Transition 2	Onset is earlier or later than natural	Earlier decrease may affect fish recruitment negatively Late decrease may affect fish recruitment positively	medium
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	A steep hydrograph might have a negative effect on larval fish back-migrations into main channel A shallower hydrograph might be beneficial to larval fish growth and eventual recruitment	medium

5.3.6 Indicator 6 – backwater dwellers

Table 0.6 Predicted response to possible changes in the flow regime of backwater dwellers in the Okavango River ecosystem

Question number	Season	Possible flow change	Predicted response of indicator	Confidence in prediction (very low, low, medium, high)
1	Dry Season	Onset is earlier or later than natural	Relatively negligible if later because it might result in a prolonged spawning season which is good Negative if earlier because then it shortens breeding season which might affect recruitment	High
2		Water levels are higher or lower than natural	Higher water levels might have a positive effect Lower water levels might have a negative effect because it might affect spawning/ breeding	High
3		Extends longer than natural	Negative because it might affect spawning/ breeding and feeding	High
4	Transition 1	Duration is longer or shorter than natural - i.e. hydrograph is steeper or shallower	A steep rise in water levels will have negative effects A shallower rise will have relatively positive effects	medium
5		Flows are more or less variable than natural	The effects might be negligible - Nil	low
6	Flood season	Onset is earlier or later than natural – synchronisation with rain may be changed	Nil - The effects may be negligible if synchronisation with rain is changed. Earlier onset might be positive while later may be negative	medium
7		Natural proportion of different types of flood year changed	Higher floods than normal are always good for general floodplain fish production Lower floods than normal are always negative for general floodplain fish production	medium
8	Transition 2	Onset is earlier or later than natural	Earlier decrease may affect fish recruitment negatively Late decrease may affect fish recruitment positively	high
9		Duration is longer or shorter than natural – i.e. hydrograph is steeper or shallower	A steep hydrograph might have a negative effect on larval fish back-migrations into main channel A shallower hydrograph might be beneficial to larval fish growth and eventual recruitment	medium

4.12 Conclusion

This study is a preliminary EFA of the Okavango Delta using several water development scenarios and predicting their impacts on the Delta's fish stocks. The results from this study were generally plausible despite a lack of comprehensive relevant data. While extensive research has been done in the Delta's fish stocks, most of this research focused either on ecological/ biological aspects or management aspects of the fishery. This study highlighted the lack of habitat specific research, with particular reference to the role of seasonal flooding on fish biology and ecology. One major recommendation from this study therefore, is to initiate a comprehensive study that established a quantitative relationship between the seasonal flood pulse and various aspects of fish population dynamics in the Delta. Furthermore, some of the indicators used in this study need to be re-defined reformulated because they are not very clear. Indicators 2 and 3 in this sense can still be integrated as one indicator of species that migrate into floodplains. The basic challenges of grouping the Delta's species into specific guilds based on habitat requirements many. This is based on the observation that most of the Delta's fish species utilize various habitats at different stages of their life history stages. It is therefore a fallacy to simply categorize H. vittatus as a channel dweller when its juveniles utilize shallow, littoral and well vegetated parts of the Delta system. Moreover, H. vittatus is also known to occupy large lagoons in the Delta which suggests that they are not necessarily restricted to one particular habitat. There are other ubiquitous species in the Delta such as the Clarias spp. (especially Clarias gariepinus) which are also not easy to group into any particular habitat. Notwithstanding these pitfalls, the objectives of the study were achieved and further research can help to clarify some of these knowledge gaps and pitfalls.

5 FLOW-RESPONSE RELATIONSHIPS FOR USE IN THE OKAVANGO EF-DSS

Response curves for fish using the three water development scenarios were developed during a Knowledge Capture Workshop held in Windhoek, Namibia from March 30 to April 4, 2009. The curves developed will be included in a CD of data that accompanies this report.

