Spariscono i pesci del Kenya e della Tanzania, Wwf: milioni di persone a rischio

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Acqua | Aree protette e biodiversità | Inquinamenti | Risorse

La crisi ecologica del fiume Mara che colpisce uomini, gnu e leoni

[12 Novembre 2020]

Il Wwf denuncia che «Una moria di pesci nel fiume Mara, lungo 395 km, sta mettendo a rischio la sopravvivenza di oltre un milione di persone in Kenya e Tanzania, oltre a quella di zebre, gnu, leoni e decine di altre specie già fortemente minacciate di estinzione».

Il Wwf ha lanciato l'allarme con il **rapporto** "Freshwater biodiversity of Mara river basin of Kenya and Tanzania" sullo stato di salute del bacino del Mara, e che si estende su oltre 13.000 Km2, il 65% in territorio keniano e il 35% in Tanzania, e che fornisce mezzi di sopravvivenza a 1,1 milione di esseri umani. «Si tratta infatti – spiega il WWf – dell'habitat che ospita la più alta densità di erbivori al mondo e altre specie iconiche come i leoni».

Un'area notissima per la più grande migrazione stagionale di gnu e zebre, con un indotto di milioni di dollari per il turismo, e per ospitare anche i grandi predatori degli erbivori. E proprio la diminuzione delle prede e la riduzione del loro habitat sono fra le cause primarie del declino dei leoni in Africa, che, evidenziano gli ambientalisti, «ormai hanno perso il 90% del loro storico areale e sono già estinti in 26 Paesi del continente. La popolazione è passata dai potenziali 200.000 leoni di 100 anni fa, a forse meno di 20.000 leoni di oggi. Questo declino è accelerato negli ultimi anni, con l'ultima classificazione Iucn che stima un calo del 43% tra il 1993 e il 2014. Un qualunque ulteriore alterazione negli equilibri ecologici di questi territori metterebbe ulteriormente a rischio il futuro dei leoni, i felini più conosciuti e amati al mondo».

La causa della moria di pesci, che stanno scomparendo dal fiume, e della conseguente grave perdita di biodiversità, per il Wwf sono «Le attività umane sempre più intensive che utilizzano l'acqua per l'agricoltura (aumentata del 203% tra il 1973 e il 2000), per produrre energia idroelettrica e per il turismo. A questo si aggiunge la deforestazione –

in particolare nella foresta keniana di Mau – che aumenta la desertificazione e riduce le riserve idriche . La popolazione, poi, cresce al ritmo del 3% annuo, aumentando costantemente la pressione umana sull'ecosistema per soddisfare i bisogni di terre, acqua e cibo. I primi a soffrire la fame saranno le popolazioni dedite alla pesca che a causa delle risorse ittiche in costante diminuzione, rischiano la carestia alimentare».

William Ojwang, responsabile acque per il Wwf nella Rift Valley, ricorda che «Quando l'ambiente viene danneggiato, sono le specie acquatiche a risentirne per prime, ma la distruzione di questo tipo di biodiversità ha un effetto negativo a cascata su tutto il resto dell'ecosistema».

Il rapporto Wwf stima che «Se gli gnu non dovessero avere più accesso al Mara river, circa l'80% della popolazione potrebbe morire: il fiume, infatti, che si trova al confine tra Kenya e Tanzania, è l'unica fonte d'acqua durante la stagione secca e il solo habitat per i coccodrilli del Nilo che hanno un ruolo ecologico molto imporante durante la migrazione».

La prima analisi sulla biodiversità del bacino del fiume Mara ha identificato 473 specie di acqua dolce autoctone, tra cui quattro mammiferi, 88 uccelli acquatici, 126 uccelli associati di acqua dolce, 4 rettili, 20 anfibi, 40 pesci, 50 specie di invertebrati e 141 piante vascolari. Almeno 10 specie (il 2% delle specie totali) sono elencate nella lista rossa dell'Iucn e tre specie – il ningu, il singida e la tilapia Victoria – sono "in grave pericolo di estinzione", minacciate dall'introduzione di pesci non autoctoni come il pesce persico del Nilo.
Il Wwf fa notare che «A causa della scarsità di dati, l'ecosistema del fiume è ancora poco conosciuto: diverse specie acquatiche non si vedono da molti anni e potrebbero essersi estinte ancora prima di essere state studiate o descritte al resto del mondo, tuttavia, per i ricercatori è probabile che la varietà di biodiversità presente nell'area sia stata comunque sottostimata».

La progressiva scarsità d'acqua in tutto il bacino e la gestione della risorsa sono anche causa di conflitti tra Kenya e Tanzania che sono ai ferri corti per la costruzione di diverse dighe nel del bacino del Mara, alcune delle quali destinate all'irrigazione.

Il Wwf conclude: «Ancora una volta si dimostra come nei diversi sistemi naturali e sociali tutto è connesso: la scarsità delle risorse naturali dovuta all'impatto e alla cattiva gestione da parte dell'uomo porta sia ad una catastrofe ambientale, dove specie cruciali e iconiche come i leoni rischiano di pagarne drammatiche conseguenze, sia ad un inasprimento dei conflitti sociali tra comunità il cui benessere dipende proprio dalle risorse naturali, sia che si tratti di acqua sia che si tratti di economia legata al turismo naturalistico. La soluzione prospettata dal Wwf è quella di una gestione sostenibile del territorio e delle sue risorse, dove i diversi portatori di interesse possano accordarsi per ridurre gli impatti e per gestire in maniera duratura il capitale naturale. Senza un vero cambio di rotta assisteremo ancora una volta ad un effetto domino che partendo dalla moria dei pesci determinerà devastanti effetti su tutta la biodiversità e le comunità locali, mettendo a rischio il futuro di milioni di persone».

Refining Environmental Flows for the Mara River, Kenya and Tanzania: Report on Fish Ecology for the Third Environmental Assessment of the Mara River

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REFINING ENVIRONMENTAL FLOWS FOR THE MARA RIVER, KENYA AND TANZANIA

REPORT ON FISH ECOLOGY FOR THE THIRD ENVIRONMENTAL ASSESSMENT OF THE MARA RIVER

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EXECUTIVE SUMMARY

WWF-Eastern Africa Regional Programme Office (WWF-EARPO), through its freshwater programme, began the task of establishing the Reserve flows for Mara River in 2006. The first two site assessments covering three sites were conducted in March and July 2007 by a team of specialists comprising a geomorphologist, hydrologist, hydraulic engineer, aquatic ecologist, riparian ecologist, water quality specialists, and socioeconomist. The first Reserve flows for the river were prescribed in October 2007 during the EFA workshop held in Narok, Kenya. At this workshop it was also agreed that continued monitoring of the river's flow levels and ecological status is critical to improve the accuracy of the prescribed flows.

The present work reports on the results of a fish sampling exercise conducted in February 2009 during the third assessment for the Mara River. The assessment covered one additional site in the Nyangores River and coincided with the period of low flows in the Mara River.

In total 14 fish species belonging to 6 genera were found to occur in the Mara River. In terms of catch weight, the minnows, *Labeo,* and catfish, *Clarias*, dominated the catches followed by barbells, *Barbus*, and elephantfishes, *Mormyrus*. In terms of the major river habitats, more fish were caught in riffles than pools. However, since the majority of riffle residents are juveniles as well as adults of small bodied species, their relative contribution to the total biomass was less compared to that from pool habitat.

Among the 14 species reported in this river, at least 2 are of prime conservational significance. *Oreochromis alcalicus grahami*, which was caught at BBM1 in the 2007 survey, is native in the region and ranked as "vulnerable" in the IUCN Red List. *Labeo victorianus*, a ubiquitously occurring fish species in the Mara River, is confined (endemic) to the Lake Victoria-Nile drainage basin and has evolved in the basin. One peculiar species, *Chiloglanis somereni*, caught at BBM2 in February 2009, has a strict requirement for fast flowing water and therefore is widely used as a guide in prescribing flows during environmental flow assessments.

When sampling sites were compared in terms of fish abundance and biodiversity, the new site in the Nyangores River was found to have the least Catch Per Unit Effort (CPUE) and the lowest fish species diversity index (H'). The higher altitude influence on water temperature and the existing dam at Kipng'eno Village were thought to set the upstream species limit for fish distribution in upper sections of the Nyangores River.

Approximately 24% of the adult males and females examined during the 2009 field survey carried ripe gonads. This observation, together with the occurrence of the relatively large number of immature/juvenile fishes and spent males and females in the populations, suggests that the present riverine conditions in the Mara River are suitable for breeding in the majority of fishes. It also suggests that spawning of fish remains associated with high flows that occurred in the previous rain period in December-January.

