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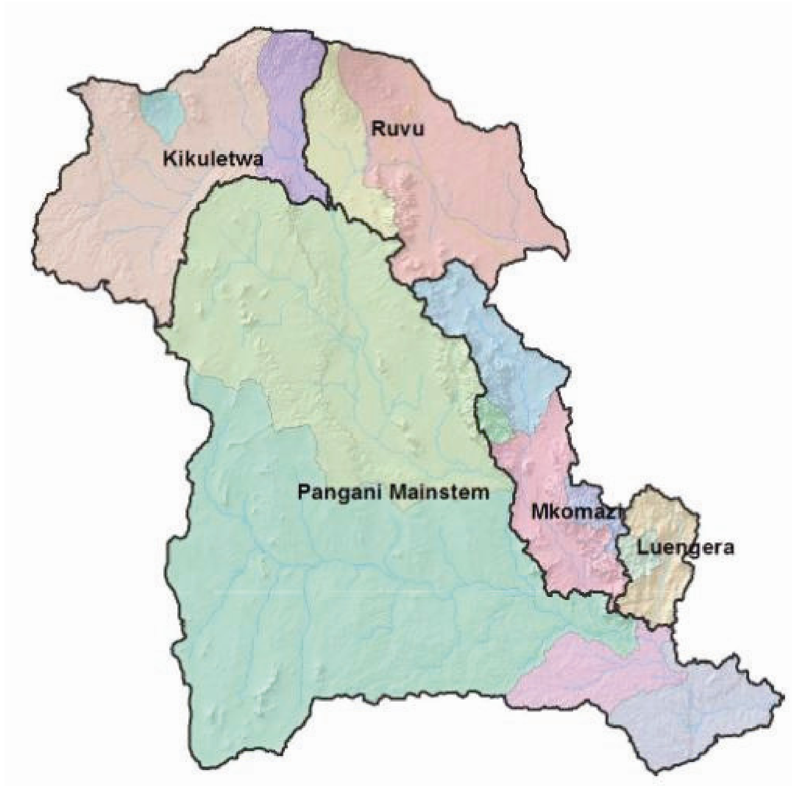
PANGANI RIVER BASIN FLOW ASSESSMENT



Fish and invertebrate life histories and important fisheries of the Pangani River Basin

O. Hamerlynck, M.D. Richmond, A. Mohammed and S.R. Mwaitega

January 2008

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Pangani River Basin Flow Assessment - Specialist Study

Fish and invertebrate life histories and important fisheries of the Pangani River Basin, Tanzania

FINAL REPORT

Hamerlynck, O., Richmond, M.D., Mohammed, A. & Mwaitega, S.R.

January 2008

SAMAKI CONSULTANTS

for

Pangani Basin Water Office, Moshi and IUCN, Dar es Salaam

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EXECUTIVE SUMMARY

This report is the product of two, short, desk-based Specialist Studies of the Pangani River Basin Flow Assessment (PRBFA) Initiative. Based on published literature, information from the Internet and from a five-day field visit in June 2007, the report describes the main aquatic biotopes of the Pangani River Basin, an area of over 43,000 km².

The relatively high conductivity within the largely volcanic basin is confirmed and a description is given of the fish and invertebrates that reside in the different water bodies - mountain streams, crater lakes, rivers, man-made reservoirs, floodplains and the mangrove fringed estuary.

Finfish and invertebrates (in this case, crustaceans) of commercial importance are further described, particularly in relation to their life histories and response to changes in river flow variables. Included is an updated list of freshwater fish in the Pangani system.

The fishery of Nyumba ya Mungu and of estuaries comparable to the Pangani are described with data from various sources. Hydrological data are used to discern linkages in fisheries output and water levels (river flow or surface area) and conceptual relationships are developed, highlighting probable links between the timing and magnitude of freshwater flows in the Pangani system and the flow-related requirements and life-history characteristics of each species.

The years 2006 and 2007 were exceptional with regard to rainfall, water levels and flows and thus the findings of several field studies conducted during that period probably do not reflect the average situation in the Pangani Basin. For example, the conductivity situation as recorded in this study, which was comparable to the early post-impoundment studies in Nyumba ya Mungu as reported in Bailey (1996) needs close monitoring over extended time periods across the entire Basin before conclusions can be drawn on the potential impacts of (increasing) conductivity on the fish, invertebrates and fisheries.

The Pangani Basin as whole has a comparatively high fish biodiversity, probably a reflection of the wide range of available habitats. Some of the characteristic species of African rivers and floodplains that have been linked to the Congo Basin such as the Rufiji and the Ruvu are absent from the Pangani (e.g. *Citharinus*, *Distichodus*, *Alestes*, *Hydrocynus*), probably a result of the geological history of the region. Various Cichlidae and the catfish *Clarias gariepinus* dominate the catches but virtually all species present are harvested in any life stage accessible to fishing gears. Invertebrate biodiversity is high in the Basin but its knowledge is still incomplete. Harvesting is almost entirely restricted to estuarine crustaceans (prawns and crabs).

The mountain stream habitat was not directly assessed in this study. Its importance for fisheries is marginal. Important biodiversity values may still be discovered in these habitats for fish and invertebrates. Maintaining forest cover and instream flows seems essential for their survival and/or restoration.

In the foothills of Mt. Kilimanjaro Lake Chala is still pristine but highly vulnerable, including its endemic fish. The Lake Jipe catchment has been plagued by water quality and quantity problems for several decades. Its fisheries have collapsed and its endemic species have declined. Though the expansion of the vegetated marshes in Lake Jipe and on the Ruvu River creates access problems for the fishers, these natural habitats play a vital role as filters and thus protect the downstream areas such as Nyumba ya Mungu from an overspill of the Jipe problems.

The main Pangani River, characterised by a high conductivity, has been strongly modified by the creation of the Nyumba ya Mungu Reservoir. Although there are doubts about the reliability of existing data, the fishery seems to be on a downward trend with reported catches over the past ten years an order of magnitude lower than those in the 1970s. There are indications that the fisheries react favourably to higher water levels and/or increased reservoir surface area above a threshold of 687 masl and 110 km² respectively. In the absence of reliable monthly catch data, the analyses have been necessarily crude. A standardised long-term monitoring programme independent from the fishery such as the one in Lake Kariba (operated by the power company) could provide highly valuable data. Bottom siltation has been mentioned as a possible cause in the decline of some species.

The Kirua swamps have basically lost their fisheries and the other ecosystem services they provided when they were functional floodplains. The remaining Pangani River bed is intensively fished through a series of weirs that form barriers to the migration of large individuals.
The Mkomazi River, though fed with high quality runoff, has become largely intermittent and its water quality is low, except in proximity to the various fresh mountain streams that supply it. The fisheries in Kalimawe Reservoir, Lake Karamba and Lake Manga are important for local livelihoods but are sensitive to the declining water supply, as are their biodiversity values.

The fisheries of the Pangani estuary are not well described but seem to be in decline. The coastline is eroding and, in the absence of important (peak) flows, the estuary may come to resemble a marine bay with a low contribution to coastal fisheries.

A small number of species with different life history characteristics were chosen as models for what could happen under future flow scenarios: the fishes *Oreochromis esculentus*, *Clarias gariepinus*, *Barbus* spp. and *Hilsa kelee* (as a possible model for estuarine clupeids or engraulids), the crab *Scylla serrata* and the prawn *Fenneropenaeus indicus*. The response curves drawn for each of these species under both pulsed flow and non-pulsed flow scenarios are expected to be valid for a guild of associated species. Important break points such as flow interruption, flows that reach river bank vegetation, flows that create additional river channels and flows that result in significant floodplain or mangrove inundation are identified. All main fish and invertebrate guilds would benefit from increased flows, especially if these are pulsed in accordance with natural flood peaks and if they achieve significant inundation of floodplains or mangrove systems.

ACKNOWLEDGEMENTS

The authors are grateful to the many fishers and fisheries staff in the Districts and in Dar es Salaam who assisted with the gathering of information on the fisheries and aquatic ecology of the Pangani Basin during the June 2007 field visit. We also appreciated the interaction and fruitful discussions with the Pangani Basin team, notably Sylvand Kamiguisha, George Lugomela, Hamza Sadiki, Kelly West, Jackie King, Cate Brown and Jane Turpie for their support in obtaining data, supplying details and general encouragement. Comments from Barry Clark, and especially those from the international reviewer Denis Tweddle, were much appreciated and have contributed to improve the document. Ms. Faatma Sobo, Principal Fisheries Officer is thanked for her time and fish catch data. The managers of the Pangani River Camp (near Mombo) are thanked for their hospitality and for sharing their valuable thoughts on river use and flows.

1 INTRODUCTION

1.1 Background to Pangani River Basin Management Programme

This specialist study forms part of the Pangani River Basin Flow Assessment (PRBFA) Initiative, aiming to develop an understanding of the hydrology of the Pangani River Basin, the nature and functioning of the river system and the links between the river and subsistence use of its resources, to provide the means to guide the allocation of water in the basin in future.

Six Specialist Studies were undertaken in early 2007, all desk-based research (see ToRs). For the two studies combined here, the consultant undertook a five day field trip to the Pangani Basin in June 2007. This provided a valuable means to obtain at least some fishery statistics from Nyumba ya Mungu reservoir and, in a limited way, examine the fisheries data collection process as well as meet fishers and sample fish specimens.

This report is the combined output of two separate studies, one on fish and invertebrate life histories, the other on fisheries. By providing all the information in a single document, the combined report reduces duplication and is more interesting, more readily understood and more likely to instigate additional research to fill the much-needed gaps that exist for this fascinating and highly-productive Basin.

Study area and zonation

The Pangani River Basin is situated in northeast Tanzania (see Fig 1), covering a total area of 43,650 km^2, of which approximately 3,900 km^2 is in Kenya. In this report, the area under the Pangani Basin Water Office (PBWO) jurisdiction is referred to as the Pangani Basin and incorporates three main catchment areas, Umba (including the Mkomazi River), Zigi-Mkulumuzi and Msangazi.

Within the Pangani Basin, land elevation reaches 5,895 m on Mount Kilimanjaro and 4,565 m on Mount Meru. The North Pare Mountain and the South Pare Mountains reach 2,113 m and 2,462 m respectively, and the Usambara Mountains to the northeast reach 2,280 m. The lowland areas, of up to 900 m elevation, comprise about 50% of the Pangani Basin.

Rainfall patterns are largely related to altitude, with the highlands receiving about 1000-2000 mm annually, and the lowlands receiving 500-600 mm. Rainfall is bimodal, occurring mainly in March-June, with short rains in November-December.

The Pangani River is the largest in the basin and rises from a series of small streams on Mt Kilimanjaro and Mt Meru. It flows over 500 km before draining via the Pangani estuary into the Indian Ocean, just south of the port of Tanga. The two major tributaries are the Kikuletwa and the Ruvu Rivers, while other tributaries include the Mkomazi and Luengera Rivers in the southeast.

The human population within the Pangani Basin is estimated at 2.6 million, with the highest density in the northern and eastern highlands, in the cities of Moshi and Arusha, the remainder being relatively sparsely populated. Land use is governed primarily by rainfall, with agriculture concentrated in the highlands and foothills, with large-scale cultivation of coffee, sugar cane and flowers, as well as small-scale agriculture, mostly irrigated. The foothills and northern sides of the Pare Mountains provide rice growing areas, with sisal grown commercially on lower areas throughout the Basin. Towards the coastal lowlands, coconut, sweet potatoes, pumpkin, cassava, okra, sisal and fruits are cultivated. Livestock herding is also conducted throughout the Basin with pastoralism particularly important in the arid regions, with herds of cattle, goats and sheep.

Around Arusha, tourism makes a substantial contribution to the economy, but elsewhere the population is largely dependent on agriculture for subsistence and employment. Within the agricultural sector, forestry, wildlife and fisheries are relatively minor within the Basin in terms of their economic contribution, but fisheries are an important source of income and food locally. Of the other sectors, mining and hydropower production are important outputs of the basin, but other sectors such as industry make a relatively small, although growing, contribution.

Irrigated agriculture is the biggest user of surface water in the basin, with urban and industrial uses and hydropower also major users. Water that remains in the environment generates aquatic ecosystem goods and services. Households living near aquatic ecosystems harvest a variety of resources, the most important being fish.

1.2 Objectives of the study

The objectives of the study are to:

a) describe the relationships between the timing and magnitude of freshwater flows in the Pangani system and the biology and life history characteristics of its key fish and invertebrate species;
b) use these relationships to infer what the historic abundance levels and distribution patterns were for these species in the Pangani catchment (where such information is lacking);
c) predict how abundance and distribution patterns may change in the future under altered flow patterns;
d) derive the relationships between water level and fishery production that will be used to predict changes in catches in Nyumba ya Mungu, Lake Jipe, Kalimawe Dam and the Pangani estuary under different flow and water-level scenarios.

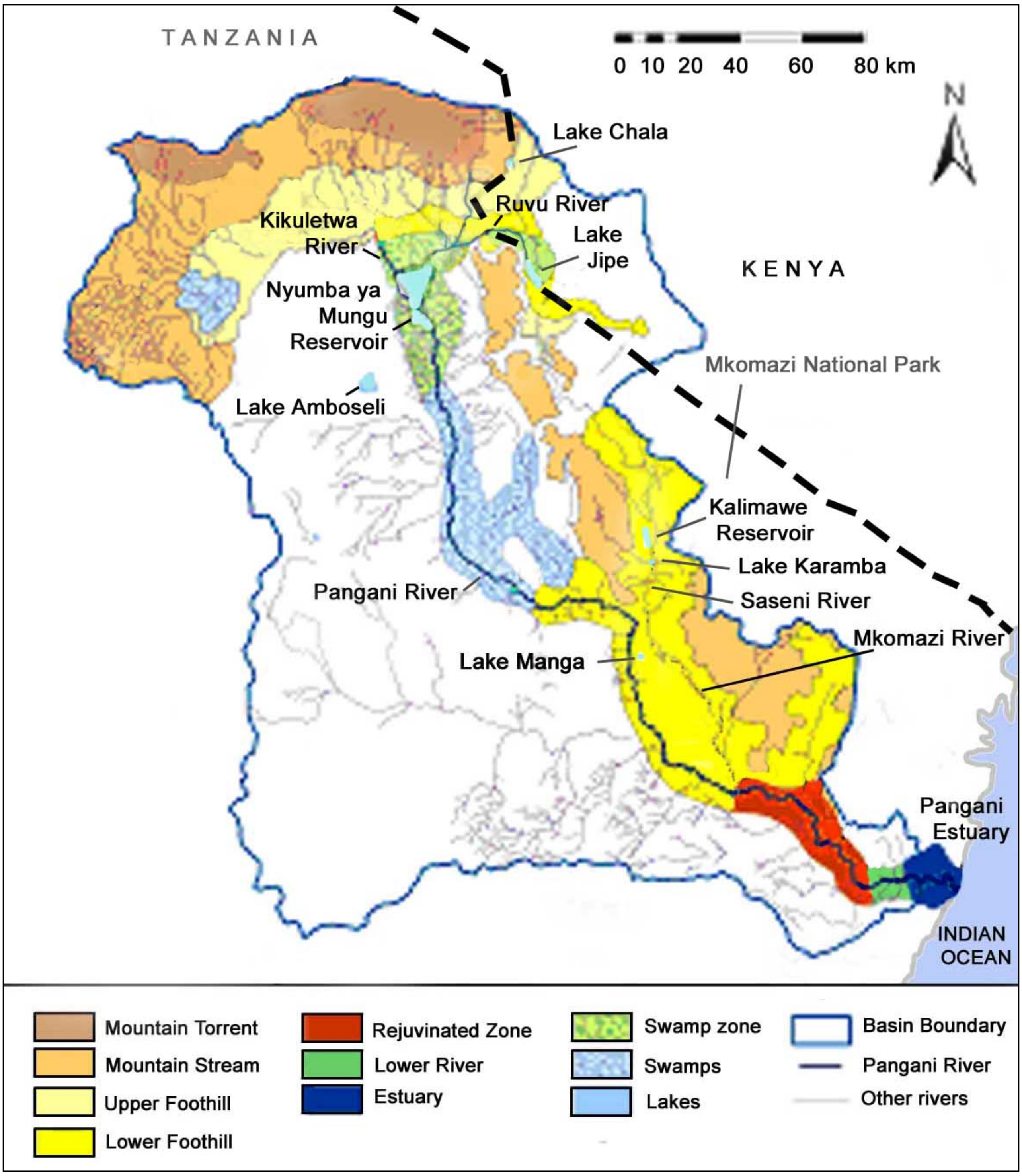

Figure 1 Map of Pangani Basin, with locations of main sampling conducted during the June 2007 field visit. Modified from Dallas *et al,* 2006.

2 METHODS

2.1 Desk study

A comprehensive desktop study was initiated to provide essential information on two aspects of the aquatic ecosystems of the Basin. The first was to establish links between life history, breeding and feeding habits of key fish and invertebrate species of economic or subsistence value in the Pangani River system (river, lakes and estuary). The important species were selected following literature and Internet searches and from the existing preliminary list of important fish and invertebrate species in the Pangani system created from research conducted for the Pangani River Basin Flow Assessment (FA).

The focus of the study is on the relationship between the biology of the species (or similar species if no data exist) and flow or water levels. The likely effects of different flow scenarios on the abundance and distribution of these species in the Basin were analysed. This contributes to the FA study by providing information on the likely effects of different flow scenarios on the health of the system and the environmental goods and services derived from the system.

The second aspect of the study was to search for historical and seasonal data on fish and crustacean catches and fishing effort at Nyumba ya Mungu, Lake Jipe, Kalimawe Dam and the Pangani estuary, including historical data or modeled data on water levels and flows for the same localities and times. This was then used to determine the relationships between water level or flow and fishery production for the major fisheries of the Pangani River Basin.

The derived links between fisheries production and water level or flow were then used to predict changes in fish catches resulting of different water allocation scenarios. The analysis used simple regression analysis or linear modeling to generate predictive relationships that were used in scenario analysis. Quantitative analysis of fishery outputs in relation to water level or flow and fishing effort were made, utilising available relevant parameters, such as gear type or season.

2.2 Field visit

Over a period of five days, from 21-25 June 2007, a field visit was made to six main sites, listed below and shown in Table 1, with most sites shown in Fig. 1.

The section on the crater lake Chala is based on a visit by one of the team (MR) to the lake in February, 2002 as a guest of the developer of the Kilimanjaro Chala Safari Lodge and a second visit in August 2006, during which time additional specimens of lake fish species were collected. A brief analysis of the aquatic ecology and fisheries of the lake was based on a six-hour trip, between 08:30 and 15:30 around the lake with a local fisher in his dugout canoe, in which his three gill-nets were inspected.

2.2.1 Water conductivity, chlorophyll and plankton measurements

Water conductivity measurements were taken using a hand held Hach HQ14d apparatus at most water bodies encountered throughout the trip, including rivers and irrigation canals, lakes and reservoirs. At times canoes were used to obtain samples from open water rather than from the generally more ‘polluted’ lake-side waters. Plankton and chlorophyll samples were also collected for later analysis.

Table 1 Summary of catchments visited and information gathered.

Catchments	Date	Main sites visited	Information gathered
Lake Chala	2-3.02.02 11.08.06	Tanzania shores from proposed hotel construction site.	Fish and crab spms., lake ecology and fisheries background details.
Lake Jipe	23.06.07	Mkisha village on southern shore.	Fish spms., water quality data, limited fisheries data, fisheries background details.
Nyumba ya Mungu Reservoir	23.06.07	Main landing sites: Kiti cha Mungu, Lang'ata Bora, plus District Fisheries offices in Mwanga.	Fish spms., water quality data, limited fisheries data, fisheries background details.
Kalimawe Reservoir	24.06.07	Fish landing site near barrage, Ndundu town in afternoon.	Fish spms., water quality data, limited fisheries data, fisheries background details.
Lake Karamba	24.06.07	Eastern shore, along irrigation canal ridge.	Water quality data, limited fisheries background details.
Saseni River	23.06.07	At bridge.	Fish spms., water quality data, limited fisheries details.
Lake Manga	25.06.07	Temporary fishers camp at centre of western shore.	Fish spms., water quality data, limited fisheries data, fisheries background details.

2.2.2 Fish species diversity and specimen collection

Preliminary information on the species present in the various water bodies throughout the Pangani Basin was gathered from discussions with the District Fisheries Officer Mr. James Tarimo, in the town of Mwanga, and examination of the fisheries data for Nyumba ya Mungu reservoir. There were no data for Lake Jipe. Information was also obtained from the fisheries recorder Mr. Francis Msuya who accompanied the afternoon visit to Lake Jipe and from discussions with local fishers on site.

The day-long visit to four village-landing sites along the east shores of the Nyumba ya Mungu reservoir on Saturday 23 June, accompanied by a fisheries recorder Mr. Liberato Malisawa, provided opportunities to gather more local information. At the Kalimawe Reservoir town of Ndungu, the fisheries recorder Mr. Sabbas Mziray was met on Sunday 24 June and provided information relevant to that water body. Local fishers were also met at the landing site in the south-west corner of the reservoir.

At each fishing site, specimens of commercially important fish species were collected through purchases from fishers. On Lake Chala, fishing was successfully done using hook and line and a selection of baits (worms, maggots, green corn and bread). All fish were fixed in 5-10% formalin solution (buffered) and after five days rinsed in freshwater and transferred to 70% ethanol. The entire collection will be deposited in the National Museum, Dar es Salaam.

At each site, discussions were held with fishers, accompanied by Fisheries Officers or recorders, regarding changes in water levels and impacts on fish life histories. Comparisons were made between the present 'wet' year, recent past 'dry' years and the 'very wet' El Niño year (1997-98). Discussions on fisheries of Lake Chala, species diversity, seasonality, water quality and general ecological issues were held with a main informant and fisher, Mr Karoli, on 2 February 2002 as well as with other fishers met along the shores of the lake.

2.3 Sources of additional fisheries data

In late June, letters of request for fisheries data were hand delivered to the Fisheries Division and Tanpesca Ltd (industrial prawn fishery company), and sent by email to Vicfish Ltd (industrial prawn fishery company) and Sea Products Ltd (mangrove crab buyer in Tanga). Information requested was monthly catch data for the selected years (see above). In early July the Fisheries Officer at the town of Pangani was met by one of the consultant team members and promised to provide monthly catch data for selected years (as above). After several weeks, no data from any of these sources was obtained.