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APPENDIX A: FULL DESCRIPTIONS OF INDICATORS

<table>
<tr><th>Ind. no.</th><th>Indicator</th><th>Angola 1</th><th>Angola 2</th><th>Angola 3</th><th>Namibia 4</th><th>Namibia 5</th><th>Botswana 6</th><th>Botswana 7</th><th>Botswana 8</th></tr>
<tr><td>1</td><td>Resident channel and lagoon dwellers, which also undergo longitudinal migrations</td><td colspan="3">Hydrocynus vittatus</td><td colspan="2">H. vittatus, Labeo lunatus</td><td>H. vittatus, S.altus</td><td colspan="2">S. robustus, S. giardi</td></tr>
<tr><td>2</td><td>Small species that undertake lateral migrations into seasonally flooded floodplains as major part of their life history strategy</td><td>Tilapia rendalli, Oreochromis spp., Clarias spp.</td><td colspan="2">Tilapia rendalli, Clarias gariepinus</td><td colspan="5">M. macrolepidotus, Schilbe intermedius</td></tr>
<tr><td>3</td><td>Large species that undertake lateral migrations into seasonally flooded floodplains as major part of their life history strategy</td><td>x</td><td>x</td><td>x</td><td colspan="5">T. rendalli, Oreochromis spp., Serranochromis spp., C. gariepinus</td></tr>
<tr><td>4</td><td>Rock dwellers</td><td>x</td><td>x</td><td colspan="3">Labeo cylindricus, Chiloglanis fasciatus, Amphilius uranoscopus</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>5</td><td>Marginal vegetation dwellers of the main channel and floodplain lagoons</td><td>Barbus bifrenatus, Barbus radiatus, Pollimyrus castelnaui, Synodontis nigromaculatus, Serranochromis angusticeps.</td><td colspan="2">Synodontis nigromaculatus</td><td colspan="2">Aplocheilichthys johnstonii, A. hutereaui, Juvenile Sargochromis spp, Marcusenius macrolepidotus, Barbus radiatus</td><td colspan="3">P.castelnaui, S.nigromaculatus, S. carlottae Ctenopoma multispine, S. macrocephalus, Hepsetus odoe,</td></tr>
<tr><td>6</td><td>Sandbank specialists (Species that prefer clear, slow-flowing or quiet, well vegetated water in the main channel)</td><td>x</td><td>x</td><td>x</td><td colspan="2">Barbus unitaeniatus, Brycinus lateralis</td><td colspan="3">B.lateralis, B.poechii, Leptoglanis dorae cf</td></tr>
<tr><td>7</td><td>Shallow, well vegetated backwater habitats</td><td>Barbus afrovernayi, Pharyngochromis acuticeps, Hemichromis elongatus, Tilapia sparrmanii.</td><td>x</td><td>x</td><td colspan="2">Aplocheilichtys spp, Barbus paludinosus, B. multilineatus, T. sparrmanii Pollimyrus castelnaui</td><td colspan="3">Aplocheillichthys spp, B.afrovernayi, B.multilineatus, P. philander, H.elongatus, T.sparrmanii, P.acuticeps, B. Paludinosus, Microctenopoma intermediumi</td></tr>
</table>

The Okavango River Basin Transboundary Diagnostic Analysis Technical Reports

In 1994, the three riparian countries of the Okavango River Basin – Angola, Botswana and Namibia – agreed to plan for collaborative management of the natural resources of the Okavango, forming the Permanent Okavango River Basin Water Commission (OKACOM). In 2003, with funding from the Global Environment Facility, OKACOM launched the Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) Project to coordinate development and to anticipate and address threats to the river and the associated communities and environment. Implemented by the United Nations Development Program and executed by the United Nations Food and Agriculture Organization, the project produced the Transboundary Diagnostic Analysis to establish a base of available scientific evidence to guide future decision making. The study, created from inputs from multi-disciplinary teams in each country, with specialists in hydrology, hydraulics, channel form, water quality, vegetation, aquatic invertebrates, fish, birds, river-dependent terrestrial wildlife, resource economics and socio-cultural issues, was coordinated and managed by a group of specialists from the southern African region in 2008 and 2009.

