Rapid Communication

First report of aquaculture-mediated introduction of the Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) into Lake Bosomtwe, Ghana

Kwasi Adu Obirikorang[1,*], Michael Ansong[2], Benjamin Apraku Gyampoh[1] and Gifty Anane-Taabeah Attu[1]

[1]*Department of Fisheries and Watershed Management, Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

[2]*Department of Silviculture and Forest Management, Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

Author e-mails: *kaobirikorang.canr@knust.edu.gh (KAO), mansong.canr@knust.edu.gh (MA), bagyampoh@knust.edu.gh (BAG), gataabeah.canr@knust.edu.gh (GA-TA)*

**Corresponding author*

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Abstract

The introduction of a non-native fish species into an aquatic ecosystem presents significant ecological risks if the species is able to successfully integrate into the ecosystem. Lake Bosomtwe in Ghana is an impact crater lake which contains an endemic and a near-endemic cichlid species. Following the establishment of an intensive Nile tilapia (*Oreochromis niloticus*) cage aquaculture facility on the Lake in 2012 and it closure in 2015, there have been several unconfirmed reports of the capture of *O. niloticus* from Lake Bosomtwe by local fishermen. On 6th February 2020, the first documented observations of *O. niloticus* in the natural environment of Lake Bosomtwe were made using seine net catches. Nine more seining activities were carried out between 6th February and 17th April, 2020, and the presence of the *O. niloticus* was confirmed during all sampling events. *Oreochromis niloticus* constituted between 2 and 10% of the captured cichlid species composition. The introduction of the species warrants larger-scale comprehensive studies on the possible detrimental interactions with native species, and on changes to ecosystem function.

Key words: alien species, biodiversity, biosecurity, cichlids, introduced species

Introduction

Introduced species have been defined by Shafland and Lewis (1984) as "any species intentionally or accidentally transported and released by humans into an environment where it was previously absent". This definition broadly covers species which are transported to locations outside their geographic range, as well as transfer or translocation of species within their geographic ranges to systems where they hitherto were absent. Introduced species are considered invasive when their introduction or spread threatens existing local biodiversity (Canonico et al. 2005). The management of invasive species remains one of the greatest ecological challenges globally, due to their perceived idiosyncratic nature and their persistent ecological and economic damage (Simberloff 2013). Introduction of invasive species has been extensively reported to be the second-leading cause of species endangerment and extinction in freshwater systems (Harrison and Stiassny 1999; Sala et al. 2000) with only habitat destruction ranking higher (Canonico et al. 2005).

Fish may be introduced to natural aquatic ecosystems where they are not native by several activities, including aquaculture. Aquaculture is a leading cause of non-native fish introductions globally, and accidental escapes from culture environments into the wild often create irreversible and unpredictable ecological impacts (Naylor et al. 2001; Zhan et al. 2017). In general, introduction of an aquaculture species into a country or area for production purposes does not necessarily imply its introduction into natural waters, particularly if production is in closed systems with high biosecurity measures such as recirculation systems. However, the establishment of such rigorous containment systems can be costly and difficult to implement (Ricciardi and Rasmussen 1998; Ham and Pearsons 2001), particularly in developing economies, where aquaculture is frequently performed in "open" systems. In aquaculture, the Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758) is the third most widely cultured fish species due to its tolerance of a wide range of environmental conditions. The global production of the species has increased exponentially over the years from 1.3 million tonnes in 2003 to about 4.5 million tonnes in 2018 (FAO 2020). Freshwater finfish, such as tilapia, are often grown in floating cages in open water bodies throughout the tropics and subtropics. Escapes from containment facilities into open waters are virtually inevitable under such production systems (McCrary et al. 2001).

In 2012, a private investor illegally set up 40 fish cages, each measuring 64-m^3, and stocked with *O. niloticus* on Lake Bosomtwe. This was done without prior approval or an operating permit from the Water Resources Commission and the Environmental Protection Agency of Ghana. This development raised concerns about the potential threat to aquatic life in the lake. Following the closure of the aquaculture farm and removal of all cages in 2015, there have been unconfirmed reports of the non-native *O. niloticus* among native species captured from Lake Bosomtwe by local fishermen who use traditionally-regulated trap fishing and cast nets. This study aims to report the first documented observation of *O. niloticus* from Lake Bosomtwe and provide initial estimates of its relative density.