On 18 July, a meeting was held with Mrs. Faatma Sobo, Principal Fisheries Officer, Head of Statistics Section, as a follow-up to the letter submitted two weeks previously. And on 20 July, the Tanpesca Fishing manager was met and discussions were held on the industrial prawn trawling for Zone 1 which includes the Pangani estuary.

2.4 Hydrological data

Hydrological data on the Pangani Basin were obtained from Dr. George Lugomela of the Ministry of Water at Ubungo. Data included overall rainfall and Nyumba ya Mungu Reservoir water levels. Surface area data for Nyumba ya Mungu were derived from Denny & Bailey (1976) and from Moges (2003).

3 MAIN AQUATIC BIOTOPES OF THE PANGANI BASIN

From the volcanic mountain-side springs to the mangrove-fringed Indian Ocean, a range of different biotopes is present within the over 43,000 km^2 of the Pangani Basin. Each biotope has its specific characteristics and therefore differently functioning ecosystems, with different susceptibilities to various threats.

Five principal aquatic biotopes are recognised below, with a general description that includes water quality (with its seasonal pattern, flow and level), both chemistry and sediment load, and available information on the invertebrate and fish faunas present in each.

3.1 Water conductivity within the Pangani River Basin

From the 28 measurements taken in the upper and middle waters of the Pangani Basin (see Table 2), high levels of water conductivity (and thus salinity) are an issue almost throughout the Basin. The only exceptions are the streams coming off the South Pare Mountains. The highest conductivity levels noted are around Lake Manga and the lower portions of the Mkomazi River. According to the US Environmental Protection Agency (EPA), the norm for drinking water is maximum 900 µS /cm. Even the central part of Lake Jipe has levels above the EPA norm.

The dominance of volcanic soils in the Ruvu and Kikuletwa catchments is the likely source for the high conductivities encountered there. The ambient survey of 1998 sampled 52 sites, with findings presented in the Dallas *et al.* (2006). The present data will contribute towards monitoring of conductivity within the Basin.

The conductivity situation could become critical in the future. It is probable that both the water quantity and quality of water in the Basin have been “positively” affected by the melting of the Kilimanjaro glaciers. Once the ice is finished there will be rainfall only and the proportional contribution of salts collected in the aquifers of the volcano will increase. Currently conductivity stood at 791 µS/cm at Kiti cha Mungu (697 µS/cm at Langata Bora), which is comparable with the 900 µS/cm recorded at the dam site in 1974. The inflow from the Ruvu had a conductivity of 587 µS/cm, no (significant) change from the 550 µS/cm of 1974 mentioned in Bailey (1996), though checks on how this changes with flows are needed, this year (2007) having been particularly wet.

3.2 Rapids, waterfalls and mountain streams

No visits were made to any of the rapids, waterfalls or to the many seasonal mountain streams, and literature on these biotopes is scarce. Two streams on the northern side of the South Pare Mountains were, however, visited during the field trip and sampled for conductivity, proving to be almost pure mountain water (with values of 50-100 µS/cm). These streams run through the Gonja Forest Reserve, below Thornton falls, and eventually feed into Kalimawe Reservoir after passing through an extensive cultivation area. It is safe to assume that most similar mountain rapids, waterfalls and streams will have clear, clean waters, though some are likely to be seasonal, with dramatic changes in water quantity.

The assessment by Dallas *et al* (2006) provides useful data on the aquatic animal life of this biotope, where it appears that fewer than five species of fish are present. There was also no sign of the various trout species introduced during the colonial era. According to local sources a lot of these rivers have been fished using poison. Invertebrates are common, especially during the wet season when potentially 20-30 taxa are to be expected found. For example, from Nduruma River, Dallas *et al* (2006) report on ‘a reasonable diversity of invertebrates’ in both seasons, with a total of 23 taxa recorded, including four families of mayflies, as well as dragonflies, caddis flies, beetles and flies. They also report on a single species of fish, the small minnow *Garra dembeensis*, which is adapted to living in fast flowing streams. Ona River, with only the stony biotope sampled, nonetheless supported a diverse assemblage of flatworms, crabs, water-mites, four families of mayflies, dragonflies, bugs, caddis flies, beetles (including Elmidae and Psephenidae) and flies, with a total of 16 taxa recorded. The water habitat was mainly fast and deep with shallow areas, large amounts of overhanging vegetation (trees), few undercut banks, and generally rocky substrate. Fish included the ubiquitous air-breathing *Clarias gariepinus*, two species of *Tilapia*, *T. sparrmanii* and one other (species not given), the Cyprinodont killifish (species not given), with the Cyprinidae *Labeo* sp. (species not given) and *Brycinus sadleri* also collected.

Table 2 Water conductivity for selected sites within the Pangani River Basin, June 2007.

Date	ID	Alt. m	Cond. µS/cm	Temp. °C	Site and description	Notes
NYM catchment						
6/23/2007	409	711	-	-	Maximum extent Lake Jipe (El Nino)	-
6/23/2007	410	714	1,806	25.4	Landing site Mkisha , edge Lake Jipe	Muddy channel
6/23/2007	411	714	924	23.9	Open water Lake Jipe	Low transparency
6/23/2007	433	694	790	23.8	Landing site Kiti cha Mungu, edge NYM	-
6/23/2007	434	692	791	23.4	Open water NYM, shore at low water	Clear water, tips of *Phragmites* visible
6/23/2007	444	695	-	-	Maximum extent of NYM Lake	-
6/23/2007	445	687	697	-	Landing site Langata Bora, edge NYM	Murky
6/23/2007	451	707	587	20.3	Ruvu River under bridge	Very clear, floating vegetation
6/25/2007		536	846	20.9	Pangani River Camp site	Main river, big flow
Mkomazi catchment						
6/24/2007	458	685	313	18.8	Kwaikoko River	Very clear, water insects on surface
6/24/2007	464	549	564	20.6	Komoksi River	Clear water, few cm depth only
6/24/2007	466	551	55	18.3	Karinga River	Clear water, good flow
6/24/2007	468	553	59	18.1	Lika, forest stream	Clear water, good flow
6/24/2007	469	555	114	20.9	Higili River from Thornton falls	Clear water, very good flow
6/24/2007	474	530	333	23.4	Natural river bed in village	Possibility of nitrate input
6/24/2007	475	531	119	20.2	Irrigation channel	Clear water, very good flow
6/24/2007	477	513	212	24.3	Landing site canoes Lake Kalimawe	-
6/24/2007	-	513	219	24.2	Open water Lake Kalimawe	Tips of Phragmites visible
6/24/2007	480	518	317	25.4	Saseni River	Big river
6/24/2007	-	-	1,278	22.4	Main bed Mkomazi R. below L. Karamba	No flow, stagnant
6/24/2007	481	500	686	22.3	Open water Lake Karamba	Very green water
6/24/2007	482	502	-	-	Maximum extent of Lake Karamba	-
6/25/2007	489	438	2,500	19.6	Landing site canoes Lake Manga	Very clear water, lots of zooplankton
6/25/2007	490	448	2,350	21.1	Edge vegetation open water L. Manga	Depth 1.2m, in December +0.7m
6/25/2007	491	435	-	-	Open water Lake Manga	-
6/25/2007	492	455	1,462	21.6	Mkomazi River bridge	Low flow
Zimui catchment						
6/25/2007	494	421	256	18.1	Zimui River from Lushoto, Usambara	-
Main Pangani (includes Mkomazi and Zimui)						
6/25/2007	495	302	689	22.4	Pangani River at Korogwe bridge	Strong flow

From the Pangani River Basin Flow Assessment Initiative reports it is known that many streams that used to be perennial have become seasonal. From recent work in the Eastern Arc Forests, there are indications that with some catchment management (e.g. reforestation with local species), these dry season flows can increase again and the mountain stream habitat restored within a few decades (Neil Burgess *pers comm.*). The streams that remain in good condition (e.g. the two rivers in the Gonja Forest Reserve) will only survive (and be a source of re-colonisation or re-introductions to restored habitats) if the forests remain intact.

Another major threat to mountain streams was noted during the field visit: their diversion into irrigation channels or into tubes as has happened to most of the inflow from the North Pare Mountains into Lake Jipe. The purpose seems to have been to keep as much water as possible for the irrigation on the northeast side of the North Pare Mountains. While impact on Lake Jipe may be minimal, the mountain stream habitat is likely to be highly impacted.

3.3 Main Rivers

Four principal rivers occupy the Pangani Basin, the Ruvu and Kikuletwa that drain into the north of Nyumba ya Mungu Reservoir, the Pangani River itself that runs from the reservoir to the Indian Ocean and the Mkomazi River that joins the Pangani River in the lower foothills, just upstream of the rejuvenated rocky cascade section. In addition, at least fifty streams exist, each over 30 km in length, that contribute to these main rivers, mainly during the wet season.

3.3.1 Pangani River

The Pangani River extends from the Nyumba ya Mungu Reservoir to the Indian Ocean, stretching over 300 km. During its passage, there are four well-defined zones: the swamp zone (about 120 km), the lower foothill zone (110 km), a rejuvenated zone (about 50 km) and the mature lower river zone (about 20 km). All zones are largely dependent on the management of the outflow from the reservoir, from which the bulk of the water in this section originates.

<u>Swamps and marshes</u>

This habitat may be seasonal and dry out completely in years with little rainfall, or shrink and shift with the drying river. It is nevertheless an important biotope from where Dallas *et al* (2006) reported 15 taxa of invertebrates from limited sampling in marginal vegetation. These included mayflies, damselflies, bugs, caddisflies, beetles and flies. Ten fish species were found, including migratory species that may be affected by the fishing weir noted upstream. The fish included four species of *Tilapia*, including *T. sparrmanni*, *Labeobarbus oxyrhynchus*, *B. toppini*, *B. urotaenia*, *Synodontis* spp. *Chiloglanis deckenii*, *Brycinus sadleri*, *Mormyrus kannume*, *Clarias gariepinus*, *Anguilla* spp., *Haplochromis* spp and *Labeo* spp. (species names not given).

<u>Lower foothill zone</u>

This section of river rarely changes, according to observations made over the last five years by the managers of the river-side camp site near Mkomazi, indicating that water flow from the Nyumba ya Mungu Reservoir has been managed to maintain water flow throughout the year. From this section of the river, Dallas *et al* (2006) reported 17 taxa, including crabs, water-mites, mayflies, butterfly larvae, dragon- and damselflies, bugs, caddisflies, beetles, flies and snails. Of note were the five different types of cased-caddisfly (Leptoceridae) in their wet season samples. The freshwater Palaemonidae prawn *Macrobrachium* was also collected, though species names were not given.

Four fish species were collected, but local fishers reported seven species including migratory fish in the upper reaches and seven species (again based on local fishers) further downstream. The list includes *Barbus oxyrhynchus* and *B. toppini*, *Labeo* spp., *Anguilla* spp, *Tilapia* spp. (including *T. sparrmanii*), *Clarias gariepinus* and *Mormyrus kannume*. They also noted the presence of a fishing weir upstream, a feature that was also reported during the present field visit, by the camp site managers on the river banks near the Mkomazi village, who claimed that numerous fish weirs were present along the lower foothill sections of the Pangani River.

Rejuvenated zone

This section of river includes fairly rapid moving waters and a predominantly rocky river bed, with pools and rocky outcrops. The running water sections change from deep and fast, shallow (bed-rock rapids) areas in the wet season, to slow, shallow areas in the dry season. Dallas *et al* (2006) recorded more invertebrates in the dry season (19 taxa) compared to the wet season (13 taxa), with most being hardy species able to tolerate reduced water quality (e.g. Oligochaeta, Corixidae, Notonectidae). Three taxa were recorded among the stones and boulders in the wet season, including leeches (Hirudinea), while 12 taxa were recorded in this stony section in the dry season (greater accessibility due to the lower water levels). The total number of taxa recorded was 22.

Ten species of fish were recorded, five of which were *Tilapia* and *Oreochromis* spp (species names not given), plus *Clarias gariepinus*, *Brycinus sadleri*, *Labeo cylindricus*, *Barbus* sp. (species names not given), Killifish and an unidentified cichlid wrongly identified as an *Aulonacara* species.

Mature Lower River

This short section of river is subjected to dramatic changes in water levels and flow due to hydro-electric dams that limit water flow. Only three taxa of invertebrates were recorded by Dallas *et al* (2006) in the wet season, including the shrimp (Atyidae), but this was increased to six during the dry season, although these included highly tolerant worms, Oligochaeta, air-breathing Corixidae, Notonectidae and Dytiscidae. The freshwater prawn *Macrobrachium* was also recorded.

Seven fish species were recorded in the wet season, but none in the dry season when the river was dry in many places. Dallas *et al* (2006) noted that some of the species were estuarine, including an eel in the dry season. This is a migratory species that matures in the river and then migrates to the ocean to spawn. The fish included *Synodontis nigromaculatus*, *Favonigobius reichei*, *Glossogobius biocellatus*, *Oreochromis* spp., a single Ambassidae, *Ambassis urotaenia*, *Chanos chanos*, *Clarias* sp., and *Anguilla bicolor bicolor*.

3.3.2 Mkomazi River

The Mkomazi River has its origins in the South Pare Mountains, and appears to be seasonal at present. The catchment above Kalimawe Reservoir is fed from streams coming off the South Pare Mountains. From the northern flank, the Kwaikoko channel, near Kisiwani (313 µS/cm), is intensively used for irrigation. The river running through Kisiwani town itself had a low flow. These rivers join the outflows from the marshes on the southwestern edge of the Mkomazi Game Reserve (MGR). At the time of the visit, all the streambeds to the east of Kisiwani were dry. As this was a particularly wet year, it is unlikely that there are still significant dry season flows in this sub-catchment (name uncertain, possibly called Nakombo). The gallery forest along this dry river bed seems to be intact so groundwater flows are likely. A second source of water is the Kifukua Springs in the central part of MGR. It would seem the artificial water holes on this sub-catchment were stocked with fish, which would be the origin of the “black” tilapia (identity uncertain) in the basin, when the dam over-flowed during an extreme flood event.

All these seasonal flows plus those from the small streams from the Pare Mountains end up in Kalimawe dam. Both upstream and downstream of the dam there is extensive irrigated agriculture. Conductivities are high in this section and whatever flows remain end up in Lake Manga, just south of Mkomazi town. Around Lake Manga there are very extensive salty soils, possibly over 100 km² in extent (for about 20 km along the main Dar es Salaam-Arusha road one observes the typical halophyte vegetation and the Mkomazi floodplain is about 5 km wide there). Any flow out of the Lake Manga area probably increases the conductivity in that section of the river (possibly creating an effective barrier for upstream migration of the true freshwater species that may exist in the Usambara catchments). Additional conductivity measurements along the Mkomazi between Lake Manga and its confluence with the main Pangani 15 km upstream of Korogwe would be interesting.

Several small and large streams from the Usambaras enter the Mkomazi along this section and, judging from conductivity in the Zimui River (256 µS/cm), dilute the salts. The resultant conductivity at Korogwe (689 µS/cm) suggests the Mkomazi catchment (with the supply from the Usambara mountains) lowers the conductivity in the main Pangani River as, just upstream of Mkomazi town the main Pangani River (at Pangani River Camp) had a conductivity of 846 µS/cm, slightly higher than in Nyumba ya Mungu (close to 800 µS/cm). The problem with having only conductivity data and not the actual chemical composition is that, in some areas, a lot of the conductivity may be nutrient loads (e.g. Lake Jipe) that can be lowered by de-nitrification in swamps.

Modeling results indicate that deforestation, public opinion and decreased health of the farmers are related to changes in land use (i.e. the introduction of a rice development project) with its associated environment degradation and poverty (Kashimbiri *et al.* 2005), . They argue that these changes might also be the cause of animal flight from the MGR and increases in human disease and deaths. They conclude that uncontrolled human activities and behaviour are the main causes of environmental degradation.

Dallas *et al.* (2006) sampled the river just south of Lake Karamba and found a total of 17 invertebrate taxa – 9 in the wet season and 14 in the dry season, although most of them are relatively tolerant to changes in water quality. These taxa including worms, mayflies, damsel- and dragonflies, caddisflies, beetles, flies and snails. Seven fish species were recorded: six in the wet and one in the dry season. *Clarias gariepinus* were present, being especially tolerant of harsh conditions such as extremely low flows (and drying up), and others included *Tilapia sparrmanii*, *Labeo cylindricus*, *Barbus jacksonii*, *B. eutaenia*, *Brycinus sadleri* and a *Synodontis* species that resembled *S. dhonti* but may have been a juvenile of another species.

3.4 Floodplains and marginal waters

Flooded or inundated flat plains, some of which develop into temporary marginal lakes, or into made-made rice paddy fields with their irrigation canals and ditches, provide a varied and important biotope to fishes, some of which may spend much of their lives in such areas (Lowe-McConnell, 1987). Water flows are typically non-existent much of the time, depths are usually only a few centimetres, and water temperatures can be high, as can salinity in such shallow areas within the Pangani River Basin where there was elevated water conductivity almost throughout (see table 2). Seasonal changes are dramatic with complete desiccation typical once or twice each year, varying from a few weeks to many months. More permanently flooded areas become swamps, or some develop into lakes.

These waters carry juveniles of many river and lake species which feed on insect larvae that become abundant during flooding periods, typically for the Pangani between March-May but occasionally between December-January. There is a rich bottom deposit and water plants may form dense areas. Typical fish encountered in these temporary biotopes are the siluroids *Clarias*, *Synodontis* and *Schilbe*, several of the tilapias, mormyrids and characids such as *Brycinus* and *Rhabdalestes*. The tilapias, *Oreochromis* and cyprinodonts have specific tolerance to the elevated water temperatures in these environments (Welcomme, 1985). All these fish spend part or all of their lives in such waters, with some visiting only periodically either during the floods or to reproduce.

3.5 Lakes and reservoirs

In the Pangani Basin there are at least seven natural lakes and two man-made reservoirs, Nyumba ya Mungu and Kalimawe. Of the lakes, Chala, Jipe, Karamba and Manga have been visited by members of the team. Others include the three Momella Lakes located northeast of Mount Meru. The main ecological features of the visited lakes and the reservoirs are described below.

3.5.1 Lake Chala

The surface waters of Lake Chala are normally clear, very likely due to the very small amount of plankton, attributed to the absence of vital nutrients. A marked seasonal colouration of the water was, however, described by fishermen. Between the months of August and September, the lake waters become cloudy and many fish swim at the surface. The fishermen claim that water temperature during this period is higher than 'normal' and there are also many more crabs around, though they are not sure why the fish come to the surface.

Such dramatic changes in water clarity can be achieved by two means. Firstly, through heavy inputs of muddy water from external sources, such as from run-off or water fed through the submerged water inlet. The second, and the most likely cause, is through plankton blooms prompted by an increase in nutrients in the surface, sun-lit waters. The latter may come about through an input of nutrients from stirring of the deeper, nutrient-rich waters.

The great depth of Lake Chala (200-300 m according to local fishers who witnessed some Kenya scientists measuring the lake depth about ten years ago) is of considerable importance to its ecology. Beadle (1981) provides three examples of lakes that are physically comparable to Lake Chala, though much shallower. Two are western Ugandan lakes (Bunyoni and Nkugute) and the third, in west Cameroon, is Lake Barombi Mbo (2.5 km diameter and 111 m deep). All three lakes are known to be strongly stratified, i.e. there is very little vertical mixing of the water. Wind driven mixing may affect the top 10 m, but below 20 m there is little movement, thus the deeper waters are anoxic and, except for the presence of a few specialised bacteria, they support no other life. Lakes Tanganyika, Nyasa and Kivu are also affected by the same phenomenon with 75% of Lake Tanganyika waters of this category. Moreover, these three lakes contain lethal amounts of hydrogen sulphide in their deeper waters, and in Lake Kivu these anoxic waters also contain vast quantities of methane (see Encyclopaedia Britannica, 2001). The waters of Lake Chala are likely to also be strongly stratified in the same way, with only the relatively shallow, top 20 m deep epilimnion supporting life, the remaining hypolimnion waters locking away nutrients (Lowe-McConnell, 1987).

Two lakes in western Uganda, Lake Bunyoni (about 2,000 m altitude, 40 x 5 km in size and 45 m deep), and Lake Nkugute (altitude 1,500m, diameter 1 km and depth 58 m) are also known to be subject to occasional disturbances caused by heavy storms. These may be after a period of relatively low temperature, often during the dry and windy season. The decrease in water clarity associated with the disturbance and the increase in the plankton quantity in Ugandan lakes is thought to involve a fraction of the deeper waters devoid of oxygen mixing with the surface waters and asphyxiating all aquatic life (see Beadle, 1981). The eventual decomposition of the plankton contributes to further reducing the oxygen content of shallow waters all over the lake, forcing the fish to the surface. The seasonal behaviour of *Oreochromis hunteri* swimming around at the surface of Lake Chala may be related to the decreased oxygen or simply to the increased plankton abundance in the surface, and should be investigated. The increase in numbers of red crabs in the shallower depths along the margins of the lake might be due to an increase in the amounts of dead fish sinking to the bottom where they would be eaten.

Waters supplying Lake Chala are explained by local fishers as originating from the melt-water of Kilimanjaro and rainfall on the porous basaltic slopes, through subterranean passages, since no rivers are present. Similarly, there are no visible exits or outflows for water and it is believed that the lake level is maintained through a submerged exit point which eventually feeds into Lake Jipe. Lake levels seem to vary very little, with the 1997-98 El Nino raising the level by as much as 1.7 m, based on dried sediment lines on lake side boulders.

There are three species of fish in Lake Chala, the most desirable and largest is the endemic *O. hunteri*, with the smaller *Tilapia* species (identity unconfirmed) second in importance due to their small size and less desirable flesh. The smallest fish of the three is a 7-10 cm haplochromid, referred to as a 'dagaa' and a nuisance to the handful of fishers in that it tends to nibble at the fins and body of the large fish when these are caught in gillnets. There exists a threat of extinction of the endemic cichlid, *O. hunteri*, from overfishing with gill-nets, and from predation on juveniles by the smaller *Haplochromis*.

