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An overview of domestication potential of *Barbus altianalis* (Boulenger, 1900) in Uganda

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ABSTRACT

Domestication of fish is a key strategy for diversification of farmed species to meet consumer's choices and demands as well as conservation of the species for sustainable provision of nutrition benefits and incomes. Initial successful induced spawning of *Barbus altianalis* was achieved, but there is low adoption attributed to lack of sufficient quality seed. This paper reviews the ecological and social-economic trends, and potential prospects that justify the domestication of this high value indigenous species, and identify gaps that could be addressed to increase seed production for commercialization. Review findings show that due to overexploitation, there is a steady decline of *B. altianalis* in Ugandan water bodies, with no current record from Lake Victoria where catches had in the past been reported. *B. altianalis* shows ability to survive in interlacustrine-riverine environments although, the juveniles are largely confined in the river or stream water. Varying levels of adaptability and tolerance to environmental conditions including oxygen and temperature by different age groups occur. The species has a great potential for culture as an omnivorous species with high chances of adapting to varying feeding strategies. Knowledge gaps in size at maturity, appropriate inducing hormones, growth conditions, egg hatchability and larvae weaning were identified as key challenges associated with *B. altianalis* domestication. Understanding the underlying natural ecological dynamics of *B. altianalis* will guide further research in the areas mentioned to ensure advancement in domestication so as to meet the rising demand for *B. altianalis*. This will curtail its overexploitation in the wild and also improve the livelihoods of the communities in the region.

1. Introduction

The overall global demand for fish has significantly increased over the years and by 2014 the world registered a total fish production of 167.2 Million Tonnes (MT) of which 73.8 MT were from farmed products (Food and Agricultural Organisation (FAO, 2016). With a projected 9.7 billion world population at a consumption rate of 20 kg person^{-1} year^{-1}, by 2050 a total production of 220 MT will be required to meet nutritional requirements. About 140 MT will come from aquaculture (Merino et al., 2012; Bene et al., 2015). Much of the production from capture fisheries has stagnated with 28.8% of the fish stocks being exploited at biologically unsustainable levels (Food Agriculture Organisation (FAO, 2014, 2016). The only hope to meet the world's fish demand is to exploit the potential of culturing fish in confined environments (Food and Agricultural Organisation (FAO, 2016).

In Africa, the contribution of cultured fish was less than 2.32% of the World's total (Food and Agricultural Organisation (FAO, 2016). Estimated annual per capita fish supply in Africa (about 9.8 kg) is less than half the world's average; and from aquaculture (6 kg) even less (World Fish Center (WFC, 2005; Food and Agricultural Organisation (FAO, 2016). Consumption levels of EPA/DHA (omega-3-fatty acids) are also below recommended levels (WHO/FAO, 2011). This deficit represents a food security threat, and fish as an affordable protein source is increasingly becoming scarce and expensive. Given that the catches from capture fisheries are stagnating, aquaculture is seen as the only plausible option to meet the rising demand for fish in the sub-Saharan region. Efforts to encourage aquaculture in Africa are constrained by the low number of cultured species, and poor quality of fish seed and fish feeds (Brummett et al., 2008; Aruho et al., 2013; Rutaisire et al., 2015).

Domestication of fish species entails adopting fish with wild characteristics into confined culture systems that are artificially managed. Fish with desirable biological, nutritional, social and economic characteristics are selected from the wild and cultured for human consumption or for ornamental use (Bilio, 2007). The transformation of wild fish into confined culture systems is a technical process that begins with understanding the environment of the fish and its reproductive