Materials and methods

Study location

Lake Bosomtwe (Latitude 6.504; Longitude −1.4145) is a crater lake situated in the Ashanti Region of Ghana, West Africa, and is one of few meteoritic lakes in the world. The southernmost section overlaps the northern section of the Bosomtwe Range Forest Reserve, which contains a mosaic of forest, wetland and mountain habitats. The Lake Bosomtwe basin has a radial drainage pattern, with 37 inflowing streams and no outflow (Whyte 1975). Five of the inflowing streams are permanent (Whyte 1975). The widest section of the lake has a diameter of 8 km and a maximum depth of 78 m (Turner et al. 1996). It represents the only significant natural lake in Ghana and the West African sub-region (Scholz et al. 2007). The lake serves as an important geological site and is one of the youngest (1.07 Ma) and best-preserved complex meteorite impact craters currently on earth (Grieve 2005; Boamah and Koeberl 2007). In 2016, UNESCO conferred a biosphere reserve status on the Lake.

According to Whyte (1975), Lake Bosomtwe and its inflowing streams have historical records of 11 species of fish, of which five are cichlids; namely *Tilapia busumana* (Günther, 1903), *Coptodon discolor* (Günther, 1903), *Sarotherodon galilaeus* (Linnaeus, 1758), *Hemichromis fasciatus* Peters, 1857 and *Chromidotilapia guntheri* (Sauvage, 1882). A sixth cichlid, *Hemichromis frempongi* (Loiselle, 1979) is endemic to the lake (Loiselle 1979; Daget and Teugels 1991; Lamboj 2004), and *Tilapia busumana* and *C. discolor* are near-endemic (Daget and Teugels 1991; Lamboj 2004; Teugels and Thys van den Audenaerde 2003). *S. galilaeus* and *C. güntheri* are mouthbrooders, whilst *C. discolor, T. busumana*, *H. fasciatus, and H. frempongi* are substrate brooders. Despite the presence of two mouth brooding planktonic feeders in the lake, the need to spawn on a firm substrate, together with the surface-feeding habit of the juvenile cichlids, makes none of the fish completely independent of the shallow area (Whyte 1975). Although non-cichlids are present in the Lake Bosomtwe basin, these tend to be restricted to the riverine sections, and cichlids dominate the fish fauna of the lacustrine environment. For reasons not clearly documented, all non-cichlid fish species from five fish families previously reported from the lake (including Cyprinidae, Clariidae, Mastacembelidae and Amphiliidae) are consistently absent from recent fish catch data from the lake (Mensah et al. 2019).

Fish sampling

On 6th February, 2020, a 100 m seine net with a depth of 6 m and 5-mm mesh was used to sample fish from the lake. The length of the seine and the mesh size was chosen to enable estimates of species abundance and size distributions to be made from catches. Seining involved encirclements where the seine net was laid using a boat and all retained fish hauled to shore with the help of the local fishermen. Nine more seining activities were carried out between 6th February and 17th April, 2020 (Table 1). Each sampling activity consisted of one seine haul. The meristic and morphometric characteristics of captured *O. niloticus* were taken and compared with information on FishBase (Froese and Pauly 2019) for confirmation.

Table 1. Abundance and length-weight data of the different cichlid species captured from Lake Bosomtwe (6th February to 17th April).

	Oreochromis niloticus	*Coptodon discolor*	*Tilapia busumana*	*Hemichromis fasciatus*	*Sarotherodon galilaeus*	*Chromidotilapia guntheri*
6th Feb	5	78	15	47	81	1
27th Feb	8	15	7	32	20	0
2nd Mar	15	70	89	46	38	0
6th Mar	4	19	8	13	26	0
7th Mar	4	42	19	13	44	0
8th Mar	24	98	149	67	74	0
10th Mar	15	45	25	45	43	0
15th Apr	3	28	17	15	72	0
16th Apr	15	43	27	6	48	0
17th Apr	7	20	27	50	48	0
Total	100	458	383	334	494	1
Weight (g)	278.33 ± 141.94	27.25 ± 11.47	15.18 ± 4.13	21.90 ± 4.97	16.66 ± 5.77	–
SL (cm)	18.82 ± 5012	8.52 ± 1.37	7.17 ± 0.77	9.00 ± 0.68	7.21 ± 0.82	–
TL (cm)	22.76 ± 5.88	11.04 ± 1.72	9.05 ± 0.93	10.98 ± 0.82	9.26 ± 1.01	––

SL: Standard length; TL: Total length.