The following specialist technical reports were produced as part of this process and form substantive background content for the Okavango River Basin Trans-boundary Diagnostic Analysis

Final Study Reports	*Reports integrating findings from all country and background reports, and covering the entire basin.*		
		Aylward, B.	*Economic Valuation of Basin Resources: Final Report to EPSMO Project of the UN Food & Agriculture Organization as an Input to the Okavango River Basin Transboundary Diagnostic Analysis*
		Barnes, J. et al.	*Okavango River Basin Transboundary Diagnostic Analysis: Socio-Economic Assessment Final Report*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Project Initiation Report (Report No: 01/2009)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment EFA Process Report (Report No: 02/2009)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Guidelines for Data Collection, Analysis and Scenario Creation (Report No: 03/2009)*
		Bethune, S. Mazvimavi, D. and Quintino, M.	*Okavango River Basin Environmental Flow Assessment Delineation Report (Report No: 04/2009)*
		Beuster, H.	*Okavango River Basin Environmental Flow Assessment Hydrology Report: Data And Models(Report No: 05/2009)*
		Beuster, H.	*Okavango River Basin Environmental Flow Assessment Scenario Report : Hydrology (Report No: 06/2009)*
		Jones, M.J.	*The Groundwater Hydrology of The Okavango Basin (FAO Internal Report, April 2010)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions (Volume 1 of 4)(Report No. 07/2009)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions (Volume 2 of 4: Indicator results) (Report No. 07/2009)*
		King, J.M. and Brown, C.A.	*Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions: Climate Change Scenarios (Volume 3 of 4) (Report No. 07/2009)*
		King, J., Brown, C.A., Joubert, A.R. and Barnes, J.	*Okavango River Basin Environmental Flow Assessment Scenario Report: Biophysical Predictions (Volume 4 of 4: Climate Change Indicator Results) (Report No: 07/2009)*
		King, J., Brown, C.A. and Barnes, J.	*Okavango River Basin Environmental Flow Assessment Project Final Report (Report No: 08/2009)*
		Malzbender, D.	*Environmental Protection And Sustainable Management Of The Okavango River Basin (EPSMO): Governance Review*
		Vanderpost, C. and Dhliwayo, M.	*Database and GIS design for an expanded Okavango Basin Information System (OBIS)*
		Veríssimo, Luis	*GIS Database for the Environment Protection and Sustainable Management of the Okavango River Basin Project*
		Wolski, P.	*Assessment of hydrological effects of climate change in the Okavango Basin*