Critical flow regime characteristics can be ascertained by studying the environmental guilds of fish present in the river, i.e. grouping fish species in the manner that they respond to changing hydrology and geomorphology. The project area has large number of fish species, many of which were in the environmental guilds ranging from moderately to highly sensitive to flow timing and/or quantity. The fishes in genera *Barbus* were in the pool guild, species which are sensitive to reductions in flow that alter the balance between riffles and pools in the river, or leave the pools anoxic. *Labeo* and to a lesser extent *Clarias liocephalus* are among the fairly sensitive species representing the lotic guild. *Labeo* are typically annual breeders whose breeding seasonality and migration patterns are tightly linked to the timing and quantity of peak flow events. Lotic guild members also require fairly high levels of dissolved oxygen, necessitating high flow velocities. On the other hand, *Chiloglanis somereni*, encountered in BBM2, is in the riffle guild, generally considered to be most sensitive genus in African EFAs due to its high requirement for fast flowing water (velocity ≥0.3 m / sec).

On the basis of fish guilds found in the Mara River it can be recommended that for BBM 1, BBM2 and BBM1.2 dry season base flows must maintain inundation of the riffles. In all three sites the wet season base flows must inundate lower banks and benches, allowing the input of nutrients from those systems to the river as well as fish passage over larger obstacles. Wet season high flows must inundate the floodplains to inundate and recharge wetlands as well as provide access to floodplain nursery grounds.

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1.0 BACKGROUND

From its headwaters on the Mau escarpment of Kenya to its mouth at Lake Victoria, the Mara River flows through wooded grasslands used for livestock grazing and small-scale irrigated agriculture, the protected areas of Masai Mara National Reserve and the Serengeti National Park, and industrial activity such as mining which have led to higher rates of water abstraction. These multiple demands for the water resources in such an arid system are increasingly becoming incompatible. The increasing abstractions will, in the future, severely degrade the riverine ecosystem and even impinge upon the most basic water needs of people living along the river. The science of environmental flows has become the accepted way of sustaining river ecosystems, for people and nature, into the future.

The present work constitutes the third Environmental Flow Assessment (EFA) aimed at determining the necessary Reserve for the Mara River. The EFA studies in the Mara River were launched during the initial Building Block Methodology (BBM) planning workshop convened at Narok, Kenya in May 2006 and later followed by two EFA field surveys conducted in March and July 2007 at three different sites (BBM1, BBM2 and BBM3) in the Mara River. The scheduling of the first two field surveys were planned to coincide with wet season high flows and dry season low flows, respectively. However, unexpectedly high flows were present during both survey efforts, resulting in stage measurements taken at medium and high flows, but no measurements for the critical dry season low flows. The specialists reconvened in October 2007 to determine the flows for the two seasons in drought and maintenance years required to achieve a healthy managed state for the Mara River.

The 2007 assignment was regarded as the first assessment of the Reserve, and continued monitoring of the river's flow levels and ecological status is considered critical to determine if the prescribed flow regime is sufficient, if more water needs to be set aside for the Reserve, or if more water can be permitted for consumptive use. Therefore, the February 2009 field survey was an attempt to capture the dry season low flows for inclusion in refining the existing environmental flow recommendations for the Mara River. In order to broaden the representation of major tributaries of the Mara River Basin, one additional site on the Nyangores River **(BBM1.2)** was included during the survey.

The present report is concerned with the fish component of the EFA conducted in the Mara River in February 2009.

2.0 METHODOLOGY

The reasons for selecting the BBM for assessing flows in the Mara River, the criteria that were used in selecting BBM sites, the characteristics of individual BBM sites and approaches used in determining the Reserve by the BBM method have been described in detail elsewhere (see Tamatamah, 2007 and WWF, 2008).

As with the 2007 survey, in a 100 m stretch at each BBM site the average watercourse dimensions were measured (i.e., depth, wetted and bankful width), substrate type identified (i.e., sand, silt, organics, gravel, cobble, boulders), and habitat (i.e., riffle, run, pool) and channel types classified (i.e., single thread, braided, level of meander). Each new sampling location was recorded/fixed using a GPS unit to ensure its accurate positioning and to allow for follow up studies to occur in the same areas.

The fish sampling method employed in the present study was the combination of gill nets and electroshocking. These methods were used in order to minimise sampling bias arising from gear/equipment selectivity and efficiency. To a large extent electroshocking was limited to those areas where members of the sampling team could enter the water, primarily along the banks and in shallow reaches. Gill nets were used in deeper and wider sections of the river where human access by wading was not possible. Each of these sampling methods was employed in each of the study sites and covered the variety of river habitat types (e.g. riffles, pools). At each site two sets of 100m by 2m multimesh gillnet panels were set parallel to the river flow for the period of 3 hours. In the wading electrofishing technique, a petrol powered generator was used to produce a voltage on the electrode placed in the water for 30 minutes at each site. Fish coming into contact with the electrical field were anesthetized and captured with dip nets.

Fish were identified in the field according to the taxonomic guides by Bernacsek (1980), Eccles (1992), Skelton (1993), and Witte & van Densen (1995). Total lengths and wet weight measurements were taken to the nearest 0.1 mm and 0.1 g, respectively. Sex of each individual fish was determined from gonad inspection following anatomical dissection and/or using external characters for larger specimens. Gonad state was assessed using a five-point scale modified after Bagenal (1978) as given in the previous fish reports of the Mara EFA. Voucher specimens of fish species were photographed using a digital camera.

A number of computational techniques were also employed to the catch obtained from experimental fishing to provide information on the relative abundance and distribution of resident fish species among sampling sites (and habitats) in the Project Area. These techniques included calculation of catch per unit effort (CPUE) and the Shannon-Weaner diversity index (H'). For the CPUE technique, the “catch” portion of the measure is expressed as the number or weight of the catch, while the “unit effort” refers to the time a uniformly designed and employed piece of fishing gear is deployed in the water.

3.0 ASSESSMENT RESULTS

3.1 River habitats

The summary of site characteristics for each BBM site during the February 2009 survey is given in Table 1, with photographic views of the sites presented in Figure 1. Generally speaking, the four sites were characterized by rocky substrate that provided a variety of stream habitats including riffles, pools and runs. In stream ecology the diversity of riverine habitats is positively correlated with diversity of flora and fauna such that sites with limited number of habitats are expected to have an impoverished aquatic fauna including fishes.

Table 1. Summary of river habitat description at the four sampling sites in the Mara River.

Site ID [Name at river reach]	**GPS Location (ARC 1960)**	**Description of BBM fish sampling sites**
BBM-1 [Amala River at Kapkimolwa Bridge]	E 0771232 N 9900938 [Altitude: 1855 masl]	• The area covering approx. 200m upstream of the Kapkimolwa Bridge. • Low flow conditions (shallow) and completely wadable across the channel by members of sampling team. • River zone: Upper foothill with some characteristics of mountain torrent zone. • Channel/substrate type: Single thread channel with mixed boulder/cobble and alluvium substrate. • Biotopes present: combination of riffles, pools and runs (consisting largely of boulder/cobbles and few sections of sand/mud). • Vegetation: Stable riparian vegetation, higher canopy cover that provide appreciable shading to the river water and no invasive aquatic vegetation. • Land use: Agriculture-livestock & crops, rural residential. Water abstraction for domestic use and as cattle watering point.
BBM1.2 [Nyangores River at Kipng'eno Village Bridge]	E 0762842 N 9918644 [Altitude: 1957 masl]	• Sampling site located approx. 200 m upstream of the Road Bridge at Kipng'eno Village. • 1000 m below this site the river has been impounded to create a dam and a fall for hydropower generation. • Low flow conditions (shallow) and completely wadable across the channel by members of sampling team. • River zone: Upper foothill in a typical mountain torrent zone. • Channel/substrate type: Largely single thread channel but braided with typical exposed bars that are vegetated near the Kipng'eno Bridge. Bedrock and large boulders characterize the river substrate at this section. • Biotopes present: Predominantly riffles and runs but with few isolated pools. • Vegetation: Stable riparian vegetation, higher canopy cover that provide appreciable shading to the Banks. No invasive aquatic vegetation. • Land use: Agriculture-livestock & crops, rural residential.

BBM-2 [Mara River at Mara Safari Club]	E 0744428 N 9879388 [Altitude: 1668 masl]	• Low flow conditions but not safely wadable across the channel by members of sampling team. • River zone: Lower foothill with steep banks (> 10m) with evidence of erosion during high/bankfull flows. • Channel/substrate type: Single thread channel covered predominantly with boulder/cobble substrate. • Biotopes present: combination of riffles, pools and run. Deep hippo pools seen in previous surveys still present about 800 m upstream and downstream of this site. • Vegetation: Stable riparian vegetation but since the river is wide, there is no significant shading of the river water. No invasive aquatic vegetation. • Land use: Largely wildlife conservation as the site is located within a group ranch conservancy. A tourist lodge on the banks of the river near this site. Hippos and crocodiles are among large aquatic animals found on site. Water abstraction for domestic use and washing. Small rural residential area approx. 1000 m from this site.
BBM-3 [Mara River at New Mara Bridge]	E 0724323 N 9828834 [Altitude: 1470 masl]	• Approximately 600m downstream of the Mara Bridge at the Kenya-Tanzania boarder. • River zone: Rejuvenated bedrock cascade • Channel/substrate type: Single thread channel covered predominantly with armored bedrock . • Biotopes present: combination of riffles, pools and runs (with isolated pockets of silt and sand trapped behind in-stream boulders and sediment portion of the riverbank). • Vegetation: Poorly developed riparian vegetation which provides no shading to the river water. No invasive aquatic vegetation. • Land use: Exclusively wildlife conservation within Masai Mara National Reserve.

