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Identification of migratory and spawning habitats of *Clarias gariepinus* (Burchell, 1822) in Lake Edward - Ishasha River watershed, Albertine Rift Valley, East Africa

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Abstract
Catfish (1103) were sampled twice monthly with beach-seines, tagged with external T-bar Anchor tags and released at four estuarine sites, in July – August; September - October 2011; February-March and; April - May 2012. The study aimed to identify catfish migratory and spawning habitats around the Lake Edward watershed. The relocations for 115 *C. gariepinus* recaptured within the lake watershed were determined and spawning condition examined. About 73% of catfish were recaptured from the littoral, 11.3% from marginal wetlands, 8.7% from the pelagic, 3.5% from river mouths and river channel, respectively. Among the ripe females, about 46% were recaptured from the marginal wetlands, 23% from river channel, and about 15.5% from the littoral and river mouths, respectively. The selected habitats were identified as migratory and spawning grounds for *C. gariepinus*. These should be conserved and protected from human activities and development programs and their connectivity ensured.

Keywords: Albertine Rift valley, Lake Edward, Ishasha River, *Clarias gariepinus*, migratory habitats, spawning grounds.

1. Introduction

Freshwater fisheries are important for food security and livelihoods among the local communities in many tropical countries [1]. This is particularly the case in the Albertine Rift region, where millions of people dependent on the African Great Lakes for both food and livelihoods [2]. However, the fastest growing population, rapid industrialization and development around the watersheds of these lakes are continuously increasing the pressure on the aquatic resources [3, 2]. The African Great Lakes are well-known for their high levels of diversity and endemicity [4, 5, 6]; and due to the spectacular abilities of speciation in some fish families such as cichlids, these lakes were considered as natural laboratories by many ecologists [7, 8, 9, 6, 10, 11, 12]. The lakes are also renowned for their valuable commercial fisheries [2]. One of these lakes is Lake Edward, located on the border between the Democratic Republic of the Congo (DRC) and Uganda; and sustains livelihoods for the large majority of local riverine communities [13, 14, 15, 16]. In Lake Edward watershed and all other African Great Lakes, there is an overlap of natural resources; these include mainly fisheries, agricultural, and recently oil and gas resources. The region is currently the hub for oil exploration by multinationals and eventual exploitation from lakes' inshore and offshore [17, 18]. This pattern, presents both economic opportunities and environmental challenges due to negative impacts associated with human activities in the uses of these resources and development of programmes related to their extraction [19]. Therefore, there is concern over the degradation of the aquatic environment, including destruction of fish breeding habitats around these lakes and their adjacent rivers, among others. Previous studies reported strong ecological and evolutional relationships existing between Lake Edward and all of the lakes of the Albertine Rift region and their affluents [20, 21, 12]. There are many rivers draining into Lake Edward, the largest are Rutshuru, Ishasha and Ntungwe Rivers located in the south-eastern and Lubiriha and Nyamugasani Rivers located in the north-eastern of the lake [22-26]. These rivers and numerous other streams and wetlands are reckoned to serve as fish ecological refuges [12, 61] and to provide important fish spawning and nursery grounds for the lake repopulation [27, 5].

However, due to their dynamic nature, riverine fish stocks are extremely vulnerable to the environmental degradation [28-30, 1]. This is particular to the potamodromous species, for which, migratory habits generally depend both on longitudinal and lateral connectivity among habitats [28, 1]. One of such species is the African catfish *Clarias gariepinus*; this species is among few and large African freshwater species known as migratory fish species. In some regions in Africa, the movement and habitat use of *C. gariepinus* have been for interest of many studies in both lotic [31-36] and lentic environments [37-41] within its natural range. Whereas, in the Albertine Rift region, though some studies have discussed the potential significance of localized seasonal movements [24, 43, 5], and despite the recognition of *C. gariepinus* movements along many rivers and streams in the Lake Edward watershed [27, 42], such information is still largely undocumented. Furthermore, Lake Edward and its affluents have always been important catfish fisheries for decades [22, 44, 23, 24, 45, 25, 20, 15], but little if not any information exists on many ecological aspects of the catfish in the lake watershed. Consequently, previous studies [46, 47, 15, 48, 19] suggested that migratory habitats, breeding and nursery grounds for fish species in the African Great Lakes and in their adjacent rivers should be identified, mapped and gazetted in order to enhance the capacity of the fisheries management and conservation planning [46, 47, 15, 48, 19]. Hence, this study aimed to identify migratory habitats and spawning and nursery grounds critical for *C. gariepinus* around Lake Edward watershed. The results from the study are vital for conservation and management of fishery resources of Lake Edward, which is a shared resource between DRC and Uganda.

2. Materials and Methods

2.1 Study area

The areas of investigation were located in Ishasha River and Lake Edward, which are the natural border separating the DRC and Uganda. Ishasha River originates from the Kigezi and Rwanda highlands and the Virunga volcanoes in the south [20]. It flows through a catchment area heavily impacted by agriculture on hills, steep slopes [49]. The river runs through four (4) protected areas, namely Mgahinga, Bwindi, Queen Elisabeth and Virunga National Parks before it pours into Lake Edward. These protected areas are vital component of conserving and managing freshwater resources, ecosystems and biodiversity of the Albertine Rift Valley [50, 51]. Lake Edward is one of the African Great Lakes of the Albertine Rift, located at 912 m of altitude, between 29° 15' and 29° 55' East and 0° 45' South. Its area is about 2,250 km^2 [20] and the catchment area of about 12,096 km^2 (4,670 sq mi); its maximum length is about 90 km and the maximum width is 40 km, the maximum depth is about 117 m. The mean depth is estimated at about 40 m with an estimated water volume of 90 km^3 [22, 25, 20, 26].

The climate is tropical with a bimodal rainfall distribution. Though, seasons are often subject to the climatic perturbations, wet seasons generally comprise from March to May and from September to November, whereas the dry seasons generally comprise from December to January and from June to August [25]. The annual rainfall is generally low 650 – 900 mm [20]. The monthly mean maxima of temperature also vary from 26.3 °C in January to 30 °C in September while, the minima vary from 15.5 to 17.8 °C. The absolute maximum temperature is about 32 °C usually in February, and the absolute minimum temperature is estimated at 14 °C mainly in January, February, June and July [22, 25].