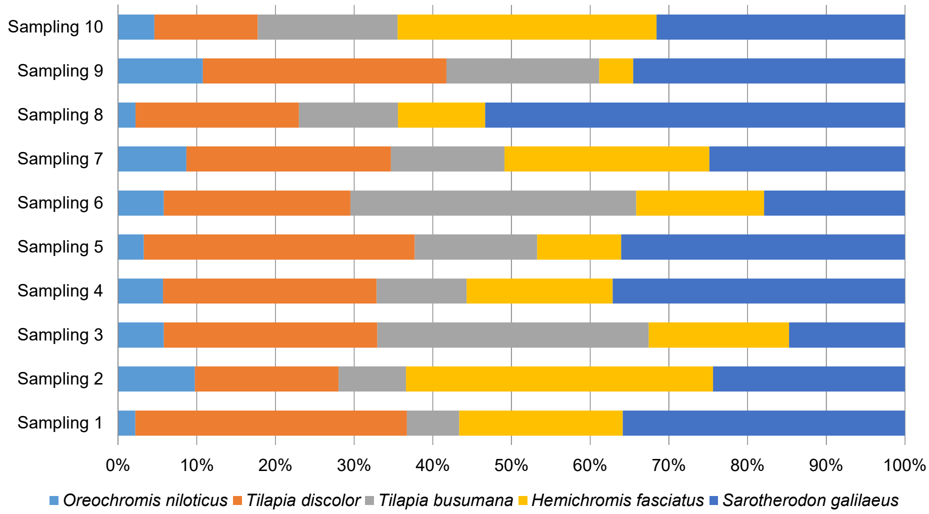

Figure 1. Catch composition of cichlid species captured from Lake Bosomtwe during sampling from February to April, 2020.

Results

A total of 1770 individual fish were sampled over the 10 sampling activities, of which 100 were identified as *O. niloticus*. With the exception of the first sampling that recorded six cichlid species, including an individual of the rare *C. güntheri,* all samples consistently yielded five cichlid species including *S. galilaeus, C. discolor, H. fasciatus*, *T. busumana*, *H. frimpongi* and *O. niloticus*. In terms of relative abundance, the *O. niloticus* constituted between 2 and 10% of the captured cichlid species composition (Figure 1). The adults of native cichlid species are generally smaller in size compared to the *O. niloticus* (Figure 2). The abundance, lengths and weights of all the fish captured in the 10 hauls are shown in Table 1.

Discussion

The common name "tilapia" non-monophyletic refers to a group of tropical freshwater fishes in the family Cichlidae, most notably, but not exclusively,

Figure 2. Size comparison of the alien and native cichlid species of Lake Bosomtwe captured in the first sampling. From top to bottom: *Oreochromis niloticus*, *Chromidotilapia güntheri*, *Sarotherodon galileaus*, *Tilapia busumana*, *Coptodon discolor*, *Hemichromis fasciatus*.

Oreochromis, Tilapia, and *Sarotherodon* spp., that are indigenous to Africa and the southwestern Middle East (Canonico et al. 2005). Tilapiine species are tolerant to sub-optimal water quality, which allows them to survive for extended periods of time under conditions that would be detrimental to other species. Certain tilapia species, such as *O. niloticus*, are well-suited to aquaculture production because of their potential for fast-growth and tolerance of a wide range of environmental fluctuations. *Oreochromis niloticus*, in particular, can acclimate readily to changes in salinity levels, can survive chronic hypoxic conditions, can feed at different trophic levels, and tolerate high stocking densities (McKaye et al. 1995; Coward and Little 2001). The wide environmental tolerances and trophic adaptability of this species coupled with its high reproductive rate, however, predispose it for successful establishment as an invasive species in natural waters into which they escape (Trewavas 1983; Costa-Pierce 2003).

Mouth-brooders like *O. niloticus* do not have strict spawning habitat requirements or environmental conditions for reproduction and can occupy a variety of habitats within an ecosystem (McKaye et al. 1995). Another peculiar trait is their ability to colonize new environments by carrying fertilized eggs in their mouths and moving to new sites. The introductions of *O. niloticus* into Lakes Victoria and Kyoga in East Africa are linked to the decline of two native tilapiine species, the *Oreochromis esculentus* and *O. variabilis* (Twongo 1995). In the case of the Lake Victoria, the introduced *O. niloticus* may have outcompeted and genetically subsumed two native cichlids (Twongo 1995; Goudswaard et al. 2002).