Figure 1. Photographic views of the February 2009 sampling sites.

BBM1 in the Amala (top left), BBM1.2 in the Nyangores at Kipng'eno Village (top right), BBM2 at Mara Safari Club (bottom left) and BBM3 and New Mara Bridge (bottom right).

3.2 Fishes

3.2.1 *Resident fish species in the study area*

The fish fauna of the upper reaches of the Mara River is one of the least known in the Lake Victoria watershed. Fisheries studies conducted as part of the environmental impact assessment for Ewaso Ngiro (South) Multipurpose Project identified (to genus level only) four types of fish—*Barbus* sp., *Labeo* sp., *Clarias* sp. and *Mormyrus* sp.—to be resident in the upper sections of the Mara River (Kenya Power Company, 1992). The number of resident fish species grew to seven following subsequent studies conducted in the Mara River during preliminary EFA surveys in 2007 (Tamatamah, 2007). During the present fish survey 229 fish specimens belonging to 6 genera and representing 14 different species were collected from four BBM sites in the Mara River, increasing the total number of fish species described from this river to fifteen (Table 2). The increase in number of fish species caught during the February 2009 survey is attributed to the use of an electroshocker, a sampling gear not employed in previous fish surveys in the Mara. Gillnets, seine nets and fyke nets used in earlier studies are selective to the type and size of fishes they catch. For this reason, it is recommended that electroshocking should be included in all fish studies including the Environmental Flow Assessment where the aim is to document resident fish fauna of the study river basin.

Records of length-weight measurements of fish taken at the four sampling sites are presented in Appendix 1 and photographs of voucher specimens of representative species are given in Appendix 2.

3.2.2 *Catch composition*

The data generated from a sample of 229 fish specimens caught at the four BBM sites indicates that the catch was dominated by members of the family Cyprinidae, which collectively comprised 70% of the total number of fishes. The *Barbus,* dominated by *B. altianalis*, were the most dominant among the cyprinids (41%) followed by the two *Labeo*, *L. victorianus* (15%) and *L. cylindricus* (14%) (Figure 2). Claridae, dominated by *Clarias liocephalus*, were the second most abundant group comprising about 25% of the total number of fish caught. Fish species in each of the remaining genera contributed less than 2% of total number of fish. These results are consistent with catch composition data recorded in previous Mara EFA surveys where Cyprinidae, dominated by *Barbus altianalis* and *Labeo victorianus*, were the most dominant species in the Mara River (Figure 3), possibly indicating that there has been no significant change in the composition of resident fish species in this river between the two sampling periods.

However, a notable observation from the February 2009 sampling is that *Chiloglanis somereni* was amongst the fish species caught at BBM2. *C. somereni* is a member of the Mochokidae family, which has been widely used in environmental flow assessments on the African continent due to its high requirement for fast flowing water.

Table 2. Fishes reported from the Mara River and its tributaries

Family	Species	Tamatamah (2007)	Present Survey (February 2009)			
			BBM1	**BBM1.2**	**BBM2**	**BBM3**
CYPRINIDAE	*Labeo victorianus*	✓	✓		✓	✓
	Labeo cylindricus		✓		✓	✓
	Barbus oxyrhynchus		✓		✓	
	Barbus altinialis	✓	✓		✓	✓
	Barbus amphigramma		✓			✓
	Barbus trispilopleura					✓
	Barbus kerstenii	✓			✓	
CLARIDAE	*Clarias liocephalus*		✓	✓		
	Clarias gariepinus	✓			✓	✓
MORMYRIDAE	*Mormyrus kannume*	✓			✓	✓
BAGRIDAE	*Bagrus docmac*				✓	
MOCHOKIDAE	*Chiloglanis somereni*				✓	
CICHLIDAE	*Tilapia zillii*					✓
	Haplochromis sp.					✓
	Oreochromis alcalicus grahami	✓				

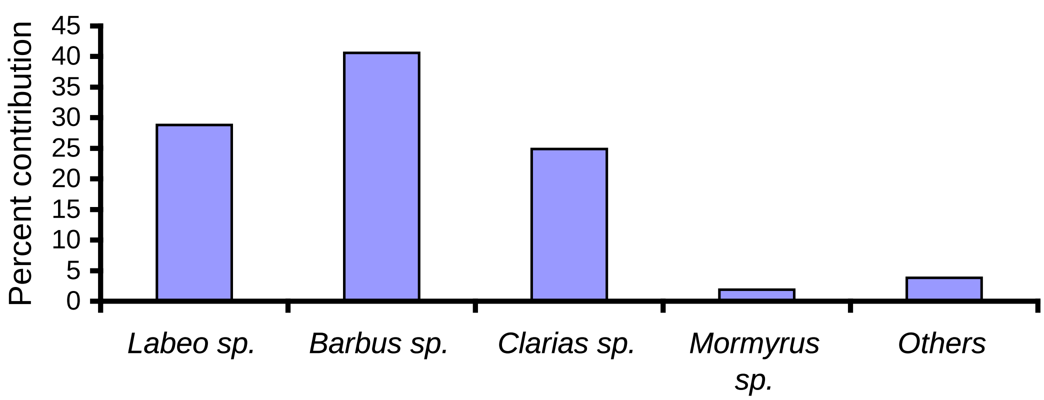

Figure 2. Relative contribution of the resident groups of fish to the total catch in February 2009. (Others = *Bagrus* sp., *Chiloglanis* sp., *Tilapia* sp. and *Haplochromis* sp.).

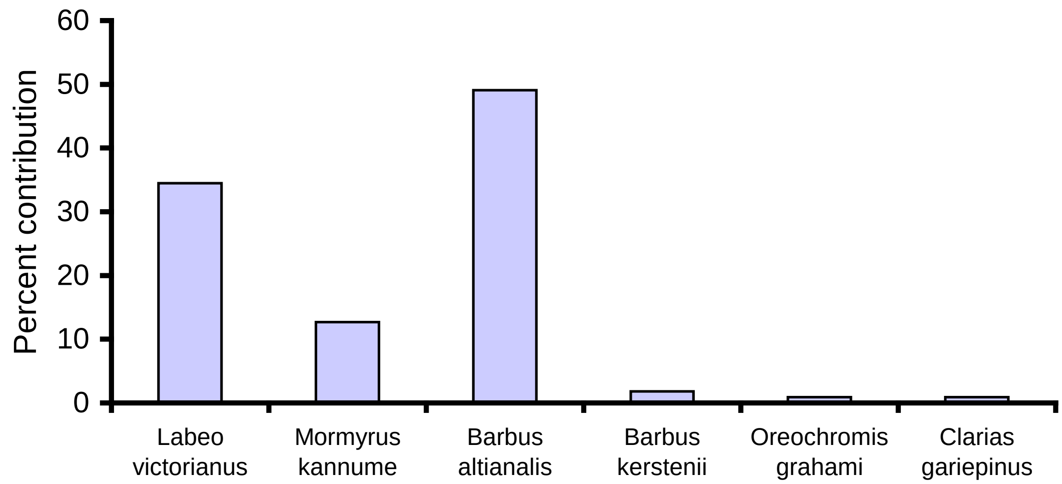

Figure 3. Relative contribution of the resident fish species to the total catch in the Mara River in July 2007 (Source: Tamatamah, 2007)

With regards to catch weight, the bulk of the biomass (> 54%) was contributed by *Labeo* followed by *Clarias* (19%), *Barbus* (15%) and *Mormyrus* (11%) (Figure 4). In terms of the major riverine habitats, more fishes were caught in riffles than pools. However, since the majority of riffle residents are juveniles as well as adults of small bodied species, the relative contribution of riffles to the total biomass was less compared to that from pool habitat (Figure 5 a, b).