Six sites were selected, including two sites along the lower course of Ishasha River, namely Kinyozo (upmost stretch) located at around 25 Km from the lake, Lulimbi (middle stretch) located at around 12 Km from the lake; and four sites in the estuarine region of the lake between river mouths of lake affluents (Ishasha and Ntungwe) and littoral zone, these include, Kagezi I, Kagezi II and Kagezi III, Ntungwe. Kagezi I, II, and III sites form a delta of river mouths of the Ishasha River distant of 3 km in average from each other, Ntungwe sampling site, is the river mouth of Ntungwe River and was distant of about 4.5 km from its closest neighbouring site (Kagezi I), all pouring into Lake Edward. The sites along the river were established based on the habitat characteristics and their accessibility. In the littoral zone, the sites were selected based on the level of interaction between the river and the lake (Fig. 1).

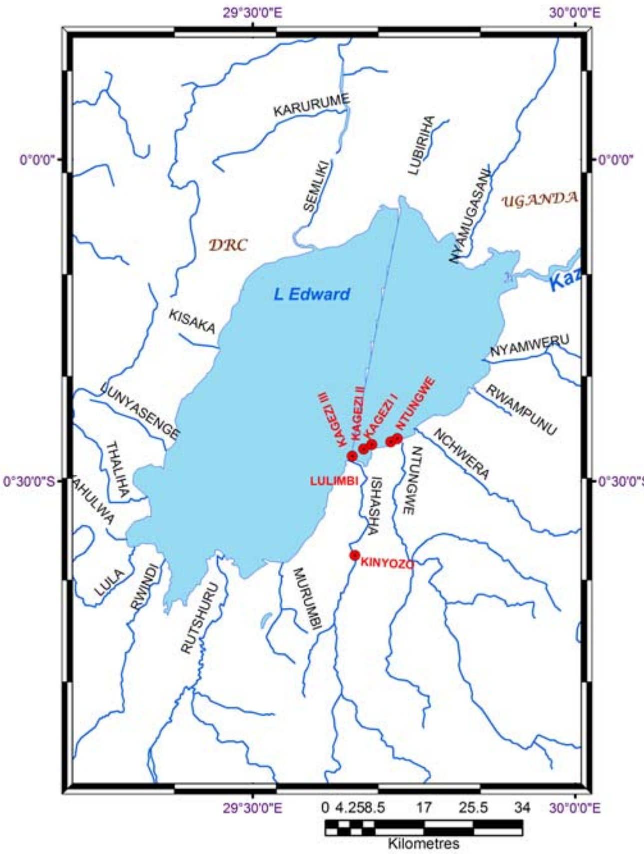

Fig 1: Study area and sampling sites (in red) along Lower Ishasha River and in the littoral zone of Lake Edward, in Virunga and Queen Elizabeth National Parks, Albertine Rift Valley.

2.2 Fish sampling and tagging

Fish tagging and release were carried out in four phases: July – August; September - October 2011; February - March and; April – May 2012. At each site, tagging was done during 2-day sampling period and, during this period; fishing was always performed between 6 h - 9 h in the morning, 12 h – 2 h in the afternoon and 4 h - 6 h in the evening. Along the river, fishing was done within a 200 meter sampling-stretch, with the aid of the beach haul seines of 15 m long, 3 m deep and 6.5 cm of mesh. In the lake, fishing was done within 400 meters in the estuarine region: river mouths-littoral zone, with the aid of the beach haul seines of 160 m long, 3 m deep and 6.5 cm of

mesh. A total of 8 trawls along the river and in average 6 trawls in the lake were completed at each site, in a 2-day sampling during every tagging period.
The captured fish were kept in plastic basins containing lake/river water, and bubbled with the battery-operated Rapala bubblers. The Fish were then measured at their total lengths (TL) to the nearest mm and weighed to the nearest grams. The information on size, sex and gonads status (spawning condition) was recorded from each specimen. The spawning condition was determined by applying a pressure on the specimens' abdomens, in order to bring out eggs or sperm from the fish. All specimens measuring between ≥ 15 cm and ≤ 30 cm TL (n = 87) were tagged with the external Fine T-bar Anchor Tags, TBF; while all specimens measuring above 30 cm TL (n = 1016) were tagged with the standard T-bar Anchor Tags, TBA (http://www.hallprint.com/T-bar_tags.html). The tags were inserted on the basis of the dorsal fin of the fish with the aid of the tag applicator. Each tagged specimen was further marked by clipping with the scissors the extreme tip of the left side of the pelvic fin. The handling time to measure, tag, physical examination and fin clip was minimized for about a minute and the fish were returned in to the lake/river [52]. Therefore, along the river, only one specimen of *Clarias gariepinus* was tagged, while a total 1102 specimens of *C. gariepinus* were tagged in the lake during the investigation period.

2.3 Tags recovery and returns
Fish recapture and tags recover were mainly performed by the local fishing communities (fishermen) and by subsequent recaptures during the sampling periods. Fishermen recapturing tagged fish provided information regarding tag number, date, place, habitat of recapture, and the spawning condition of the recaptured specimen. Information about the tagging program was designed in posters and flyers; these were publicized across the lake basin in both countries (DRC and Uganda) at each landing site (fishing village) around the lake and along the rivers. Subsequent sensitization sessions were frequently carried out in different fishing villages to further encourage tag returns.