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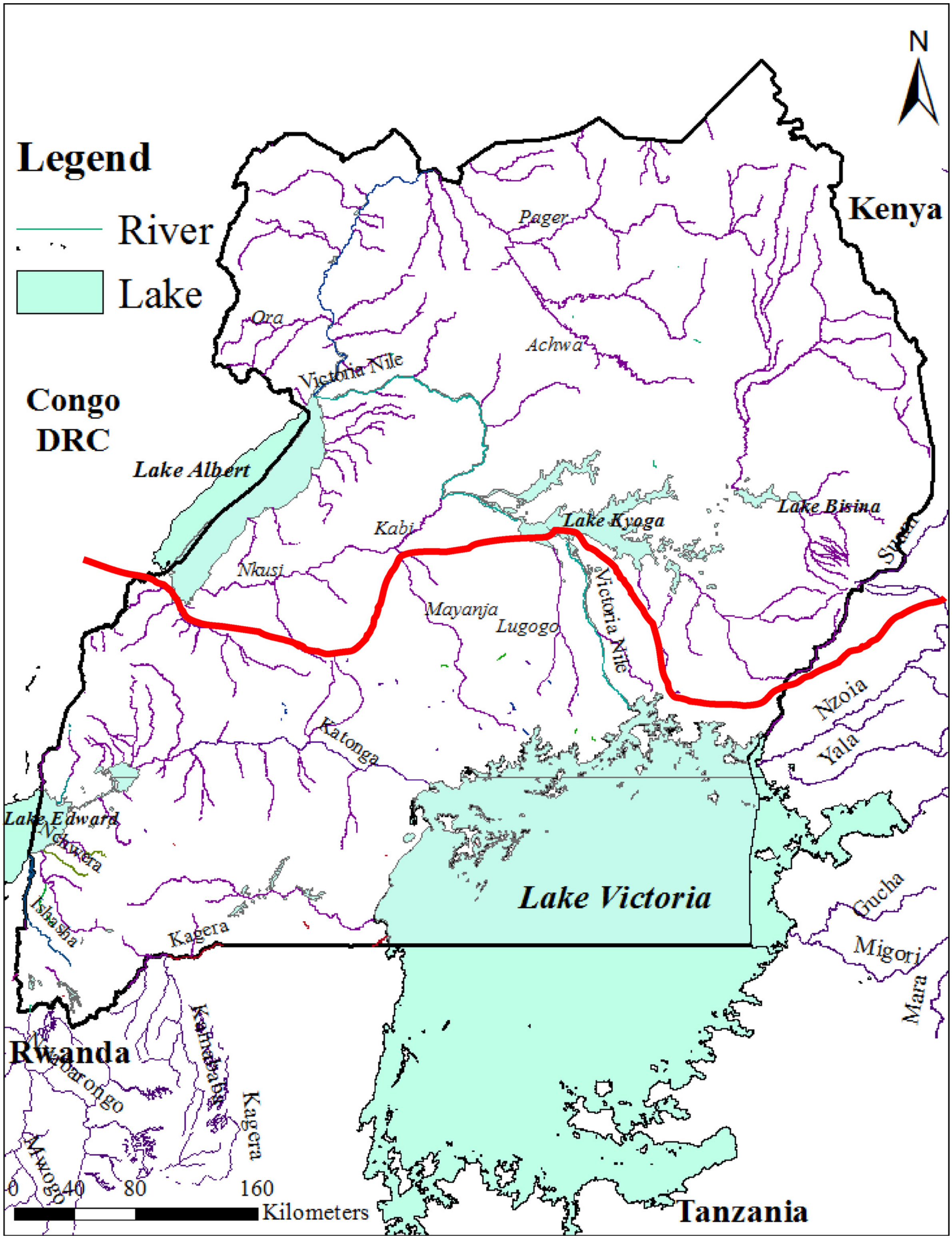

Fig. 1. Map showing lakes and rivers where *B. altianalis* is distributed but excluding the lakes and rivers above the red line. *The Map was made using Arc GIS Vision 10.2 Soft ware* (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

biology before being artificially induced to spawn (Mylonas et al., 2010; Teletchea and Fontaine, 2014; Rutaisire et al., 2015). Successful artificial spawning must be accompanied by larval weaning and grow-out feeding technologies. The response to the growing demand of animal protein due to the increasing world population is enormous and is characterized by the great desire for domestication of high value fish species to bridge the demand gap.

