Swimming in the mud – a short review of environmental parameter ranges tolerated by *Clarias gariepinus*

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Abstract. The African catfish (*Clarias gariepinus*) is a fish species farmed around the world, especially in areas where environmental conditions are poor for fish rearing. It is a species that can contribute to improving the economic development in regions lacking resources. It is a valuable source of proteins and essential fatty acids. Moreover, the fish displays high tolerance to different environmental conditions, like low oxygen levels, or high temperatures, being farmed in aquaculture systems from extensive to RAS types. This is possible due to its specific anatomy and physiology. The growth rate is also high, reaching 1 kg in 1 year, if some conditions are met. These make the African catfish a species of great interest for aquaculture. The aim of this review is to summarize the value range of different water quality parameters in *C. gariepinus* farming.
Key Words: aquaculture, african catfish, dissolved oxygen, temperature.

Introduction. The African catfish *Clarias gariepinus* (Burchel, 1822), also known as the "sharptooth catfish" or "North African catfish" presents great interest for aquaculture, especially in Africa and Asia. The culture of the species is also present in some European countries, like Hungary, and in South America. Farming technologies are in continuous development (Akinwole & Faturoti 2007), but have been studied later than for other commercially important fish species, in the second half of the XXth century, with artificial reproduction being developed after the 1980s. African catfish farms tend to use more intensive rearing systems, but extensive systems where the fish is usually reared in polyculture with Tilapia species exist (Hecht 2013). The fish soon became the preferred aquaculture species in some African countries, being more popular than Tilapia species. In 2016, more than 230000 tonnes of *C. gariepinus* were produced worldwide, Nigeria being the biggest producer, followed by Netherlands, Hungary, Kenya, and others (http://www.fao.org/fishery/culturedspecies/Clarias_gariepinus/en).

Some important advantages make the African catfish a competitive aquaculture species. The meat quality is good (Oladipo & Bankole 2013), fresh fillet presenting a crude protein content usually between 15-20% and a crude fat level ranging from 4 to 7%. The moisture content is usually above 70%, while the ash levels are between 3.5-4.5%, in most cases. For the average consumer, the best advantage is that it has few bones. Even though the fillet quality is high, the fish is still avoided by consumers in some markets, because of its visual aspect, slightly darker color of the meat and because it does not have scales, the last being a religious reason. However, the demand is still very high, especially in African countries.

The anatomical and physiological traits of the fish have direct implications in the farming technology. The fish is hardy and can tolerate a large range of adverse farming and environmental conditions. For example, it can be farmed in stocking densities of 350-400 kg/m^3, in RAS (Prokešová et al 2015). It also has a fast development, reaching the commercial weight in less than 1 year. It presents sexual maturity in less than 1 year, being able to reproduce. The protein sources used in its feed can be vegetal, further lowering costs. Although the fish is considered carnivorous, it manifests omnivorous behavior, feeding on a large variety of food, from detritus, phytoplankton, fruits and seeds to fish, birds and small mammals (Skelton 2001; Dadebo et al 2014). It can utilize the vegetal protein from feeds.

Another big advantage is its ability to adapt to environments with low levels of oxygen. The African catfish can inhabit areas with temporal water, in which shallow ponds remain, with very low O_2 levels and high CO_2 levels. Thus, the fish is an obligated and sometimes facultative air breather. The fish possess gills, for water breathing, and other organs for air breathing, namely labyrinthine organs (or dendritic organs), suprabranchial chamber membranes and gill fans (Ahmed et al 2008; Mbanga et al 2018). This makes it very suitable for intensive productions with high stocking densities.

The aim of this short review is to centralize and present the value range of some water quality parameters for *C. gariepinus*. This may serve as a handy resource for those interested in the aquaculture of the African catfish.