2.4 Data Analysis
The tagging sites and recapture locations were recorded with a GPS etrex 10 Garmin and mapped with the aid if Arc-Map-GIS 10.1 software. The fishing being a permanent activity year-round in all habitats, the catch per unit effort (CPUE) for recaptured fish was assumed to be uniform between habitats. Furthermore, since the study was not designed to provide stock assessment data, the fish biomass aspect in the area was not considered. The fish migratory habitats were then determined based on the frequency counts of recaptured fish in each habitat, expressed in percentage; and the habitats from which ripe females were recaptured were identified as spawning grounds [53]. The Standard Statistical analysis of Chi - Square (χ^2) was performed to determine if significant differences ($p < 0.05$) existed in the selection of the recapture locations (migratory habitats) as well as of the spawning grounds. Only the recapture data having the three key pieces of recapture information, including tag number, date, and location of recapture, categorized for quality as "full" [54] was considered for mapping and analysis.

3. Results
3.1 Migratory Habitats
A total of 1103 specimens of *Clarias gariepinus* were tagged, from which one hundred fifteen (115) *C. gariepinus* were recaptured, representing about 10.43% of the total of tagged fish. These *C. gariepinus* were recaptured from thirty-nine (39) different areas located inside and outside of Lake Edward (Fig. 3). The areas were grouped into five (5) different habitats, based on their ecological characteristics and geographical locations; and they were identified as - pelagic zone, - littoral zone, - river mouths (of lake affluents), - river channels (of lake affluents), and – lake/river marginal wetlands (Fig. 3).
C. gariepinus showed a significant habitat selection (χ^2= 18.576, df = 12, $p < 0.05$) from the tagging sites toward the different recapture habitats. However, about 73% of the total recaptures of *C. gariepinus* were caught in the littoral zone of the lake; about 11.3% of the total recaptures were caught in the marginal wetlands, and about 8.7% of the total recaptures of *C. gariepinus* were caught in the pelagic zone. Whereas, about 3.5% of the total recaptured *C. gariepinus* were caught around the river mouths and along river channel of the lake affluents, respectively (Fig. 2).

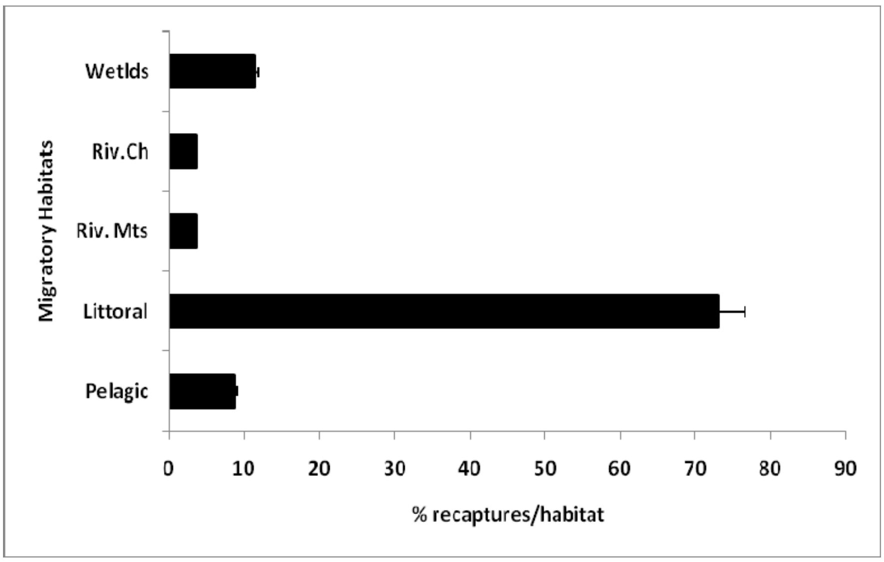

Fig 2: *C. gariepinus* recaptured in different habitats around Lake Edward watershed.

The results reveal the heterogeneity of *C. gariepinus* in their selection of migratory habitats. The results allow also identifying the major components/habitats between which *C. gariepinus* undertake their movements. The results suggest that the largest percentage of recaptures caught in the littoral zone indicates that this area could be considered as amongst the major migratory habitats for *C. gariepinus* in Lake Edward. *C. gariepinus* recaptured around the river mouths showed that these areas could be used as migratory transitional zones. The recaptures along the river channels of the lake affluents indicate that the fish were caught during their movements to or back from rivers and or marginal wetlands. Whereas, the high percentage of *C. gariepinus* recaptured in marginal wetlands could be the indication that these areas are serving among the major migratory habitats for *C. gariepinus*.
Furthermore, a critical look at Fig. 2 shows that there is a fluctuation in the number of recaptures between different habitats. There is an increase in percentage of recaptures, in one hand, from the marginal wetlands toward the littoral zone via river mouths and river channels of the lake affluents; and on another hand, from the pelagic toward the littoral zone. This follows the pelagic – littoral – wetlands habitats flow gradients; showing the evidence of existing movements of *C. gariepinus* following the go and flow lake – wetland movement patterns.