Barbus altianalis, (or *Labeobarbus altianailis*) also known as the Ripon barbell is one of the potentially high-value fish species threatened with overexploitation (Rutaisire et al., 2015; Ondhoro et al., 2016). It is a large cyprinid that grows up to about 90 cm total length and 10 kg individual weight (Greenwood, 1966). The species is widely distributed in the Lake Victoria region and in many rivers and streams, except in Lake Albert. It is considered a delicacy among many communities in

Uganda, Eastern Democratic Republic of Congo (DRC) and Eastern Kenya. The recent successful first induced spawning of wild *B. altianalis* (Rutaisire et al., 2015) opened an opportunity for its increased commercial production through domestication as well as for its conservation. However, like many other newly domesticated species, there are challenges of producing sufficient good quality fish seed (Naylor and Burke, 2005; Mylonas et al., 2010). Lack of sufficient quality fish seed has been attributed to high larval and embryonic mortalities as well as low-quality larval and juvenile feed. These are all linked to lack of knowledge about improved artificial breeding techniques, optimal conditions for egg hatchability and larval growth, feeding ecology, digestive structure of the species and better larval weaning strategies. This paper reviews a number of aspects related to the efforts directed toward *B. altianalis* commercialization. It highlights potential gaps to be addressed in future strategies for popularization of *B. altianalis* through domestication and its sustainable exploitation for nutritional benefits and economic development.

1.1. Contribution of cyprinid fish to fish culture

About 325 fish species (including hybrids) are cultured worldwide, the majority are from Asia (Food Agriculture Organisation (FAO, 2014, 2016), and with cyprinids and tilapias forming the bulk of the tonnage (Chiu et al., 2013; Statista, 2014; Food and Agricultural Organisation (FAO, 2016). Over 70% of all cultured species in India, Bangladesh, Iran, Pakistan, Thailand, China and Japan are cyprinids (Food and Agriculture Organization (FAO, 2012). Cyprinids have therefore significantly contributed to the economies and food security in Asia. Some of these species were introduced into Africa, where in some countries they have become invasive and have interfered with other species (DeGrandchamp et al., 2008; Lorenzen et al., 2012). To avoid these problems, promoting indigenous high-value species is considered a good strategy for production and conservation purposes (De Silva et al., 2009; Teletchea and Fontaine, 2014). However, the domestication of fish species must conform to the tenet of responsible aquaculture to ensure environmentally sound and sustainable culture, conservation of indigenous wild stocks as well as constant supply and replenishment of domesticated fish for sustained food security (Merino et al., 2012; Diana et al., 2013).

In sub-Saharan Africa much fewer species (< 27) are cultured and these are dominated by tilapias and the African catfish species (Machena and Moehl, 2001; Hecht et al., 2007; Brummett et al., 2008). However, there are many indigenous African species of high value that can be cultured. Among them are the African cyprinids (carps). In Uganda, efforts have focused on domestication of high-value species including the Nile perch, catfish, bagrids and cyprinids (Rutaisire and Booth, 2004; Basiita et al., 2011; Aruho et al., 2013; Rutaisire et al., 2015). The domestication of these species is expected to increase the diversity of farmed species, enhance production and productivity, as well as relieve pressure on wild stocks thus leading to genetic conservation of the species in the wild.

1.2. Distribution and ecology of Barbus altianalis

Barbus altianalis is an interlacustrine-riverine species that is widely found in Ugandan open water bodies, the rivers and streams that are interconnected within the Lake Victoria Basin (Greenwood, 1966) (Fig. 1). Elsewhere in East Africa, *B. altianalis* is found in the River Kagera, Lake Kivu and its affluent rivers (Snoeks et al., 2012) as well as in the rivers Nyando, Nzoia, Yala and Sondu-Miriu on the Kenyan side of Lake Victoria (Chemoiwa et al., 2013). Along the River Nile catches are reported only in the Upper Victoria Nile and the lake area where the river joins Lake Kyoga at Mbulamuti, Kamuli district but there are no reports of the species after Lake Kyoga (Greenwood, 1966; fishermen, personal communication, July 10, 2016). In South western Uganda it is found in Lakes Edward and George which are widely interconnected through rivers, including Ishasha, Chiruruma, Nyamugashani, Rwindi, Rutshuru, Ntungwe, Nchera and Ruhibi (De Vos and Thys van den Audenaerde, 1990; Muwanika et al., 2012; Snoeks et al., 2012). These rivers drain from vast surrounding areas and are fed by other smaller streams where this species is also reported. The rivers join together into Semliki River which moves northwards towards Lake Albert. However, there are no reports of this species in Lake Albert except for a closely related species *B. bynni* (Greenwood, 1966).