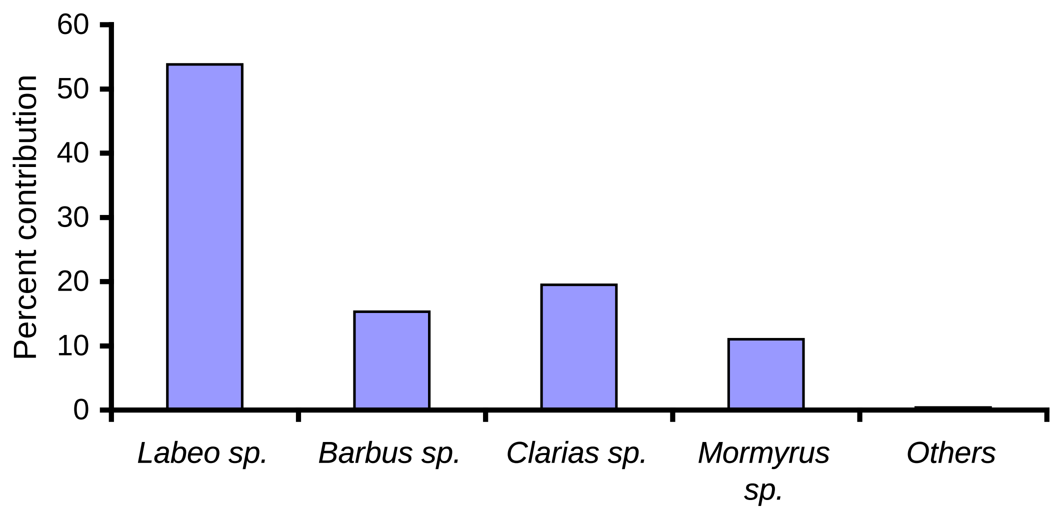

Figure 4. Relative contribution of the resident groups of fish to the total biomass in February 2009. (Others = *Bagrus* sp., *Chiloglanis* sp., *Tilapia* sp. and *Haplochromis* sp.).

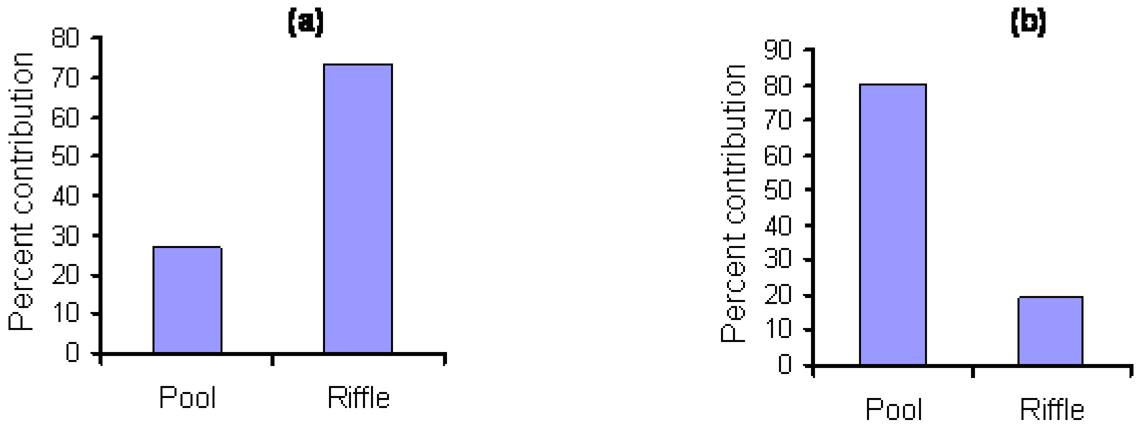

Figure 5. Relative contribution of riffles and pools to the total catch (a) and biomass (b).

3.2.3 ***Fish distribution***

The two *Labeo* species (*L. victorianus* and *L. cylindricus*) and *Barbus altianalis* were the most widely distributed fish species caught in all except BBM1.2 in the Nyangores River. Although *Labeo* favors clear, running waters in rocky habitats of small and large mountainous streams, they also do well in sediment-rich rocky biotopes in middle and lower sections of large rivers. In breeding season *Labeo* migrates upstream in numbers to breed in clear running waters in rocky substrates. During migration they use the mouth and broad pectoral fins to climb damp surfaces of barrier rocks and weirs. These features help to explain their wide altitudinal occurrences along the Mara River Basin. Of the two *Labeo*, *L. victorianus* is confined (endemic) to the Lake Victoria-Nile drainage basin (FishBase.org).

As for the two *Clarias* species, *C. liocephalus* was restricted to the higher altitude BBM sites in the Nyangores and the Amala while *C. gariepinus* was more of the mid and lower altitude resident. The distribution of these two species along the Mara River is consistent with the findings of Tougels (1986). He observed that *C. liocephalus* were abundant in high mountain streams and torrents covered by rocky substrate and were largely absent in water having temperatures higher than 18 °C. *C. gariepinus*, on the other hand, occurs mainly in quiet waters and pools but may also occur in fast flowing rivers and in rapids. The species is widely tolerant of extreme environmental conditions and possesses an accessory breathing organ which enables it to breath air in dumpy or under very dry conditions. These features make *C. gariepinus* of least priority for use in estimating Reserves for troubled river systems.

Chiloglanis somereni, a species widely employed in estimation of environmental flows in rivers across the continent, was caught by electroshocking in a riffle site at BBM2. In the

Kenyan waters the species is said to be found only in westward flowing rivers affluent to Lake Victoria (FishBase.org).

In order to account for possible site differences in fish species richness, the Shannon-Weaner diversity index (H′) was computed for fish data from each of the fish sampling sites. This index allows for a more accurate measure of biodiversity than a simple account of number of species present in a given site or habitat. Table 3 presents the Shannon-Weaner species diversity indices for sampling sites in the Mara River. The fish diversity indices ranged from zero at BBM1.2 where only one species of fish was recorded to the highest value of 1.87 at BBM3 where nine different species were recorded. However, the computation of analysis of variance (ANOVA) showed that there were no significant differences in fish species diversity and evenness between the sampling sites ($p = 0.148$). Although ANOVA did not show significant site differences in diversity and evenness, it seems biologically significant that only one species of fish was caught at BBM1.2, despite the fact that the electroshocker, the most non-selective gear, was also employed at this site. It is likely the high elevation nature of this site makes its waters unsuitably cool for some true warm water species in the Mara River. It is also likely that the existing dam and waterfall just downstream atat Kipng'eno village curtail upstream fish migration.

Table 3. Shannon-Weaner fish species diversity indices for the BBM sites in the Mara River.

Sampling site	**Species diversity index**	**Species evenness**
BBM1	1.38	0.77
BBM1.2	0	0
BBM2	1.84	0.84
BBM3	1.87	0.85

In addition, as a measure of standing biomass, catch rates (i.e. catch per unit effort - CPUE) were used as an indicator of relative abundance of fish species from the sites under survey. The two gillnets were set and left in water for 3 hours, which gave 3 gillnet-hour of effort. Similarly, 30 minutes of electroshocking at each sampling site gave 0.5 electroshocking-hour of effort. Considering a situation in which 100 fish were caught, for example, catch per unit effort was calculated by dividing the number of fish caught by the gillnet-hour (100/3) and electroshocking-hour of effort (100/0.5), resulting in a CPUE of 33.3 fish per gillnet-hour and 200 fish per electroshocking-hour, respectively. Values of CPUE computed for the four sampling sites during the February 2009 survey are given in Table 4. Higher CPUE were recorded with electroshocking than gillnets. Contrary to the computed fish species diversity indices, ANOVA showed that there were significant differences in CPUE between the two sampling gears (i.e. gillnets versus electroshocker) ($p = 0.007$). Likewise, there were significant BBM site differences in CPUE with electroshocking operation ($p = 0.006$) but not with gillnetting ($p = 0.406$) (Figure 6).

While low CPUE recorded at BBM1.2 in the Nyangores can be explained in terms of low fish species diversity, a similarly low CPUE at BBM3 was a result of the incised nature of the channel which confined the flow to the middle and deeper section of the river. These conditions forced members of the sampling team, for example, to operate the electroshocker from the banks rather than wading in through the channel. Likewise, it complicated the process of setting and hauling of gillnets, thus resulting in low sampling success.

Table 4. CPUE data for four sampling sites in the Mara River

Sampling site	**Catch per Unit Effort (CPUE)**	
	Gillnet	Electroshocking
BBM1	5.3	118
BBM1.2	0.33	66
BBM2	3.33	154
BBM3	2.7	52