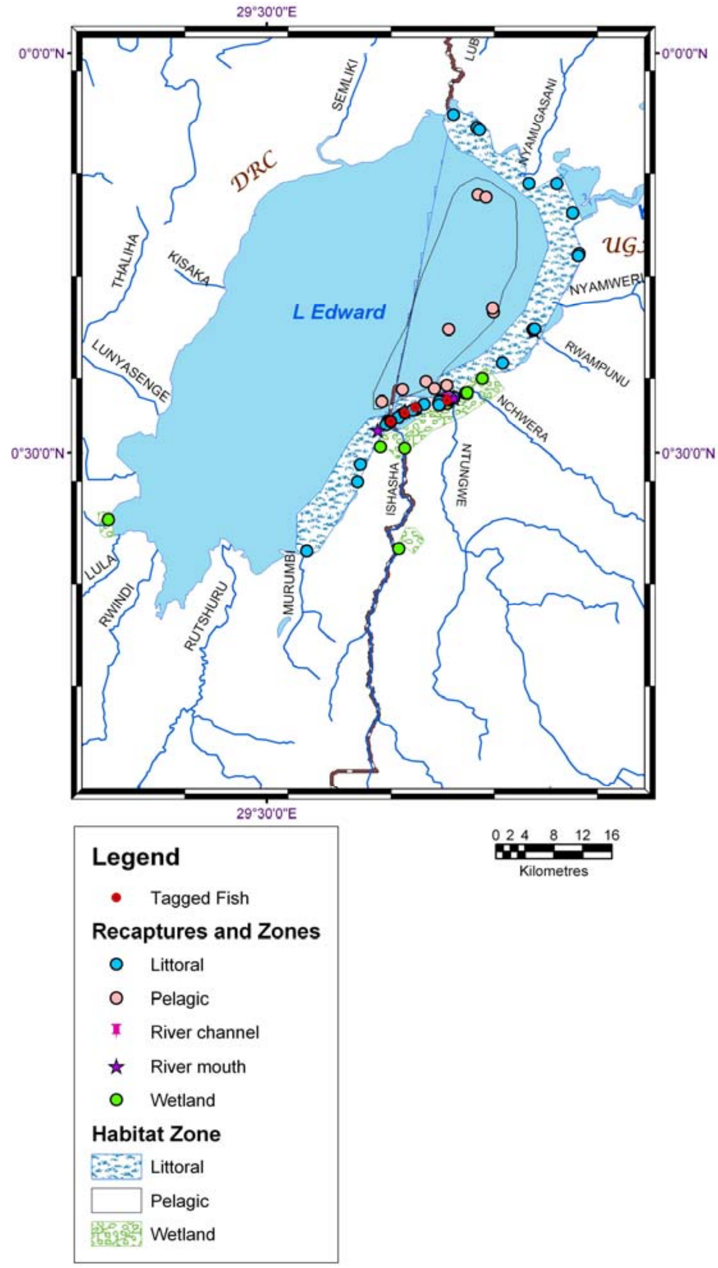

Fig 3: The recaptures of *C. gariepinus* in different habitats in and outside of Lake Edward.

The observation of the fish recaptured in every individual habitat indicates that, in the pelagic zone, *C. gariepinus* were recaptured from six (6) different pelagic fishing areas. These include Bizibibi, Kagezi (Ishasha) I, Katwe-Kagoro, Mikindo, Ntungwe, and Rwenshama pelagic fishing areas. From which four (4) areas, including Kagezi (Ishasha) I, Katwe-Kagoro, Mikindo and Ntungwe have got more recaptures of *C. gariepinus*, each with 20% of the total of pelagic recaptures, respectively; whereas, other pelagic fishing areas (Bizibibi and Rwenshama) have got less recaptures of *C. gariepinus* (10% each), Table. 1.
The results indicate that the four (4) fishing areas in the

pelagic zone from which relatively high percentage of *C. gariepinus* were recaptured, were related to river mouths of some of major lake affluents (Ishasha, Nyamugasani, and Ntungwe Rivers, respectively). Therefore, these zones could be considered as important migratory zones for *Clarias*.

In the littoral zone, *C. gariepinus* were recaptured from twenty (20) fishing zones, whereas most of *C. gariepinus* were caught from six (6) fishing zones. The zones include Ntungwe with 29.8%, Kagezi (Ishasha) II with 14.3% and Kagezi (Ishasha) I with 8.3%, Kagezi (Ishasha) III and Bizibibi both with 7.1%, and Rwampunu with 6% of the total of littoral recaptures respectively, as shown in Table. 1. These zones were followed by two (2) other fishing zones, namely Katwe-Kagoro and Kiyinja fishing zones from which 4.8% and 3.6% of the total of littoral recaptures were recaptured respectively, Table. 1. Four (4) fishing zones, including Bizibibi-Ntungwe, Kagezi (Ishasha) I – Bizibibi, Kayanza - Kyondo and Offshore Kazinga Channel have got each about 2.4% of the total of littoral recaptures, Table. 1. While, about 1.2% of the total of littoral recaptures were recaptured from each of the remaining eight (8) fishing areas, Table. 1.

The results show that, the six (6) fishing zones from which most of *C. gariepinus* were recaptured around the littoral zone were directly related to some of the lake affluents. These include Ntungwe River for Ntungwe fishing zone, Ishasha River for Kagezi I, II, and III fishing zones, Rwampunu River for Rwampunu fishing zone, Nyamugasani River for Katwe - Kagoro fishing zone and Bizibibi River for Bizibibi fishing zone. These results clearly demonstrate the impact of these rivers (lake affluents) on the movements of *C. gariepinus* in the littoral zone. Therefore, the results suggest that, these zones could be identified as amongst major migratory habitats for *C. gariepinus* in the littoral zone of Lake Edward.

The observation of the fish recaptured from the river mouths showed also that *C. gariepinus* were recaptured from four (4) river mouths of different lake affluents; these include Bucundezi (Ntungwe II), Kagezi (Ishasha) II, Kihera (Ishasha IV), and Rwampunu river mouths, each with 25% of the total of river mouths recaptures, Table.1. The observation discovered further that, these *C. gariepinus* were recaptured at river mouths of affluents that were different from which they were initially tagged. The results suggest that these river mouths could be considered as transitional zones for *C. gariepinus* migrating between the lake and their respective affluents. The results further reveal that *C. gariepinus* can migrate from a river mouth of one lake affluent towards many other river mouths of different lake affluents.

The observation of the fish recaptured along the river channels of the lake affluents showed that all *C. gariepinu*s were caught along one river channel, namely Ntungwe River, Table. 1. The observation showed also that each of the specimens recaptured along this river channel migrated from a different tagging site where they were initially tagged.

The explanation for these results is that Ntungwe River is among the most important migratory habitats (affluent) for *C. gariepinu*s. The movements of *C. gariepinu*s are not restricted between the affluents and the lake only, as the fish moved from one affluent to others via the lake. Therefore, the interriverine movements of *C. gariepinu*s existed between affluents pouring into Lake Edward.

The observation of the fish recaptured from the marginal wetlands showed that *C. gariepinus* were caught from eight (8) different marginal wetlands, namely Bizibibi, Cyahulwa, Ishasha, Kihangiro, Kinyozo, Nchwera, Ntungwe, and Number Munana wetlands. From which one wetland, namely, Kihangiro wetland was marginal to the lake, while, the remaining seven (7) wetlands were marginal to different lake affluents and were located outside the lake. Therefore, most of *C. gariepinus* were recaptured from Number Munana wetland, with about 46% of the total of the wetland recaptures. While, about 8% of the total of the wetland recaptures were recaptured from each of the remaining seven (7) wetlands, respectively, Table. 1.