Water parameters. The most important water parameter values are presented. All measurement units have been converted to roughly the same measurement unit for an easier read. Ammonium, ammonia, nitrite and nitrate values have been transformed where necessary from µM of NH_4-N, NH_3-N, NO_3-N and NO_2-N to mg L^{-1} of NH_4, NH_3, NO_3 and NO_2, respectively. Some optimum and lethal values of water parameters are presented in Table 1, based on data processed from the references cited in the text. The values presented should be read with the consideration the water parameters are interdependent, and they greatly influence each other. It is well known that a high temperature lowers the dissolved oxygen values, or that water measurements after fish feeding show a higher level of nitrogen compounds and lower oxygen. Thus, the water parameters should be regarded as a system in which a slight change in one value influences the whole system.

Temperature. The optimal temperature for incubation and hatching of African catfish eggs is 30^{0}C, but the incubation can be carried out between 20-35^{0}C; however, under 20^{0}C, the mortality rate is very high (Haylor & Mollah 1995). This is confirmed by other authors, which suggest lethal temperatures above 35.1^{0}C and under 17.5^{0}C for embryonic development (Prokešová et al 2015). In the larval stage, the optimum temperature seems to be 30^{0}C, according to Britz & Hecht (1987). The result is similar with a previous optimum recommended temperature in this life stage, of 32±1.5^{0}C (Clay 1979). The larvae have a good development between 25-33^{0}C, while in lower temperature values size variability is more present (Britz & Hecht 1987). In this stage, a temperature of 15^{0}C is not lethal, but in 10^{0}C mortality rates are high (Hoffman et al 1991). A decrease in specific growth rate has been observed in fingerlings (juveniles) when temperature decreased from 27 to 23^{0}C (Degani et al 1989). From this stage, catfish can be farmed in a temeperature range from 26 to 34^{0}C (Uys 1989; Degani et al 1989; Wedekind 1991; Ogunji & Awoke 2017). Catfish with a mean body weight of 400 g show a decrease in hemoglobin, total plasma protein and hematocrit when the temperatures are too high (41^{0}C) or too low (23^{0}C) (Adeyemo et al 2003).

Dissolved oxygen. This is a water parameter that needs to be closely monitored for most fish species, fish life being highly dependent on the level of dissolved oxygen in the water. A great advantage in African catfish farming is the fact that the fish is not that dependent on water dissolved oxygen. It can live in hypoxia conditions, sometimes for weeks or months in dessicated areas (Figure 1). However, it needs high humidity, to remain moist. It can breath air, but the physiological mechanism is not fully understood (Belão et al 2015). This can bring cost advantages in a fish farm, needing a lower volume of water change, less electricity, no oxygen reserves, higher stocking densities and others. Still, an oxygen level between 3-6 mg L^{-1} is recommended for a faster development (Adewolu et al 2008), because the fish consume oxygen in the physiological processes (Mohamed et al 2013), slowing metabolism under poor oxygen conditions for long periods of time. Some authors recommend a minimum of 6 mg L^{-1} O_2 (Boyd 1990).

Figure 1. African catfish (*Clarias gariepinus*) waiting for the rainy season in a dry pond, demonstrating its ability to survive without water (source: www.catchmefishing.com).

pH. In natural habitats, *C. gariepinus* thrives in a slightly acid water pH, 6.23-6.43 (Kolawole et al 2011). Other authors report a good growth of the fish under farming conditions in a pH from 6.98 to 8.36, the upper value indicating a fairly basic pH (Amisah et al 2009). Some sources give an even higher value, up to 8.9 (Peteri et al 1992). In a 2 week period, African catfish fry survivability is 94.17%, 96.67%, 99.17%, 99.17% and 51.67% in pH values of 5, 6, 7, 8 and 9, respectively, while for pH values of 2, 3, 4, 10, 11 and 12, no fish survived (Ndubuisi et al 2015).

Ammonium. The ammonium level is usually between 1.28-15.45 mg L^{-1} NH_4 (Bovendeur et al 1987). The results were confirmed by others, who observed 15 mg L^{-1} of ammonium in RAS and 1.8 mg L^{-1} in ponds with African catfish (Haylor 1989; Peteri et al 1989). Other results report an ammonium level up to 19.7 mg L^{-1} in RAS (Pruszyñski & Pistelok 1999).

