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Incidence of Fish Off-flavor for the first time from Lake Tana, Ethiopia: Causes and Possible Management Strategies

Workiyie Worie Assefa[1]* and Goraw Goshu[2]

[1] Bahir Dar University, College of Science, Department of Biology and Blue Nile Water Institute, P. O. Box 79, Bahir Dar, Ethiopia

[2]College of Agriculture & Environmental Sciences and Blue Nile Water Institute, Bahir Dar University, Bahir Dar, P. O. Box 79, Ethiopia

ABSTRACT

Assessment of water quality and plankton community composition analyses was conducted in northeastern portions of Lake Tana in June 2012. The aim of the assessment was to examine the off-flavor causing bioprocesses and agents in Nile Tilapia (O. *niloticus*) and recommended management interventions. The samples of physico-chemical, biological characteristics and sediment quality was collected in four places, namely Wagtera and Tigresefer from Rib river mouth and Tana Kirkos from Gumara river mouth and Zegae areas (Reference site). These sites are the field where the problem of off-flavor has been noticed. Preliminary results indicated generally very poor water quality conditions on the investigated areas and the values for most important water quality indicators indicated worse conditions of the water. The major planktons identified from samples taken from the water and from gut content analysis of the filter feeder Nile Tilapia indicated that the water as well as the gut was mainly of Cyanobacteria *Microcysitis aeruginose* and *Anabaena spp.* The cyanobacteria were present in very high density and these bacteria are known from literature that they are responsible for the mass production of Geosmin ($C_{12}H_2O$) MIB (2Ethylisoborneol): Cause for off-flavor in Nile Tilapia (*Orechromius niloticus*). The background water quality data revealed eutrophication conditions of the water, which is a conducive environment for the mass production of cyanobacteria. The mass production of cyanobacteria is apparently due to eutrophication of the water as a result of high nutrient load that could be sourced from the recession agriculture on the shore areas of the lake and generally from nutrient loads of Rib and Gumara rivers. A range of mitigation measures has been suggested to solve the problems. An immediate solution to avoid the off-flavor, include by keeping Nile tilapia in clean static water for two weeks and use of Lemmon juices before eating are somehow helpful. The effect of various treatments, i.e., salting and drying, smoking, microwave heating, marinating and fermentation on off-flavor of tilapia are also helpful. Long term solutions mainly should focus on source reduction of nitrate and phosphate nutrients from the recession agriculture as well as the diffuse catchment through having a buffer zone of wetlands, stopping the encroachment of wetlands, stopping recession agriculture, developing nutrient management strategy and watershed management is the last and ultimate and long lasting solution.

KEYWORDS: Eutrophication, Cyanobacteria blooming, Lake Tana, Nile tilapia, off-flavor, Water quality

*Corresponding Author:

Workiyie Worie Assefa

Bahir Dar University, College of Science, Department of Biology and Blue Nile Water Institute, P. O. Box 79, Bahir Dar, Ethiopia Present address: Research Scholar at the University of Bordeaux, Bordeaux, France.