The absence of *B. altianalis* in Lake Albert and the lower section of the Victoria Nile as well as the upper Nile after Lake Albert could be linked to abiotic and biotic factors. Both species are morphologically similar except that the body depth of *B. altianalis* is equal to or slightly longer than the length of the head (Greenwood, 1966; Muwanika et al., 2012). The number of dorsal spines for *B. altianalis* are 3, dorsal soft rays 9–11, anal spines 2–3 and 5–6 anal soft rays (De Vos and Thys van den Audenaerde, 1990), whereas the dorsal spine for *B. bynni* is one, dorsal soft rays are 12–13 and the anal soft rays 8 (Leveque et al., 2003; Muwanika et al., 2012). According to the competitive exclusion principle (Zaret and Rand, 1971; Alley, 1982), it would be expected that the two species occupy the same "niche" however; they may not co-exist due to competition for the same resources. Another reason could be that their response to physico-chemical water parameters is different. Despite the common origin of the species (Greenwood, 1981; Joyce et al., 2005), lakes in the Lake Victoria region can have different hydrological and limnological characteristics (Russell and Johnson, 2004) which could be why the two *Barbus* species are not found in the same water body. There is need for a better understanding of the ecology of both species in light of their close similarity. The observed differences in niche may point to the need for different conservation strategies or culture techniques.

The available genetic and phenotypic evidence does not confirm any cryptic process leading to evolution of different lineages for *B. altianalis* species in the Lake Victoria region (Nakamya, 2010; Muwanika et al., 2012). Worthington (1932) categorized *B. altianalis* by their location into subspecies that included *B. altianalis altianalis* Boulenger, 1900 (found in Lake Kivu and Rusizi River); *B. altianalis eduardianus* Boulenger, 1901 (from lakes Edward and George); and *B. altianalis radcliffii* Boulenger, 1903 (from lakes Victoria and Kyoga, and the Upper Victoria Nile). De Vos and Thys van den Audenaerde (1990) and Nakamya (2010) disagree with this classification, which was based on location and not on any species characteristics. Moreover, Banyankimbona et al. (2012) and Vreven et al., 2016 suggested classifying the species under genus *Labeobarbus* instead of *Barbus*. Before the development and conservation of broodstock for continuous replenishment of the cultured stocks, the existence of any strains, natural hybrids, subspecies or species across water bodies should be investigated. Until then, the species or "subspecies" are still regarded as one species under the genus *Barbus*.

Fish growth may vary due to varying environmental conditions across water bodies. For example, faster growth under culture conditions is reported for *Oreochromis niloticus* from Lake Victoria than from other lakes in Uganda (Mwanja et al., 2016). It is therefore necessary to compare growth rates of *B. altianalis* from various water bodies to ascertain its performance under culture conditions. However, in the early stages of domestication attention should be focused on its artificial reproduction (Bilio, 2007; Teletchea and Fontaine, 2014). The research by Rutaisire et al. (2015) was useful in inducing successful spawning in *B. altianalis* collected from the Upper Victoria Nile. Whereas the effect of seasonality on spawning can be expected to be the same within the same region for the same species, length at maturity and fecundity may vary across water bodies due to microclimatic differences and other factors. Such parameters must be defined specifically for each water body (Aruho et al., 2013). Some of the critical information, such as length at sexual maturity, was not provided in previous studies and is required to guide culturalists in collecting the appropriate size of fish for breeding.