Table 1: *C. gariepinus* recaptured in different habitats and locations (% of recapture per respective habitat (% recap./hab).

Recap. Habitat	Recap. location	% recap./hab.
Pelagic	Bizibibi	10
	Kagezi (Ishasha I)	20
	Katwe-Kagoro	20
	Mikindo	20
	Ntungwe	20
	Rwenshama	10
Littoral	Bizibibi	7.1
	Bizibibi-Ntungwe	2.4
	Bucundezi	1.2
	Kagezi (Ishasha) I	8.3
	Kagezi (Ishasha) II	14.3
	Kagezi (Ishasha) III	7.1
	Kagezi-Bizibibi	2.4
	Kamuhororo	1.2
	Kasalya	1.2
	Kayanza-Kyondo	2.4
	Kazinga	2.4
	Kibahari	1.2
	Kiyinja	3.6
	Lubiriha	1.2
	Mazinga	1.2
	Mikindo	1.2
	Ntungwe	29.8
	Number Munana	1.2
	Nyamugasani	4.8
	Rwampunu	6
River mouth	Bucundezi/Ntung. II)	25
	Kagezi (Ishasha) II	25
	Kihera (Ishasha IV)	25
	Rwampunu	25
River channel	Ntungwe River	100
Wetland	Bizibibi	8
	Cyahulwa	8
	Lulimbi	8
	Kihangiro	8
	Kinyozo	8
	Nchwera	8
	Ntungwe	8
	Number Munana	46

Legend: Recap. Habitat = Recapture Habitat; Recap. location = Recapture location

The results allowed discovering that, the majority of *C. gariepinus* were recaptured in the wetlands that were marginal to the affluents from which they were not tagged. These include, *C. gariepinus* recaptured from Bizibibi, Nchwera, and Ntungwe marginal wetlands were tagged from Ntungwe, Kagezi (Ishasha) II and Kagezi (Ishasha) III are tagging sites. *C. gariepinus* recaptured in Number Munana wetland were tagged from Kagezi (Ishasha) I and Kagezi (Ishasha) II tagging sites. The most remarkable case was the *C. gariepinus* recaptured from Cyahulwa wetland, which is marginal to the Cyahulwa River on the south-west coast (side) of the lake. The recaptured *C. gariepinus* tagged from Kagezi (Ishasha) III tagging site, a branch of the Ishasha River delta, located on the southeast side of the lake. The *C. gariepinus* crossed the lake and entered into the Cyahulwa River from the Kamandi Bay.

The selection of the wide range of wetlands around the lake watershed by *C. gariepinus* demonstrates that marginal wetlands are among the most vital habitats for *C. gariepinus*. The results suggest that the above mentioned wetlands could be considered among the major migratory habitats for *C. gariepinus*.

The presence of *C. gariepinus* in the wetlands marginal to the affluents, in which they were not tagged, clearly indicates that C. *gariepinus* can move from one affluent and migrate into wetlands that are marginal to different other affluents. Emphasizing the existence of inter riverine movement between affluents of Lake Edward. This pattern reveals also that, *C. gariepinus* could likely be using multiple and independent migratory habitats distributed in the marginal wetlands across different affluents around Lake Edward watershed. Their presence into each of the affluents' marginal wetlands, demonstrates that *C. gariepinus* must have first moved along the river channel of the affluents from the lake before reaching the respective marginal wetlands; thus the river channels served as migratory routes linking *C. gariepinus* between the lake and affluents' marginal wetlands.

3.2 Spawning grounds

The spawning conditions of recaptured females of *C. gariepinus* in different habitats are presented in Figure 4.

The observation of the fish recaptured found out that, about 50% of the total of the recaptures were females of *C. gariepinus*. And the assessment of spawning condition among the recaptured females of *C. gariepinus* found out that, about 77% of the total recaptured females were found without eggs (unripe); while about 23% of the total of recaptured females were found with ripe eggs in the abdomens and therefore ready to spawn.

The analysis showed a significant habitat selection (χ^2= 38.45, DF= 4, $p < 0.05$) between the unripe and ripe females recaptured in different habitats. Therefore, unripe females were recaptured into three (3) different habitats, including pelagic zone, littoral zone and marginal wetlands. Most of these were recaptured from the littoral zone, with about 84.5% of total of unripe females. This was followed by the pelagic zone from which about 11% of total of unripe females were recaptured, while only about 4.5% of total of unripe females were recaptured from the marginal wetlands. However, no unripe specimen was recaptured around the river mouths and along the river channels of lake affluents during the investigation period; as shown in Fig. 4. On the other hand, ripe females were recaptured from four (4) different habitats; these include the littoral zone, river mouths, river channel of lake affluents and marginal wetlands. Most of these were recaptured from the marginal wetlands with about 46% of total of the ripe females. This was followed by the river channel, with about 23% of total of ripe females, while, 15.5% of total of ripe females were recaptured from river mouths of lake affluents and littoral zone, respectively, as shown in Fig. 4.

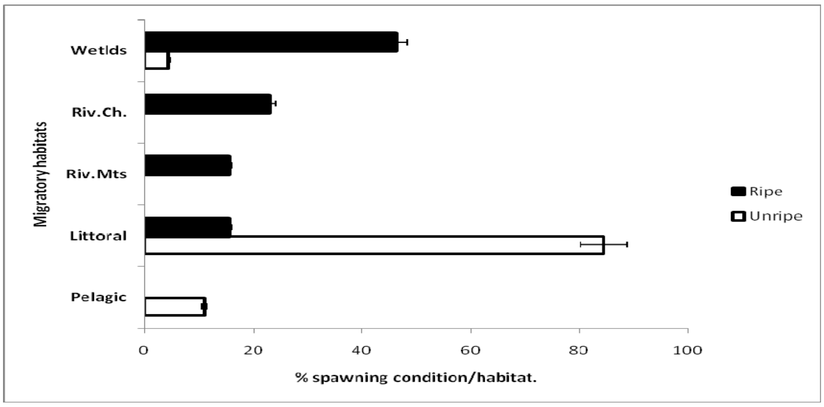

Fig 4: Spawning condition of female specimens of *C. gariepinus* recaptured in different habitats.