E-mail address: workiyieworie.assefa@etu.u-bordeaux1.fr; workiye2008@gmail.com

INTRODUCTION

The term off-flavor is used to describe the accumulation of odorous compounds within water or tissue produced from biological origins. Several studies have shown that geosmin and 2-methylisoborneol (MIB) have been implicated as the cause of off-flavor incidents in fish from natural environs as well as aquaculture ponds elsewhere[1,2,3]. As reported the source of these compounds are known to be produced by blue-green algae and actinomycete bacteria. They are semi-volatile terpenoid organic compounds, and easily absorbed by gills of the fish and eventually stored in fat tissues. MIB causes a flavor to be imparted to the flesh described as musty and geosmin results in earthy or muddy flavor and odors[4]. According to studies off-flavor phenomenon is most commonly associated with eutrophic environmental conditions such as high temperature and nutrient enrichment that could create an ideal condition for the developments of heavy Cyanobacteria and actinomycete populations[4]. Nevertheless, anthropogenic eutrophication is becoming a major problem in freshwater systems elsewhere in the world. The main driving factor of eutrophication is the excessive input of nutrients into a surface waterbody that were previously scarce through natural and human activities[5]. Both phosphorus and nitrogen supplies contribute to it, although for many lakes, excessive phosphorus inputs are the primary cause[5,6]. The most conspicuous symptom of eutrophication is a large increase in plankton, algae and aquatic macrophytes, especially of phytoplankton, which can develop an intense algal bloom[5]. Some physical parameters such as increased light and temperature assist the development of eutrophication processes. Eutrophic waters in freshwater systems may mainly develop noxious blooms of Cyanobacteria (blue-green algae). Cyanobacteria may cause an off-flavor of drinking water, release toxic organic compounds into the water that can kill livestock and may pose a serious health hazard to humans; the decomposition of dead algal biomass creates a large O_2 demand, depleting its concentration in water. The anoxic conditions are extremely stressful to aquatic animals, such as fish and anoxia also facilitates the production and release of hydrogen sulfide (H_2S) and other noxious gases[5,6]. Cultural eutrophication, in general, represents a degradation of water quality and ecological conditions, and it is an important environmental problem in many areas. It regards the ability of water bodies to be a source of drinking water; support commercial and sport fisheries and be utilized for recreation. It can likewise contribute to loss of habitats such as aquatic plant beds in fresh and marine waters. Thus, plays a role in the loss of aquatic biodiversity[5,6,7].

In 2012, environmental related taste (off-flavor and odor) change on Nile tilapia (*O. niloticus*) for the first time appeared in the country's largest waterbody, source of Blue Nile, Lake Tana, which has a surface area of 320000 hectares. This problem was reported to government offices and research institutions immediately it occurred by the fishers and consumers resident in different district bordering the lake. Consequently, socioeconomic survey was conducted in April 2012 by a team of researchers aiming to know the extent of the problem and the opinion of the community and consumers. From the preliminary socioeconomic survey, they speculated that the possible and likely causes for the change may be cultural eutrophication due to nutrient loading and they recommended that water quality, sediment analysis, gut analysis, fish tissue test, phytoplankton and zooplankton community composition should be done as soon as possible[8]. Established on the good words of the survey report, we conducted a detailed water quality analysis, including plankton in June 2012 to examine the off-flavor causing bioprocesses and agents in Nile Tilapia (O. *niloticus*) and recommended management interventions. Therefore, the objectives of these assessments were:

- To assess water quality condition where the problem has been manifested
- To identify and enumerate phytoplankton and zooplankton community composition
- To analyze the nutrient load of the study site and relate to the massive growth of phytoplankton
- To relate fish taste change with water quality deterioration

MATERIAL AND METHODS

Study area description

Lake Tana is the largest lake in Ethiopia with a surface area of 3200 km^2 and a watershed of 16500 km^2 located at 1830 m above sea level. It is a meso-oligtrophic type with an average depth of 9m and maximum depth[9] of 14m. The lake is fed by seven major permanent rivers (Gumara, Rib, Megech, Gilgel Abay, Arno-Garno, Gelda and Dirma) and more than 60 seasonal rivers. The Lake Tana sub-catchment area has been picked out as the growth corridor for Amhara region and the national level as well considerate the rich potentials of the catchment area for development. The lake emerged as one of the global top 250 lake regions most important for biological diversity[10]. The lake and its catchment area are rich in biodiversity. For example, it harbors 15 unique species flock of *Labeobarbus*, the only cyprind species flock in the world, after the ones in Lake Lanao vanished because of overexploitation[11].

The survey team found that the problem (off-flavored fish occurred) extends from Dera to Dembia district bordering the north eastern parts of Lake Tana flood plains[8]. In this study, however, we only assessed the Fogera flood plain (where the problem is highly magnified) located in the eastern parts of the lake about 50 km north of Bahir Dar (Figure 1) due to logistic and time limitation. The sampling sites, thus, were selected purposely and includes Rib River mouth (Lat. 11°59'.335, Long. 37°33'.913); Gumara River mouth: (Lat. 11° 54'.24, Lon 37° 29'.469) and Zegae (Lat. 11° 42'.425, Long 37° 24'.906) and its altitude also ranges from 1582 m to 1808 m above sea level.