Country Reports Biophysical Series	***Angola***	*Andrade e Sousa, Helder André de*	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Sedimentologia & Geomorfologia*
		Gomes, Amândio	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Vegetação*
		Gomes, Amândio	*Análise Técnica, Biofísica e Socio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final:Vegetação da Parte Angolana da Bacia Hidrográfica Do Rio Cubango*
		Livramento, Filomena	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina:Macroinvertebrados*
		Miguel, Gabriel Luís	*Análise Técnica, Biofísica E Sócio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Subsídio Para o Conhecimento Hidrogeológico Relatório de Hidrogeologia*
		Morais, Miguel	*Análise Diagnóstica Transfronteiriça da Bacia do Análise Rio Cubango (Okavango): Módulo da Avaliação do Caudal Ambiental: Relatório do Especialista País: Angola Disciplina: Ictiofauna*
		Morais, Miguel	*Análise Técnica, Biófisica e Sócio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final: Peixes e Pesca Fluvial da Bacia do Okavango em Angola*
		Pereira, Maria João	*Qualidade da Água, no Lado Angolano da Bacia Hidrográfica do Rio Cubango*
		Santos, Carmen Ivelize Van-Dúnem S. N.	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório de Especialidade: Angola: Vida Selvagem*
		Santos, Carmen Ivelize Van-Dúnem S.N.	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango:Módulo Avaliação do Caudal Ambiental: Relatório de Especialidade: Angola: Aves*
	Botswana	*Bonyongo, M.C.*	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Wildlife*
		Hancock, P.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module : Specialist Report: Country: Botswana: Discipline: Birds*
		Mosepele, K.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Fish*
		Mosepele, B. and Dallas, Helen	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Aquatic Macro Invertebrates*
	Namibia	*Collin Christian & Associates CC*	*Okavango River Basin: Transboundary Diagnostic Analysis Project: Environmental Flow Assessment Module: Geomorphology*
		Curtis, B.A.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report Country: Namibia Discipline: Vegetation*
		Bethune, S.	*Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO): Transboundary Diagnostic Analysis: Basin Ecosystems Report*
		Nakanwe, S.N.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Aquatic Macro Invertebrates*
		Paxton, M.	*Okavango River Basin Transboundary Diagnostic Analysis: Environmental Flow Module: Specialist Report:Country:Namibia: Discipline: Birds (Avifauna)*
		Roberts, K.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Wildlife*
		Waal, B.V.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia:Discipline: Fish Life*
Country Reports Socioeconomic Series	***Angola***	*Gomes, Joaquim Duarte*	*Análise Técnica dos Aspectos Relacionados com o Potencial de Irrigação no Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final*
		Mendelsohn, .J.	*Land use in Kavango: Past, Present and Future*
		Pereira, Maria João	*Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Qualidade da Água*

		Saraiva, Rute et al.	*Diagnóstico Transfronteiriço Bacia do Okavango: Análise Socioeconómica Angola*
	Botswana	*Chimbari, M. and Magole, Lapologang*	*Okavango River Basin Trans-Boundary Diagnostic Assessment (TDA): Botswana Component: Partial Report: Key Public Health Issues in the Okavango Basin, Botswana*
		Magole, Lapologang	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Land Use Planning*
		Magole, Lapologang	*Transboundary Diagnostic Analysis (TDA) of the Botswana p Portion of the Okavango River Basin: Stakeholder Involvement in the ODMP and its Relevance to the TDA Process*
		Masamba, W.R.	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Output 4: Water Supply and Sanitation*
		Masamba,W.R.	*Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Irrigation Development*
		Mbaiwa.J.E.	*Transboundary Diagnostic Analysis of the Okavango River Basin: the Status of Tourism Development in the Okavango Delta: Botswana*
		Mbaiwa.J.E. & Mmopelwa, G.	*Assessing the Impact of Climate Change on Tourism Activities and their Economic Benefits in the Okavango Delta*
		Mmopelwa, G.	*Okavango River Basin Trans-boundary Diagnostic Assessment: Botswana Component: Output 5: Socio-Economic Profile*
		Ngwenya, B.N.	*Final Report: A Socio-Economic Profile of River Resources and HIV and AIDS in the Okavango Basin: Botswana*
		Vanderpost, C.	*Assessment of Existing Social Services and Projected Growth in the Context of the Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin*
	Namibia	*Barnes, J and Wamunyima, D*	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Socio-economics*
		Collin Christian & Associates CC	*Technical Report on Hydro-electric Power Development in the Namibian Section of the Okavango River Basin*
		Liebenberg, J.P.	*Technical Report on Irrigation Development in the Namibia Section of the Okavango River Basin*
		Ortmann, Cynthia L.	*Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module : Specialist Report Country: Namibia: discipline: Water Quality*
		Nashipili, Ndinomwaameni	*Okavango River Basin Technical Diagnostic Analysis: Specialist Report: Country: Namibia: Discipline: Water Supply and Sanitation*
		Paxton, C.	*Transboundary Diagnostic Analysis: Specialist Report: Discipline: Water Quality Requirements For Human Health in the Okavango River Basin: Country: Namibia*

Environmental protection and sustainable management of the Okavango River Basin

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Kavango River at Rundu, Namibia

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