Fig. 4 clearly illustrates that, in one hand, most of ripe females of *C. gariepinus* were recaptured from the lake adjacent habitats; these include marginal wetlands, river channels of lake affluents and, the affluents' river mouths. And on the other hand, most of unripe females of *C. gariepinus* were recaptured from the habitats located within the lake, namely pelagic and littoral zones. The results clearly indicate that, *C. gariepinus* could be migrating from the lake to the adjacent habitats most likely to spawn. Therefore, the results suggest that the predominance of ripe females in the marginal wetlands demonstrates that wetlands appeared to be used as spawning grounds. The ripe females recaptured along the river channels indicate that these could be caught during their migration to spawn in the wetlands or at the spawning grounds alongside the affluents. The results further suggest that ripe females recaptured around river mouths of lake affluents and littoral zone of the lake could be caught either in their transit for spawning into the marginal wetlands via the river channels or they could be using these habitats as their spawning grounds as well. The absence of ripe females in the pelagic zone among the recaptures is an indication that *C. gariepinus* could likely not be spawning in the pelagic zone of the lake.

The observation of the ripe females recaptured in every individual habitat show that, in the littoral zone, the ripe females were recaptured from two (2) different fishing zones, namely Bizibibi and Kayanza - Kyondo littoral zones, each with 50% of the total of ripe females of the littoral zone. Around the affluents' river mouths, the ripe females were recaptured from also two (2) different river mouths, namely Kihera (Ishasha IV) and Bucundezi (Ntungwe II) river mouths, each with 50% of the total of ripe females of river mouths. Along river channels, all the ripe females were recaptured from the Ntungwe River channel. While, in the marginal wetlands, the ripe females were recaptured from four (4) different wetlands, namely Cyahulwa, Kinyozo, Ntungwe, and Number Munana marginal wetlands. Most of ripe females were found in Number Munana wetland with about 50% of the total of ripe females of marginal wetlands, while; only about 16.6% of the total of ripe females of marginal wetlands were recaptured from each of the remaining three (3) wetlands, respectively.

The results suggest that Bizibibi and Kayanza - Kyondo littoral zones; Kihera (Ishasha IV) and Bucundezi (Ntungwe II) river mouths; Ntungwe River channel; Cyahulwa, Kinyozo, Ntungwe and, Number Munana marginal wetlands could be considered among the major essential habitats and spawning grounds for *C. gariepinus* in Lake Edward watershed.

4. Discussions

The results revealed the heterogeneity of *C. gariepinus* to migrate into several habitats. The ability of *C. gariepinus* to use a wide range of habitats was evidenced in a number of previous studies. For example, Greenwood [55, 56], Teugels [53], CLOFFA [57], Chapman *et al*. [58] reported that in the Great Lakes region, *C. gariepinus* can be found in lakes and their affluent rivers and in wetlands. In tropical ecosystems, *C. gariepinus* habitat ranges from deep water to shallow littoral areas [59]. *C. gariepinus* occur mainly in quiet waters within lakes and pools and prefer rather shallow and swampy areas with a soft muddy substrate and calmer water [53, 60].

The spatial patterns in recaptures movements of *C. gariepinus* showed evidence of migration between Lake Edward and its adjacent environments. These include lake affluents, namely Ishasha, Ntungwe, Nchwera, Bizibibi and Cyahulwa Rivers among others and their marginal wetlands, including Lulimbi and Kinyozo wetlands marginal to Ishasha River; Number Munana and Nchwera wetlands marginal to Nchwera River; Ntungwe, Bizibibi and Cyahulwa wetlands marginal to their respective rivers; and Kihangiro wetland marginal to Kihangiro Bay (lake). This corroborates with the studies of Bowmaker [32], Welcomme [28] and Lowe-McConnell [43, 5] who stated that, *C. gariepinus* is known as well-defined potamodromous fish that undertakes pronounced and extensive upstream migrations from the lakes and rivers to streams and wetlands. The migrations of *C. gariepinus* between a water body and its tributaries have been reported in other lakes in Africa. In Botwana, *C. gariepinus* was reported to migrate from Lake Kariba up Mwenda River [32], and in Lake Victoria, the potential migrations of *C. gariepinus* from Lake Victoria up Sondu-Miriu River in western Kenya and in others affluent was discussed [56, 62].