3.5.2 Lake Jipe

The high conductivity observed 924 µS/cm in the open water of Lake Jipe seems to derive from the Kilimanjaro catchment through the Lumi River that originates on the northeastern side of the mountain. The river flows through Kenya, where from Google Earth images what appear to be fish ponds are seen, as well as possibly irrigation channels along its course, then eventually into Lake Jipe on its northwestern side and merges with the swamps with the outflow to the Ruvu River (the main origin of which is on the southeastern slopes of Kilimanjaro). The high conductivity is probably independent of the comparatively small flows from the North Pare Mountains, although these and the management of the remaining higher-ground forests may have an important impact on the sediment supply and therefore the siltation process. The agricultural practices may also contribute to nutrient loads (fertiliser).

Wildlife Division (2004) has produced an overview of the problems of Lake Jipe on the Ramsar website (http://www.ramsar.org/outreach_actionplan_tanzania_jipe.pdf). The problems seem to be old. The siltation is most likely to derive from the deforestation of the slopes of Kilimanjaro (and possibly the North Pare Mountains). Mtalo (2005) described poor farming practices that accelerate erosion in the catchment leading to increased sedimentation in the lake. Also, related to the former, the water quantity is likely to have gone down. There is reference to "detailed" studies of the Lake Jipe situation but no such information has been found.

The main focus for this lake is the need for a credible restoration of the water quality. In that sense it would be good to have very old data on the "pristine" lake (depth, water transparency, water quality, nutrients) and what have been the major changes and trends. Some indication of fish catch levels at that time, when mention is made of important densities of piscivorous birds (darter, cormorants, etc.) in the past, would also be useful, as would information from the time when there was a fisheries recorder. Such information is difficult to access.

Three species of fish are reported from Lake Jipe. The most important is the endemic *O. jipe*, also said to be the largest and most abundant in the past. Since 1976, a small tilapia, possibly *O. esculentus*, became established and is now dominant, but only reaches 10 cm length. It is locally known as 'mwekundu' due to its reddish colouration. A third species of tilapia is possibly *T. zillii* and said to be of little value for its poor quality flesh. *O. jipe* no longer occurs in the numbers of the past nor is it as widespread, being restricted to the vegetated margins of the lake.

3.5.3 Lake Karamba

This is a small natural lake below Kalimawe dam in what were originally marshes where the Saseni River (317 µS/cm) used to join the main Mkomazi River. The water supply has become unreliable and the lake frequently dries out but during flood peaks it can also expand and flood a few hundred metres of the low-lying irrigated rice fields that surround the Lake. The open water of the lake (686 µS/cm) looks rather eutrophic with a high concentration of phytoplankton (deep green). Its high conductivity in comparison to the water supply suggests that this may originate from agricultural runoff with a high nitrate and phosphate content. In spite of its small size and intermittent nature the lake is therefore quite productive but perhaps at risk from anoxia. The cichlid 'Otisi' (probably *Tilapia zillii*) and *Clarias* were noted, supporting a small group of fishers.

3.5.4 Lake Manga

Lake Manga is a shallow brackish lake (conductivity 2,350 µS/cm) branched off the Mkomazi River where it changes course from a North-South direction between the South Pare and the Usambara Mountains to a more southeasterly one along the Western Usambaras to join the main Pangani River 14 km upstream of Korogwe.

From the satellite image of 1 January, 1987 (Fig. 2) during or just after a major flood event, one can surmise the origin of the high salinity of the soils in the area. It seems likely that for extended geological periods the Mkomazi River was endorheic and ended in the low lying area of the current Lake Manga. Each dry season the water would evaporate and the dissolved salts in the water concentrated in the soils (at 1,000 µS/cm a cubic metre of water contains about 6.4 kg of salts). Subsequently, the outflow to the east reconnected the Mkomazi to the main Pangani River. The floodplains around Lake Manga and further to the east function as a natural flood peak attenuation.

Figure 2 Satellite image showing Lake Manga.

The invertebrate life in the margins of the shallow lake was prolific at the time of the field visit with numerous crustaceans, insect larvae and oliogochaetes. Fish present included *Barbus jacksonii*, *Astatotilapia* cf. *burtoni*, *Synodontis* sp., *Labeo* cf. *coubie* and three species of cichlid, *Oreochromis esculentus*, *O.* cf. *jipe* and *Tilapia* sp. During the June visit, about 10-20 fishers were camped on the western shores.

3.5.5 Kalimawe Reservoir

Kalimawe Dam was built on the Mkomazi River in 1956, principally for irrigation. The reservoir is fed from streams coming off the South Pare Mountains but as this is the catchment with the highest relative water use of the whole basin (58% of the runoff being consumed) it is also one of the most fragile and the reservoir has often been closed to fisheries when the water level was too low.

The main sources of water for Kalimawe Reservoir seem to be the forest reserves on the eastern fringes of the South Pare Mountains but in spite of the good flows observed there was no flow downstream of Lake Karamba, i.e. all the water is used up in the irrigation schemes upstream and downstream of Kalimawe Reservoir. There was a small flow however in the Mkomazi River where it crosses the Dar es Salaam-Arusha road, just upstream of Lake Manga where conductivity was measured at 1,426 µS/cm. In Kalimawe Reservoir, water conductivity was low during the visit (219 µS/cm) and there were 4-6 species of piscivorous birds suggesting it is productive though likely over-fished (given the small sizes of fish observed). No information was gathered on invertebrate diversity and abundance, but the healthy reed beds and aquatic bird life suggest that there are healthy populations of aquatic animal life other than fish. Fish species collected were the haplochromid *Astatotilapia* cf. *burtoni*, and three other species of cichlid, *Oreochromis esculentus, O.* cf. *pangani* and *Tilapia* sp.

3.5.6 Nyumba ya Mungu Reservoir

With a (full) surface area of about 180 km^2, and maximum length of 32 km, this reservoir is the largest in East Africa (Bailey, 1996). Two principal rivers feed into the northern shores, one from the northwest, Kikuletwa River draining from the mountains near Arusha, and the Ruvu River from the northeast, originating in Lake Jipe. The water depth averages 6 m and the lake margins expand and contract frequently. Bird life on these margins is prolific.

Much has been written about this reservoir since its construction in 1965. Bailey (1996) and Nhwani (1988) provide comprehensive overviews on the changes to the fishery, describing the change from prolific catches in the early years after impoundment, to progressive reduction in catches, based on government fisheries data. The reservoir is the single most important source of fish in the entire Pangani basin, though numbers of fishers have varied, as have catches, from 28,500 tonnes per year during 1970 to present-day catches of 3,000 tonnes or less in dry years. Principal fish species presently caught are the cichlids *O. esculentus*, *O. jipe*, *Tilapia zillii*, *T. rendalli*, *Clarias gariepinus*, *Barbus* sp., *Labeo* sp. and a smaller catfish of the *Synodontis* genus (Nhwani, 1988; Bailey, 1996). In 1994 there were eleven species of fish (Bailey, 1996).

The northwestern margin is gradually silting and consolidating with thick beds of bulrush forming dense swamps, some of which were cut away and burnt, but submerged vegetation, notably *Naja* and *Potamogeton* species, have extended along the eastern shores (Bailey, 1996).

The conductivity situation may become more critical in the future. It is highly likely that both the water quantity and quality have benefited from the melting of the Kilimanjaro glaciers. Once the ice is finished there will be rainfall only and the proportional contribution of salts collected in the aquifers of the volcano will increase. Conductivity was measured by us at 791 µS/cm at Kiti cha Mungu (697 µS/cm at Langata Bora), which is comparable with the 900 µS/cm recorded at the dam site in 1974. The inflow from the Ruvu was 587 µS/cm, no (significant) change from the 550 µS/cm of 1974 mentioned in Bailey (1996), though there is a need to check how this changes with the flows, this year (2007) having been particularly wet.

The important thing for water quality and fisheries (and water storage capacity for hydro-power) in Nyumba ya Mungu is to carefully consider, or avoid, a large-scale mechanical (or worse, chemical) removal of aquatic vegetation (*Typha* and *Papyrus*) from the Lake Jipe and the swamps on the connection to the Ruvu River. This has excellent transparency downstream of the marsh, measured at 587 µS/cm in June 2007, very close to the 550 µS/cm mentioned in Bailey (1996) for the 1974 situation). There is a need to first address the causes of the deterioration of water quality in Lake Jipe before potentially allowing the problem to propagate into Nyumba ya Mungu. The result would be a deltaic siltation of that branch resembling the landbuilding and marshy delta formation observed on the Kikuletwa branch across the reservoir.

3.6 Pangani Estuary

The Pangani estuary extends from the ocean to about 23 km inland. Based on ten sites, Kamugisha *et al* (2006) provide the most recent and comprehensive description of the estuary, including details on water quality, fisheries and benthos for two seasons - during high flow (May 2006) and low flow (September 2006). Their work forms the basis of this section.

Zooplankton density across all sites was considerably higher in the low flow than in the high flow seasons. The community was overwhelmingly dominated by copepod crustaceans in the high flow season, then by the larval stages of brachyuran crabs in the low flow season. These authors report that the abundance of zooplankton in the Pangani estuary falls within the range reported for other tropical and subtropical estuaries around the world, albeit on the upper end of this range.

Figure 3 Oblique satellite image of Pangani River estuary, showing the mangrove forest fringe upstream.

3.6.1 Intertidal zone

The abundance of benthic macro-invertebrates (>1 mm size) in intertidal zones was low for both seasons. Kamugisha *et al* (2006) report that brachyuran crabs and polychaete worms dominated in the middle reaches (sites 2-8) in the high flow season, while isopods and anomurans (hermit crabs) made important contributions near the mouth, and amphipods and macruran shrimps dominated in the upper reaches. In the low flow season, polychaetes were prominent up the whole length of the estuary, while bivalves were important in the upper reaches, brachyuran crabs in the middle reaches and isopods at the mouth.

3.6.2 Shallow subtidal zone

The subtidal environment similarly supported low densities of benthic macro-invertebrates with polychaete worms, amphipods and brachyura (crabs) being the most abundant groups. Benthic community composition for the two seasons varied up the length of the estuary. Crustacean groups of commercial importance include the penaeid prawns (e.g. *Penaeus*) and mud or mangrove crab (*Scylla serrata*) in the estuary and coastal waters and the large-clawed paleomonid shrimp (*Macrobrachium*) in the higher reaches (and beyond). In the estuary, the abundance of benthic invertebrates falls within this range reported for both intertidal and subtidal component, but in both conditions (low and high flow water) lying at the lower end of the range of values reported.

The estuarine fish community, examined by Kamugisha *et al* (2006) from beach-seine and gill-net fishing catches from 10 sites distributed along the 23 km length of the estuary comprised 26 families and 53 species. Lower river and estuarine fish species such as the Gobies *(Glossogobius* spp.), Milkfish *(Chanos chanos*), and Ambassids (*Ambassis unitaenia*) are euryhaline, frequently migrating between the sea and the river.

Overall, species from the families Leiognathidae, Clupeidae, Engraulidae, Ambassidae Gerreidae, and Mugilidae dominated the fish community. Community composition was similar in the high and low flow seasons in spite of the huge change in abundance and biomass, with only slightly fewer species recorded in the low flow survey. The number of teleost species in seine net catches was highest in the lower and middle reaches of the estuary in both the high and low flow seasons. All fish caught were smaller than 35 cm (TL), comprising either small species or juveniles of large marine species.

From these brief studies, Kamugisha *et al* (2006) conclude that figures of fish diversity are low, in some cases considerably lower than figures reported for many similar sized, tropical and subtropical estuaries. They argue that these low yields are most likely a function of the present relatively poor state of health of the system. In terms of fish diversity, additional sampling effort, utilising a range of techniques (e.g. night fishing, light attraction fishing, baited traps and anesthetics (clove oil)) would most certainly yield new species and increase the number of fish families recorded for the estuary.

In summary, these authors describe how low diversity and invertebrate abundances are probably a function of the following features of the estuary, some of which are also evidence of the degradation:

- limited and very narrow intertidal expanses
- the high proportion of very fine silt/mud which reduces colonisation by fauna
- low benthic invertebrate abundance
- large tidal prism which ensure that sediments in the estuary are highly mobile
- deeply incised estuary channel
- very low water oxygen concentrations in upper reaches
- extremely high phytoplankton biomass
- use of destructive fishing practices and over-fishing in nearby coral reef areas

The Pangani estuary is currently in a poor condition. The use of destructive fishing practices and over-fishing outside the estuary contributes to reduce available stock from which fish will interact with and recruit into the estuary. Both environments suffer as a result. Catches of prawns offshore by the industrial trawlers are reported to have plummeted over the last five years and the mouth of the estuary has retreated since the 1960s by about one kilometre (Shaghude, 2004), presumably through lack of depositional material carried downstream by the Pangani River.

4 IMPORTANT FISHES OF THE PANGANI RIVER BASIN

4.1 Overview of fish diversity

For Tanzania, Eccles (1992) describes 46 species from 14 families for the Pangani Basin. During the survey and experimental fishing by Dallas *et al* (2006), twenty three fish species were recorded while the present four-day sampling, combined with the previous trip to Lake Chala, produced at least 15 species. The species list from Eccles (1992) and Bailey (1996) have been combined with the findings of the Pangani Basin studies and are presented in Table 3. This list now includes a maximum of 59 possible species, excluding typical estuarine fish species such as the milkfish *Chanos chanos*, *Ambassis gymnocephalus*, *Gerres filamentosus* and *Valamugil buchanani.* Some of the *Tilapia* and *Oreochromis* specimens still remain to be fully identified and there a few uncertainties even from Eccles' list. The total number of fish in the Pangani Basin is probably between 50 and 60. The inclusion of all estuarine species would raise the number of species by at least another 50 or so species (see Kamugisha *et al*., 2006). The Greater Rufiji River by comparison, yielded 40 freshwater species, albeit from a limited survey (see Hopson, 1979).

The list of truly freshwater species in Table 3 belong to 14 families with the best represented and their typical genera being the Cyprinidae (*Barbus*, *Labeo* and *Garra*), Cichlidae (*Tilapia*, *Oreochromis* and *Haplochromis*), Mochokidae (*Synodontis, Chiloglanis*), Mormyridae (*Mormyrus*), Gobiidae (*Glossogobius*), Characidae (*Brycinus, Rhabdalestes*), Anguillidae (*Anguilla*), Clariidae (*Clarias*), Chanidae (*Chanos*) and Cyprinodontidae (*Nothobranchius*).

Throughout the basin, cichlids (*Oreochromis* and *Tilapia*) and minnows/carps (Cyprinidae) are the most widely distributed, found in almost all zones except the mature river zone. Dallas *et al.* (2006) reported that the killifish (Cyprinodontidae) were the next most common and were recorded in all zones except the mountain streams and the lower mature zone. The lower foothills had the highest diversity of fishes of all the zones, followed by the mature river zone (see Fig. 1) with the mountain stream zone the least diverse, mainly supporting only the minnow *Garra dembeensis* (with unconfirmed reports of cichlids in the past). Some of these species (such as *Oreochromis pangani*) are endemic to the Pangani River system.

Compared to the basins throughout Africa, the fish diversity of the Pangani is noteworthy. For the whole of Africa, there are at least 2,000 indigenous freshwater fish species, from 42 families (Lowe-McConnell, 1987). The main river systems and number of fish families are: Nile - 17 families; Zambezi - 18 families; Lake Victoria - 12 families; Lake Tanganyika - 19 families. The greatest concentrations of fish species are within the African Great Lakes, Malawi, Tanganyika and Victoria, with the bulk coming from the family Cichlidae, most of which are endemic to single lakes. Beyond the Great Lakes, the Rufiji/Ruaha, Pangani, Malagarasi, Shire and Tana River basins also have high species richness, again predominantly cichlids, many of which are lake endemics (Darwall *et al*., 2005). The Pangani River Basin has supports at least 15 families, a high number for such a relatively small basin, reflecting the rich range of biotopes. Total species number (59) is low compared to the Nile Basin (115), Zambezi (110), Niger (134) and the over 240 fish species from Lake Victoria. Within East Africa, the Rufiji, Pangani and Tana River systems were identified as important centres for freshwater biodiversity (Darwall *et al*., 2005).

Of note for the Pangani Basin is the absence of characteristic tropical African rivers species such as *Citharinus*, *Distichodus* and *Alestes*. These species are of Congo origin and are prominently present in the Rufiji, Wami and Ruvu rivers. The absence of the predator *Hydrocynus*, common in nearly all larger river systems in Africa is also remarkable. All these typically riverine fish normally perform lateral movements into floodplains and therefore easily colonise temporary or permanent (man-made or natural) lakes. Their absence from Nyumba ya Mungu and probably from the other lakes and impoundments is probably an indication of the fact that, in contrast to the more southerly east flowing rivers, the Pangani was never connected to the Congo system. Alternatively flood-dependent species can go extinct during prolonged droughts. Such crises have been observed in Sahelian river systems during the droughts of the 1970s and 1980s. In the Chari river, species such as *Distichodus*, *Citharinus, Labeo* and *Alestes* declined drastically in abundance (Carmouze *et al*., 1983) and may go extinct if the drought conditions persist (a situation comparable to the downstream impact of an impoundment without managed flood releases).

For its size of 43,650 km², the basin does have a comparatively high biodiversity judging from the correlation established by Welcomme (1985) for African rivers ($N=0.449A^{0.477}$, with N the number of species and A the surface area in km²) which “predicts” the presence of 45 species. Even accounting for the variation in the level of detail to which African river system fish faunas had been investigated in 1985, the altitude range and the diversity of habitats within the basin contributes to this comparatively high fish diversity.

4.2 Important fish species, their biology, life histories and links to river flow

This section describes thirteen species of fish from six families considered to be the most important in the Pangani River Basin. Details are provided of their main anatomical features and feeding aspects of interest, reproduction and distribution. In general, cichlids appear to breed throughout the year, in DRC at least, most fish spawn at the start of the two high water seasons (Trewavas, 1983). Criteria for selection of the species included commercial value (as a food fish), biodiversity importance (taxonomic uniqueness at species level or above e.g. family), inclusion of representatives of species with different flow linkages, potentially valuable in the aquarium industry, and likely ecological importance in the food web.

With the current level of knowledge on the estuarine fisheries of the Pangani it is not obvious to select important species. The experimental catches by Kamugisha *et al*. (2006) showed high densities of various typically estuarine families Engraulids, Clupeids and Mugilidae but also of more typically marine species from the Serranidae, Gerridae and Carangidae but this does not necessarily reflect their importance in the fishery. From a functional point of view most of these species are likely to react in a similar fashion to changes in river flows (see 8.2.4).

4.2.1 Family Cichlidae

This family is the most significant in terms of fish biomass and endemicity within the Pangani Basin from where 15 species have so far been identified (see Table 3). Five have been selected from three genera, demon-strating a range of different feeding and breeding features. All the species below were photographed while fresh.

Plate 1 *Astatotilapia* cf. *burtoni* from Kalimawe Reservoir.

Astatotilapia* cf. *burtoni (Günther, 1893) ‘Ngobelo’ (see Plate 1). Skelton (1993) describes males of the genus as having few large anal fin ocelli, chest scales not markedly different or smaller than those from the lower body and bicuspid teeth. The specimens agree with this description but the species identification is tentative. It is found in slow-flowing stream and rivers, deltas, ponds, lagoons, and shallow inshore waters in lakes, where it feeds on varied food item including small fishes, insect larvae, diatoms, algae, and plant debris.

Reproduction - Most Haplochromids such as *Astatotilapia* spp. are mouth-brooders with well-marked spawning seasons and greatest activity between September through May (see Lowe, 1956), which for the Pangani River Basin is equivalent to before the short rains (November-December) and before the main wet season (March-June).

Table 3 Principal freshwater fishes of the Pangani River Basin, based on Eccles (1992) with additional records (a) Dallas *et al* (2006), (b) Bailey (1996), (c) doubtful identity in Eccles (1992), and (+) indicating species in the present collection. Numbers in parentheses are species totals for each family.

Fish family and species
ANGUILLIDAE - Freshwater eels (2)
Anguilla bengalensis labiata
A. bicolor bicolor [a]
AMPHILIIDAE - Mountain catfish (1)
Amphilius uranoscopus
ARIIDAE - Sea catfishes (1)
Arius africanus
BAGRIDAE - Bagrid catfishes (1)
Bagrus orientalis
CHARACIDAE - African tetras (5)
Brycinus (Alestes) affinis
B. sadleri [a]
Petersius conserialis
Rhabdalestes leleupi
R. tangensis [a]
CICHLIDAE – Cichlids (15)
Oreochromis esculentus +
O. pangani girigan
O. pangani korogwe
O. pangani pangani
O. jipe +
O. variabilis
O. hunteri +
Tilapia rendalli
T. zillii
T. sparrmanii [a]
Astatotilapia bloyeti
A. cf. burtoni +
Haplochromis sp.+
Ctenochromis pectoralis
Aulonacara sp.[a] [likely to be error]
CLARIIDAE - Air-breathing catfish (1)
Clarias gariepinus
CYPRINIDAE - Minnows & carps (17)
Barbus paludinosus
B. cf. eutaenia [a]
B. jacksoni +
B. kerstenii +
B. lineomaculatus
B. quadripunctatus
B. radiatus
B. toppini [a]
B. usambarae
B. zanzibaricus
Labeo cylindricus
Labeo cf. *coubie* +
Labeobarbus oxyrhynchus
Garra dembeensis
Neobola fluviatilis ? [c]
CYPRINODONTIDAE Killifishes (4)
Pantanodon podoxys
Aplocheilichthys kongoanenis
Nothobranchius melanospilus
N. guentheri [a]
N. palmquisti
ELEOTRIDAE - Sleepers (1)
Eleotris fusca
GOBIIDAE - Gobies (3)
Glossogobius giuris
G. biocellatus [a]
Favonigobius reichei [a]
MOCHOKIDAE - Squeakers (5)
Chiloglanis deckenii
Synodontis afrofischeri
S. leopardus
S. nigromaculatus +
S. punctulatus +
MORMYRIDAE – Elephant fishes(1)
Mormyrus kannume [b]
SCHILBEIDAE - Butter catfishes (2)
Schilbe moebiusii
Pareutropius longifilis

Distribution - *A. burtoni* is reported to be restricted to Lake Tanganyika and associated rivers According to the IUCN Red List website,; however, it is currently very common in upper and middle Akagera River and associated lakes, where most likely it has been introduced. Present specimens from Kalimawe Reservoir and Lake Manga needs verification.