Sampling and in situ measurement

Plankton samples were taken by the 60µm mesh size of general net at the Old Rib river mouth (Tigrea-Sefer), Gumara river mouth and Zegae area transecting from the shore towards the lake in June 2012. The samples, then, fixed with formaldehyde (Zooplankton) and lugol's solution (phytoplankton). Phytoplankton samples were also taken from the Rib moth in April 2012. Some physico- chemical parameters were measured in situ by a multi-parameter, Maji- probe. Temperature, conductivity, TDS, salinity turbidity, pH and dissolved oxygen were measured in situ using a portable all-in-one meter (Maji multi-parameter water quality meter, Model WAG WE5 1500). Water for physico-chemical variables, including Chl a, and algal nutrients were sampled at the surface. Samples were transferred and stored under ice until analyses were made in the laboratory. The sediment of the lake was sampled using the Ekman grab sampler[12]. For gut analysis we bought fish samples from fishers. Each fish, then, was dissected and the gut contents were transferred to a labeled plastic bag containing 5% formaldehyde solution.

Laboratory analysis

For phytoplankton Enumeration sub-samples usually 1 ml transferred into a Sedgwick Rafter cell and left for 24 hours to settle. Similarly, qualitative analyses of phytoplankton were determined by a Sedgwick Rafter cell settling the sample for 24 hours after sub-samples of 1 ml has been transferred. Phytoplankton counted and identified by means of a compound inverted light microscope (magnification 10X to 400X) using descriptions, illustrations and keys in the literature. For zooplankton and other invertebrates, 10 ml subsample was taken and placed in a counting chamber and then identified under a WILD type stereoscope (magnification 6X to 50X). Plankton counts in both cases were expressed in terms of cells/ml water.

Total alkalinity was determined from the unfiltered water sample through titration with 0.1 N HCl with bromocresol green/methyl red used as an endpoint indicator[12]. Water samples were filtered through Whatman GF/C filter paper and the filtrate was used for the determination of dissolved inorganic nutrients. Soluble reactive phosphorus (SRP) was determined spectrophotometrically using the Ascorbic Acid method, ammonium ($NH4$ +-N) was analyzed with the Indo-phenol Blue method and nitrate (NO_3-N) was analyzed using the Sodiumsalicylate method[13]. Nitrite (NO_2-N) determination was carried out using the reaction between sulfanilamide and N-naphthyl-(1)-ethylendiamin-dihydrochloride. Total hardness and iron and sulfide were also analyzed following standard procedures[13]. For Chl a, water samples were filtered onto duplicate Whatman GF/C glass-fiber filters and the filters were deep-frozen overnight to facilitate extraction. Then the filters were homogenized and extracted in 90% acetone for 12h. Chl-a was determined spectrophotometrically after centrifugation at 665 nm without phaeopigments correction[14].