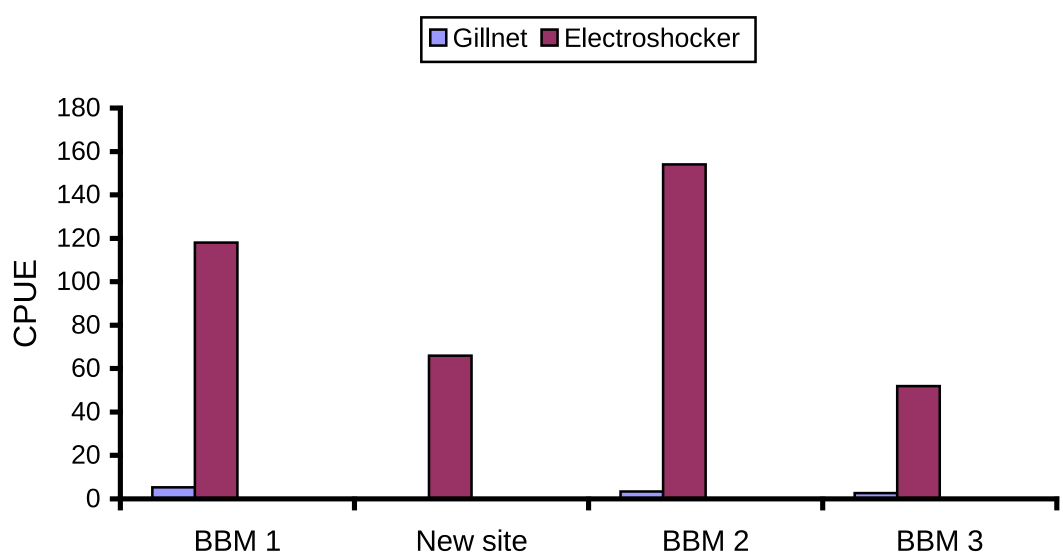

Figure 6. CPUE recorded by the two sampling gears in February 2009

3.2.4 *Sexual maturity and breeding*

The present study was conducted in February at the peak of low flows in the Mara River. However, sporadic rain spells were reported in the study area several weeks prior to this survey. For all fish species in which more than 50 specimens were caught during this survey, their catch data were analyzed to obtain the proportion of adult males and females in the sexually active stages (Figure 7). Overall, the combined 14-species data showed that 23.5% of the adult fishes carried ripe gonads. This finding in conjunction with the occurrence of a relatively large number of immature/juvenile fishes and spent males and females in the populations indicated that short rain spells in December/January were responsible for observed spawning activity in the river. The onset of breeding activity for the majority of tropical fish species is associated with rising water levels at the beginning of the rain seasons (Welcomme, 1985; Lowe-McConnell, 1975).

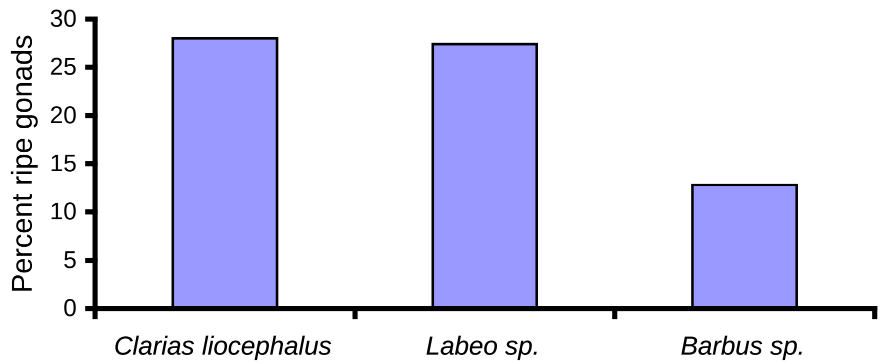

Figure 7. Percent of adult fishes carrying ripe gonads in February 2009

3.2.5 *Fish Biodiversity Status of the Mara River*

Fish fauna of the Mara River, though not distinctively unique from other East Africa rivers, includes two species important for biodiversity. These include *Oreochromis alcalicus grahami* which appear in the IUCN Red List under the "vulnerable" species category (IUCN, 2001) and *Labeo victorianus* which appears to be confined (endemic) to the Lake Victoria-Nile drainage basin (FishBase.org). Because fish fauna of the Mara bears such significant conservational status/concerns, its protection is of paramount importance.

3.3 Present state of fish and flow-related information on fish species of the Mara River

Critical flow regime characteristics can be ascertained by studying the environmental guilds of fish present in the river, i.e. grouping fish species in the manner that they respond to changing hydrology and geomorphology of the river (Welcomme et al., 2006).

This scheme is well adapted to holistic environmental flow assessment framework methodologies such as DRIFT and BBM (Arthington et al., 2003; King et al., 2003) that rely on limited knowledge and expert opinion rather than detailed local study. Understanding of fish guild responses have helped to guide river rehabilitation and restoration projects as well as releases of water for environmental maintenance.

Based on the scheme of Welcomme et al. (2006), fish fauna of the upper and middle sections of the Mara River fall into two major environmental guilds: rhithronic or main channel communities (comprising guilds inhabiting riffles and pools) and the potamonic guild which includes lotic (longitudinal migrants), lentic (floodplain), and eurytopic (low dissolved oxygen tolerant) communities (Table 5).

The **rhithronic communities** of the *true riffle* guild in the Mara River are represented by *Chiloglanis*, which in the present study were caught in the riffle sections at BBM 2. Riffle species have extended breeding seasons and deposit their eggs among the rocky riffles. *Chiloglanis* are generally insectivorous. Species inhabiting riffles have been widely used in EFA studies because they have fairly well defined and strict flow requirements and usually require very well oxygenated water. Because they inhabit riffles and rocky areas, these species are sensitive to low flows which bring about habitat changes. Species in the *pool guild* of the **rhithronic communities** in the Mara River are represented by *Barbus*. They generally inhabit the slack regions of back eddies where emergent and floating vegetation may occur. They tend to be insectivorous, feeding on the drift dislodged from the riffles or on insects falling into the river from riparian vegetation. They may be either breeding in the riffles (limnophilic) or by attaching their eggs to vegetation (phytophilic). They usually have well defined home ranges, and habitats delimited by depth, current strength and the distribution of vegetation. These species are also disturbed by changes to the flow regime that desiccate the pools or leave them for long periods without flow so they become anoxic. They also generally rely on the delicate balance between pool and riffle of the main channel and respond negatively to any influence that changes this balance.

Labeo are the true *lotic* guild of the **potamonic communities** in the Mara River. *Labeo* are generally longitudinal migrants that move within the main river channel or up and down tributaries as juveniles seek riffle/rapid habitats and adults inhabit both riffles and pools. They require relatively high dissolved oxygen levels (second to riffle guilds) and as such they are sensitive to reductions in water quality and may locally disappear under eutrophic conditions or when their river is dammed and prevents migration. Lotic guild species have one breeding season a year that is closely linked to peak flows, and they rely on increased flow as a cue for migration and maturation. They are also vulnerable to changes in the timing of high flow events that are inappropriate to their breeding seasonality and for the needs of drifting larvae. At the present survey there were no true *lentic guild* species of the **potamonic communities,** i.e. non-migrant floodplain residents tolerant to low dissolved oxygen concentrations or even to complete anoxia.

The *Oreochromis*, *Tilapia*, *Haplochromis*, *Clarias gariepinus* and *Mormyrus* are among the true representatives of the **eurytopic** (generalized and extremely adaptable) **guild** in the Mara. This guild occupies the riparian zone and particularly the vegetation of the main channel and floodplain waterbodies, and individuals may move onto the floodplain to occupy similar habitats during flooding. The species usually tolerate low dissolved oxygen. They are generally repeat breeders or may breed during both high and low flow phases of the hydrograph, as such breeding may be independent of flow cues. They are able to adapt behaviourally to altered hydrographs, are extremely flexible and may adopt other habitats (especially *Oreochromis*, *Tilapia*, and *Haplochromis*) as river conditions change. Thus, they generally increase in number as other species decline. Species in this guild are colonizers of regulated systems and often increase to pest levels following control of flooding and stabilization of river hydrographs, or declines in water quality through eutrophication. The habits of this guild make them suitable for rearing in ponds and they have been widely distributed for aquaculture (Welcomme, 1988). Species in this guild may be affected negatively by changes in riparian structure that suppress vegetation.

Table 5. Representative fish species in major environmental guilds in the Mara River

Fish community type	**Ecological guild**	**Representative fish genera/species in the Mara**	**Percent of the total catch**	**Sensitivity to flow**
Rhithronic communities	Riffle guild	*Chiloglanis*	1.7	Critical
	Pool guild	*Barbus*	40.7	High
Potamonic communities	Lotic guild	*Labeo, Clarias liocephalus*	52.4	Very high
	Lentic guild	No representative species in the Mara	-	High
	Eurytopic guild	*Clarias gariepinus*, *Tilapia*, *Oreochromis*, *Haplochromis*, *Mormyrus.*	5.2	Low

It can be inferred from the information presented in Table 5 that the highest percent (94.8%) of resident fish species in the Mara River comprise the flow-sensitive guilds, and the eurytopic guild has the lowest number of individuals in the catch. This suggests the river is still in fairly good condition, and that maintaining the Reserve is indeed critical to maintain the current fish fauna in this river.

3.4 Classification of Sites: Present Ecological State (PES)

In order to use the EFA process in targeting management strategies, the sites were ranked according to their present and desired ecological state. Present Ecological State (PES) recognizes the natural, or reference, conditions at each site and includes a judgment of how far each site has changed from those conditions. Sites were ranked from A (natural) to F (critical/extremely modified). Then sites were assigned a Trajectory of Change, indicating whether each component was getting better or worse under the current river management regime. Sites were also classified according to their Ecological Importance and Sensitivity (EIS), indicating their importance for maintenance of ecological diversity and system functioning on local and wider scales, their ability to resist disturbance and their capability to recover from disturbance. Finally, sites were assigned an Ecological Management Category (EMC), summarizing the overall objective or desired state for each site. Sites were ranked from A (natural) to D (largely modified); as categories E and F were not considered sustainable, they were not included in the EMCs.