Importance - Its potential commercial value to the aquarium industry, its role as a predator of juvenile tilapia especially and its endemicity. A similar species confirmed is *A. bloyeti* (Sauvage).

Oreochromis esculentus (Graham, 1928) 'Shaba' or 'Roketi'. Copley (1958) describes this fish a typical Tilapia with high humped back, fins darker, tinged with red (intensified when breeding), and a caudal fin which is plain-coloured and a distinguishing feature. Greenwood (1966) states that this fish feeds almost entirely on phytoplankton from which only the diatoms are digested, with insect larvae and planktonic crustaceans taken less frequently, though these may be more important for young fish.

Reproduction - *O. esculentus* are mouth-brooders with well-marked spawning seasons and greatest activity between September through May (see Lowe, 1956), which for the Pangani River Basin is equivalent to before the short rains (November-December) and before the main wet season (March-June). They are sexually mature at the relatively small size of 15 cm (TL), and spawning takes place in deep water after which the adult fish move with the fry to more weedy areas (Copley, 1958).

Distribution - Indigenous to Lake Victoria but now well-established in NYM, Kalimawe Reservoir, and probably further afield.

Importance - Commercial value, comprising over 90% of the catches from Nyumba ya Mungu, although fish size rarely exceeds 15 cm.

Oreochromis hunteri Günther (1889) 'Chala tilapia'. The identification of this species was based on visual comparison with the illustration and text in Eccles (1992) and from the Fishbase website details and photographs. Maximum size (SL) is reported at 30 cm (Eccles, 1992), though fishermen indicated that it grows to 50 cm. The length of the specimen photographed was calculated as 43 cm. They are slow, gently moving fish, frequently seen feeding by scraping algae off submerged surface such as fall trees, rocks and even fish nets. Trewavas (1983) includes a note by Lowe (1955) whereby young fish were seen feeding on the bottom, between rocks and boulders, accompanied by numerous crabs. There was no information on adult diet. Fishermen report that they also eat flying termites ('kumbi kumbi') that fall onto the lake surface. Said to be the most desirable food fish from the lake with excellent flavoured flesh.

Reproduction - There is no information on breeding (Trewavas, 1983) but it is reasonable to assume that *O. hunteri* breeds throughout the year, without marked seasonal differences, in the same way as *O.jipe* in NYM.

Distribution - Lake Chala (endemic), but possibly more widely introduced.

Importance - Commercial value, its attractiveness in terms of appearance and its endemicity.

Oreochromis jipe (Lowe, 1955) 'Asilia'. This species is superficially very similar to the closely related *O. girigan*, *O. pangani* and *O. korogwe*, with details of dentition and fins needed to separate species. *O. jipe* has an upper profile of the head steep and nearly straight, the most common number of scale along lateral line is 34 and vertical stripes on the caudal fin may be diagnostic in the field (Trewavas, 1983).

Reproduction - In NYM, *Oreochromis jipe* breeding was noted throughout the year with no peak season detected (Trewavas, 1983).

Distribution - Indigenous to Lake Jipe, but now well-established in NYM, Kalimawe Reservoir, and fish ponds near Taveta (Kenya), in Usambara Mountains and ponds near Tanga and Korogwe (see Trewavas, 1983).

Importance - Commercial value and its endemicity.

Tilapia zillii (Gervais, 1848) 'Nyeupe' 'Dindila' and also known as 'St. Peter's fish'. The body colour is olivaceous, with a blue sheen; lips are bright green and chest pink (Greenwood, 1966). There are 6-7 dark bars, of variable intensity, on flanks. The dorsal, caudal and anal fins are olivaceous with yellow spots. Dorsal and anal fins often outlined by narrow orange band. May reach 29 cm. Can tolerate very high salinity. Principally a bottom feeder, feeding mainly on leaves/stems of rooted aquatic plants, epiphytic algae and periphyton, at least in Lakes Volta and Kainji (Lowe-McConnell, 1987) but may also sift through bottom particles (Trewavas, 1983).

Reproduction - A non mouth-brooder, spawning in a prepared nest (or depression) with one parent always on guard, protecting the eggs, and fanning the water to maintain oxygenation and to keep the eggs clean of detritus (see Greenwood, 1966). This species breeds throughout the year.

Distribution - NYM, Lake Jipe, other parts of Africa (e.g. Lakes Volta and Kainji) and Jordan Valley.

Importance - Commercial value.

4.2.2 Family Cyprinidae

The minnows and carps is the best represented fish family in the region, with 17 species so far reported from the Pangani basin from four genera. Included below are two small species of *Barbus,* one large *Labeo* and the tiny *Garra*. Each is important for a range of reasons, either as a food fish of predatory fish species, of ecological importance or of minor importance as a food fish to humans. Most cyprinids feed either on insect larvae or by grazing algae and detrital layers 'awfuchs' from firm surfaces (Skelton, 1993). Of the four cyprinids included here, only *Garra dembeensis* was not collected and photographed in the present study.

Barbus kerstenii Peters, 1868 'Dagaa'. One of 49 species of *Barbus* in Tanzania (see Eccles, 1992). Up to 75 mm. This fish is distinctive due to its bright orange spot on operculum (Greenwood, 1966). Caudal and anal fins clear orange; dorsal fin faintly orange; other fins clear. Feeds mostly on insect larvae, in fast and slow streams and lakes.

Reproduction - Rain-triggered migrations to favoured breeding grounds, with simple scattering of ova over patches of weed, on the stream bed or over sandy beach areas of lakes. The sticky ova adhere to the substrate until the fry hatch from when they develop on their own without parental care. Breeding season generally begins with the onset of the long rains in April (Greenwood, 1966). In rivers, a definite migration exists to favoured spawning grounds, entering streams off NYM shores (Bailey *et al*., 1976) while in lakes migrations occur to the river mouths and up the rivers. Skelton (1993) explains that some species of the Cyprinidae leap across barriers when migrating upstream (noted for the Grumeti River start at the Kalimawe Dam by an informant during the field visit) while others use their mouth and broad pectoral fins to climb over damp surfaces such as rocks or weirs.

Distribution - Saseni River, Pangani Basin, and widespread through eastern Africa.

Importance - Low commercial value, potential for the aquarium industry and importance as a food fish for other larger species.

Barbus jacksonii Günther, 1889 'Dagaa'. Up to 135 mm. This fish has three distinctive black dots on its flank; the first slightly ahead of the dorsal fin, the second slightly behind the dorsal fin and the third at the base of the caudal fin (Greenwood, 1966). It also has a dorsal fin with three spines and eight rays, the last unbranched ray very strong and bony but not serrated on posterior surface. Feeds on insect larvae and bottom debris.

Reproduction - Similar to *B. kerstenii* (see above).

Distribution - Saseni River, Lake Manga, Lake Victoria, Uganda. Importance - Low commercial value, potential for the aquarium industry and importance as a food fish for other larger species.

Labeo coubie Rüppell, 1832. 'Ningu'. One of 12 species in Tanzania (Eccles, 1992). Reported by Greenwood (1966) to grow to 74 cm in Lake Albert (Uganda). Dorsal fin with 3 unbranched rays and 12-14 branched rays. Young fish greyish-silver, with many wavy black lines on flanks, and large black spot at base of caudal fin. Reproduction - Similar to *B. kerstenii* (see above).

Distribution – Nile and Chad basins (Reid, 1985), reportedly Pangani Basin (Eccles, 1992) but taxonomic review is advised.

Importance - Commercial value.

Garra dembeensis (Rüppell, 1836). A small upper river fish, reaching 11 cm. The lower lip forms a circular pad which acts as a sucker used as a holdfast organ that enables it to cling to rocks in the mountain streams.

Reproduction - Similar to *B. kerstenii* (see above). Distribution - Pangani Basin and Lake Victoria Basin, (Eccles, 1992), including Kikuletwa delta, Samaga (Bailey *et al*., 1976).

Importance - Ecological value in the upper river biotopes in which it is the often the only fish species present.

4.2.3 Family Characidae

The African tetras are represented by five species in the Pangani basin from three genera.

Brycinus sadleri (Boulenger, 1906). Grows to 10 cm, and feeds on plants and associated invertebrates in Lake Victoria (Lowe-McConnell, 1987) and inhabits shallow vegetated areas.

Reproduction - Assuming this species behaves the same as *Rhabdalestes leleupi* in Nyumba ya Mungu which is fertile from February to June (see Bailey *et al*., 1976), it indicates a seasonal, high water trigger to reproduction.

Distribution - Lake Victoria basin and Pangani system.

Importance - Low commercial value, has potential for the aquarium industry and importance as a food fish for other larger fish.

4.2.4 Family Clariidae

In the region, there is only a single, distinctive and well-known catfish species in this family.

Clarias gariepinus (Burchell, 1822) 'Kambale'. Distinctive and ubiquitous large catfish, reaching 1.4 m, reaching over 20 kg. Omnivorous, eating almost anything from filter-feeding on plankton to small fish and even mammals and birds.

Reproduction - *Clarias gariepinus* breeds during the rains, when large numbers of mature fish migrate to flooded shallow grassy verges of rivers and lakes where vast numbers of eggs are laid on vegetation and hatch within 1-2 days (Skelton, 1993). Larvae are free-swimming but remain within the vegetation cover. Around Lake Victoria, Greenwood (1966) reports that *C. gariepinus* breeds in small temporary streams, with runs upstream in April and December (at night).

Distribution - Widespread throughout Pangani River Basin and most of central Africa.

Importance - High commercial value.

4.2.5 Family Mochokidae

Of the five species found in the Pangani Basin, four are from the genus *Synodontis*.

Synodontis punctulatus Günther, 1889 'Ngogo'. Reported to grow to 25 cm, but catches are generally of smaller-sized fish. Generally, not desirable in net fishing due to awkward snagging and tearing of nets.

Reproduction - For the Rufiji floodplain lakes, breeding fish (with eggs) are seen by local fishers in a similar species, *Synodontis maculipinna*, during the wet season (Richmond *et al.*, 2006).

Distribution - Ruvu, Pangani Basin north to Somalia (Eccles, 1992), throughout NYM (Bailey *et al*., 1976). Specimens were collected from three sites within the Pangani Basin.

Importance - Valued as an important food fish, also with potential for the aquarium industry and importance as a food fish for other larger fish.

4.2.6 Family Mormyridae

At least 14 species recorded for Tanzania, with only a single species so far collected in the Pangani River Basin.

Mormyrus kannume Forsskål, 1775. Grows to 80 cm (Eccles, 1992), and in Lake Victoria this species has a varied diet depending on location and type of substrate (hard or soft) and on lunar phase. It feeds on diverse insect larvae and shrimps and is well adapted to soft muddy bottoms (Lowe-McConnell, 1987).

Reproduction - In Lake Victoria, it breeds within the lake, generally on rocky bottoms, with ripe fish found throughout the year (Lowe-McConnell, 1987).

Distribution - Lake Victoria basin and Pangani system, including NYM inflows (Bailey *et al*., 1976).

Importance - Uniqueness (single representative of unusual family) and likely importance as a food fish for larger fish (or fish-eating birds). Though it has limited commercial importance, it is readily accepted as a food fish (Bailey *et al*., 1976).

4.2.7 Fish distribution

Table 4 Selected freshwater fishes of the Pangani River Basin and distribution within the Basin, with abundance measured as: - absent, + rare, + + present, + + + common.

Species	Rapids & streams	Main rivers	Floodplains & marshes	Lakes	NYM Reservoir
Astatotilapia sp.	-	++	++	++	++
Oreochromis esculentus	-	++	++	+++	+++
Oreochromis hunteri	-	++	++	+++	-
Oreochromis jipe	-	++	++	+++	++
Tilapia zillii	-	++	++	+++	-
Barbus kerstenii	-	+++	++	+	-
Barbus jacksonii	-	+++	++	+	-
Labeo coubie	-	+++	++	+	+
Garra dembeensis	+ + +	+++	++	+	-
Brycinus sadleri	-	+++	++	+	-
Clarias gariepinus	-	++	++	++	++
Synodontis punctulatus	-	++	++	++	++
Mormyrus kannume	-	+++	+	+	++

4.2.8 Fish breeding guilds

<u>Year-round breeders</u>

Fish that are known to have ripe ovaries throughout the year, demonstrating no obvious seasonality with respect to water levels are *Mormyrus kannume* (Mormyridae), and of the Cichlidae, *Oreochromis jipe*, *O. pangani* (with no correlation to water levels in NYM (Bailey *et al*., 1976), and its relative *Tilapia zillii*. Stunting and early breeding is reported when water levels drop.

<u>Flood-induced spawners</u>

Fish in this group are strongly influenced by seasonal changes in water levels and the breeding season is triggered by the onset of the long rains in April as levels start to rise. These are potamodromous fish, such as the *Barbus* and *Garra* minnows and *Labeo* carps (Cyprinidae), the airbreathing catfish *Clarias* (Clariidae) and the squeaker catfish *Synodontis*, as well as mouth-brooding haplochromids and some cichlids (e.g. *Oreochromis esculentus*).

As water levels rise, mature fish migrate to flooded shallow grassy verges of rivers and lakes, laying large numbers of eggs on vegetation, on the stream bed or over sandy beach areas of lakes. *Clarias* is known to make runs upstream in April and December, during the night. Up rivers, fish travel to their favoured spawning grounds upstream with some species leaping across barriers while others use their mouth and broad pectoral fins to climb over damp surfaces such as rocks or weirs. The sticky ova adhere to the substrate until the fry hatch after a few days from when they develop on their own without parental care. The small fish are free-swimming but remain within the vegetation cover, sheltered from predation and close to the food supplies of insects and algae.

Most Haplochromids such as *Astatotilapia* spp. are mouth-brooders with well-marked spawning seasons and greatest activity from September through May (see Lowe, 1956), which for the Pangani River Basin is equivalent to before the short rains (November-December) and before the main wet season (March-June).

O. esculentus are mouth-brooders with well-marked spawning seasons and greatest activity between September through May (see Lowe, 1956), which for the Pangani River Basin is equivalent to before the short rains (November-December) and before the main wet season (march-June), with pawning coinciding with the wet season (Bailey *et al*., 1976). They are sexually mature at the relatively small size of 15 cm (TL), and spawning takes place in deep water after which the adult fish move with the fry to more weedy areas (Copley, 1958). Under normal conditions, *Oreochromis* are seasonal breeders, but some may breed all year round (Fryer & Iles, 1969).

5 IMPORTANT CRUSTACEA OF THE PANGANI RIVER BASIN

The diverse range of biotopes within the Pangani River Basin provides benthic habitats that support unique assemblages of aquatic plants and animals. Among the invertebrates, the flatworms, oligochaete and annelid worms, arthropods (mainly insects and crustaceans) and molluscs (snails and bivalves) are the main phyla present. Typically each biotope will support a characteristic community of species from among these groups with composition and abundance changing in response to water flow variables. Among these five invertebrate taxa, the crustaceans are the most important in economic terms, though members are also of critical importance ecologically, such as the copepods which contribute enormously to the zooplankton on which so many fish depend. The importance of the sub-phylum Insecta cannot be over-stated, providing food for fish and acting as vectors of many diseases of humans and wildlife. Unfortunately, information of these groups is generally lacking in detail and the study by Dallas *et al* (2006) provides probably more details on this group than any other. The sub-phylum Crustacea is diverse and but the shrimps and the crabs are the focus in terms of this analysis. There are important freshwater and estuarine species in both groups.

5.1 Overview of crustacean diversity

Comprehensive studies of the crustacean fauna from the Pangani are lacking, and information gathered here is from three isolated studies, namely a visit to Lake Chala by one of the team members, and the reports by Darwall *et al*. (2005), Kamugisha *et al.* (2006), Reed and Cumberlidge (2006) and Dobson *et al.* (2007). Literature from other, similar environments is also referred to.

Mangrove fringed estuaries, such as the Pangani, are well-known for their crustacean diversity, from zooplankton to macro-crustaceans such as crabs and shrimps. Indeed, decapod crustaceans are among the most conspicuous fauna (see Jones, 1984). Typical members of the crab fauna belonging to the swimming crabs or Portunidae, with common examples such as *Thalamita*, *Portunus*, *Charybdis* and *Scylla;* the fiddler and ghost crabs or Ocypodidae with *Uca, Ocypode* and *Macrophthalmus*; the Grapsidae with typical genera *Metapograpsus*, *Sesarma* and *Neosarmatium* (Jones, 2002). Most of these have little or no commercial value, as with many hermit crabs which are also certain to be present in the estuary. There are 5-6 large and commercially important penaeid shrimps, while many smaller shrimps have no commercial value.

Tanzania's freshwater environment supports far fewer species of large crustacean, but crabs and shrimps are represented. Darwall *et al*. (2005) lists 37 freshwater crabs from Eastern Africa, with crab distributions centred on the three largest lakes, namely, Lakes Malawi, Tanganyika and Victoria, but also the Pangani and Tana River basins. The taxonomy of the freshwater crabs of Tanzania was recently revised by Reed and Cumberlidge (2006) who treat this assemblage as a distinct regional subset of the African continental fauna. These authors recognised 25 species belonging to three genera (*Potamonautes*, *Platythelphusa* and *Deckenia*). These three genera are from different families, and only member of this group is included here. Of the freshwater shrimps, the most conspicuous are species of *Macrobrachium* with several known from the East Africa (see Bailey and Critchon, 1971).

5.2 Important Crustaceans, their biology, life histories and links to river flow

This section describes four species of crustaceans, each from different families, with one located only in freshwater biotopes and three from the estuary. Details are provided of their main anatomical features and feeding aspects of interest, reproduction and distribution.

5.2.1 Family Potamonautidae

Reed and Cumberlidge (2006) list fourteen species of this genus for Tanzania.Little is known about population densities of freshwater crabs, or their ecological importance, in African rivers (Dobson *et al.*, 2007). From their study of 19 rivers draining Mt Kenya, crabs, mainly *Potamonautes odhneri*, were recorded from 14 of the 21 sites. Although numerically unimportant relative to other macro-invertebrates, crabs accounted for at least 70 % of total macro-invertebrate biomass from forest and shaded agricultural sites, and averaged around 40 % in open agricultural sites. It is possible that crab reproduction occurs mainly or exclusively in forested areas, which would therefore act as a recruitment source for populations farther downstream in agricultural areas.

Potamonautes platycentron (Hilgendorf, 1897) 'Kaa' A large red, large crawling crab with carapace width 4-5 cm (see Plate 2). Common along the shores, visible at depths to 8 m and a frequent by-catch of the gill-net fishery. It is probably a scavenger for dead fish or other animals and organic matter than fall to the bottom. Several specimens were easily caught with hooks, on all baits tested. One specimen is deposited at the UDSM.

Plate 2 *Potamonautes platycentron* from Chala.

Reproduction – Not known.

Distribution - Lake Chala, Usambara Mountains, Usa River, Maranga and Lindi (Lake Tanganyika), supposedly endemic to the Pangani Basin.

Importance - Mainly its endemicity and being a pest of gill-netters.

5.2.2 Family Portunidae

A very diverse family with about 50 species of true swimming crabs in the family found in Tanzania.

Scylla serrata (Forsskål, 1775). 'Kaa' Large crab with carapace width to 22 cm. Mostly found in estuarine and sheltered coastal habitats with large populations usually associated with mangrove forests. Distribution and abundance depend on developmental stage, with juveniles most abundant on intertidal flats, while subadult and adult crabs may be more subtidal in habit (Hill, 1975; Hill *et al*., 1982; Le Vay *et al.*, 2001), moving into the intertidal zone to forage during high water. Crabs remaining intertidally at low tide tend to dig burrows, though burrowing behaviour appears to vary between species and between individuals of the same species. In South Africa, *S. serrata* of all sizes construct burrows from which juveniles and some adults make limited movements, always returning to the burrow in the intertidal zone.

Reproduction - Mature crabs mate when females are in their soft-shell condition, about 48 hours after moulting. Embryonic development within the egg takes from two to four weeks, depending on water temperature (Gribble *et al.*, 2002). In tropical estuaries there may be a small seasonal spawning peak linked to periods of high productivity, due to seasonal monsoons or cyclones during the summer months or by post-monsoonal upwelling (Heasman *et al*., 1985). Female *Scylla* then migrate offshore to spawn, with distances varying between species and on local environmental conditions. Spawning females have been caught up to 95 km offshore and at depths of 60 m in South Africa (Hill, 1994) or further, and deeper. The presence of a high proportion of females with spent ovaries in coastal populations of *S. serrata* indicates that many are able to return to the coast after spawning (Heasman *et al*., 1985). Larval development takes place in coastal waters prior to recruitment of late larvae (megalopa) or first crab stages to the mangrove estuarine environment after about two weeks. Few detailed studies of juvenile recruitment have been undertaken. In tropical populations juvenile abundance may be related to seasonal variation in rainfall and salinity (Poovichiranon, 1992). Despite seasonal peaks, however, recruitment appears to be continuous throughout the year in tropical populations (Chandrasekan & Natajaran 1994; Le Vay *et al*., 2001).

Distribution - Indo-West Pacific.

Importance - High value as a food and export item.

5.2.3 Family Penaeidae

These are typical shrimps with reduced chelae, living over mud or sand bottoms in shallow coastal areas. In Tanzania, the white prawn *Fenneropenaeus indicus* makes up to 66% of the catch, 18% are giant prawn *Penaeus monodon* and the tiger prawn *Penaeus semisulcatus*, 15% are brown shrimp *Metapenaeus monoceros*, and the flower shrimp *Penaeus japonicus* makes up 1% (Haule, no date; Teikwa & Mgaya, 2003).

Fenneropenaeus indicus (H. Milne Edwards, 1837) [syn. *Penaeus indicus*] ‘White shrimp’. Distinctive pale cream shrimp, with usual length of 8-12 cm.

Reproduction - Most penaeids reach sexual maturity in less than one year and produce large numbers of eggs. Among the species occurring in the Pangani estuary, females migrate offshore to release eggs and the larvae recruit back into the estuary where the salinity is usually low (King, 1995).