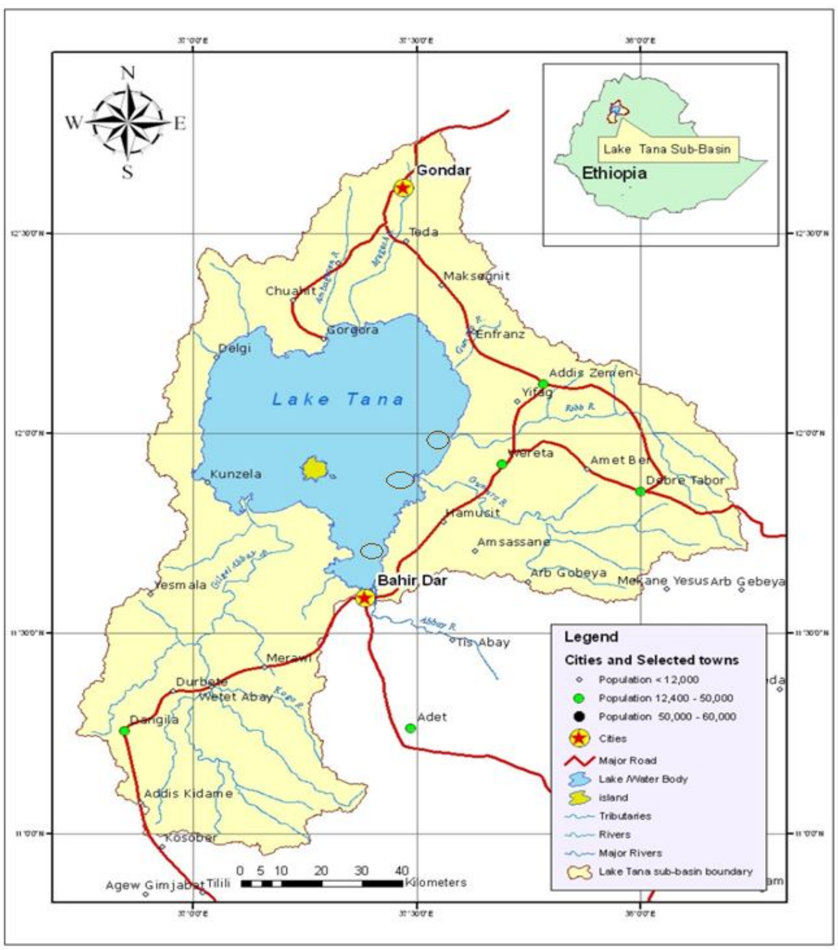

Figure 1: Location map of Lake Tana Basin showing the major rivers feed it and sampling sites represented by ellipse dots (Source: Amhara Bureau of Agriculture)

Results

Phsico-chemical characteristics

The water phsico-chemical characteristics of the study areas were presented in Table 1.

Table 1: Physico-chemical characteristics of the sampling sites

Parameters	Sampling sites				
	Rib River Mouth	Rib River pelagic	Gumara River pelagic	Gumara River mouth	Zegae (Reference site)
Temperature (^{O}C)	22.1	23.4	23.1	23.5	23.5
ORP (mv)	162.1	87.4	128.2	89.5	77.5
pH	8.34	7.11	7.11	7.79	8.19
DO (mg/l)	3.28	3.12	2.32	3.12	3.58
EC (µS/cm) at 25 ^{O}C	170	172	42	166	174
TDS (mg/l)	110	111	27	107	113
Salinity (mg/l)	0.08	0.08	0.02	0.08	0.08
Turbidity (NTU)	398	114	321.1	403	51.6
Fe^{2+} (mg/l)	2.8	0.7	3.35	7	0.05
S^{2-}(mg/l H_2S)	0.1484	0.106	0.2014	0.2756	0.0954
NO^{3-}(mg/l)	0.1403	0.3168	0.176	0.2244	0.2772
NO^{2-} (mg/l)	0.0759	0.01386	0.0891	0.1056	0.1254
NH_3 (mg/l)	3.96	0.72	4.38	8.16	0.06
$PO_4^{3-(}$mg/l)	1.09	0.32	0.97	2.13	0.23
Sediment available P (mg/l)	35.5	37.59	23.89	25.34	13.5
Alkalinity (mg/l $CaCO_3$)	183	90	240	363	103
Total Hardness (mg/l $CaCO_3$)	265	143	>500	>500	102
Chl-a (µg/l)	25	20	30	35	6
Lat	11°59’. 335	11° 58’.895	11°54’.24	11 ° 53’.785	11° 42’.425
Long	37°33’. 913	37 ° 33.51	37 ° 29’.46	37 ° 28’.983	37 ° 24’.906
Alt (m)	1803	1806	1808	1802	1582

The results showed that the water quality of the investigated area is deteriorated and most values are greater than set by WHO water quality standards and the values of phosphate ranged from 0.28-2.23

mg/l, nitrate 0.14-0.32 mg/l and Chl-a concentration 6µg/l to 35µg/l, Iron 0.05-7mg/l, sulfide 0.09mg/l 0.27mg/l hydrogen sulfide, ammonia 0.06-8.16 mg/l NH3, nitrite 0.08-0.14mg/l NO_2, Alkalinity 90-360 mg/l Ca CO_3 and turbidity ranged from 51.6- 403 NTU. Temperature variations between 22℃ to 24℃ being the highest recorded at the Gumra river mouth and Zegae sampling sites. The variation of pH, DO and salinity were not as such significant between sites (Table 1). In general, the river mouths were experienced maximum values except nitrate and nitrite while the minimum values were detected at the Zegae sampling site.