Domestication of *B. altianalis* in culture systems requires determining appropriate conditions that will be suitable for spawning, egg incubation and larval growth. *Barbus altianalis* is found in both lacustrine and riverine environments. The adults migrate upstream for breeding (Copley, 1958; Tomasson et al., 1984) and prefer breeding in clear gravel running water (Skelton et al., 1991). The juveniles are found moving in 'schools' in riverine waters (Greenwood, 1966; Witte and de Winter, 1995). This suggests that the eggs are laid in fresh slow running clean water with a constant oxygen supply and that the juveniles require high oxygen concentrations for their energy requirements in the river environment. This also indicates that the incubation temperature required for the optimal growth and survival of larvae and juveniles may be lower compared to that of the lacustrine environment since river water generally has a lower temperature than lake water (Wetzel, 2001). The oxygen demand should be met in subsequent culture systems by maintaining sufficient aeration during the incubation process. Most cyprinids, including *Barbus* (Skelton et al., 1991), *Labeobarbus* (de Graaf et al., 2004) and *Labeo victorianus* (Rutaisire and Booth, 2004) are active in running water during the breeding season. However, studies from Lake Tana on *Labeobarbus* by de Graaf et al. (2004) have shown that some carps live and spawn in the lacustrine environment. Most cyprinids show divergence in relation to feeding behavior, breeding and habitat (Winfield and Nelson, 2012), and are capable of adapting to varying environments. Whether *B. altianalis* could easily adapt to confined culture conditions and breed naturally in ponds or other culture systems requires further investigation. The association of *Barbus* species with clean water habitat may suggest a difference in habitat occupation strategy from the cultured common carp *Cyprinus caprio*. Contrary to common carp which survive well in a constantly turbid and silted environment (Basavaraju et al., 2002; Weber and Brown, 2009), *B. altianalis* may require a clear and undisturbed water environment during its culture.

Cyprinids have a diversity of feeding strategies and morphological adaptations depending on their habitat (Winfield and Nelson, 2012): some are carnivores, others are plankton feeders, suckers, insectivores, omnivores, plant feeders or detritivores (De Silva and Anderson, 1995; Rust, 2002). Field data suggest that *B. altianalis* has a generalist diet that includes plants, fishes, insects (chironomids), gastropod mollusks, crustaceans, detritus material, algae and weeds (Corbet, 1961; Balirwa, 1979; Witte and de Winter, 1995). The large spectrum of food items consumed by *B. altianalis* suggests that the fish feeds at all levels of the water column and utilizes most available food items in the environment, although this also depends on the habitat and the life stage of the fish. How the species will respond to feeding in a confined cultured environment needs to be investigated, especially when sinking or floating artificial diets will be used.

Morphology and histology of the gut system can provide additional information about the feeding behavior and adaptive strategy of *B. altianalis*. The digestive morphology of several species has been studied to relate structural functionality with adaptation to feeding habits (Cataldi et al., 1987; Murray et al., 1996). Increased attention to such studies is primarily triggered by the development of feeding technologies of candidate species for culture (Banan-Khojasteh, 2012). Structural variations probably confer differences in digestive capabilities. Specialized regions along the gut maximize different physiological processes to ensure uptake of nutrients (Buddington et al., 1987; Dabrowisk and Celia, 2005). Better knowledge of the digestive system of *B. altianalis* will provide more insights into its functionality and feeding behavior, and can form a basis for developing feeding strategies for this fish under culture.