Distribution - Indo-Pacific. N.B. The allied species of importance are *Penaeus monodon* and *Metapenaeus monoceros* with similar life histories and breeding requirements.

Importance - This species is the main contributor (over 60%) to the prawn catches from Tanzania.

5.2.4 Family Palaemonidae

Typically, this family includes hundreds of marine species, but a few freshwater and estuarine shrimps are included from the sub-family Palaemoniinae. Most live in the rivers and estuaries,

Macrobrachium rude (Heller, 1872) ‘Kamba’. An unmistakeable shrimp with two long, ‘furry’ chelae, and body length to 13 cm. Lives in clear rivers and streams.

Reproduction - Larvae are released into the sea and juveniles return to the estuaries and rivers to develop.

Distribution Western Indian Ocean to India.

Importance - Minor fishery and likely to be important ecologically as predator of juvenile fish.

6 FISHERIES OF THE PANGANI RIVER BASIN

6.1 Overview of the fisheries management of the Pangani River Basin

After meetings and discussion with the fisheries officers met with during the four-day field visit, especially in the offices of the District Fisheries Officer at Mwanga and following the discussion with the Head of the Statistics Section of the Fisheries Division in Dar es Salaam, Mrs. Faatma Sobo, an understanding of the type and availability of fisheries data for the Pangani River Basin was achieved. The situation is not encouraging. For most of the area there are no fisheries data, and of the few data that do exist, there may be two types: fresh fish landings (in kilogrammes) and dried/smoked fish export (in numbers of fish). The value of fish exports, in Tanzania shillings, is also available for some sites.

One of the problems facing fisheries monitoring and data recording is that fisheries recorders are not employed by the Fisheries Division, but instead by the local District offices. Each District has its own natural resource monitoring priorities, man-power and financial resources and some may not view fisheries as a sector worthy of close monitoring or may not have the means by which to do so even if fisheries do contribute significantly to the economy of the District.

The summary of the findings is that there were never any data collected for Lakes Chala, fisheries data for Lake Jipe ceased being collected twenty years ago, there are no data held by the Fisheries Division for Kalimawe Reservoir, despite indications to the contrary by the Ndundu-based Fisheries Recorder met with during the June field visit. For the Pangani estuary, local fisheries data are collected but not transferred to the central Fisheries Division database and the industrial prawn trawler data is collected by zone without specifying the specific estuary or section of the zone. Pangani is in Zone 1, which also includes the Saadani and Bagamoyo shorelines and estuaries, but according to Tanpesca Ltd, which operates at least five industrial trawlers, there is no prawn trawling off the Pangani estuary.

There are only data for Nyumba ya Mungu, but the Fisheries Division has no data since 1997, and only in ‘hard copy’ pre-1997. Some data were available from one landing site under the Moshi District jurisdiction for 2006 and to May 2007. The field visit in June was fortunate to obtain data for the period between 1995 through mid 2007, with data sets covering monthly dried fish exports and value from selected landing sites on the eastern shores of the reservoir, and total annual landings for the whole reservoir.

The six sections that follow present what is known of the fisheries within the Pangani Basin, with descriptions of five main freshwater bodies (floodplains, the lakes Chala and Jipe, Kalimawe and Nyumba ya Mungu reservoirs, and the Pangani estuary). The history of fisheries and species in each, the conditions and problems and salient fisheries management issues are described. The river fisheries are not discussed because of the lack of data on yields and fishing effort, even though there are small-scale fisheries in all of the smaller and the main two rivers (Mkomazi and Pangani), with gears such as weirs and fence traps set across the entire river being widely used. One of the advantages of reflooding the Kirua swamps would be that the series of weirs across the Pangani River, which most probably negatively affect fish productivity, could be circumvented by the fish populations

6.2 Floodplains and marginal waters

For tropical floodplain fisheries, productivities expressed as Catches per Unit Area flooded (CPUA) are mostly taken from the very broad approach of Welcomme (1975) to be 50 kg/ha flooded/year. In a later study (Welcomme, 1985) these figures were confirmed though a range of 40 to 60 kg/ha flooded/year was proposed. In the inner delta of the Niger River in Mali yields were of the order of 40 kg/ha flooded/year in high flood years but increased to 120 kg/ha flooded/year in the drought years. Laë (1995) attributes this increase in yield to a higher contribution of juvenile fish in the catches.

In Bangladesh, national fisheries statistics indicate CPUA of between 60 to 130 kg/ha/year but more detailed investigations suggest it may even reach up to 400 kg/ha/year (Craig *et al*., 2004)., The Bangladesh floodplains are, however, more species-rich than the East African rivers (over 200 species compared to about 50), characterised by about 30 species that are very anoxia-tolerant (the so-called "blackfishes") that can thrive in paddy fields and other stagnant waters, by very large catches of a herring-like *Tenualosa ilisha* and by targeted consumption of very small species down to 2 cm in length (Craig *et al*., 2004).

These characteristics are not found in East African river systems. The relationships seem to hold not only for natural floodplains but also for managed flood releases. On the Kafue flats Chabwela *et al.* 2000 and CEH (2001) compare the fish catches in the natural floodplain prior to the impoundment with catches following managed flood releases. Though the correlation coefficients between annual catch and peak discharge in March are low (R^2 of 0.23 and 0.19, respectively) in each of the linear regressions (catch in tonnes = 1.0014 x discharge in Mm^3 + 5,432.8 for the natural system and catch = 1.0273 x discharge + 5,457.6 for the managed flood releases) there is no detectable difference between the natural and the managed flood release fish catches for monthly average flows between about 200 to 1500 cumecs (500 to 4,000 Mm^3/month).

Because of the opportunistic nature of floodplain species one can expect that flooding of the Kirua swamps will immediately allow fish populations to bounce back as was observed in the inner delta of Mali (Laë, 1997). However, as the fish fauna in the Pangani Basin seems to be impoverished in the type of species most likely to benefit from increased flooding, it is safe to assume that productivity in the restored floodplains in the Pangani Basin would be in the lower range of 40 kg/ha/year

6.3 Lake Chala

There are no reported human uses of the lake other than fishing, which according to the Environmental Impact Assessment document for the proposed hotel development is "unauthorised". Since the national border with Kenya runs directly through the middle of the lake, it may be considered 'international waters'.

Three fish species are known from the lake though fishers report between three and five species of fish (all of which appear to be cichlids) in the lake, including one very small species (possibly juvenile). Known species are the endemic *Oreochromis hunteri* (a critically endangered species, Darwall *et al*., 2005), two other cichlids, possibly *Tilapia* sp. and an haplochromid. No catfish are reported from the lake. The crawling crab, *Potamonautes platycentron* of carapace width about 5 cm, is endemic to the lake but not fished and considered a nuisance of gill-netters due to damage to fish caught in nets and entanglement.

Six Tanzanian fishers were met during the 2002 visit, but 15 fishers are reported to use the waters on the Tanzania side, from five dugout canoes. Probably the same number operate from the Kenya side. Most fishing is conducted using gill-nets (3 and 4 inch mesh, 2 ply) or hook and handlines. Nets are 50-90 m length, of about 2.5 m depth and strung with floats and stone weights. A single fisherman might use 20 nets. Nets were introduced in about 1997, before which only hook and line were used. Canoes are made from cut trees fringing the lake.

Best fish catches are during the seasonal turbidity period of August-September, when the 'Chala tilapia' swims at the surface and is caught with gill-nets. Fishermen catch an estimated 20-30 fish per day, each weighing between 1-2 Kg. During this season, the nets are modified for use at the surface rather than set for the bottom as usual for the rest of the year, and the increased catches are possibly due to the cloudy waters affecting the fish's ability to detect the net.

The contribution of the fishery to the local economy must be insignificant, yet *O. hunteri* is under risk of being over-fished to the point of extinction if net fishing continues.

6.4 Lake Jipe

Based on local discussions, the fisheries of Lake Jipe were productive in the 1960s with 150 fishers from eight fishing camps (including Mkisha, Jipe, Vibungu, Madudunzi, Urondo, Makuyuni and Marangareni). By 1968, the number increased to 2,000 fishers. Principal fish caught were tilapia-type and Clarias. The water bulrush *Typha* and *Papyrus* were seen for the first time in the 1950s and their encroachment into the lake is well documented elsewhere (e.g. Yanda, 2007; Wildlife Division, 2004 - overview at www.ramsar.org/outreach_actionplan_tanzania_jipe.pdf).

By the 1970s, fish catches had declined and *O.esculentus* was introduced and since became the dominant species contributing about 90% of the present day total catch. This fish (locally distinctively reddish in colouration), though dominant, is not found over 10 cm length. The two other species are allegedly, *O. jipe* and *Tilapia zillii*. No sardine-type fish 'dagaa' are caught from Lake Jipe. *O. jipe* was common throughout the lake but presently is restricted to the reed margins. The latter species, and *Clarias* are reportedly the most flavoursome and desirable fish from the lake.

Crocodiles were numerous in Lake Jipe, to the extent that in 2004 the government issued licenses to cull 200 crocodiles. Hippopotami are also living in the lake. Freshwater prawns are absent from the lake but resident in Ruvu River.

Fish catches for the year 2006 were low. Despite low catches and the emigration of many fishers, about 50 fishers continue to fish Lake Jipe, mainly during the best months of May and June, shortly after the floods when best catches are realised. Cast nets are the main fishing gear used. The *Clarias* catfish is also caught throughout the year but especially after the flood period. During the wet season the lake level does rise but only catches of *Clarias* were reported to increase.

Though the contribution of the fishery to the local economy is significant, the lake ecosystem is under severe threat from siltation and encroachment by bulrushes. The endemic *Oreochromis jipe* is unlikely to be over-fished to the point of extinction since it has a confirmed presence in many other water bodies of the Pangani Basin. The focus of any management intervention should be to stabilise the situation and attempt to restore the ecology of Lake Jipe.

6.5 Kalimawe Reservoir

Kalimawe reservoir was constructed in 1956 by the British Colonial Government to support the agricultural activities of the Pare pastoralists who were evicted from the Mkomazi Game Reserve (MGR) in 1951 (www.york.ac.uk/res/celp/webpages/projects/cpr/tanzania/tanzania.htm).

The reservoir is located on the Mkomazi River. It was designed for agricultural purposes, mainly irrigation, but nevertheless became stocked with cichlids and catfish, either deliberately or by accident (e.g. fish from flooded waters of Lake Dindila in the MGR), and became an important fishery resource.

Kalimawe reservoir is approximately 10 km from Ndundu village, from where many fishers and fish-traders visit, with four other small villages (Chadimbwi, Msorola, Mparanganga and Mkonga) bordering the reservoir. The northern shores are within the Mkomazi Game Reserve. The report from York University (above link) claims that fish curing, food vending and construction of temporary camps around the reservoir have consumed trees and other vegetation, negatively impacting the area and leading to an increase in siltation from sheet and gully erosion caused by storm water and unsuitable farming practices (no terracing on slopes, unstable soils trampled by livestock). During the field visit, the fisheries recorder from Ndundu also claimed that the average depth was originally 25 m but has now been reduced to only 15 m.

The water department's canal, and the Kalimawe reservoir on which it is dependent for water, often dry up due to irregular weather fluctuations. When water levels are low and fish stocks are inadequate, the Department for Natural Resources (Fisheries Section) closes the reservoir to fishers, forcing local residents and seasonal migrants from elsewhere who depend on fishing to migrate out of the village to find other means of income generation. People in this village alternate between irrigation farming, fishing and herding as ways of earning a livelihood in an unpredictable environment.

From December to June the reservoir sometimes overflows at the dam, with some fish seen swimming up the Mkomazi River. The identity of these fish has not been ascertained but they are probably species of cyprinid such as *Barbus* and *Labeo*. During the short rains, (December to January) the reservoir floods creating masses of floating grasses ('mwata', probably *Vossia cuspidata*), where fish are said to seek refuge for feeding and breeding, inaccessible to fishers. In January to June, the best catches of fish are realised, as the water recedes from shores, exposing the fish to the nets of fishers. In this season, fish caught are healthy with rich fat reserves.

There are about 60-80 fishers using Kalimawe reservoir, all using small canoes and either gill-nets or cast nets. During the south monsoon season, when afternoon winds can be strong, fishers set their gill-nets in the evening (about 4 pm) and haul before noon the following day. They do not venture into deeper water due to their canoes being unsuitable for strong waves.

Daily catches per fisher average 30 kg in the good season, dropping to 20 kg during the worst season. Overall fisheries yields for 2006 for each species were: Cichlids (*Tilapia* and/or *Oreochromis*) 672 tonnes; catfish *Clarias* 43 tonnes and sardine-like cyprinids (locally called 'dagaa') 11.5 tonnes, with a total catch of 726 tonnes (valued at just over half a million Tanzania shillings). There are possibly five cichlids in the reservoir: *Tilapia zillii*, *T. nigra*, *Oreochromis jipe*, *O. esculentus*, and an unidentified haplochromid, possibly *Astatotilapia burtoni*.

The Ward Fisheries Officer is responsible for managing the lakes. This involves restocking with cichlids and other species and closing the lake to fishing for three or four months when necessary. The only management activity seems to be the licensing of fishers by the District council, though plans were described by the above to restrict fishers from accessing certain parts of the reservoir to protect breeding on grow-out fish stocks.

6.6 Nyumba ya Mungu Reservoir

6.6.1 Background

Created in 1965, the Nyumba ya Mungu reservoir's principal purpose is to generate hydro-electricity. The reservoir serves the power plant at Nyumba ya Mungu (8 MegaWatt) and other power plants further downstream, namely Hale (21 MW), Old Pangani (15 MW) and New Pangani (66 MW). With a maximum surface area of 180 km^2 and 32 km length, the reservoir is the largest in East Africa (Bailey, 1996). Water depth averages 6 m.

The principal fish species presently caught are the cichlids *Oreochromis esculentus*, *O. jipe*, *Tilapia zillii*, *T. rendalli*, the catfish *Clarias gariepinus*, the cyprinids *Barbus* spp. and *Labeo* spp.

and the smaller catfish of the *Synodontis* genus (Nhwani, 1988; Bailey, 1996). It was noted that *O. esculentus* was introduced about 1970 in response to low catches in the reservoir. In 1994 there were eleven species of fish (Bailey, 1996). Local fishers report that some species have been lost that needed stone or gravel bottoms, now covered in silt. The reservoir is the single most important source of fish for the entire Pangani Basin.

6.6.2 Fisheries data, effort and gears

The bulk of data on the fishery were obtained from the District Fisheries Office at Mwanga, covering the six landing sites (now full villages) on the eastern shores and within the jurisdiction of that office. Bailey (1996) mentions a total of ten sites. Data included catches and dried fish export from 1997 to 2006. Catch data from one landing site village (Moshi Vijijini) under the Kilimanjaro District jurisdiction was also obtained.

There are seven main landing sites (villages) in the Mwanga District (see Table 5) and at least one other in Kilimanjaro District (Moshi).

Table 5 NYM eastern landing sites, numbers of fishers, canoes and licence revenues for 2007.

Landing site	No. fishers	No. canoes	Licence revenues (Tsh)
Njia panda	45	45	175,500
Kiti cha Mungu	40	40	156,000
Nyabudu	50	50	195,000
Kagongo	120	120	468,000
Lang'ata bora	300	300	1,170,000
Handeni	100	100	390,000
Totals	665	665	2554,500

About 1,000 fishers operate simple canoes and gill-nets in the main, but some handline fishing is also conducted. Beach seine nets have apparently been effectively banned.

Four catches from individual fishers were sampled during the field visit (see Table 6). These varied from 8.5 kg to over 31 kg and averaged 21.6 kg. Mean fish sizes were 14.0 cm for the common (>90 % of catches) small tilapia (probably *O. esculentus*), 14.5 cm for the larger, possibly *Tilapia zillii* and 17.8 cm for one of the endemic cichlids, probably *O. jipe.*

Table 6 Sample catches, Nyumba ya Mungu (June 2007).

Sample	Total catch (kg)	Length of net (yards)	No. fish caught
1	31.05	4,500	400-500
2	20.25	4,000	No data
3	8.5	2,700	130
4	26.74	2,100	410
Total	86.54	-	-

6.6.3 Seasonality of catches

Catches vary with season and the fishers consistently report that the greater the amount of rain, and increase in the water level, the greater the catches. This is also true for *Clarias* which becomes abundant after the floods. Data from the northern village under Kilimanjaro jurisdiction reflects a seasonal trend in landings (Table 7 and figs. 4 and 5), with yields increasing after the main rainy season producing highest catches in March and April, with a second short but productive period in August. Reasons for the second peak are not clear and may include wind-induced mixing and increased productivity, or a wind-induced reduction in July leading to raised harvests in August. Data for the exported dried/smoked tilapia from the eastern shores of the reservoir revealed a similar seasonal trend.

Fishers also reported that during the El Nino year (1997-98) there were significantly high catches. Catches are also said to vary also along the lake, with best yields shifting from the northern to the southern extremes throughout the year, though no pattern was ascertained.

Table 7 'Raised' monthly catches of the three principal species for Moshi Vijijini, NYM, for 2006.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Tilapia	12.30	24.12	67.49	62.42	10.92	27.15	21.98	145.27	45.88	30.76	37.59	0.00	485.88
Clarias	1.58	0.76	22.82	11.17	41.98	26.24	24.76	13.21	14.04	50.89	47.50	0.00	254.95
Synodontis	0.00	0.00	7.69	39.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	46.98
Total	**13.89**	**24.88**	**98.00**	**112.88**	**52.90**	**53.39**	**46.74**	**158.49**	**59.92**	**81.65**	**85.08**	**0.00**	**787.81**

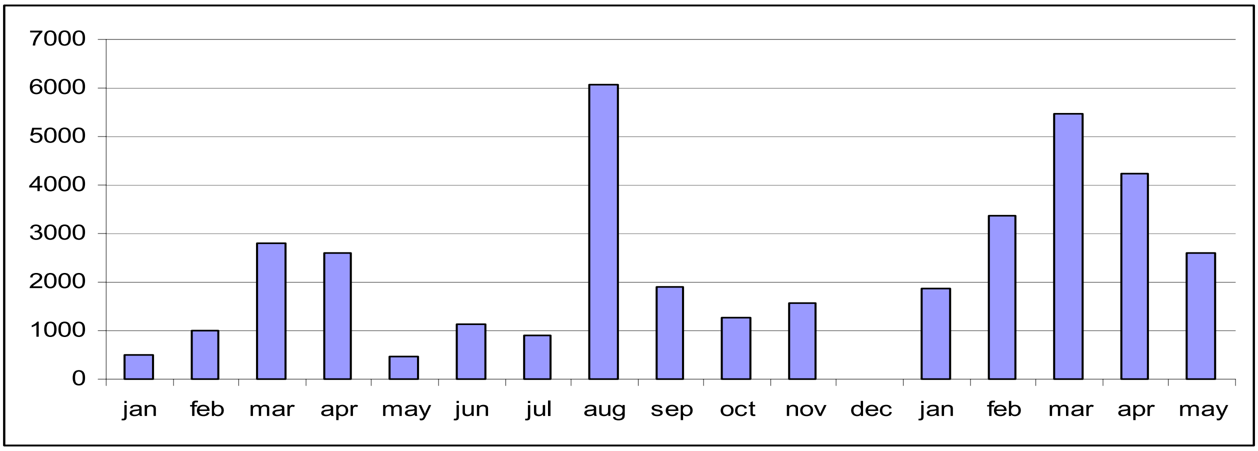

Figure 4 Sample catches (kg) from 15 fishers from Moshi Vijijini village of NYM for 2006-07 for *Tilapia* (incl. *Oreochromis* spp.).

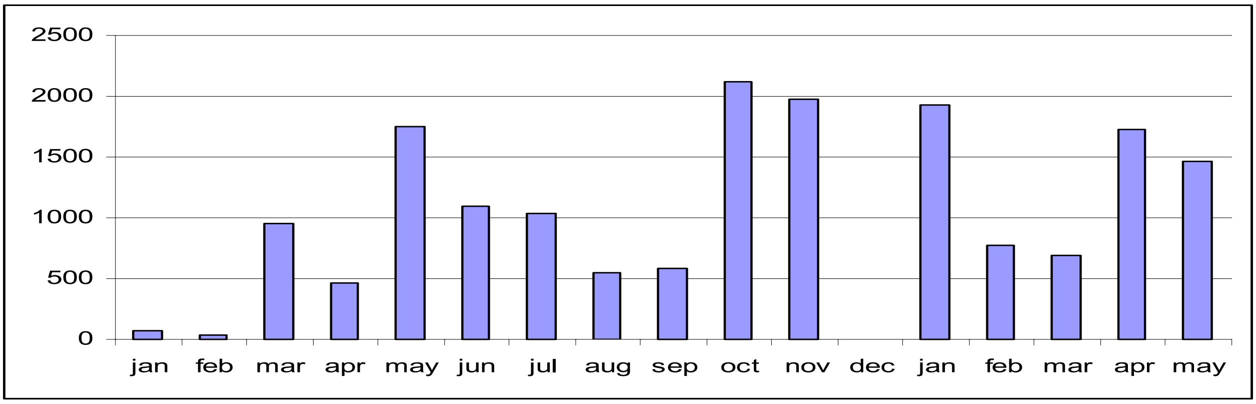

Figure 5 Sample catches (kg) from 15 fishers from Moshi Vijijini village of NYM for 2006-07 for *Clarias*.

Table 8 Total catches Nyumba ya Mungu (1973-2006), see also Fig. 6.

Year	Catch (t)	Year	Catch (t)	Year	Catch (t)	Year	Catch (t)
--	--	1981	3,726.0	1991	1,584.9	2001	288.0
--	--	1982	2,652.0	1992	1,456.2	2002	337.0
1973	2,779.0	1983	2,400.0	1993	536.5	2003	253.0
1974	2,282.0	1984	2,198.7	1994	897.7	2004	249.0
1975	4,610.0	1985	2,973.7	1995	232.9	2005	--
1976	5,116.0	1986	3,974.0	1996	842.2	2006	787.8
1977	4,989.0	1987	3,225.0	1997	304.0	--	--
1978	--	1988	1,645.0	1998	807.0		
1979	1,516.0	1989	1,587.9	1999	761.9		
1980	4,105.0	1990	1,992.4	2000	461.9		

6.6.4 Annual variations in catch

Within the first ten years after impoundment, catches were very high (Bailey, 1996) . These reached 28,500 tonnes for 1970 and settled at present-day levels of about 3,000 tonnes or less in dry years. The last ten years have yielded the lowest catches (Table 8).