Biological characteristics

The phytoplankton and zooplankton community composition and relative abundance of the study area were presented in Table 2. The samples were known to contain more than 15 taxonomic groups. The phytoplankton was represented by blue-green algae, green algae and diatoms while zooplankton by Copepods, Daphnia and Rotifers.

Figure 2: Cyanobacteria blooming and scum at the eastern part of the Lake Tana shore where the problem has been occurring, Rib river mouth

The two Cyanobacteria community types characterized the dominant genera include *Microcystis* and *Anabeana* species at the Rib and Gumara river mouths (Table 2). In relative terms, diatoms were more abundant to that of green algae. Cyanobacteria are nutritionally inadequate and also produce chemicals that deter grazers such as Daphnia. Accordingly, Daphnia were absent or very rare occurrence in Gumara and Rib river's mouth. But, it was high in number at Zegae where the water is clear and Cyanobacteria number is down. On the other hand, Copepods appeared in good numbers of Gumara and Rib river mouths which can be an indication of Cyanobacteria blooming. In general, excessive growths of cyanobactia were observed at river mouths whereas the reference sites, Zegae area was characterized by very low numbers (See the scum in Fig. 2 and 3).

Table 2: Phytoplankton (individual/ml) and Zooplankton community compositions of the sampling sites (- = Not observed; + = few in number; ++ = small number; +++= high number; ++++ = numerous in number)

Taxa	Sampling sites		
	Rib River pelagic & mouth	Gumra River pelagic & mouth	Zegae
Cyanobacteria			
Microcystis flos-aquae	500	350	300
Microcystis aeruginosa	49850	19200	525
Microcystis werenbergii	850	539	0
Merismopedia spp.	105	95	0
Anabeana circinalis	15000	500	29
Planktothrix spp.	135	65	0
Aphanizomenon spp.	25	0	0
Green Algae			
Straurstrum	+	-	_
Ulothrix	+	+	_
Diatoms			
Synedra	++	+	_
Cymbella	++	+	_
Melosira	++	++	++
Zooplankton			
Copepods	++	+++	-
Daphnia	_	+	+++
Ritefers	+	+	+

Fish-gut content analyses

The analyses have proven that the major plankton identified in the stomach of 25 Nile tilapia collected from the old Rib river mouth are Microcystis flos-aquae, Microcystis aeruginosa, Anabeana spp., Oscillatoria spp. *and Copepods.* Green algae (*Straurstrum, Pediastrum, Spirogyra, Scenedesmus, Chlamydomonas, Cosmarium*) and diatoms (*Melosira, Cymbella, Gyrosigma*) were likewise mentioned in a modest number. Daphnia and rotifers were rarely met in the stomachs of Nile tilapia. In general, the stomach of the fish was dominantly filled with cyanobacteria.

DISCUSSION

The analyses of water samples and tilapia fish gut content confirmed that Phytoplankton samples were amazingly dominated by the genera *Microcystis and Anabaena* forming a bloom at Rib river and Gumara river mouths compared to that of the reference site, Zegae (Table 2). Nevertheless, the other sampling sites, including blooming occurred had very low concentrations of other phytoplankton (diatoms and green algae). Studies have shown that bloom-forming cyanobacteria are the primary group of phytoplankton that dominates nutrient-rich (eutrophic) aquatic habitats together with other favorable environmental factors. Of course, Cyanobacteriea (blue-green algae) are ubiquitous in nature and constitute almost all environments, are usually driven through anthropogenic eutrophication.