1.3. Trends and socio-economic prospects of Barbus altianalis fishery

Fish were generally abundant in Ugandan water bodies at the turn of the 20th century. Declining stocks due to overfishing were first reported by Graham (1929), and by the mid 20th century Lakes Edward and George experienced drastic declines in all fish species (Balirwa, 2007). From Lake Victoria, *B. altianalis* along with *Labeo victorianus* and other big catfishes constituted a substantial part of the catch in a fishery that was dominated by *Tilapia esculentus* before the 1950s (Cadwalladr, 1965; Balirwa et al., 2003). The introduction of the carnivorous Nile perch (*Lates niloticus*) in the late 1950 s led to reduction of the stocks of haplochromines but also the other large fish species, including *B. altianalis*. Catches of *B. altianalis* from the Ugandan part of Lake Victoria declined from 859 tonnes in 1966 to less than 1 t in 2000 (Balirwa et al., 2003). Although contributing only 1.5% to the total catch reported in 1957 (Lake Victoria Fisheries Service (LVFS, 1958), *B. altianalis* was and is still greatly cherished by many communities in Uganda for its cultural and taste attributes (Food and Agriculture Organization (FAO, 1991; Aruho, 2017). Currently it is difficult to find any *B. altianalis* in catches from Lake Victoria (Ondhoro et al., 2016). The remaining stocks are confined to the Upper Victoria Nile, the river Kagera and other tributaries of Lake Victoria. The continued destruction and disturbance of their habitat by unregulated human activities, including the construction of dams along the Nile River, are likely to further reduce the remaining stocks and can eventually lead to their extinction (Ondhoro et al., 2016). It is therefore vital to initiate strategies that not only involve precautionary principles of management but also domestication.

The catch statistic trends in other parts of the country are poorly documented as is for other fish species (Cowx et al., 2003; DFR, 2012). Apparently most catches are reported from Lake Edward (Kasese District Fisheries Department Report, 2012; Ondhoro et al., 2016). The mean catch size of *B. altianalis* from Lake Edward is 2.24 kg and fetches the highest price of about 12,000 Uganda shillings per kg (US$3.8) compared to other fish species that are much smaller on average (traders, personal communication, July 10, 2016; Kasese District Fisheries Fepartment Report, 2012). Catches are seasonal and fishermen tend to catch them at night during the "dark nights" (no moon light) and during the rainy season when the moon is obscured by clouds (fishermen, personal communication, July 10, 2016; Ondhoro et al., 2016). After this period, the fishermen resort to catching other species. This seasonal fishing further escalates its demand and leads to higher prices. Records of *B. altianalis* catches from Upper Victoria Nile and many other inland streams are scanty. Informal estimates for fish sold at the Owen Falls Dam fish market indicate that on average 70 kg of *B. altianalis* are sold daily (unpublished data from Jinja and Kayunga District Fisheries Department, 2012). This translates into 2.5 t, worth US$ 73,000. However, catches are low and fishing is sometimes interrupted by the electricity generation activities from Owen Falls, Kiira and Bujjagali Dams along the River Nile (Ondhoro et al., 2016).

Barbus altianalis is not only cherished by communities in Uganda but also by populations in parts of Western Democratic Republic of Congo (DRC) and Eastern Kenya. In Uganda, the fish is a delicacy largely in the south west, central and eastern regions. In southwestern Uganda, demand is much larger and a large part of the catch is exported to DRC (unpublished data, ARDC Kajjansi, 2016). Its demand in the southwestern region is linked to cultural attachments across the Banyabutumbi, Bakonjo, Bamba and other tribes which form a large market with growth potential for *B. altianalis* along with other fish species (Odongkara et al., 2005; Nabwiiso, 2015). These communities believe that the fish has nutritive value that increases milk production of breast feeding mothers and offers sexual libido to men (unpublished report, ARDC Kajjansi, 2016). Ninety percent of respondents in central and Eastern Uganda preferred the fish in smoked form while 90% of respondents from the western region (including DRC) preferred the fish fresh (unpublished ARDC report, 2016). The remaining 10% preferred the fish salted. It is not necessary to remove the smooth, soft scales of the fish which can therefore be consumed directly. These scales may contain useful nutrients for human consumption yet to be investigated.

1.4. Progress in culture of Barbus altianalis and other indigenous cyprinids

There are several indigenous cyprinid species in Uganda and in the region that are potentially viable for commercial production. These include *B. altianalis*, *B. byanii, Labeo horie, Labeo victorianus and Labeo coubie.* Their domestication and the development of culture technologies is a vital strategy to ensure their production and productivity through culture and conservation. A number of technologies for their domestication are under way. Artificial reproduction and feeding have been well established in *Labeo victorianus* which is now being promoted commercially (Rutaisire and Booth, 2004; Owori, 2009). For *B. altianalis*, artificial reproduction has successfully been developed (Rutaisire et al., 2015) but production of seed for commercialization is yet to be realized. High embryonic and larval mortalities of up to 55% and 11%, respectively were recorded (Rutaisire et al., 2015). This could also be due to lack of feeding technologies, unfavorable environmental conditions for artificial spawning and diseases, challenges commonly associated with the domestication of new fish species (Bilio, 2007; Lorenzen et al., 2012; Migaud et al., 2013).