The annual total catches (Figure 5, with the correction for 1983) plus the data from Bailey and Nhwani can be divided into three different periods. Following the predicted boom just after impoundment (Bailey, 1995; Lowe-McConnell, 1987), a more or less stable period of catches of between 2,000 and 5,000 tonnes extended to 1987, then a second level of catches to around 1,500 tonnes until 1992, followed by a third period of decline to levels below 1,000 tonnes. The time series since the year 2000 is particularly worrying although a slight peak was observed during and after El Nino (1998 and 1999). The fishery was closed in 1978 because of cholera, hence the lack of fisheries data for that year.

The catches from 1993 onwards are extremely low, much lower than the 2,000 to 3,700 tonnes calculated by Bailey (1996). The totals from 1994 to 2004 (Figure 5) were obtained from the Mwanga District Fisheries Office during the June field visit. The more recently-obtained data, from Vijijini Moshi, obtained in Dar es Salaam, show catch figures 'raised' for the entire Nyumba ya Mungu reservoir, for 2006 as: *Tilapia* 485.88 tonnes, *Clarias* 254.95 tonnes and *Synodontis* 46.98 tonnes, with a total of 787.81 tonnes.

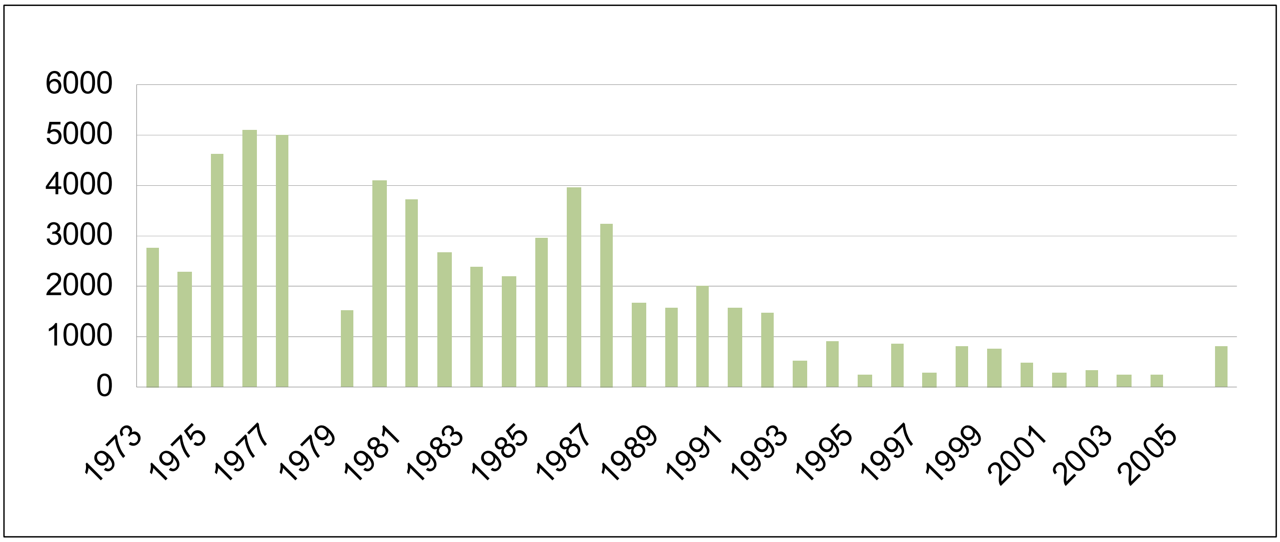

Figure 6 Total annual fish catches (tonnes) for Nyumba ya Mungu reservoir.

It may be that since the ban of beach seine nets, catches are in fact slowly increasing, but further investigation is needed to verify this. Equally possible is that the data are not reliable. From a detailed analysis of fish landings at villages in the northeast of Unguja Island, Zanzibar, in which all catches were weighed, Jiddawi and Stanley (1999) found no correlation between their data and that produced by the Fisheries Department for the same sites and dates. It was not possible to elucidate how the total catch data have been derived, nor if the methodology has evolved over the years. There is also an unexplained "jump" within the Nyumba ya Mungu dataset in the value of the catch per kg from about 35 Tsh/kg to about 350 Tsh/kg between 1994 and 1995.

6.7 The Pangani and Bagamoyo estuaries

The literature review failed to find published data on the Pangani estuary relating to fishing effort, yields or species, despite the verbal promise to be provided with data by the Pangani District Office. Efforts to obtain hydrological data for other nearby estuaries (Wami and Rufiji) for time periods that could be compared to available fisheries data were also unsuccessful. According to the socioeconomics survey (Turpie *et al.*, 2006) 25% of households engage in fishing activities in the estuary. This is only marginally higher than in the mesic lowlands (14%) and Kirua swamps area (17%) and much lower than in the lakes area (53%). Some 550 households would engage in marine fisheries but possibly only 30 to 40 would be fishing in the estuary. During the low flow period they target fish and crabs, while in the high flow period the fishers concentrate on prawns. Catch data reported do not seem to be very reliable but prawn catches are reported to amount to 1.8 to 2.4 tonnes a year out of a total catch for the Pangani District of 42 to 58 tonnes. Judging from the reported species composition this would seem to be predominantly marine fisheries (Turpie *et al.*, 2006)

To understand the fisheries of the Pangani estuary, we examined comparable situations. The comparison with other comparable sites to describe what the fishery might be like at the Pangani estuary is attempted with information gathered from the Bagamoyo area, about 100 km south. The Wami and Ruvu rivers combine into a wide estuary north of Bagamoyo that provides lists of species and some fisheries data from the artisanal and industrial prawn trawler fishery.

Sobo (1999) reported total annual finfish catches for Bagamoyo of over 5,000 tones in 1990 and less than 1,400 in 1994. Artisanal vessels numbered 186 in 1994 and 348 in 1990. The prawn-trawler industry had between 5-10 vessels each month during the March to September season, and also provides data on finfish catches. Their landings varied from about 34 tonnes in March to 29 tonnes in September (Sobo, 1999).

Shellfish fisheries at Bagamoyo include the swimming crab *Portunus pelagicus* and a fishery based on the four-five species of penaeid that reside in these waters (Mgaya *et al*., 1999). Their yields and estimated biomass showed a clear seasonal pattern. Bwathondi *et al*. (2002) calculated the biomass of prawns as about 116 tonnes for the month of March, dropping to 16 tonnes in June. Sobo (1999) has reported 1997 catches for the industrial fishery at Bagamoyo at about 27 tonnes in March with about 13 tonnes in August. Teikwa and Mgaya (2003) found that the prawn *Fenneropenaeus indicus* was the most abundant, more so during the rainy season.

The narrow Pangani estuary is fringed by some 750 ha of mangrove forest that provides habitat for larvae and burrowing crabs. The larger and valuable *Scylla serrata* requires the mangrove forest for shelter during mating times and juvenile prawns need the mangrove habitat in which to develop. This is the estuary's most valuable resource, and one whose loss is the major threat to sustainability of prawn fisheries (King, 1995). Destruction of inshore nursery areas by coastal development and pollution contribute to that loss.

The Pangani is also distinctive for the relatively small area of subtidal waters shallower than 5 m depth, which is the environment that supports the fishery of crustaceans such as prawns and blue swimming crabs. The small area of optimum estuarine depth reduces the production of typical estuarine fish and crustacean species. Nevertheless, there is still likely to be a small fishery by tens or hundreds of fishers (pending on the tide) that utilise the productive intertidal areas, to collect edible bivalve cockles and clams, catch crabs and prawns and fish using a range of nets and lines.

Despite the lack of shallow depths and reported shrinking of the open-water shelf (Shaghude, 2004), the estuary should support some finfish and crustacean production. The volume of catch may be as little as 500 tonnes per year (about 40 tonnes per month or 2 tonnes per day, assuming 22 days fishing effort per month) or it could be double that estimate. The steep seaward slope of the estuary and the narrow depth that can be fished by industrial trawlers precludes this gear from being utilised. Other, more labour-intensive but less destructive methods could be used to catch prawns, enough to employ a few local fishers (perhaps 10-20).

The Bagamoyo fishery, despite fragmentary data, demonstrates strong seasonal trends in catches associated with the wet season months of March to June and thus increased river flow. This relationship is a well-known feature common to most estuarine fisheries, and one that has declined at the Pangani estuary when the river was interrupted by hydro-electric barrages and increased abstraction. Geographically the estuary now serves as an inlet for the sea rather than the source of freshwater to the coastal zone, within which it can interact and attract marine life.

7 RELATIONSHIP BETWEEN FISHERIES ABUNDANCE AND WATER LEVELS

Many types of fish (freshwater and marine) and amphibians migrate for feeding and breeding purposes. They do so on time scales ranging from daily to annual, and distances ranging from a few metres to thousands of kilometres. Timing of the migrations is triggered by physio-chemical changes to their environment, including water depth, temperature and chemical composition.

Dallas *et al.* (2006) observed that different types of fish were caught from various sites during the two seasons with several fish families including Mormyridae, Mochokidae, Anguillidae, Clariidae, Cichlidae, Ambassidae and Chanidae appearing at some sites only during the wet season, while killifish and eels only appeared at two sites during the dry season.

Potamodrous fish make short spawning runs when rains begin, with typical examples from the Pangani Basin being *Clarias gariepinus*, *Labeobarbus oxyrhynchus*, *B. toppini* and *Labeo* spp.. These all need increased water flow to trigger reproduction when they migrate either upstream or laterally into flooded areas for spawning (Skelton, 1993). Amphidromous fish spend equivalent amounts of time in both seawater and freshwater environment e.g. goby, with some species such as the ambassids and *Chanos chanos* breeding in freshwater and then returning to the sea to grow. Low freshwater flows will negatively affect their breeding success.

Riverine fish tend to be more abundant during the wet season because tropical riverine species synchronise their spawning activities with the rainy season (Welcomme, 1985). The exception to this general pattern are the cyprinids, some clupeids, schilbeids and some benthic species of bagrid and mochokids that are tied to their habitats in lakes and large rivers (Lowe-McConnell, 1987). As water levels in lakes, rivers and inundated grasslands or forests start to rise, most species migrate upstream then laterally into flooded areas where foods are varied and abundant (Matthes, 1964). The number of recorded migratory species determined for Pangani River Basin was between 11-15, with other comparable basins being the Rufiji (14 spp.), Tana (15 spp.), Malagarasi (18 spp.) (Darwall *et al.,* 2005). These authors also explain that their analysis can only provide a preliminary picture as the actual numbers of migratory species will be higher than shown as the breeding ecology of many species was not recorded.

From fluctuations in number of two species of *Oreochromis* and *Tilapia rendalli*, Dudley (1972) deduced that seasonal differences in abundance do exist and that breeding success and recruitment to the stock was much better for years having good floods. Local fishers met at Nyumba ya Mungu confirmed the same. Later work concluded that in low water situations, fish stunt and then mature at a smaller size (Welcomme, 1985).

7.1 Nyumba ya Mungu Reservoir finfish fishery

Monthly rainfall data for the whole basin were obtained together with weekly water levels in the Nyumba ya Mungu reservoir. With fisheries production being more strongly correlated with water body volume than rainfall, the reservoir data were the only data utilised in the analyses that follows.

The conclusion reached from discussions with over fifty fishers and four fisheries officers is that fishery yields increase with increases in rainfall and lake or river water levels. The perception by fishers is of a strong correlation between water level and catch, which is true in floodplains because spawning and feeding habitat become available to fish and also because small fry can more easily avoid predation.

Table 9 Water level, surface area and total catches at Nyumba ya Mungu (1973-2006).

Year	Max. level (amsl)	Surface area (km^2)	Catch (t)	Catch/ha (kg)	Year	Max. Level (amsl)	Surface area (km^2)	Catch (t)	Catch/ha (kg)
1973	688.59	133.96	2779	207.4	1991	688.19	129.42	1584.9	122.5
1974	687.47	121.41	2282	188.0	1992	685.58	101.50	1456.2	143.5
1975	685.48	100.50	4610	458.7	1993	683.76	83.91	536.5	63.9
1976	682.50	72.67	5116	704.0	1994	685.87	104.45	897.7	85.9
1977	685.15	97.20	4989	513.2	1995	687.49	121.63	232.9	19.1
1979	690.01	150.65	1516	100.6	1996	687.31	119.66	842.2	70.4
1980	689.33	142.55	4105	288.0	1997	687.48	121.52	304	25.0
1981	689.49	144.44	3726	258.0	1998	690.11	151.85	807	53.1
1982	687.58	122.62	2652	216.3	1999	688.59	133.96	761.9	56.9
1983	687.48	121.52	2400	197.5	2000	686.89	115.13	461.9	40.1
1984	685.70	102.72	2198.7	214.0	2001	685.88	104.56	288	27.5
1985	686.07	106.51	2973.7	279.2	2002	686.09	106.72	337	31.6
1986	686.13	107.13	3974	371.0	2003	686.35	109.42	253	23.1
1987	684.24	88.39	3225	364.8	2004	684.37	89.63	249	27.8
1988	685.99	105.68	1645	155.7	2005	--	--	--	
1989	687.99	127.17	1587.9	124.9	2006	687.38	120.43	787.81	65.4
1990	689.74	147.41	1992.4	135.2	2007	--	--	--	--

7.1.1 NYM water levels and fishery production

Attempting to correlate total catches with the annual maximum water level (from the weekly reservoir data), however, produces an inconclusive scatter of points (see fig. 7) with very different catches possible for very similar water levels.

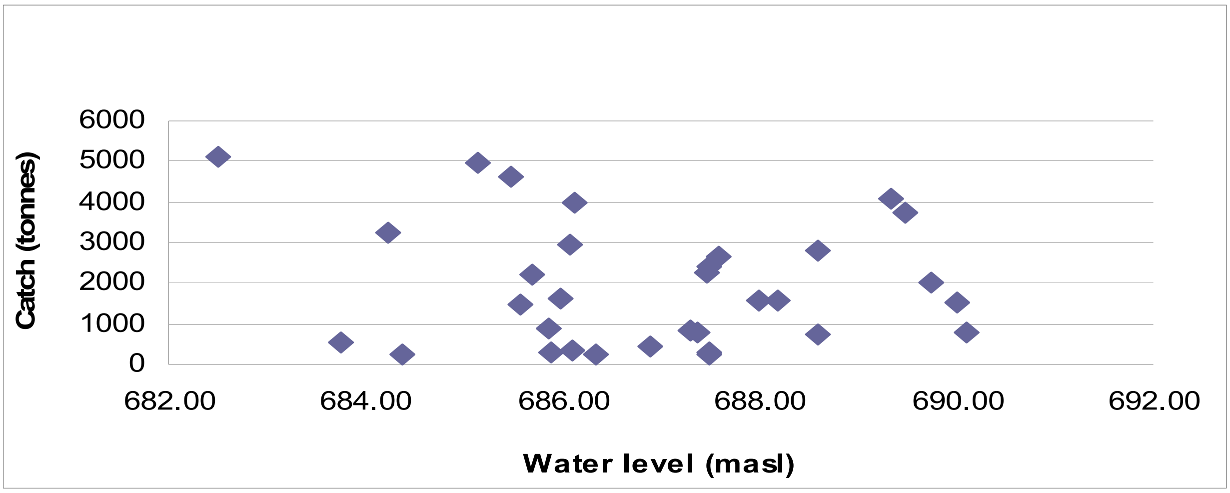

Figure 7 Total fish catches for Nyumba ya Mungu with maximum water level per year.

A second approach is to examine different periods in which the fisheries seem to differ in some fundamental way. Looking only at the catch/max level correlation since 1993, there seems to be a weak trend (correlation coefficient 0.38) with the post El Nino years 1997 and 1998 weighing in heavily (Figure 8).

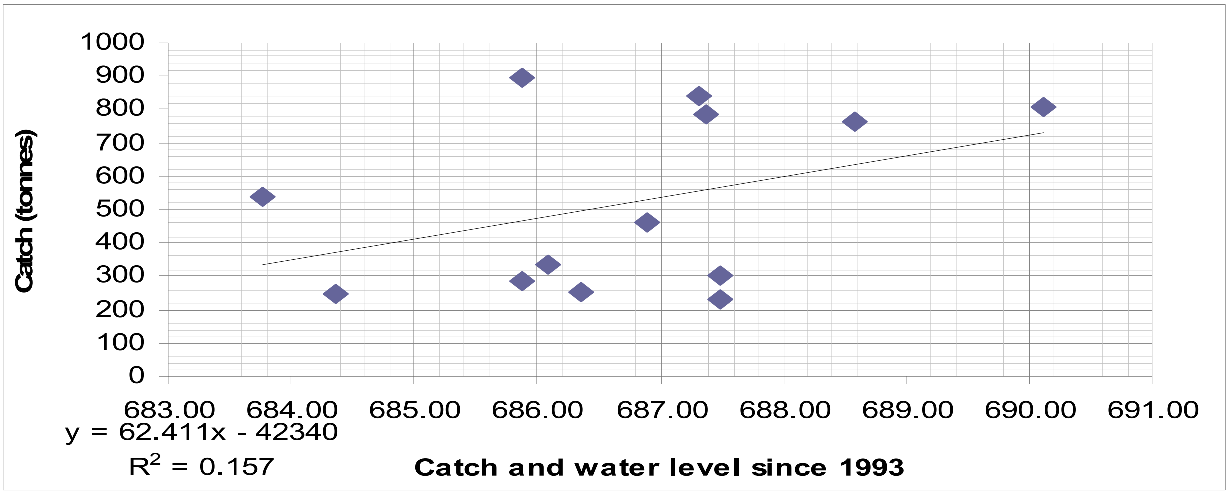

Figure 8 Total catches for NYM with maximum water level for years with yields less than 1,000 tonnes, i.e. since 1993.

A third option is that below a certain water level, the catchability of the fish increases dramatically and the catches are thus not a reflection of productivity but simply of fishing effort. This suggestion needs verification from other sources. When only the right part of the plot in Figure 6 is utilised, for water levels above 686 amsl, a stronger (but still weak) trend and a correlation coefficient of 0.43 are obtained (Figure 9).

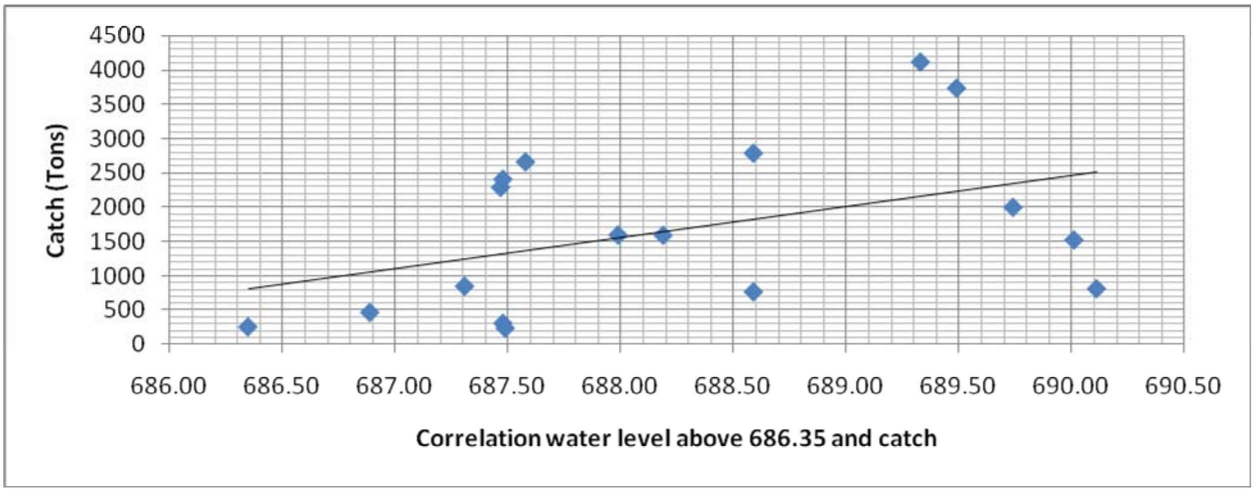

Figure 9 Total catches for NYM with maximum water levels above 686.35 m.

7.1.2 NYM surface area and fishery production

The water level in Nyumba ya Mungu varies greatly, with the difference between the highest and the lowest weekly level between 1971 and 2006 standing at 10.3 m. With the relationship between water level and surface area (Moges, 2003) this translates into a variability in the surface area of the lake between 51 and 151 km².

It appears that water level alone does not explain the low productivity in recent years (Figures 7 to 9) because it is likely that the reservoir was overflowing during El Nino, just as in the current year (2007) and in years in the past that had five times bigger catches. Also it would ecologically be much more appropriate to use a "hydrological year" between two successive lowest water level points (around week 13, March). This would avoid adding fish catch data from different flood events. For example, this would add the last months of 1997 with presumably high catches and high water levels to the 1998 peak. To be able to analyse this in more detail the monthly fish catch data would need to be made available and a clear understanding as to how they are calculated (in the different time periods) would be required. If fish catch data are collected independently from (dried) fish export data (and if a complete dataset of these can be obtained from all the districts touching NYM) an independent verification of the catch data would be possible. Alternatively, a long-term monitoring programme independent from the fishery such as the one in Lake Kariba (Karenge & Kolding 1995) could provide highly valuable data.

NYM, like other impoundments in highly seasonal environments, can be assumed to function according to the same ecological mechanisms as floodplains: high water levels will flood vegetation and create favourable conditions for feeding and reproduction of fish while at the same time reducing predation and catchability. Now that a relationship between flooded surface area and water level has become available the catch data (1973 to 2006, with 1978 and 2005 missing) have been plotted with the calculated surface area for the maximum water level in that year. The elevation-surface area from Moges (2003) is:

A = 1.2442(h-672.132)1.62+17.6 with A the surface area in km² and h the elevation in m above mean sea level.