In Lake Bosomtwe, a major concern is that the indigenous cichlid species of the lake, particularly the mouth brooders, have low fecundity rates and are already particularly vulnerable to increased fishing pressure by native fishermen from the communities around the Lake. The high growth and fecundity rates of *O. niloticus* may negatively impact native species abundance through competition for food and space, and result in significant alteration of community structure and ecosystem processes. The small size of Lake Bosomtwe (8 km wide) may heighten its vulnerability to the species invasion and predispose the native species to population declines. The establishment of *O. niloticus* in Lake Bosomtwe adds to a worrying trend of increasing number of alien fish species or strains in the natural waters of Ghana, largely as a result of accidental introductions via aquaculture. There have been reports of illegally-introduced GIFT (Genetically Improved Farmed Tilapia) strains of *O. niloticus* escaping from cage farms and interbreeding with native populations within the lower parts of the Volta River basin in Ghana (Anane-Taabeah et al. 2019). Poor biosecurity measures coupled with poorly defined national conservation goals accounts for the expansion of alien species' range which could pose a significant threat to the diversity of ichthyofauna in Ghana.

Conclusions

It is clear from the historical records dating back from the earliest sampling in 1902 that *O. niloticus* has never been sampled from Lake Bosomtwe or the surrounding streams which drain into it. It is thus almost certain that this is the case of a relatively recent introduction of the species, and a likely consequence of the establishment of the cage aquaculture farm.

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References

Anane-Taabeah G, Frimpong EA, Hallerman E (2019) Aquaculture-mediated invasion of the genetically improved farmed tilapia (GIFT) into the Lower Volta Basin of Ghana. *Diversity* 11: 188, https://doi.org/10.3390/d11100188

Boamah D, Koeberl C (2007) The Lake Bosumtwi impact structure in Ghana: a brief environmental assessment and discussion of ecotourism potential. *Meteoritics and Planetary Science* 42: 867–882, https://doi.org/10.1111/j.1945-5100.2007.tb01061.x

Canonico GC, Arthington A, Mccrary JK, Thieme ML (2005) The effects of introduced tilapias on native biodiversity. *Aquatic Conservation* 15: 463–483, https://doi.org/10.1002/aqc.699

Costa-Pierce BA (2003) Rapid evolution of an established feral tilapia (*Oreochromis* spp.): the need to incorporate invasion science into regulatory structures. *Biological Invasions* 5: 71–84, https://doi.org/10.1023/A:1024094606326

Coward K, Little D (2001) Culture of the 'aquatic chicken'. *Biologist* 48: 12–16, https://doi.org/10.1136/gut.48.1.12

Daget J, Teugels GG (1991) *Hemichromis*. In: Daget J, Gosse J-P, Teugels GG, Thys van den Audenaerde DFE (eds), Check-list of the freshwater fishes of Africa, Vol. 4. CLOFFA, ISNB, Brussels; MRAC, Tervuren; and ORSTOM, Paris, pp 187–194

FAO (2020) The State of World Fisheries and Aquaculture 2020. Sustainability in action. The Food and Agriculture Organization, Rome, 344 pp, https://doi.org/10.4060/ca9229en

Froese R, Pauly D (eds) (2019) FishBase, version 12/2019, http://www.fishbase.org (accessed 25 March 2020)

Goudswaard PC, Witte F, Katunzi EFB (2002) The tilapiine fish stock of Lake Victoria before and after the Nile perch upsurge. *Journal of Fish Biology* 60: 838–856, https://doi.org/10.1111/j.1095-8649.2002.tb02413.x

Grieve RAF (2005) Economic natural resource deposits at terrestrial impact structures. In: McDonald I, Boyce AJ, Butler IB, Harrington RJ, Polya DA (eds), Mineral Deposits and Earth Evolution. Geological Society London Special Publication 248, London, UK, pp 1–29, https://doi.org/10.1144/GSL.SP.2005.248.01.01

Ham KD, Pearsons TN (2001) A practical approach for containing ecological risks associated with fish stocking programs. *Fisheries* 26: 15–23, https://doi.org/10.1577/1548-8446(2001)026<0015:APAFCE>2.0.CO;2