1.4.1. Artificial spawning and factors for optimal egg incubation and larval growth

Manipulation of reproductive systems to induce maturation and ovulation in fish using inducing hormones has widely been adopted in commercial aquaculture to facilitate year-round supply of sufficient fish seed to farmers (Bromage et al., 1995; Mylonas et al., 2010). The high embryonic and larval mortality observed during the induced spawning of *B. altianalis* (Rutaisire et al., 2015) could partly be attributed to a lack of knowledge of appropriate hormones and requires urgent attention to improve the artificial spawning technique. During artificial spawning in *B. altianalis*, some critical stages of embryonic development were affected more than others even when the temperature was constantly maintained at the same temperature of incubation. Egg hatchability and larvae survival is not affected by temperature alone but by a combination of important environmental factors including dissolved oxygen, salinity, light regimes, ammonia levels and hatching facilities among others (Brooks et al., 1997; Kamler, 2008; Villamizar et al., 2011). For instance, the dissolved oxygen concentration was reportedly lower (3–4 mg L^{-1}) in Lake Edward and the Upper Victoria Nile (Ondhoro et al., 2016) than the minimum of 5 mg L^{-1} that is generally considered suitable for culture systems (Boyd, 1998; Ondhoro et al., 2016). It is not clear how the oxygen requirements would affect *B. altianalis* in captivity. Some species evolve to cope with changes in environmental factors under culture conditions (Lorenzen et al., 2012) but these changes must be clearly understood for various species. It is imperative that these parameters are optimally established to increase the survival of embryos and larvae of *B. altianalis* in captivity.

1.4.2. Feeding Barbus altianalis in captivity

The mortalities observed during the growth of *B. altianalis* larvae were linked to inappropriate feeds and timing (Rutaisire et al., 2015). The introduction of starter feeds, both in terms of feed type and time of introduction, is species-specific for most cyprinid larvae (Kujawa et al., 2010). In some species, at first feeding the digestive system is well advanced with functional enzymes which allow digestion of exogenous feed particles while in other fish species the digestive system may not be properly developed yet (Riubeiro et al., 1999; Garcia et al., 2001; Ostaszewska et al., 2003). The weaning behavior of *B. altianalis* larvae that will provide optimum survival and growth under culture conditions still needs to be clearly understood. It is imperative to establish the growth rates and survival of juveniles under culture conditions. The juveniles of *B. altianalis* are largely confined to a riverine environment while the adult fish can freely move and survive in both riverine and lacustrine environments (Ondhoro et al., 2016). This suggests varying survival strategies in feed response and preference for various age groups. *B. altianalis* is reported to be an omnivorous species (Corbet, 1961; Balirwa, 1979), hence its response to feeds in culture environment may be influenced by what is available as natural food and by the presence of other fish species, especially in polyculture systems. Therefore successful domestication of *B. altianalis* necessitates knowledge of its feeding dynamics in confined environments.

1.5. Conclusions

Barbus altianalis is a high-value demanded cyprinid species with a great potential to generate incomes in local and international markets and provide nutritional benefits for the local communities if successfully cultured. Despite initial success in spawning, there are observed limitations of quality seed supply attributed to knowledge gaps in size at maturity, appropriate inducing hormones, growth conditions and larvae weaning technologies, where further research is recommended for successful domestication. The ability for this omnivorous species to survive in a range of aquatic environments illustrates its potential to be raised in captivity but investigations are needed to determine appropriate diet formulations for different age groups in captivity where for instance Juveniles were reported to be confined only in riverine environment.

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