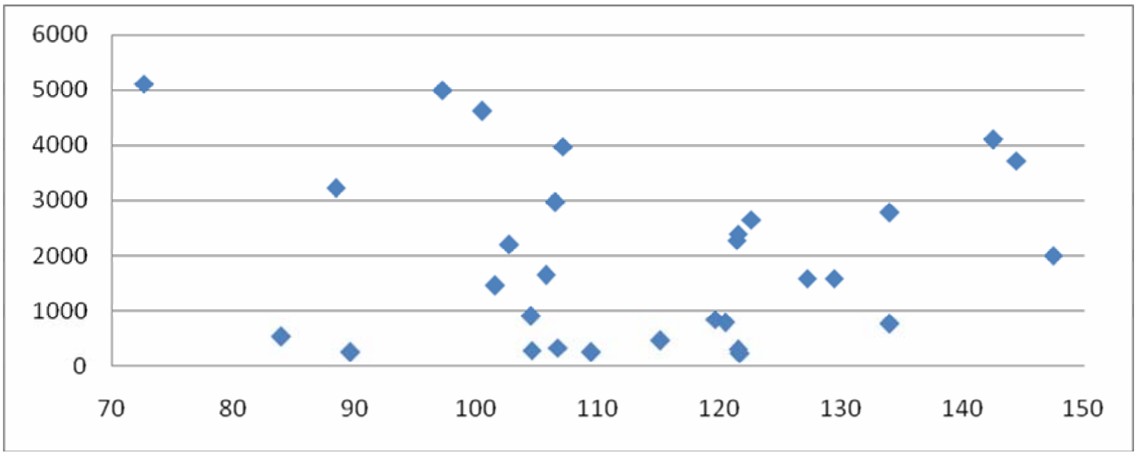

Figure 10 Annual total catch in NYM reservoir (in tonnes) plotted against surface area of the reservoir (in km²) at the maximum water level for that year.

As with the previous plots the lower water levels/surface areas only show a cloud of points, but for surface areas greater than 110 km² a trend can be seen. As has been observed earlier the catch levels in NYM seem to have gone through various phases – perhaps reflecting new equilibrium states of the ecosystem (or possibly different ways of calculating total catch). We have therefore only used the catch and surface area data since 1995 to elucidate a trendline that could have some predictive value for catches. It should be noted that previously trendlines were established using all the data since 1993 but there are some doubts as to the reliability of the 1993 and 1994 catch data as from 1995 onwards the value of the catch per kg jumps from 35 Tsh per kg to about 300 Tsh per kg. We have not been able to find an acceptable explanation for this.

To improve the conditions for fish production in NYM, the water level would need to be high enough to cover an area of at least 110 km² (Fig. 11) but would preferably be much higher, flooding at least 130 km² as there remains a very substantial variability in the catch for surface areas around 120 km² (catches varying between just over 200 to nearly 800 tones). Here again, analysis of the monthly catch and water level data would be valuable as there is probably an optimal amplitude of water level change within any one year rather than an ideal "stable" water level. The data currently at our disposal do not allow such an analysis.

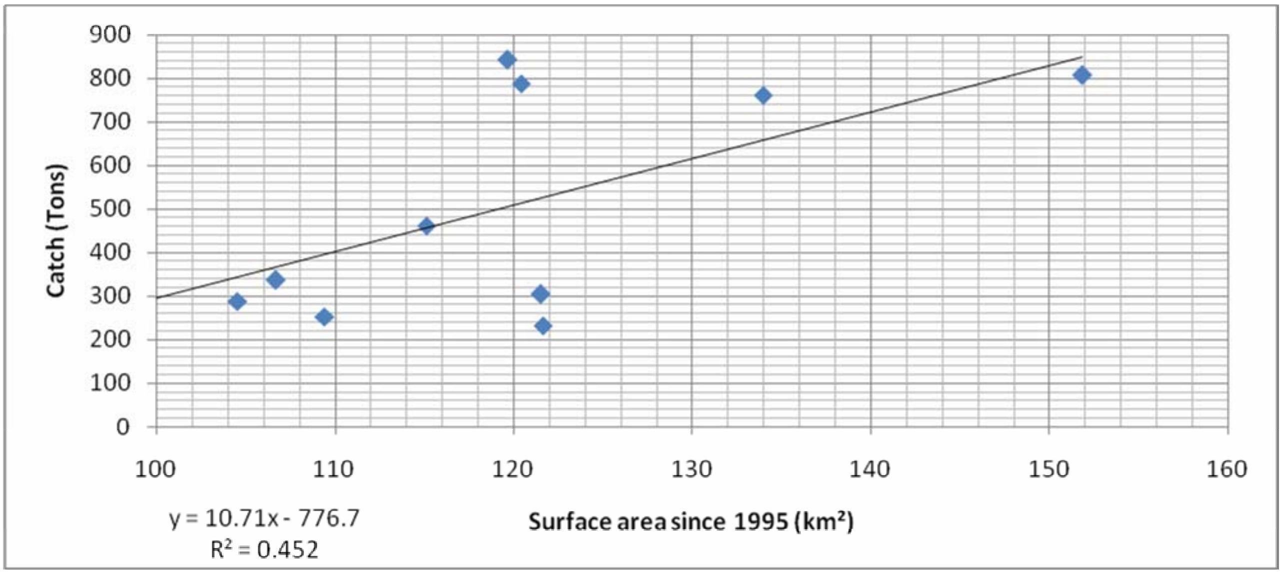

Figure 11 Total Annual Catch in NYM since 1995 plotted against flooded surface area at maximum water level in the same year.

7.2 Fisheries of the Pangani and similar estuaries

The fishery of the Pangani estuary is currently not well described. Fishers concentrate on prawns during high flows and on fish and crabs during low flows. The current Pangani estuarine fisheries not be reacting to changes in water levels *per se* but to a combination of factors that are strongly correlated amongst themselves such as flow, salinity, turbidity, nutrient levels, plankton, etc. Therefore the general literature on estuarine and nearshore fisheries was explored for indications of potential changes in the Pangani if higher flows would be made available to the estuary.

7.2.1 Estuarine finfish fisheries

Clupeids are the dominant group in the catches in large and small West African estuaries (Baran, 1995) and also in the Rufiji (Richmond *et al.,* 2002). Small pelagics off the Nile delta were also the group hit hardest after the impoundment at Assouan (Halim *et al.*, 1995). Small pelagics are high fecundity species that mature early and are low in the food chain (feeding predominantly on either phytoplankton or zooplankton). They therefore have a good capacity to react to any increased fresh water outflow, especially if it is nutrient rich (up to a certain level – they are highly sensitive to anoxia) and can be expected to react favorably to increased runoff. Mullets can be expected to react in a similar manner.

Paradoxically, Binet *et al.* (1995) report a negative correlation between *Sardinella* catches and river flows in West Africa (see Fig. 12) but it must be taken into consideration that in this high rainfall area, the entire coastal zone can be considered as a "coastal estuary" (Baran 1995) with low salinities into the ocean, beyond the reach of artisanal fishing units. At the salinity levels in the current and the potentially less saline Pangani estuary if higher flows can be achieved, this phenomenon is unlikely to play a role and one can safely assume that catches of estuarine clupeids will increase.

In the Cross River Delta in Nigeria (with flows a few orders of magnitude higher than in the Pangani) Moses *et al.* (2002) report a linear correlation between the Mean Monthly Catch (MMC) and Catch Per Unit Effort (CPUE) of the marine fisheries and temperature (air and water) and also salinity. It should be noted that this is a high rainfall area with only three months receiving less than 100 mm and three months receiving over 400 mm and a large flood amplitude (up to 9.4 m above the dry season level). As a result, the salinity range covered was very low (1.5 to 18.4 ppt) in comparison to that likely to be encountered in the main part of the Pangani Estuary. Still, within that range MMC would triple, as would CPUE when moving to the more saline area.

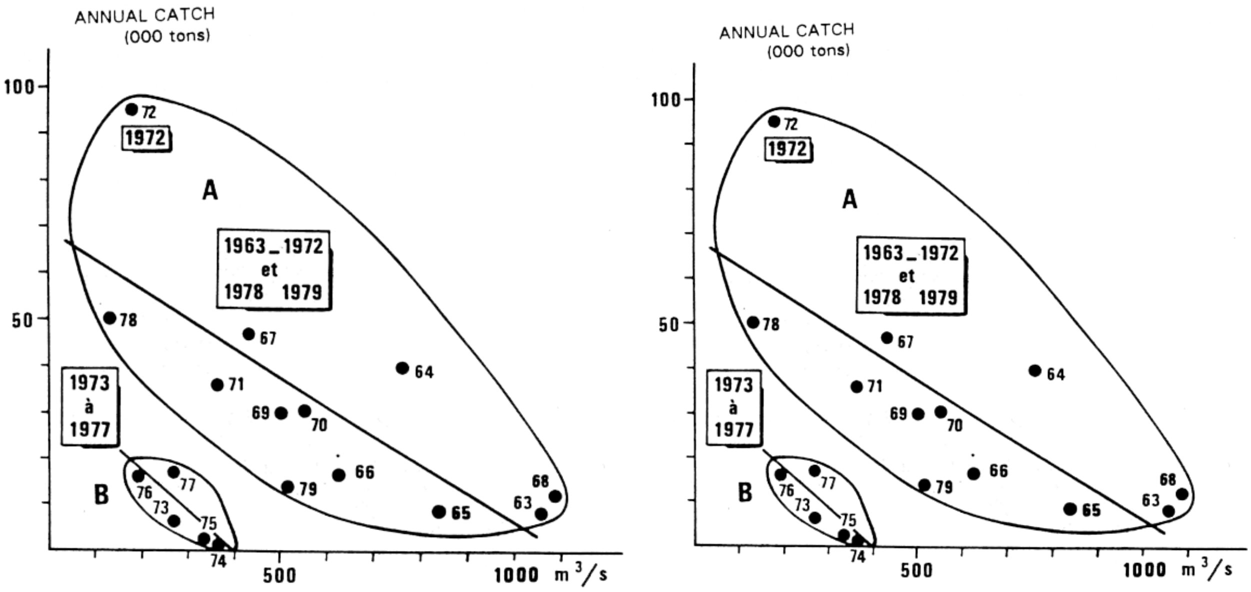

Figure 12 Correlations between catches of *Sardinella aurita* in Ghana and Ivory Coast and the outflow of the Bandama and Comoë rivers (from Binet *et al.*, 1995).

Though the species guilds differ between West African and East African estuaries, one can assume that similar functional groups are common to both areas. Herring-like shads and sprats/sardines make up nearly 50% of the estuarine catch in the Cross River area – very similar to the Rufiji where *Hilsa* is dominant. In the Cross River, Bagridae and Clariidae make up 55 % of the freshwater floodplain catch with Cichlidae constituting 16% - a result also comparable to East African floodplains. Extrapolating to the Pangani in a qualitative, but not quantitative, way may therefore be valid.

Currently, the comparable "inner estuary" area in Pangani, i.e. the zone that corresponds to the 2-20 ppt salinity range is likely to be small and show restricted seasonal dynamics even though in 2006 these were pronounced (Kamugisha *et al.*, 2006). However, 2006 is likely to have been an exceptional year as it shows one of the largest water level amplitude changes in the Nyumba ya Mungu Reservoir for the post El Nino period (6.7 m compared to the average 2.07 m for 1998-

2005 and 2.6 m for the entire time series since 1971). This extent of the vital inner estuary zone can therefore increase under flood scenarios with pronounced peaks in the freshwater inflows. If the area becomes significant (e.g. covering more than 10% of the estuary) it may be useful to split it up in a 2-12 ppt area and a 13-18 ppt area (or more conveniently 2-15 and 15-20 ppt). In such a case one could predict from Moses *et al*. (2002) that MMC and CPUE will be 3 times higher in the higher salinity zone than in the lower salinity zone. To make a quantitative extrapolation it would be necessary to assess current MMC and CPUE in the low salinity zone.

At the other extreme, for hypersaline (former) estuaries Diouf (1996) has shown that in the Siné-Saloum, fish communities persisted comparatively well both in terms of species composition and "resident" biomass. However, the export function, i.e. the contribution of the estuary to the enrichment of the adjacent coastal waters disappears. The present day situation in the Pangani estuary is likely to be comparable: there is no commercial shrimp trawling as catch rates are insufficient for trawling operations and there are no fish catch statistics because there is no significant export of fish from the (former) estuary. Still, in all likelihood at the species level, as long as the mangrove ecosystem survives, all the relevant estuarine fish and crustaceans are still present and can potentially rebound quickly if a significant dilution by fresh water is re-established.

Any additional freshwater output into the estuary especially if pulsed according to the natural flood peak(s), is likely to increase the productivity of the coastal and estuarine fisheries of both fish and crustaceans. The limiting factor to this positive correlation may be that very high freshwater outputs will create a "coastal estuary" (Baran 1995) and may push some of the most productive species (clupeids, etc.) out of reach of small-scale fisheries in some seasons. This is unlikely to happen under any of the Pangani scenarios.

7.2.2 Estuarine Invertebrate fisheries

For Tanzania, the peak outflows of coastal rivers occurs between March and May, with the exception of the Pangani which has a constant run off, accompanied with shrimp peak catches during the months of April, May and June (Haule, no date). Crustacean fisheries show a marked seasonal abundance during the wetter months for the nearby Bagamoyo estuary (see Mgaya *et al*., 1999; Bwathondi *et al*., 2002; Sobo, 1999), while for the Colorado River estuary, Galindo-Bect *et al.* (2000) found a significant relationship ($P < 0.001$) between total catch and rate of freshwater discharge. They accept that mechanisms affecting the fishery production are unknown. The influences of salinity and nutrient gradients on survival of early life stages are yet to be determined.

A number of studies report the collapse of coastal fisheries following impoundments e.g. the Nile (Halim *et al*., 1995), the Niger River (Moffat & Linden, 1995) and the Indus (Meynell & Qureshi, 1995). Similarly, the estuarine fisheries of the Senegal River all but disappeared after creation of the Manantali and Diama impoundments (Bousso, 1997). For tropical shrimp, *Penaeus* spp., which have an obligatory estuarine life history stage, there are similar indications from different areas that productivity is positively correlated with fresh water outflow of the adjacent estuary. Examples include the coastal shrimp fisheries (Lhomme & Garcia, 1984) around St. Louis at the mouth of the Senegal River (Fig. 13) between 1965 and 1978.

A similar correlation has been established between the *Penaeus* catches on the Sofala Bank and the flow from the Zambezi (Gammelsrød, 1996) and from the Gulf of California (Galindo-Bect *et al*., 2000). All these rivers are much larger than the Pangani, with discharge well above 3,000 mm/year (annual mean flows of over 100 cumecs) but from the restoration of the deltaic floodplains of the Senegal river it is known that even small flows of 5-10 cumecs flooding a few thousand hectares for 2-3 months will immediately result in a spectacular return of *Penaeus* postlarval production (Hamerlynck & Duvail, 2003). This is also why the species is targeted by aquaculture: almost any warm brackish water with some detritic food source stocked with larval *Penaeus* will be highly productive.

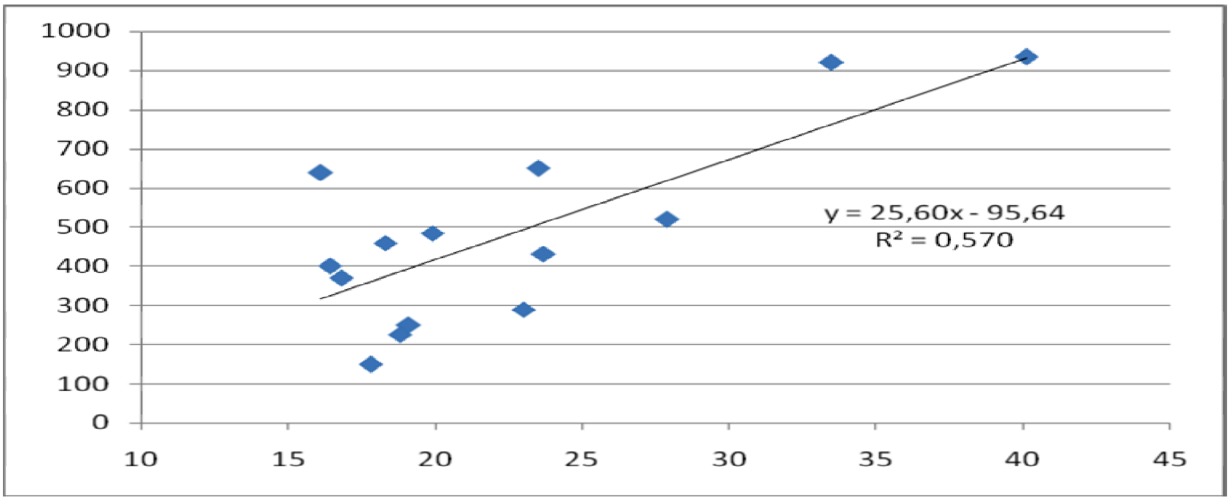

Figure 13 Annual Mean Flow of the Senegal River (in cumecs) and CPUE for the *Penaeus* fishery at St. Louis (in kg/hour) as recalculated from Lhomme & Garcia (1984).

Thus, though the Pangani does not have a semi-industrial *Penaeus* fishery, any correctly timed increase in freshwater outflow will increase production and can be expected to positively affect local livelihoods. Though the "collapse" of the Pangani estuarine fisheries is not well documented, it can be safely assumed that it does correlate with low flows. As long as the fringing mangrove remains intact, the opportunistic nature and resilience of most estuarine species can be expected to allow them to bounce back rapidly with any improvement of fresh water outflow, especially if it is timed to coincide with the natural flood peaks.

Expressing this quantitatively is tentative but deltaic floodplains are more productive than river floodplains. In the EIA for the Senegal River Diama impoundment, the artificial estuary was expected to yield 80 kg/ha/year of harvestable fish and shrimp (Gannett *et al.*, 1980) but in coastal lagoons in Togo, in the open situation where the lagoon is connected to both the river and the ocean, yields of 400 kg/ha/year were recorded (Laë, 1997). This should be considered an extreme situation but yields of 100 to 150 kg/ha/year for flooded coastal deltas can be expected if one combines the catches of both the estuarine and the coastal fisheries.

In summary, the ideal (future Pangani) estuary will have a functional mangrove zone at least seasonally (preferably during the long rains), a substantial zone of 5 to 20 ppt and considerable tidal flooding of the deltaic floodplains and mangrove with such low salinity waters.

8 RELATIONSHIP BETWEEN IMPORTANT SPECIES AND FLOW VARIABLES

8.1 Important species and flow regimes

8.1.1 *Oreochromis esculentus*

This cichlid is a flood-induced spawner, which typically moves into deeper water to spawn then carries fry to shallow flooded areas for feeding and shelter. It is also likely to spawn throughout the year to a lesser degree, thus maintaining good populations at all times. It can be expected to react favorably by boosting production to any increased extent of flooded area or increase in water level. Larger flooding will likely boost production, while the absence of flooding the production will be low but steady. Parental care may prevent fry from being carried to unfavourable areas during extreme flooding.

8.1.2 *Clarias gariepinus*

This is a highly opportunistic and resilient species, which has made it a major target species for aquaculture development. It can survive periods of low oxygen and has a highly flexible reproductive strategy. In seasonal environments it will spawn at the first main flood (Clay, 1979) but in Lake Victoria it can switch from two breeding seasons under normal bimodal rainfall conditions (April and December) to a single breeding season in case of drought (Owiti & Dadzie, 1989). It is an omnivore and occurs abundantly in almost all soft bottom habitats from permanent lakes to rivers to temporary pools, can migrate short distances over land and support a certain amount of drying out when it digs into the mud during the dry season. In the Lower Rufiji it is one of the three species (together with *Oreochromis urolepis* and *Macrobrachium* spp.) that survives, and thrives in spite of considerable fishing pressure, in the floodplain associated lakes that have not been reached by a flood peak for four years (Hamerlynck & Duvail, unpubl. data).

In the Pangani it can be expected to react favorably to any increased extent of flooded area both under a unimodal and a bimodal flood regime. Any increase in water level in the impoundments will also favourably affect its productivity, especially if flooding extends into the vegetation.

8.1.3 *Barbus* sp.

This genus includes at least 13 species. *Barbus* in Nyumba ya Mungu enter streams in the wet season to spawn (Bailey *et al*., 1976). n the assumption that they all have similar reproduction requirements and behave in the same way with respect to changes in flows variables, it is sufficient to group all species under a single treatment. As flood-induced spawners, they can be expected to react favorably to any increased extent of flooded area or increase in water level in the impoundments, especially if flooding extends into the vegetation. Extreme flooding may reduce survival of young fish by carrying them into unfavorable areas (Welcomme, 1985).

8.1.4 Estuarine clupeids comparable to *Hilsa kelee* (dominant in Rufiji fisheries)

In their review of estuarine Clupeidae and Engraulidae juveniles, Blaber & Blaber (1980) found that the existence of marked turbidity gradients from sea to estuary during the summer (rainy season) recruitment period may aid fry in locating estuarine nursery grounds. In addition to the presence of calm water in estuaries and paucity of predators, juveniles seek out shallow, turbid water areas. Thus they argue that it may not be estuaries *per se* that are attractive to juvenile fish, but shallow turbid waters.

Simier *et al.*, (2006) studied the Gambia River estuary and found that fish densities were correlated to turbidity and salinity but not to temperature. The role of seasonal salinity fluctuations in structuring fish assemblages was shown by Barletta *et al*. (2005) for a tropical estuary in Brazil. There, the dry season produced stable hydrological conditions, and estuarine-dependent species were ordered along a well defined salinity gradient. When the freshwater runoff increased during the rainy season, salinity decreased and the estuary became suitable for freshwater and brackish-water species.

In the Sine Saloum delta, however, which is an ''inverse'' estuary with nearly no freshwater input (Simier *et al.,* 2004), transparency was relatively high everywhere (from 2.1 to 3.2 m), while salinity was higher or equal to that of seawater. The seasonal variations of these factors were very slight and fish assemblages were mainly organised in space, according to the branch of the delta and, in the large Saloum main branch, to the distance from the bank. The Sine Saloum delta is not dissimilar to the Pangani estuary, where sediments loads and salinity are fairly stable. Increases in water flow, with sediments, are likely to boost production of any sardine-type fishery.