Ammonia. African catfish tolerates a NH_3 level of 2.5 mg L^{-1}, but the level of ammonia should not exceed 0.34 mg L^{-1}, because it can deteriorate gill morphology (Schram et al 2010). Other sources state that a level of 0.05 mg L^{-1} should not be exceeded in hatcheries (Boyd 1990). In RAS, the level of NH_3 usually reaches 0.2 mg L^{-1}, and in ponds 0.5 mg L^{-1} (Haylor 1989; Peteri et al 1989). The fish has defense mechanisms against NH_3 (Ip et al 2004), but in high levels, growth and feed intake are reduced. The adult fish can survive for a short period of time, up to 24 hours, a sub-lethal level of ammonia of 2200 mg L^{-1}, but with haematological and hormonal disturbances (Ajani

2008). In its body, the fish can tolerate ammonia concentrations from 0.18 to 0.30 mg g^{-1}, even after 4 days of aerial exposure (Ip et al 2005).

Nitrites. Nitrite is an unstable compound that quickly reacts. Wide ranges of nitrite levels are reported to be tolerated, the results being sometimes contradictory. Ajani et al (2007) conducted a study regarding the responses of African catfish to high levels of nitrites in the water. When exposed to a sublethal dose of nitrite (100 mg L^{-1}), the fish presented similar problems as when exposed to ammonia, namely unbalanced haematological and hormonal profiles. There was no mentioning about mortalities. In another study, similar problems are observed by using a dose of 0.2 mg L^{-1} NO_2 (Ajani & Adeyemo 2012), but at this concentration, much smaller, some mortalities were observed. Ajani (2006) establishes the 96 h LC_{50} of NO_2 for African catfish, which is 200 mg L^{-1}. The recommended nitrite level for farming African catfish is below 1.9-2 mg L^{-1} NO_2, with possible growth defficiencies in long term exposure above this level (Roques et al 2013; Haylor 1989; Peteri et al 1989).

Nitrates. According to Schram et al (2014), the levels of nitrates (NO_3) should not exceed 619 mg L^{-1}. The highest concentration in the experiment was 1673 mg L^{-1} NO_3, but the feed intake and growth rate are reduced in concentrations higher than the recommended value. Insignificant mortalities were observed in the experiment (Schram et al 2014). In RAS, there are usually levels of NO_3 around 132-133 mg L^{-1}, which are not dangerous for the African catfish (Bovendeur et al 1987). In another study regarding the water quality in RAS for African catfish, the nitrate levels go as high as 216-220 mg L^{-1} (Prinsloo et al 1999). Nitrate is less toxic than nitrite.

Total dissolved solids. A level of 174.7 mg L^{-1} of total dissolved solids can be found in the natural habitat of the African catfish (Olaifa et al 2004). In intensive systems, a value of 3.2-3.3 mg L^{-1} total dissolved solids was observed (Al-Hafedh & Ali 2004). In Asa River, Nigeria, the total dissolved solids may range from 704 to 1800 mg L^{-1} (Kolawole et al 2011).

H_2S. Hydrogen sulfide is a very toxic gas for fish. In incubation and the first life stages, H_2S should be absent from the water (Boyd 1990; Ayoola 2009). However, larger catfish can withstand a level of 0.2-0.4 mg L^{-1} H_2S (Haylor 1989; Peteri et al 1989), being one of the few fish tolerant to the gas.

Salinity. In intensive farming, the salinity can reach values of 4.5-4.6 g L^{-1} (Al-Hafedh & Ali 2004). The African catfish is sometimes present in estuaries, being found in brackish water with 10 g L^{-1} salinity (Whitfield et al 1981). A salinity value over 7.5 g L^{-1} in the larval stage produces mortality in a population, while a salinity of 10 g L^{-1} produces total mortality after 2 days (Britz & Hecht 1989). A recommended range of salinity for larvae is 0-2.5 g L^{-1}, while higher values are recommended in profilaxy or treatments against different pathogens (Britz & Techt 1989). Other authors suggest a hatching salinity up to 5 g L^{-1} and confirm the lower salinity values for larval survivability (Gbulubo & Erondu 1998). As the fish grows, it can tolerate higher levels of salinity, thus, fingerlings tolerate 10 g L^{-1} and adults 15 g L^{-1} salinity (Clay 1977; Chervinsky 1984).