3.4.1 *The Present Ecological State* (PES)

BBM 1 was classified as B: slightly modified, evidenced by the following:

- Most of the resident fish species in the upper sections of the Mara River were caught at this site.
- *Oreochromis alcalicus grahami* is native to the system and ranked as "vulnerable" in the IUCN Red List. Likewise, some regional conservation rankings identify *L. victorianus* as an endemic fish species to the Lake Victoria basin. These species were caught at this site.

BBM 2 was classified as A/B: Pristine to slightly modified, evidenced by the following:

- Almost all resident fish species in the upper sections of the Mara River were caught at this site.
- The site had a fairly high fish species diversity index score second to that of BBM3.
- *Chiloglanis somereni*, one of the most flow-sensitive species, was caught at this site only.
- *L. victorianus*, an endemic fish species to the Lake Victoria basin, was also caught at this site.

BBM 3 was classified as A/B: Pristine to slightly modified, evidenced by the following:

- Almost all resident fish species in the upper sections of the Mara River were caught at this site
- *L. victorianus*, an endemic fish species to the Lake Victoria basin, was also caught at this site.
- The site had the highest fish species diversity index (H' score approaching 2.0).

BBM 1.2 was classified as C: moderately modified, evidenced by the following:

- A single species of fish caught, making it the site with the lowest species diversity index score.
- The river has been impounded for hydropower generation 1 kilometre downstream of the site. The fall below the dam arguably may curtail upstream fish migrations.
- Intense human activities such as designated areas for car washing.

3.4.2 *The Trajectory of Change*

A negative (-) score was assigned as the trajectory of change for all four BBM sites.

- Baseline information (estimates of fish abundance, biomass or catch per unit effort) for the component is lacking and therefore difficult to indicate, with certainty, the direction of change under the present river management regime. A negative value is given to indicate that the component has possibly slightly changed from natural conditions. Very low waters resulting from unregulated abstractions and unmonitored river levels also contributed to the assignment of a negative trajectory score to the BBM sites.

3.4.3 *Ecological Importance and Sensitivity* (EIS)

For all except BBM 1.2 in the Nyangores the EIS was high, due to the following factors:

- BBM 1
    - *Oreochromis alcalicus grahami* is categorized as "vulnerable" in the IUCN Red List and *L. victorianus* is endemic to the Lake Victoria basin; hence there is a strong motivation for maintaining or improving the present river management regime.

- BBM 2
    - Presence of *L. victorianus*, which is endemic to the Lake Victoria basin, and *Chiloglanis somereni*, which represents highly flow sensitive species, provides strong motivation for maintaining or improving the present river management regime.
    - The site is within a group ranch conservation area.

- BBM 3
    - Presence of *L. victorianus* which is endemic to the Lake Victoria basin.
    - The site is within the conservation area (Masai Mara National Reserve).

3.4.4 *Ecological Management Category* (EMC)

In all except BBM 1.2 the EMC was set at A/B, Pristine to slightly modified (the same level as the PES) in order to maintain the present good conditions. For BBM 1.2 the EMC was set at B to improve the state of this site.

3.5 Objectives and motivations for fish species at BBM sites

The main objective was stated as "the fish community in the Mara River should include a large proportion of both highly and moderately flow sensitive species such as *Chiloglanis* and *Labeo*, respectively." Furthermore, fish species diversity should not be less than 2 (i.e. H' $\geq$ 2), which also translates into even distribution of individuals among species.

Table 6 provides details of specific objectives and motivations for fish, derived at BBM sites.

Table 6: Specific objectives and associated motivations for fish species at BBM sites

Objective	Motivation
Maintain the low flow requirements during the driest month of a drought year	• to inundate appreciable area of the channel to sustain flow-sensitive species of fish such as *Chiloglanis* and *Labeo* in sites where they occur.
Maintain the low flow requirements during the wettest month of a drought year	• to inundate more riffle sections to increase habitat diversity for fish. • to inundate more area of the channel to permit fish passage over obstacles.
Maintain the low flow requirements during the driest month of a maintenance year	• to inundate more habitats to provide natural variability to maintain diverse fish species assemblage • to maintain active channel flows to inundate benches and sustain emergent vegetation • to permit more fish passage over obstacles • to inundate pools to improve water quality (DO, temperature, etc.)
Maintain the low flow requirements during the wettest month of a maintenance year	• to provide cue for migration in spawning migrant fishes such as *Labeo*. • to inundate macrophytes and emergent vegetation along banks to provide more habitats (shelter, feeding) for fishes, especially juvenile stages
Maintain small pulses of higher flow that occur in the drier months	• to prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates • to flush out organic matter, thus improving water quality for fish • to facilitate nutrient transfer between floodplains and the river to increase primary productivity and food for fishes.
Maintain major peaks in the river's flow level that occur at a given recurrence interval	• to maintain macro channel features and provide diversity of physical habitats for fish • to scour and flush bed of sediment deposits to expose riffles which were clogged with sediments • to provide cue for spawning migrant fishes such as *Labeo* to

	start upstream spawning migration. • to inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity). • to inundate higher bank vegetation to provide more habitat (shelter, feeding, breeding) for fishes.

3.6 Target indicators for fish

The following fish species were used as indicators with the objective of maintaining abundances comparable to reference conditions:

Target species: Species that are highly to fairly sensitive to flow: *Chiloglanis* sp. (riffle guild), *Labeo* sp. and *Clarias liocephalus* (lotic guild) and *Barbus* sp. (pool guild).

4.0 RECOMMENDED FLOWS

The flows required to meet the desired stated objectives were assessed for all BBM sites in the Mara River. The following flows were considered:

(i) Dry season low flows for maintenance years
(ii) Wet season low flows for maintenance years
(iii) Wet season high flows for maintenance years
(iv) Dry season low flows for drought years
(v) Wet season low flows for drought years
(vi) Wet season high flows for drought years

Comparing fish species lists produced during the 2007 and 2009 EFA studies, *Chiloglanis somereni* and *Clarias liocephalus* are the two flow sensitive species which were not encountered in the 2007 surveys. In addition, flow levels observed in February 2009 were much lower than either of the original EFA sampling events. In fact, the flows were lower than recommended Reserve levels for dry season low flows at BBM1, BBM2 and BBM3. Even at BBM2 where *Chiloglanis* were encountered during this sampling period, the observed velocity of 0.21 m/s is considered below the minimum recommended velocity for this species during most phases of the life cycle. According to Water for Africa (2008), fast-rheophilic fishes including *Chiloglanis* require fast-flowing water (0.3 m/s) during most phases of their life cycle, although they can survive the dry season drought years at velocities lower than 0.3 m/s. For the present study, this indicates that while flow levels recorded in February 2009 may provide conditions for bare minimum survival of the flow sensitive species, they are not sustainable as dry season minimum flows in the long term. As a result, new motivations and flow recommendations would be required for all BBM sites. The flows observed at BBM sites in February 2009 and Reserves for different flow categories prescribed during the 2007 EFA workshop are given in Tables 7 and 8, respectively. New recommended Reserves/flows after the February 2009 field visit are given in Table 9. Tables 10, 11, 12, 13, 14 and 15 describe the February 2009 fish requirement for various flows in terms of velocity, which was then converted to depth and discharge using hydraulic simulations generated by the Hydraulic Engineer in February 2009. The motivations for each flow and the consequences of not providing them are also described for each site.

Table 7. Summary of flow characteristics measured at the BBM sites during February 2009 Field visit.

Site	Mean velocity (m/s)	Total discharge (m^3/s)
BBM1	0.11	0.2
BBM1.2	0.19	0.6
BBM2	0.21	1.0
BBM3	0.11	1.1

Source: Ndomba (2009)

Table 8. Fish requirement (velocity, depth and discharge) for various flows determined during Mara EFA Workshop in October 2007

Flow category	**BBM 1**			**BBM 2**			**BBM 3**		
	Vel. (m/s)	Depth (m)	Q (m^3/s)	Vel. (m/s)	Depth (m)	Q (m^3/s)	Vel. (m/s)	Depth (m)	Q (m^3/s)
Dry season low flows for drought years	0.29	0.197	0.3	0.23	0.22	1.0	0.21	0.36	2.0
Dry season low flows for maintenance years	0.35	0.26	1.0	0.45	0.32	4.0	0.37	0.58	6.0
Wet season low flows for drought years	0.35	0.26	1.0	0.45	0.32	4.0	0.37	0.58	6.0
Wet season low flows for maintenance years	0.43	0.34	2.0	0.56	0.37	6.0	0.60	0.86	15.0
Wet season floods in a drought year	0.56	0.49	4.0	0.80	0.47	12.0	0.70	0.98	20.0
Wet season floods in a maintenance year**	0.77	0.78	12.0	0.94	0.52	16.0	1.50	1.80	90.0

** For this flow category the prescribed discharges are required to occur twice in January-February for one-time breeders and 2-3 times per year for repeated breeders.

Table 9. Recommended Reserve for various flows determined after February 2009 Field visit.