There are a number of environmental factors that favor the massive growth of nuisance cyanobacteria: high temperatures and low wind; a large supply of phosphate; low ratio of nitrogen to phosphorus; ammonium as a nitrogen source and flushing/altered water residence time[15]. The physical and chemical factors were very suitable for cyanobacteria bloom flourish in the eastern parts of the Lake Tana shore (Table 1). The only river that outflows from Lake Tana is Blue Nile River; however, the outlet has been regulated at the Chara Chare weir for irrigation and hydropower purpose since at the beginning of 2002. Certainly, this shall increase the water residence of the lake providing good opportunity for the growth of Cyanobacteria. Cyanobacteria also have a full scope of temperature tolerance, but rapid growth rates are normally reached when the water temperatures exceed 20°C which is in accord with the present result (Table 1). Cyanobacteria contain the photosynthetic pigment chlorophyll-a, but unlike other phytoplankton they also contain phycobiliproteins which provides a competitive advantage in harvesting more light energy efficiency over other phytoplankton when light is limited due to high turbidity. Thus, the high turbidity measured at Rib river and Gumara river mouths

(Table 1) favor higher growth rates of cyanobacteria than those of green algae, which allow them to out-compete green algae in highly turbid waters.

In almost all freshwaters, primary production is limited by the availability of inorganic phosphorus, occurring as the ion phosphate (PO_4^{-3})[5]. As a mere guide, the influence of nutrient levels of cyanobacterial growth can be measured in terms of total phosphorus (TP) concentrations in the water body. In general, a total phosphorus level of 10–25 µgL-1 presents a moderate risk in terms of the growth of cyanobacteria. For concentrations of less than 10 µg L^{-1} there is a low risk of cyanobacteria growth and a level greater than 25 µg L^{-1} provides high growth potential. The concentration of the total phosphorus we obtained where cyabobacteria blooming is occurring greater by many folds about 85 times than the standard, particularly in Gumara river mouth (Table 1). Additionally, high concentration of ferrous iron is also an indication of the mobilization of phosphorus from the anoxic sediments into open waters that can maintain eutrophication. Therefore, the combination of such conditions certainly created a sustainable source of nutrient that has been favored the massive growth of Cyanobacteria, which is the symptom of eutrophication. Furthermore, [17] reported that higher values of phosphate, nitrate and Chl-a values were also detected in Gumara and Rib areas than Zegea during dry seasons of the year (got coincided with the occurrence the current off-flavor hit) and the water quality of the lake shores is poorer than the pelagic one that can create conducive environment for blooming. Cyanobacteria also have the capacity to store abundant nutrients (e.g., phosphorus) and some species can convert gaseous nitrogen to ammonia via nitrogen fixation; both features afford cyanobacteria more uniform approach to limiting nutrients compared to eukaryotic microalgae[18]. As compared to other phytoplankton, the structure of the cyanobacterial cell wall allows greater hyper-osmolarity, reducing energy expenditure for active solute transport[19]. The presence of gas vacuoles allows cyanobacterial cells to adjust their vertical position in the water column, either by floating toward light sources or sinking in deeper waters to access higher nutrient concentrations or avoid photooxidative damage[20,21]. Cyanobacteria, unlike most autotrophs, can directly absorb and utilize bicarbonate[18] in addition to CO_2, a competitive advantage under conditions of increased photosynthesis and depleted CO_2 concentrations.

Eutrophication is principally caused by inappropriate land use, in which phosphorus is no longer held in the soil but is washed into lakes. Nutrients can come from many sources, such as fertilizers applied to agricultural fields; erosion of soil containing nutrients; internal load from the mud of the lake itself and sewage treatment plant discharges. In Lake Tana catchment basin, farmers have been applied modern agricultural input (fertilizers, pesticides and insecticides) to boost crop production without any standard and hence the excess nutrients would eventually reach the lake. Expansion of additional farming lands by youths through deforestation is also common in the basin (pers. obs.). Recession agriculture is also common in the investigated areas. Gumara and Rib rivers carry huge sediments towards the lake. The compounding of these effects increases the nutrient load of the surveyed areas and makes a rapid development of cyanobacteria. The most susceptible aquatic organisms affected by this phenomenon in Lake Tana will be fishes. Decomposition of dead massive algal biomass decreases the amount of dissolved oxygen, resulting in the destruction of fish and therefore falls in population of fish, harming the fish industry and alters the ecosystems of the lake in general[22].