Chlorophyll-a. In traditional ponds, a level of chlorophyll-a of 0.5-1.3 mg/m^3 does not bother the catfish (Toko et al 2007). El Naggar (2007) reports a much higher concentration, between 65-72 mg/m^3 chlorophyll-a in earthen ponds with African catfish and Nile tilapia (*Oreochromis niloticus*). Up to 2000 mg/m^3 of chlorophyll-a can be tolerated by the African catfish (Haylor 1989; Peteri et al 1989).

Table 1

Some water quality parameters for African catfish (*Clarias gariepinus*)

Life stage		Parameter								
		T (^0C)	DO ($mg L^{-1}$)	pH	NH_4 ($mg L^{-1}$)	NH_3 ($mg L^{-1}$)	NO_2 ($mg L^{-1}$)	NO_3 ($mg L^{-1}$)	H_2S ($mg L^{-1}$)	Salinity ($g L^{-1}$)
Eggs, larvae	Optimum range	30-32	4-6	6-8	-	<0.05	-	-	0	<2.5
	Lethal range	<17.5 >35.1	-	<5 >9	-	-	-	-	>0	>5
Fingerlings, adults	Optimum range	26-34	4-6	6-8	1.5-16	<0.34	<2	<619	0	<10
	Lethal range	-	-	<5 >9	-	>2.5	-	-	>0.4	>15

Note: T – temperature; DO – dissolved oxygen.

The scientific literature provides some information about other parameters. In the natural habitat of *C. gariepinus*, the total suspended solids value in the water can range from 766 to 1499 mg L^{-1} (Kolawole et al 2011). The CO_2 levels in hatcheries should not exceed 10 mg/L and Iron should be under 0.5 mg L^{-1} (Boyd 1990). A chemical oxygen demand of 48 mg L^{-1} can be tolerated by the African catfish (Haylor 1989; Peteri et al 1989). However, some values are uncertain, mainly because the fish is considered sturdy and rezistent to changes in its environment, and the more subtle effects of the water parameters are less studied. This is proven by Ibrahim & El Naggar (2010) who notice that a 60% variation in water quality affects the bioproductive performances of African catfish in a small percentage, of only 11%. When the fish faces harder and harder conditions, that would kill other species, it adapts and continues to grow. This is why it has been transported to various areas in Asia, where it can grow in small ditches, pits, or small earthen ponds, with minimum costs. Moreover, the African catfish, as other species of fish, grows more tolerant to adverse environmental conditions, as it passes the larval and fry life stages.

It is a fish that it is highly appreciated, especially in Africa and Asia. In India, fry traders have smuggled it in the country, and the fish makes its way to Eastern Asia. The fish is banned in India, because it has a role in the decline of the local catfish *Clarias batrachus* and other fish species, being more rezistent and adaptable (Khedkar et al 2014).

Conclusions. The African catfish (*C. gariepinus*) possesses great adaptive traits to environmental conditions that would be lethal to other fish. It tolerates high levels of nitrogen compounds in the water, it can breathe air, making the lack of dissolved oxygen a lesser problem, it can tolerate even hydrogen sulfide in small quantities and brackish water salinities, making it a species suitable for farming in almost all kinds of environments. Furthermore, it has a good growth rate, eats a wide variety of feeds, and reaches sexual maturity in 1 year, all advantages that complement its tolerance to water parameters. One disadvantage is that it cannot tolerate low water temperatures, limiting its farm distribution in colder places.

Since it thrives in inappropriate conditions, most studies focus on bioproductive performances in these conditions, but there is an ambiguity concerning the establishment of clear limits for optimum and lethal values for some water or even land environmental parameters. Still, more and more studies focus on this species, and more information is discovered, as the fish gains more popularity.

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