Flow category	**BBM 1**			**BBM1.2**		
	Aver. Vel. (m/s)	Aver. Depth (m)	Aver. Q (m^3/s)	Aver. Vel. (m/s)	Aver. Depth (m)	Aver. Q (m^3/s)
Dry season low flows for drought years	0.19	0.19	0.30	0.18	0.219	0.8
Dry season low flows for maintenance years	0.37	0.27	1.25	0.28	0.33	2.00
Wet season low flows for drought years	0.37	0.27	1.25	0.28	0.33	2.00
Wet season low flows for maintenance years	0.30	0.48	2.00	0.39	0.45	4.00
Wet season floods in a drought year	0.36	0.67	4.00	0.56	0.63	8.00
Wet season floods in a maintenance year**	0.52	1.12	12.00	0.71	0.78	13.00

Flow category	**BBM 2**			**BBM3**		
	Aver. Vel. (m/s)	Aver. Depth (m)	Aver. Q (m^3/s)	Aver. Vel. (m/s)	Aver. Depth (m)	Aver. Q (m^3/s)
Dry season low flows for drought years	0.29	0.14	0.40	0.18	0.36	1.40
Dry season low flows for maintenance years	0.49	0.18	1.00	0.35	0.71	7.00
Wet season low flows for drought years	0.49	0.18	1.00	0.35	0.71	7.00
Wet season low flows for maintenance years	0.60	0.38	6.84	0.52	0.98	15.00
Wet season floods in a drought year	1.63	0.28	12.00	0.61	1.11	20.00
Wet season floods in a maintenance year**	1.77	0.32	16.00	1.25	1.87	90.00

** For these flow categories the prescribed discharges are required to occur twice in January-February for one-time breeders and 2-3 times per year for repeated breeders.

Note: The table gives average values for the most critical river cross-sections (taken at riffles areas) at each BBM site. Therefore, the maximum velocities could vary between 1.4 to 2.3 times the average velocities recorded here.

Table 10. Recommended flows for the dry season low flows for drought years

Site	Average Velocity (m/s)	Average Depth (m)	Discharge (m^3/s)	Motivation	Consequences of not providing this flow
BBM1	0.19	0.19	0.30	The low flows during the driest month of a drought year are required to: • maintain hydrological connectivity in the system (upstream-downstream) • maintain inundation of critical habitats (eg., riffles) in order to sustain moderately flow-sensitive species such as *Labeo* and *Clarias liocephalus* caught at this site.	Could have catastrophic effect on the survival of *Labeo* and *C. liocephalus*. Young and immature stages of *Labeo* and *C. liocephalus* do not tolerate pools, and once inundation of riffles and channel connectivity is not maintained, their survival is threatened. Although *C. liocephalus* is a relatively hardy/tolerant fish, its strict water temperature requirements (< 18°C) require that reasonable water flow (≥ 3 m/s) is maintained during drought months to minimize large diurnal fluctuations in water temperature.
BBM1.2	0.18	0.219	0.8	The low flows during the driest month of a drought year are required to: • maintain hydrological connectivity in the system (upstream-downstream) • maintain inundation of critical habitats (eg., riffles) and maintain low water temperature necessary for survival of the moderately flow-sensitive species found at this site (i.e. *Clarias liocephalus*).	Could have catastrophic effect on the survival of *C. liocephalus*. *C. liocephalus* do not tolerate water temperatures above 18ºC
BBM2	0.29	0.14	0.40	These flows are required to: • maintain hydrological connectivity in the system (upstream-downstream) • maintain inundation of critical habitats (eg., riffles) in order to	Could have catastrophic effect on the survival of sensitive species such as *Chiloglanis*. *Chiloglanis* do not tolerate pools, and once inundation of

				sustain (survival of) flow-sensitive species caught at this site (e.g. *Chiloglanis* sp) Most of the EFA studies in Africa have used *Chiloglanis* sp. as the most sensitive species and therefore used them as the basis for recommending flows for respective river basins. *Chiloglanis* has a very high requirement of fast flowing water in riffles with recommended minimal flow for normal growth given as ≥ 0.3 m/s. The velocity prescribed for this BBM site provides enough depth to fully inundate the riffles, which made up > 75% of riverine habitats during present survey. *Chiloglanis* were caught only from this site.	riffles and channel connectivity is not maintained, their survival is threatened.
BBM3	0.18	0.36	1.40	• maintain hydrological connectivity in the system (upstream-downstream) including pools and backwaters that sustain eurytopic species such as *Clarias gariepinus*, *Tilapia*, *Haplochromis*, and *Mormyrus*. • provide natural habitats variability to maintain diverse species assemblage	Could have catastrophic effect on the survival of even the most tolerant species such as *Clarias gariepinus*, *Tilapia*, *Haplochromis*, and *Mormyrus*.

Table 11. Recommended flows for the dry season low flows for maintenance years

Site	Max Velocity (m/s)	Max Depth (m)	Discharge (m^3/s)	Motivation	Consequences of not providing this flow
BBM1	0.37	0.27	1.25	The low flows during the driest month of a maintenance year are required to • inundate more riffle sections to increase habitat diversity and therefore fish species diversity • maintain active channel flows to inundate benches and	Will curtail optimal growth rate of many species and present diversity. It may result in lowering fish standing biomass in that reach of the river.

				sustain emergent vegetation that fish need for shelter/cover • permit more fish passage over obstacles • flush out pools to improve water quality (more favourable habitats for fish). The recommended discharge results in an average hydraulic depth which is enough to cover appreciable portion of mid-channel riffles. The resultant maximum velocity is also suitable for juveniles *Labeo*, *Clarias liocephalus* and *Barbus*, which need appreciable inundated vegetation for cover/shelter and feeding.	
BBM1.2	0.28	0.33	2.00	These flows are required to: • inundate more riffle sections to increase habitat and fish species diversity • maintain active channel flows to inundate benches and sustain emergent vegetation that fish need for shelter/cover • flush out pools to improve water quality necessary to maintain *Clarias liocephalus*.	Will curtail optimal growth rate of *Clarias liocephalus*.
BBM2	0.49	0.18	1.00	• maintain inundation of critical habitats (eg., riffles) in order to sustain (survival of) moderately and highly flow-sensitive species caught at this site (e.g., *Labeo*, *Chiloglanis*, etc)	Will curtail survival and/or optimal growth rate of fish species such as *Labeo* and *Chiloglanis*
BBM3	0.35	0.71	7.00	Inundate the main channel (especially vast area of riffles, pools and benches) to provide a variety of habitats for resident fish species. The recommended discharge results in an average hydraulic depth which is enough to cover appreciable	Will curtail high fish species diversity recorded at this site.

				portion of mid-channel riffles and pools. The resultant maximum velocity is also suitable for adults and juveniles of flow sensitive species and other species which need appreciable inundated vegetation for cover/shelter and feeding.	

Table 12. Recommended flows for the wet season low flows for drought years

Site	**Max Velocity (m/s)**	**Max Depth (m)**	**Discharge (m^3/s)**	**Motivation**	**Consequences of not providing this flow**
BBM1	0.37	0.27	1.25	The low flows during the wettest month of a drought year are required to • inundate more riffle sections to increase habitat diversity • maintain active channel flows to inundate benches and sustain emergent vegetation • permit more fish passage over obstacles • inundate and flush out pools to improve water quality (more favourable habitats for fish). The primary motivation for maintaining reasonably higher low flows in a wet season of the drought year would be to inundate the main channel (especially riffles and benches) to provide a variety of habitats for resident fish species. This would provide more resources (space, food, etc.) than that available during the dry season. This allows fish to grow faster. The recommended discharge would result in an average hydraulic depth that would cover an appreciable portion of mid-channel riffles. The	Limit available fish habitats resulting in low fish (and macroinvertebrate = fish food) standing biomass in that reach of the river.

				resultant average velocity would be suitable for young and immature stages of *Labeo*, *Clarias liocephalus* and *Barbus*, which need appreciable inundated vegetation for cover/shelter and feeding.	
BBM1.2	0.28	0.33	2.00	• inundate more riffle sections to increase habitat diversity for *Clarias liocephalus* found at this site. • maintain active channel flows to inundate benches and sustain emergent vegetation used as shelter for fish and insects used as food for fish.	Limit available fish habitats resulting in low fish (and macroinvertebrate = fish food) standing biomass in that reach of the river.
BBM2	0.49	0.18	1.00	• inundate more riffle sections to increase habitat diversity for highly flow sensitive species such as *Chiloglanis*. • maintain active channel flows to inundate benches and sustain emergent vegetation • permit more fish passage over obstacles • inundate and flush out pools to improve water quality (more favourable habitats for fish) for pool and eurytopic guild fishes found at this site.	Limit available fish habitats resulting in low fish (and macroinvertebrate = fish food) diversity and standing biomass in that reach of the river. One of the highest fish diversity scores was recorded at this site
BBM3	0.35	0.71	7.00	• inundate more riffle sections to increase habitat diversity for many moderately floe sensitive species found at this site • maintain active channel flows to inundate benches and sustain emergent vegetation • permit more fish passage over obstacles • inundate and flush out pools	Limit available fish habitats resulting in low fish (and macroinvertebrate = fish food) diversity and standing biomass in that reach of the river. One of the highest fish diversity scores was recorded at this site

				to improve water quality (more favourable habitats for fish) for pool and eurytopic guild fishes found at this site.	