8.1.5 *Scylla serrata*

Spawning females move offshore to spawn then return to the coastal areas after spawning. Larvae develop in coastal waters prior to recruitment of late larvae (megalopa) or first crab stages to the estuarine mangrove environment after about two weeks. Attraction of the megalopa to the estuary may be associated with rainfall and salinity (Poovichiranon, 1992), though recruitment appears to be continuous throughout the year in tropical populations (Chandrasekan & Natajaran 1994; Le Vay *et al*., 2001). The population at Pangani may increase if flows produce more sediment to attract larvae.

8.1.6 *Fenneropenaeus indicus* and associated species

Most penaeids reach sexual maturity in less than one year and produce large numbers of eggs. Among the species occurring in the Pangani estuary, females migrate offshore to release eggs and the larvae recruit back into the estuary where the salinity is usually low (King, 1995). With its obligatory estuarine phase, there are similar indications from different areas that productivity is positively correlated with freshwater outflow of the adjacent estuary, e.g. Lhomme & Garcia (1984) for the Senegal River. Rainfall strongly affected prawn catches in Bagamoyo (Teikwa & Mgaya, 2003) and is known to initiate the migration of prawns from the estuaries, either by lowering the salinity or simply by mechanical flushing and disturbance of the sediments.

8.2 Response curves

In this section, on the basis of best available knowledge, an attempt is made to provide graphs that chart the response of key guilds in the system to changes in flow. The central point in each graph is the current situation labeled as “present day”. The x-axis represents “discharge” and the y-axis represents an unspecified measure of “productivity”. Neither of the axes is parametric and changes from the present day situation should be read as increase, decrease or stability. No quantitative interpretation in the sense of doubling, tripling or percentage increases can be derived from them, only the three trends mentioned above though changes in slope indicate stronger responses. A distinction is made between pulsed and non-pulsed flows as the response curves are predicted to be very different under these two types of discharge.

8.2.1 River species

All typical river species, e.g. *Labeo*, *Barbus*, *Mormyrus* will react favorably to increased flows. Under a pulsed flow scenario (Fig. 14) the increase is expected to be important at any discharge level higher than today as the river bank vegetation will flood thus creating favorable conditions for feeding, shelter and reproduction. Under an increase in non-pulsed flow (Fig. 15) this will not be the case as the river bank vegetation will adapt by retreating up the bank. With increased long rains flows a second step in the increase is likely as old meanders and dried channels where the river has a braided character will flood, thus increasing the available habitat. At lower flows, depending on the extent of the incident, they will die out either locally or totally when river flow stops.

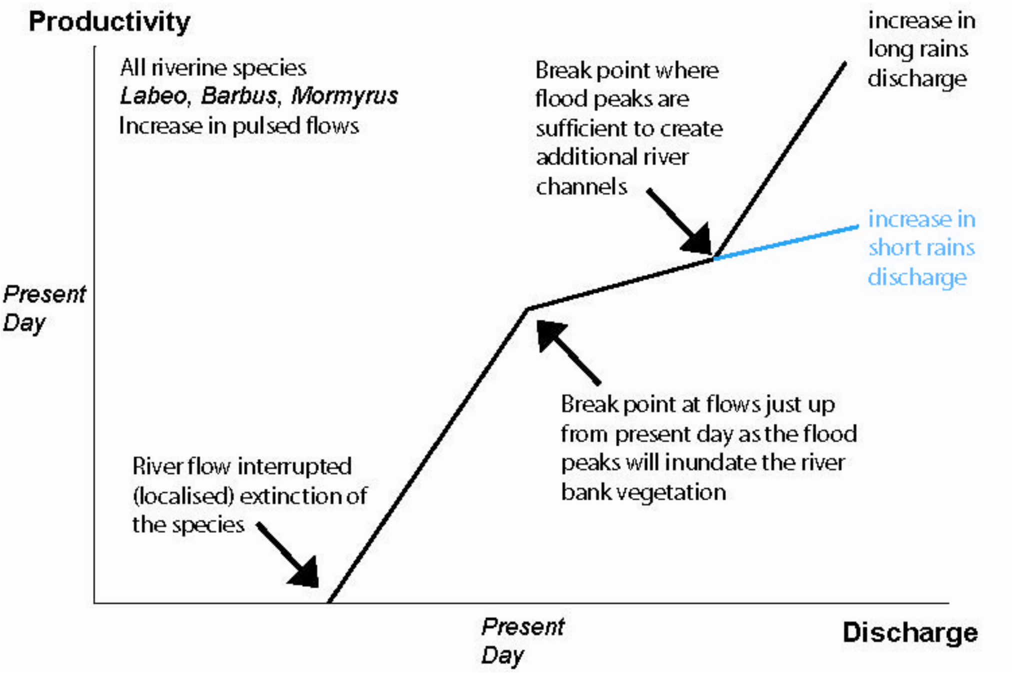

Figure 14 Pulsed flows in the river.

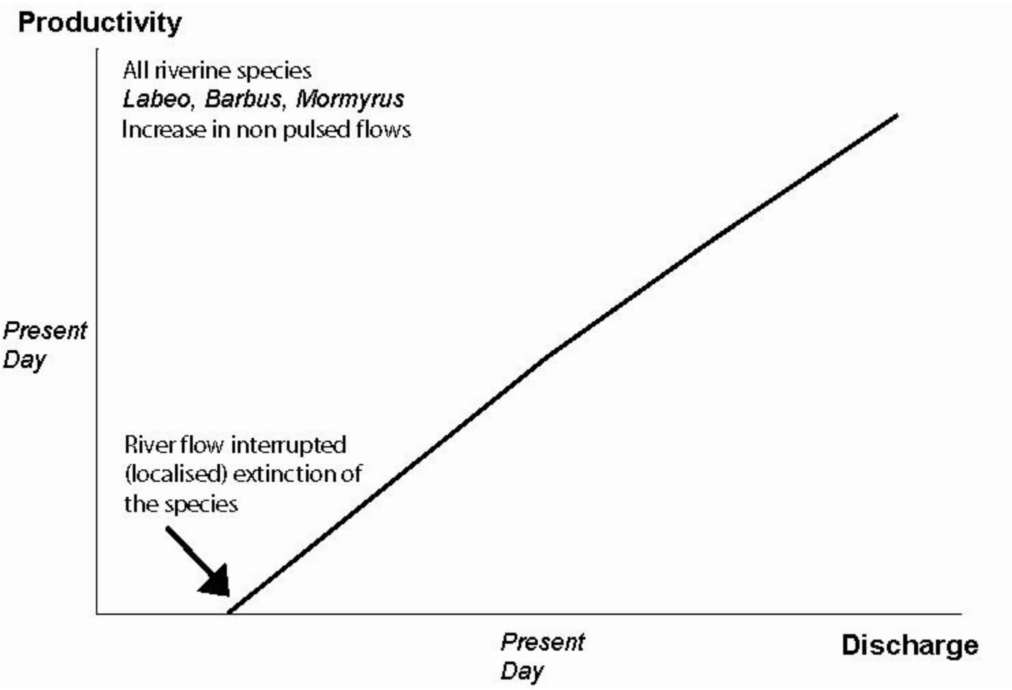

Figure 15 Non-pulsed flows in the river.

8.2.2 Floodplain species

All species will react favorably to increased pulsed flows (Fig. 16) but the major breakpoint is where bank full levels are exceeded and the floodplain is covered for a substantial length of time. It is not expected that this point will be reached during the short rains pulse. For non-pulsed flows (Fig. 17) no breakpoints are expected, just expansion of the habitat as is the case for the river fishes. Because of the special adaptations of the floodplain species they will go extinct at a lower level than the river species.

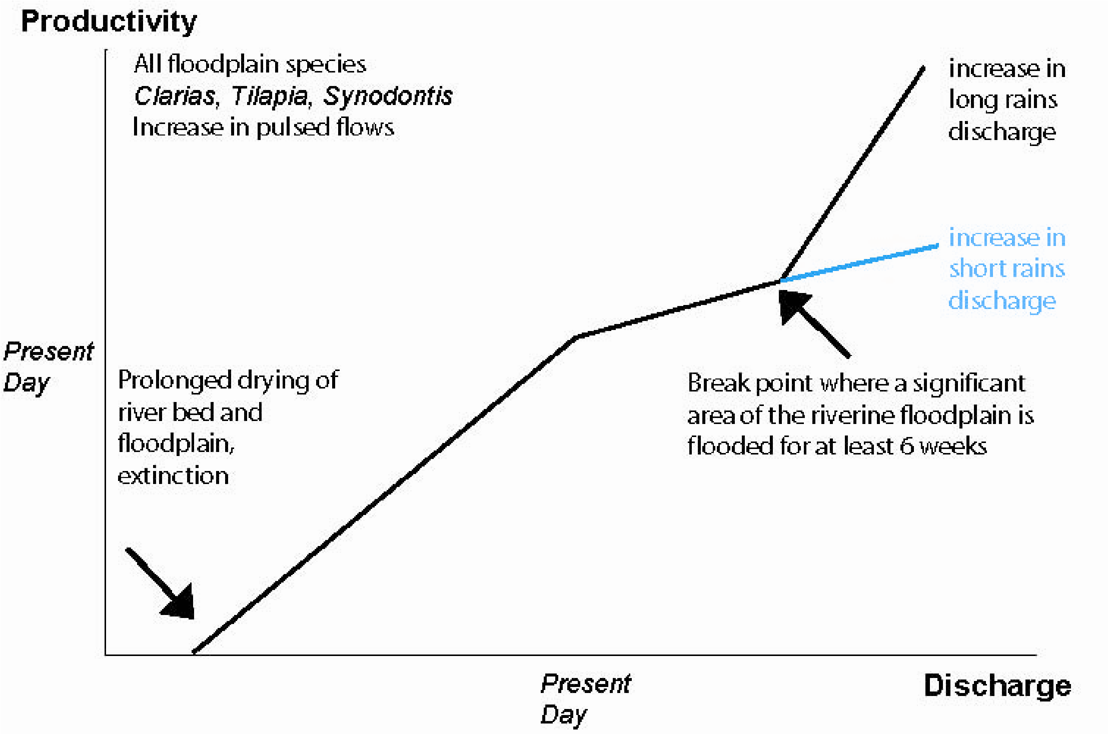

Figure 16 Pulsed flows in the floodplain.

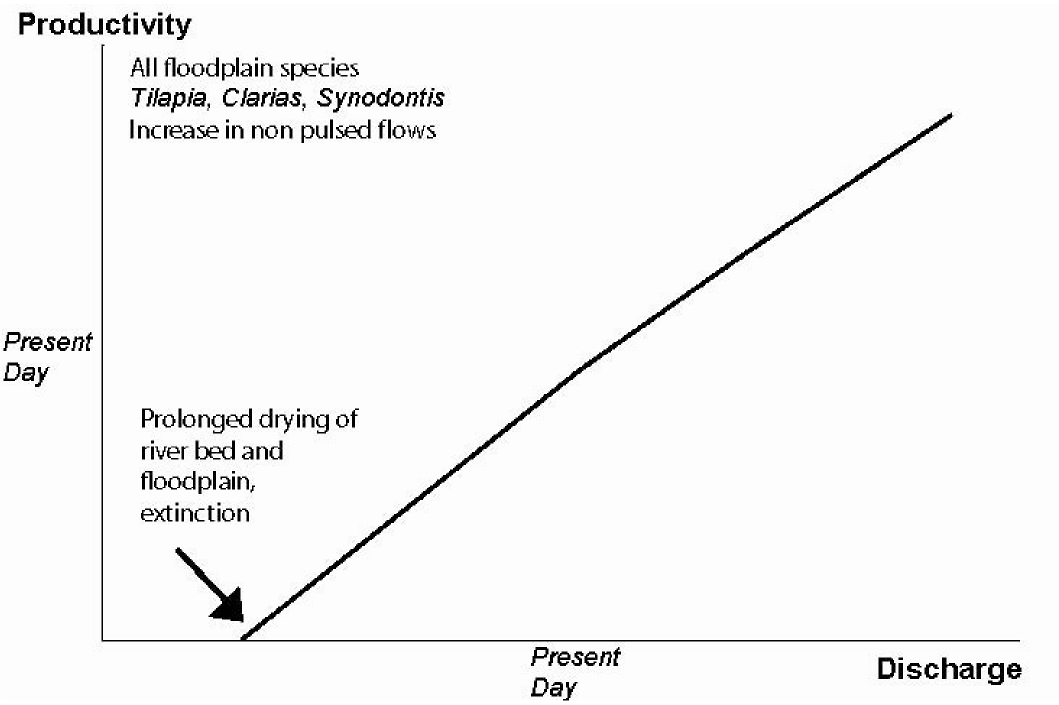

Figure 17 Non-pulsed flows in the floodplain.

8.2.3 Lakes and reservoirs

The functioning of the lakes, where currently virtually only floodplain species are present, will be similar to the floodplain responses.

8.2.4 Estuary

Flows higher than present day - Within the range of conceivable flow scenarios, we expect all estuarine species to react favorably to increased flows, in particular those timed to coincide with the natural flood peaks. It seems unlikely that the short rains peak will flood a significant proportion of the estuarine floodplains but at a level where the long rains peak would do that we expect a sharp rise in productivity. If flows decrease below the present day ones we expect further decreases in all species and commercial extinction if there is significant die-off of the mangrove.

Flows lower than present day – There are no arguments for the steep decline below present day flows but there is a need to signal that the situation seems quite critical. In fact, the present situation may be such that the estuary is on that part of the curve since the putative “collapse” of the estuarine fishery a few years ago.

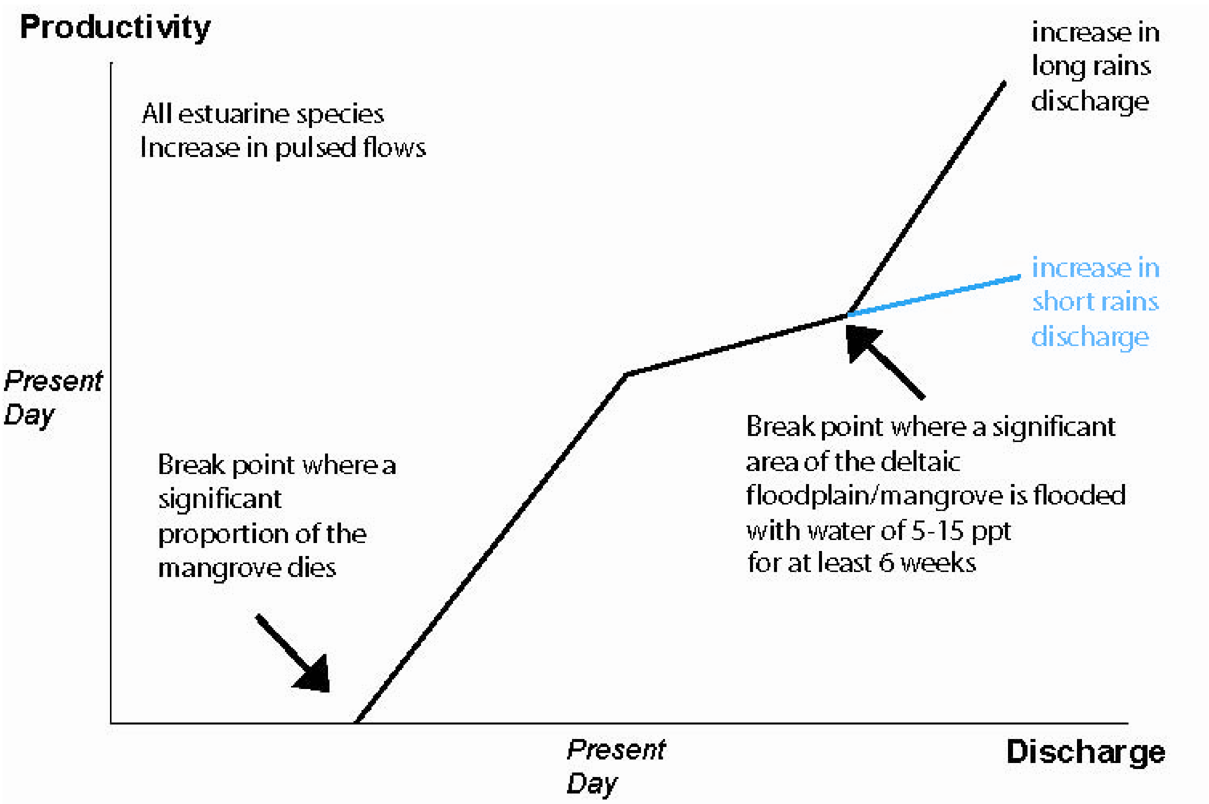

Figure 18 Pulsed flows in the estuary.

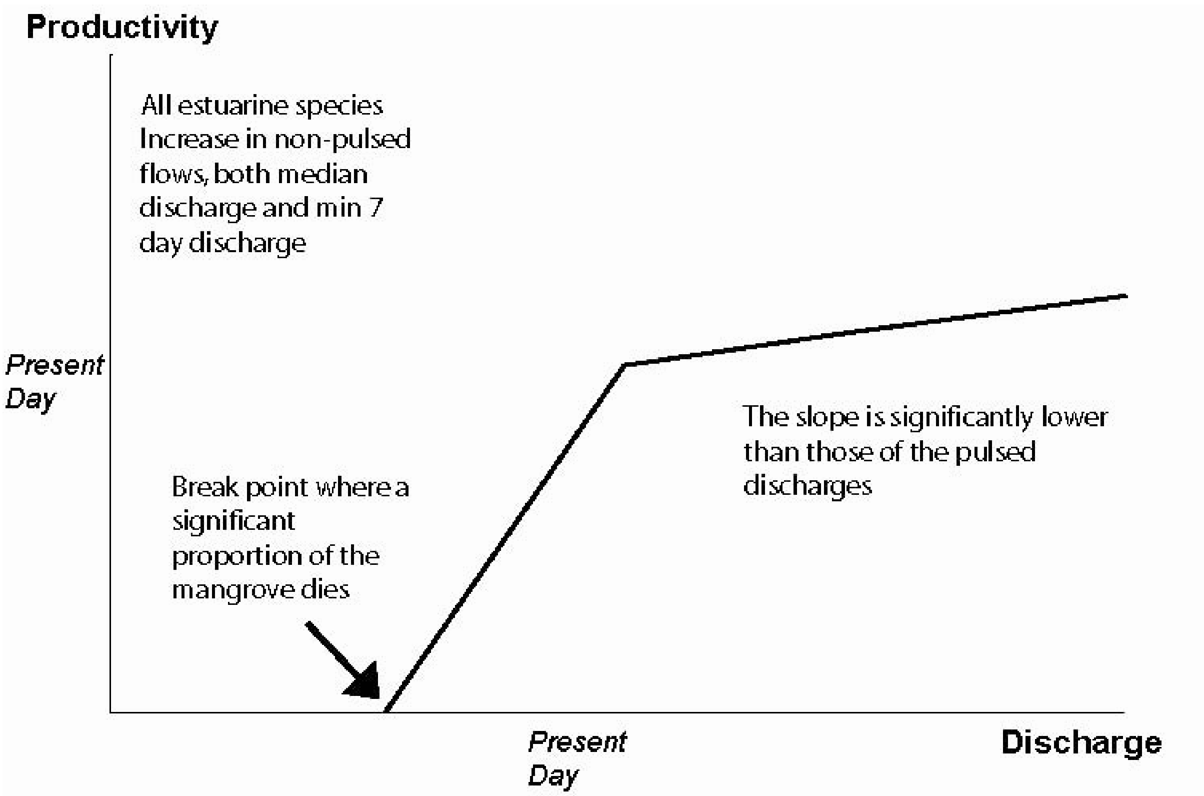

Figure 19 Non-pulsed flows in the estuary.

9 CONCLUSIONS AND RECOMMENDATIONS

The Pangani River Basin supports a diverse aquatic ecosystem, with over 50 freshwater fish species supporting numerous lake, reservoir and estuarine fisheries. The Pangani estuary has suffered from a change in its flood regime with a marked reduction of the dry season high flows and the wet season low flows due to hydro-power installations and increased water abstraction (Beuster *et al*., 2006). Its fishery is likely to be similar, but much smaller, than that off Bagamoyo, about 100 km south.

Important fish species were identified and their life histories described in relation to water flow variables. Freshwater fisheries are dominated by cichlids, representing over 90% of the catch in Nyumba ya Mungu Reservoir, and catfish making a small but reliable contribution in most water bodies. The latter reservoir is the single most significant fishery in the entire 43,000 km² basin.

A similar approach was taken with invertebrate species of the estuary where, based on species present and fisheries of Bagamoyo, penaeid prawns, mud crabs *Scylla serrata* and estuarine sardines *Hilsa kelee* are used as typical species with which to consider different flow variables.

There are many short-comings in the fisheries data for all the main water bodies in the Basin. These are Jipe, Nyumba ya Mungu, the Pangani River floodplain and the Pangani estuary. The main recommendations are as follows:

1. Fisheries data - Better quality fisheries data would allow better modelling attempts. A first step would be an understanding of how the total annual catch data are derived. A second level of improvement could be achieved if reliable monthly fisheries data could be made available. This would allow correlations to be made with “hydrologically” defined seasons instead of calendar years that are often mixtures of hydrological events that have no biological relevance. A third step would be the collection of fisheries independent data through a standardised long-term monitoring programme. In fact such a monitoring system should be part of the obligations of any major water user (hydropower, large scale irrigation) in the system.

2. Pangani Estuary - In the estuary, various sources agree on a (recent) “collapse” of the fishery but there are no data to corroborate this. It would be interesting to know if the increased flows of 2006-2007 have led the revival of the fishery. To make predictions on the estuarine fisheries, notably on Penaeid dynamics, recent flow data from the Wami and Rufiji would be valuable and at least an annual survey of the Pangani estuary catches preferably in combination with flow, salinity, turbidity, nutrient, plankton and tidal data.

3. Managed flow releases - Manipulating the water release from NYM to mimic the natural flood cycle as much as possible has the potential to restore the natural functioning of floodplains in the system. Flooding substantial surface areas downstream can enhance fish breeding, reduce catchability during the early growth stages and thus improve the fisheries.

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11 DATA SETS

Accompanying this report is a set of 20 Excel data files that include all the data used in the report plus some that was not incorporated. Data includes landing site fish catch, fish catch (dried) export data, Nyumba ya Mungu water levels and rainfall and water conductivity figures from the June 2007 field visit.