Harrison IJ, Stiassny MLJ (1999) The quiet crisis: a preliminary listing of the freshwater fishes of the world that are extinct or 'missing in action'. In: MacPhee RDE (ed), Extinctions in Near Time. Kluwer, New York, USA, pp 271–331, https://doi.org/10.1007/978-1-4757-5202-1_12

Lamboj A (2004) The Cichlid Fishes of Western Africa. Birgit Schmettkamp Verlag, Bornheim, Germany, 255 pp

Loiselle PV (1979) A revision of the genus *Hemichromis* Peters 1858 (Teleostei: Cichlidae). *Annals of the Museum of the Royal African Centre of Science and Zoology Series 8* 228: 1–124

McCrary JK, van den Berghe EP, McKaye KR, Perez LJL (2001) Tilapia cultivation: a threat to native fish species in Nicaragua. *Encuentro* 58: 3–19

McKaye KR, Ryan JD, Stauffer JR, Perez LJL, Vega GI, van den Berghe EP (1995) African tilapia in Lake Nicaragua: ecosystem in transition. *Bioscience* 45: 406–411, https://doi.org/10.2307/1312721

Mensah A, Sanful P, Agyeman Y, Trolle D, Nunoo F, Asase A (2019) Sustainable ecosystem services of Lake Bosumtwi, Ghana - implications for livelihoods and food security. *Nature & Faune* 32: 58–60

Naylor RL, Williams SL, Strong DR (2001) Aquaculture-A gateway for exotic species. *Science* 294: 1655–1656, https://doi.org/10.1126/science.1064875

Ricciardi A, Rasmussen JB (1998) Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1759–1765, https://doi.org/10.1139/f98-066

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke MLF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH (2000) Biodiversity: global biodiversity scenarios for the year 2100. *Science* 287: 1770–1774, https://doi.org/10.1126/science.287.5459.1770

Scholz CA, Karp T, Lyons RP (2007) Structure and morphology of the Bosumtwi impact structure from seismic reflection data. *Meteoritics and Planetary Science* 42: 549–560, https://doi.org/10.1111/j.1945-5100.2007.tb01060.x

Shafland PL, Lewis WM (1984) Terminology associated with introduced organisms. *Fisheries* 9: 17–18

Simberloff D (2013) Invasive Species: What Everyone Needs to Know. Oxford University Press, New York, USA, 352 pp

Teugels GG, Thys van den Audenaerde DFE (2003) Cichlidae. In: Paugy D, Lévêque C, Teugels GG (eds), The fresh and brackish water fishes of West Africa. Volume 2. Coll. faune et flore tropicales 40. Institut de recherche de développement, Paris, France, Muséum national d'histoire naturelle, Paris, France and Musée royal de l'Afrique Central, Tervuren, Belgium, pp 521–600

Trewavas E (1983) Tilapiine fishes of the genera *Sarotherodon*, *Oreochromis* and *Danakilia*. British Museum of Natural History, London, 583 pp, https://doi.org/10.5962/bhl.title.123198

Turner BF, Gardner LR, Sharp WE (1996) The hydrology of Lake Bosumtwi, a climate-sensitive lake in Ghana, West Africa. *Journal of Hydrology* 183: 243–261, https://doi.org/10.1016/0022-1694(95)02982-6

Twongo T (1995) Impact of fish species introductions on the tilapias of Lakes Victoria and Kyoga. In: Pitcher TJ, Hart PJB (eds), The Impact of Species Changes in African Lakes. Chapman & Hall, London, UK, pp 45–57, https://doi.org/10.1007/978-94-011-0563-7_4

Whyte SA (1975) Distribution, trophic relationships and breeding habits of the fish populations in a tropical lake basin (Lake Bosumtwi-Ghana). *Journal of Zoology* 177: 25–56, https://doi.org/10.1111/j.1469-7998.1975.tb05969.x

Zhan A, Ni P, Xiong W, Chen Y, Lin Y, Huang X, Yang G, Gao Y (2017) Biological invasions in aquatic ecosystems in China. In: Wan F, Jiang M, Zhan A (eds), Biological Invasions and Its Management in China. Invading Nature - Springer Series in Invasion Ecology, Vol 11. Springer, Dordrecht, The Netherlands, pp 67–96, https://doi.org/10.1007/978-94-024-0948-2_4