Table 13. Recommended flows for the wet season low flows for maintenance years

Site	Max Velocity (m/s)	Max Depth (m)	Discharge (m^3/s)	Motivation	Consequences of not providing this flow
BBM1	0.30	0.48	2.00	The low flows during the wettest month of a maintenance year are required to • provide cue for migration and spawning in fishes such as *Labeo* caught at this site. • inundate macrophytes and emergent vegetation along banks (some fish need vegetation to deposit their eggs). The primary motivation for having low flows in a wet season of the maintenance year would be to inundate vast areas of the channel (including lower bank aquatic vegetation – sedges) and increase habitat diversity. Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season.	Will curtail optimal growth rate for all fish species in the river reach and result in stunted growth and low fish standing biomass. Will affect successful recruitment in the next spawning season. Adult fish which are poorly fed during resting period would have poor spawning and therefore poor recruitment success.
BBM1.2	0.39	0.45	4.00	Inundate vast areas of the channel (including lower bank aquatic vegetation – sedges and riffles) and increase habitat diversity. Increased habitat diversity would provide ample resources (shelter and food) enabling *Clarias liocephalus* found at this site to attain good body condition index,	Will curtail optimal growth rate for all fish species in the river reach and result in stunted growth and low fish standing biomass. Will affect successful recruitment in the next spawning season. Adult fish

				fast growth rates and accumulate enough energy for successful spawning in the coming season.	which are poorly fed during resting period would have poor spawning and therefore poor recruitment success.
BBM2	0.60	0.38	6.84	Inundate vast areas of the channel (including lower bank aquatic vegetation – sedges and riffles) and increase habitat diversity. Riffles are important for flow sensitive species including *Chiloglanis* found at this site Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season. Provide cue for migration and spawning in fishes such as *Labeo* caught at this site.	Will curtail optimal growth rate for all fish species in the river reach and result in stunted growth and low fish standing biomass. Will affect successful recruitment in the next spawning season. Adult fish which are poorly fed during resting period would have poor spawning and therefore poor recruitment success. BBM2 and BBM3 were the sites with highest fish diversity scores.
BBM3	0.52	0.98	15.00	Provide cue for migration and spawning in fishes such as *Labeo* caught at this site. Inundate vast areas of the channel (including lower bank aquatic vegetation – sedges and riffles) and increase habitat diversity. Riffles are important for flow sensitive species including *Labeo* found at this site. Increased habitat diversity would provide ample resources (shelter, food, hiding from predators, etc.) enabling fish to attain good body condition index, fast growth rates and accumulate enough energy for successful spawning in the coming season.	Will curtail optimal growth rate for all fish species in the river reach and result in stunted growth and low fish standing biomass. Will affect successful recruitment in the next spawning season. Adult fish which are poorly fed during resting period would have poor spawning and therefore poor recruitment success.

Table 14. Recommended flows for the wet season floods in a drought year

Site	**Max Velocity (m/s)**	**Max Depth (m)**	**Discharge (m^3/s)**	**Motivation**	**Consequences of not providing this flow**
BBM1	0.36	0.67	4.00	Small pulses of flood that occur in the drier months are necessary to: • prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates • maintain active channel features • flush out organic matter, thus improving water quality • facilitate nutrient transfer between floodplains and the river Some small floods are necessary in the wet season of a drought year, to inundate areas of the channel above the riffles in order to provide additional habitats for near-optimal growth of fish species. The floods will also help to flush out organic matter deposited on lower banks and small pools that would otherwise impact on water quality.	Curtail optimal growth rates of fish in terms of less living habitats and poor water quality.
BBM1.2	0.56	0.63	8.00	• prevent sediment build-up on river bed, thus increasing habitat variability for fish and invertebrates (fish food). Sediment build-up could choke riffles which are critical for survival of flow sensitive species caught at this site (i.e. *Clarias liocephalus*). • maintain active channel features flush out organic matter, thus improving water	Curtail optimal growth rates of fish in terms of less living habitats and poor water quality.
BBM2	1.63	0.28	12.00	• prevent sediment build-up on river bed, thus increasing	Curtail optimal growth rates of fish in terms of less living

				habitat variability for fish and invertebrates (fish food). Sediment build-up could choke riffles which are critical for survival of flow sensitive species caught at this site (e.g., *Chiloglanis* and *Labeo*). • maintain active channel features • flush out organic matter, thus improving water quality	habitats and poor water quality. Low fish diversity
BBM3	0.61	1.11	20.00	Some small floods are necessary in the wet season of a drought year, to inundate areas of the channel above the riffles in order to provide additional habitats for near-optimal growth of fish species. The floods will also help to flush out organic matter deposited on lower banks and small pools that would otherwise impact on water quality. Lotic, pool and eurytopic guild species were caught at this site.	Curtail optimal growth rates of fish in terms of less living habitats and poor water quality. Result in low fish diversity

Table 15. Recommended flows for the wet season floods in a maintenance year

Site	Max Velocity (m/s)	Max Depth (m)	Discharge (m^3/s)	Motivation	Consequences of not providing this flow
BBM1	0.52	1.12	12.00	• maintain macro channel features and provide diversity of physical habitats for many species of fish found at BBM1 • scour and flush the bed of sediment deposits to expose riffles which were clogged with sediments. Riffles are preferred habitats of flow-sensitive species such as *Labeo* and juveniles of other species found at this site. • cue spawning migrants such	Failure in recruitment success of the resident fish species. Less physical habitat due to sediment deposition on the river channel bed.

				as *Labeo* to start upstream spawning migration. • inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity). Two of the three fish species caught at this site (*Labeo* and *Barbus*) have one breeding season a year that is closely linked to peak flows. *Labeo* and *Barbus* also rely on increased flow as cues for migration and maturation. For these species, one flood would be necessary at the beginning of rainy season to bring about maturation of gonads and trigger upstream spawning migration into suitable spawning grounds (e.g. small tributaries for Labeo). Another flood towards the end of wet season will be necessary to allow spawners and their young to drift back into the main river channel The third type of species caught at this site (*Oreochromis* sp.) are generally repeat breeders, although in drought years may even breed during low flow phases of the hydrograph. For *Oreochromis*, 2 flood flows in the wet season would be advantageous for their repeated spawning habits.	
BBM1.2	0.71	0.78	13.00	• maintain macro channel features and provide diversity of physical habitats for *Clarias liocephalus* found at this site. • scour and flush the bed of sediment deposits to expose riffles which were clogged with sediments. Riffles are preferred habitats of the highly flow sensitive fish (*Clarias liocephalus*) found at this site. • inundate and recharge larger higher banks, allowing for	Failure in recruitment success of the resident fish species. Less physical habitat due to sediment deposition on the river channel bed.

				nutrient transfer into the main river channel (increase primary and secondary productivity). *Clarias liocephalus* is predominantly an insectivore.	
BBM2	1.77	0.32	16.00	• maintain macro channel features and provide diversity of physical habitats for many species of fish found at BBM2 • scour and flush the bed of sediment deposits to expose riffles which were clogged with sediments. Riffles are preferred habitats of the most flow sensitive species (i.e. *Chiloglanis*) caught only at this site • cue spawning migrants such as *Labeo* to start upstream spawning migration. • inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase primary productivity).	Failure in recruitment success of the resident fish species. Less physical habitat due to sediment deposition on the river channel bed.
BBM3	1.25	1.87	90.00	• maintain macro channel features and provide diversity of physical habitats for many species of fish found at BBM3 • scour and flush the bed of sediment deposits to expose riffles which were clogged with sediments. Riffles are preferred habitats of flow-sensitive species such as *Labeo* and juveniles of other species found at this site. • cue spawning migrants such as *Labeo* to start upstream spawning migration. • inundate and recharge larger higher banks, allowing for nutrient transfer into the main river channel (increase	Failure in recruitment success of the resident fish species. Less physical habitat due to sediment deposition on the river channel bed.

				primary productivity). Two of the three fish species caught at this site (*Labeo* and *Barbus*) have one breeding season a year that is closely linked to peak flows. *Labeo* and *Barbus* also rely on increased flow as cues for migration and maturation. For these species, one flood would be necessary at the beginning of rainy season to bring about maturation of gonads and trigger upstream spawning migration into suitable spawning grounds (e.g. small tributaries for *Labeo*). Another flood towards the end of wet season will be necessary to allow spawners and their young to drift back into the main river channel Members of eurytopic guild caught at this site (*Tilapia, Clarias gariepinus*, *Mormyrus* and *Haplochromis*) are generally repeat breeders, although in drought years may even breed during low flow phases of the hydrograph. For these species, 2 flood flows in the wet season would be advantageous for their repeated spawning habits.	

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