In the present study, the locations from which high numbers of recaptures were reported in both pelagic and littoral zones were associated with major lake affluents. This pattern demonstrates the impact of lake affluents on the migrations of *C. gariepinus*, and indicates the attachment of *C. gariepinus* to migrate into riverine environments, and further emphasizes the importance of the connectivity between lake and its adjacent environments. Moreover, the absence of ripe fish recaptured in the pelagic; the presence of some ripe fish in recaptures from the littoral zone; and the predominance of ripe fish in the recaptures from adjacent habitats mainly marginal wetlands, river mouths and river channels give evidence that, migrations of *C. gariepinus* from Lake Edward towards its adjacent habitats could primarily be triggered by spawning and also feeding, among others. This means that, once in the pelagic zone, most of fish prefer to dwell around the locations near the river mouths from where they can easily move up the rivers at due time. Dwelling near the river-lake junctions also provides access to food carried by the rivers including terrestrial inputs from the upriver watersheds (allochtonous materials) [5], which *C. gariepinus* can feed on. Besides, the nutrients contained in the river flows swept from the agricultural lands and municipal untreated wastes from the rivers' headwaters [63], can allow a rapid growth of phytoplankton around these areas [21, 26]. In turn, abundant phytoplankton can attract more young fish and adult of small species of Haplochromines, *Aplocheilichthys*, *Barbus* species, among others, and other species such as *Oreochromis* species, which have been reported by Damas [22], Poll and Damas [44], Hulot [45], Verbeke [25] and Grennwood [56] to constitute major diet for *C. gariepinus* in Lake Edward. Studies carried out by Bruton [37]; Merron [35]; Lung'ayia [62]; Kadye and Booth [64]; and Yalcin *et al*.[65] revealed an omnivorous, feeding habit of *C. gariepinus* in its natural environment, with items such as fish, fish eggs, invertebrates, macrophytes, plant materials, plankton, reptiles, and amphibians being common in its stomach contents. Associating the above patterns, it becomes reasonable to suggest that, due to the absence of ripe fish, *C. gariepinus* recaptured in the pelagic zone could be associated with feeding. Therefore, the pelagic regions (especially Kagezi (Ishasha), Katwe-Kagoro, Mikindo and Ntungwe, with more recaptures) could be considered as important zones for *C. gariepinus* migrations. However, due to the presence of some ripe fish in the recaptures in littoral zone and the presence of more ripe fish in those of adjacent habitats, recaptures in the littoral zone and adjacent habitats could be associated to both breeding and feeding. Thereby, these areas could be regarded as fish essential habitats for *C. gariepinus* migrations, among others, in the Lake Edward –Ishasha water system. The studies on habitat use and movements of *C. gariepinus* within its natural range [32, 33, 59, 37, 38, 39, 40, 35, 66] and invaded habitats [67, 68, 64, 36, 41] reveal that its movements and habitat use within the investigated environments are primarily driven by its foraging and reproduction biology. Accordingly, Seegers [69] and Brummett [70] stated that *C. gariepinus* undertake lateral migrations from the larger water bodies in which they feed and mature to temporarily flooded marginal areas to breed.

The results clearly illustrated the impact of lake affluents on the movements of *C. gariepinus* in the littoral zone. Similar pattern was reported by Kadye and Booth [41] in the Glen Melville Reservoir, in Eastern Cap, South Africa. They observed that, most *C. gariepinus* were found relocated in the upper section (littoral) of the reservoir and river mouth of the stream pouring into the reservoir. The authors related such choice to spawning and/or feeding reasons; being that the habitats offered favourable ecological features for the species, such as rocky substrate interspersed with submerged trees. The littoral zone and river mouths of the investigated areas presented almost similar types of habitats as reported in the reservoir, some which included a mosaic of different substrata including rocks, gravel, sand, clay with many submerged trees and *Papyrus* and other macrophytes debris. However, in Lake Kariba, Bowmaker [32] discovered large shoals of adult *C. gariepinus* in the littoral zone, a few meters from the Mwenda river mouth at the time of their single breeding run. Accordingly, the author suggested that, the reason for *C. gariepinus* be located at such area, could be breeding in the flooded areas of the lake's shoreline (littoral). In the current study, the predominance of recaptures in the littoral zone and the presence of some ripe (spawners) fish among recaptures could be taken as the evidence that *C. gariepinus* breed in flooded areas of the littoral of Lake Edward, and therefore supports the findings of Bowmaker [32]. The present results corroborate with common customs of the locals in the investigated areas; they generally set traps and baited lines in the littoral flooded areas in order to catch *C. gariepinus* that come to breed. However, the study suggests that, the presence of unripe fish in the littoral zone recaptures could be associated with feeding among others; this following the findings of Northcote [71] stating that, during spawning migrations, none spawners fish generally follow the spawners in order to feed on their eggs and fry. Accordingly, Lung'ayia [62] also found none - spawners of *C. gariepinus* with stomachs full of fish eggs and fish remains captured together with the spawners along Sondu-Miriu River. Nevertheless, the predominance of recaptures in the littoral zone, however could further be an indication that, *C. gariepinus* likely spends much more time around the littoral zone of the lake, where it could get enough food year round due to the high exogenous inputs in this zone. In the previous studies, *C. gariepinus* was found particularly abundant in the littoral zone of Lake Edward [44, 45, 25].

River mouths have always been considered as ecotones, transitional zones connecting two or more different environments; as such, they are generally rich in species and offer favourable conditions to large number of biodiversity [72]. In Lake Edward, *C. gariepinus* were recaptured in the river mouths of many lake affluents, different from where they were tagged. Showing that, in Lake Edward water system, *C. gariepinus* can migrate from a single river mouth toward river mouths of several other different affluents. This suggests that, most of river mouths of lake affluents can provide suitable habitats for *C. gariepinus*. According to previous studies, *C. gariepinus* was found by far, as very dominant species in the fish catches from the river mouths of all affluents around Lake Edward [22, 44]. Similarly, Hulot [45] found more *C. gariepinus* especially in the river mouths of lake affluents and around the *Papyrus* wetlands. The above authors attributed the high abundance of *C. gariepinus* in river mouths of lake' affluents to the species' feeding needs; stating that, *C. gariepinus* preferred river mouths with *Papyrus* fringes in which they feed on myriads of the prey including small A*plocheilichthys*, *Haplochromis*, young of *Oreochromis* and *Barbus* species. For instance, Poll and Damas [44] recorded a *Tilapia* of about 35 cm TL from the stomach of a large *C. gariepinus*.

In the present study, females of *C. gariepinus* recaptured in the river mouths were found ripe, this means ready to spawn. Suggesting that, the reasons for *C. gariepinus* abundance in river mouths of Lake Edward affluents are to associate not only with feeding, as mentioned by the previous ecologists; but with breeding as well. In the light of current results, it becomes possible to suggest that, on one hand, *C. gariepinus* might be recaptured while on await to their way, to spawn along the rivers or into the marginal wetlands via the river channels; in this case, river mouths could be considered according to Bowmaker [32] as pre-breeding habitats. On the other hand, *C. gariepinus* might be recaptured during spawning; in this case, the river mouths are to be considered as spawning grounds for *C. gariepinus.* In both cases, the study shows the ecological importance of river mouths of the affluents of Lake Edward as essential habitats for *C. gariepinus.*

The results evidenced the movements of *C. gariepinus* between Lake Edward and its affluents. However, in many records from other parts of Africa, *C. gariepinus* was reported moving from one body of water to another [55], suggesting its high mobility to move between different separated habitats [53]. Therefore, all the records about the river channel recaptures were caught from Ntungwe River. But, the recaptures from river mouths of different affluents and those from the marginal wetlands of different affluents constitute clear evidence that *C. gariepinus* migrate not only along Ntungwe, but along other affluents as well. The ripe *C. gariepinus* recaptured along the river channel indicates that, they were caught during their spawning migration. This means that, they might be recaptured either during their way to the spawning grounds alongside the river or into the marginal wetlands. Spawning migrations along rivers were reported in many other water systems in Africa. For instance, van der Waal [73] reported longitudinal and lateral breeding migrations of *C. gariepinus* in the Upper Zambezi in the Caprivi region, Namibia. In the Okavango Delta, Botswana, Merron [35] observed large shoals of *C. gariepinus* migrating upstream in the main river channels during the annual drawdown. Greenwood [55], Witte and de Winter [74,] reported that *C. gariepinus* migrate from Lake Victoria into spawning grounds found in flooded riverine areas and temporary streams to spawn. Bowmaker [32] identified *C. gariepinus* among fish species that migrate upstream Mwenda River from Lake Kariba for breeding purposes. Lung'ayia [62] observed that spawning *C. gariepinus* among others migrated from Lake Victoria and marginal swamps into the Sondu-Miriu River. Lowe-McConnell [5] reported that, in tropical regions, many of the non- cichlids fish species, such as *Clarias* species migrate up affluent rivers to spawn.

The present study found out that *C. gariepinus* could move along river channels into their ways to in marginal wetlands, suggesting that, due to the fact that major affluents of Lake Edward from which *C. gariepinus* were found migrating are not seasonal rivers, these could be used more probably as migration routes connecting *C. gariepinus* migrants from the lake to spawning grounds located into marginal wetlands. The study further reveals the existence of inter-riverine movements of *C. gariepinus* between different affluents pouring into Lake Edward. The inter-riverine movements, in addition to the presence of ripe *C. gariepinus* along the river channel, reveal the strong ability of *C. gariepinus* in the search of suitable habitats for spawning.

Marginal wetlands were found second to littoral zone for the number of recaptures within the lake basin, and the movement patterns show the evidence of migration of *C. gariepinus* from lake into rivers and lake marginal wetlands; suggesting the importance of marginal wetlands as among major migratory habitats for *C. gariepinus.* Therefore, the presence of unripe fish and the predominance of ripe ones in the recaptures from wetlands reveal that *C. gariepinus* most likely migrate into marginal wetlands primarily for spawning and feeding. Spawning migrations of *C. gariepinus* between water bodies such as lakes, rivers, and reservoirs and their adjacent wetlands and floodplains were discussed in many studies carried out in Africa. For instance, Greenwood [55] reported that *C. gariepinus* move from Lake Victoria into spawning grounds found in marginal wetlands and areas of submerged vegetation in the flood plain. Jubb [75] reported that, *C. gariepinus* migrate from several rivers of South Africa in order to spawn in the floodplains around grassy places inundated by floodwaters. Burgess [76] stated that *C. gariepinus* generally move from major water bodies at night in search for breeding areas in wetlands and vegetated flooded areas; at the same time, they feed on a wide variety of prey such as insects, young birds, rotting flesh and plants, among others [77, 76]. Similarly, FAO [78] reported that in many African tropical aquatic ecosystems,

C. gariepinus undertake lateral migrations from the larger water bodies into swampy and flooded marginal areas in order to breed.
The results further revealed the resilience capacity of *C. gariepinus* to migrate and spawn in multiple and independent grounds in the marginal wetlands across different affluents of Lake Edward. The migratory behaviour of *C. gariepinus* might be regarded as an attempt by *C. gariepinus* to increase the chance to secure more suitable habitats for its offspring to thrive. This strategy could also be associated with its high tolerance to environmental extremes and breathing ability, as acknowledged by Greenwood [55], Teugels [53], de Moor and Bruton [77], Burgess [76], Seegers [60] and FAO [78]. Thus, due to the fact that the species does not use parental care for ensuring the survival of its offspring, however the spawning site is carefully chosen [79], the strategy is likely used by *C. gariepinus* as a survival mechanism for perpetuating the species once one or more habitats are adversely affected. Accordingly, Lowe-McConnell [43] and Welcome [28] reported that blackfishes including *Clarias* species have a wide range of behaviours adapted to survive in the often adverse conditions of the floodplains.

5. Conclusions
The study identified and mapped migratory habitats and spawning grounds for *C. gariepinus* around Lake Edward watershed. The spatial patterns of fish movements evidenced migrations between Lake Edward and its adjacent environments; which appeared to primarily be triggered by spawning and feeding, among others. Littoral zone, river mouths and river channels of lake affluents, and lake and river marginal wetlands revealed to be important migratory habitats for the *C. gariepinus*. Within the lake watershed, some areas, namely Bizibibi and Kayanza - Kyondo littoral zones; Kihera (Ishasha IV) and Bucundezi (Ntungwe II) river mouths; Ntungwe River channel; Cyahulwa, Kinyozo, Ntungwe and, Number Munana marginal wetlands were specifically identified among the spawning grounds for *C. gariepinus*. From the species resilience capacity to migrate and spawn into multiple and independent habitats across the lake watershed, it can be concluded that *C. gariepinus* can be considered to be more vulnerable to habitat degradation, loss of connectivity between habitats, and overfishing, thereby vulnerable to the fisheries. It is therefore recommended that these habitats should be considered as fragile and sensitive areas. They should benefit from a special consideration for conservation and be protected from any human destructive activities and development programs. Any activity or development scheme around these vital habitats represents direct and major threats not only for *C. gariepinus* and other migratory species, but for the whole aquatic biodiversity and the fisheries and related sectors around Lake Edward and adjacent ecosystems.

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