From literature survey, the Cyanobacteria genera identified in this work are widely acknowledged as sources of tastes and odor compound and algal toxins (cyanotoxins). Currently, some 30 species of cyanobacteria are known; yet, not all produce toxins. The organisms most often associated with toxin productions are *Microcystis*, *Oscillatoria*, *Cylindrospermopsis*, *Anabaena*, *Planktothrix*, *Nodularia*, *Aphanizomenon* and *Lyngbya*. These cyanobacteria produce three types of toxins, namely hepatotoxins, neurotoxins and dermatoxins. Such toxins have been linked to the deaths of livestock, fishes and humans elsewhere[4]. Cyanobacteria also release powerful secondary metabolites such as geosmine and 2-methylisoborneol (MIB) that can change the taste and odor of sediments, water and fish. Geosmine and MIB impart objectionable earthy/musty odors to the water [4]. We also checked that muddy flavor (locally called “Dilb Dilb”, “Emik Emik) has been occurred in Tilapia fish at all growth stages, which is concomitant with the literature. Therefore, the off-flavor of the fish in Lake Tana could be caused by the contamination of geosmine and 2-methylisoborneol (MIB) produced by bloom forming Cyanobacteria (Table 2). Geosmine in river water affected rainbow trout farms in the UK[23]. With wild and farmed freshwater fish in Asia, the earthy-musty taint of commercially important fish species, *Oreochromis niloticus*, was reported[24]. Aquatic species are exposed to these chemical compounds through the ingestion of cyanobacteria, consumption of contaminated food items, and/or absorption of dissolved compounds from the water column after leakage from cells or cell lysis[4]. Nile tilapia is planktivorous mainly grazed upon phytoplankton and efficiently assimilated Cyanobacteria in tropical lakes research say[25]. Ingestion of cyanobacteria can be accidental or intentional, but Planktivorous fish, such as carp and tilapia, intentionally ingest cyanobacteria.

Aquatic species also are exposed to cyanobacterial metabolites through the aquatic food web. Metabolites accumulate in the tissue of the consumer facilitating the transfer through the food chain and it will be transferred to other fishes in the lake as well. In Lake Tana, most fish utilizes zooplankton, which consumes the primary producer, phytoplankton and some of them also eat fish[26]. Hence, following the food chain and web, the off-flavor problem now restricted to tilapia fish may be transferred to others as long as the cyanobacteria blooming get continued. For example, hepatotoxins were transferred to Atlantic salmon through the ingestion of toxin-containing crab larvae[27,28]. Trophic transfer also has been demonstrated under laboratory conditions in which hepatotoxins were transferred from zooplankton to fish[29]. The good news is, unlike toxins, geosmin and MIB have no known effects on human health[30]. However, [31]confirmed that fish livers, viscera and muscle tissue contain the toxin microcystins that could creat potentail human health problem in the vicinity of the lake.

A significant portion of the community and even a few scholars argued that the cause for off-flavor of Nile tilapia in Lake Tana is the occurrence of water hyacinth. However, we did not encounter any supporting literature that water hyacinth produces taste and odor compounds responsible for the taint of Nile tilapia flesh in the natural system, though the high nutrient load in Rib-Goragora area has been a potential enabling environment for the proliferation of water hyacinth in these areas[17]. Additionally, the parts of the lake where the off-flavor occurred did not coincide with the area invaded by the invasive species, water hyacinth (per. obs.). This alien species invaded Lake Tana specifically the northern part in recent time and gets spread over quickly and heavily infested greater than 2500 hectares area (per.obs.). Water hyacinth has been known to be an effective aquatic plant to strip nitrate and phosphate nutrients from aquatic bodies and it has been expected that the nitrate and phosphate loads would be lower where there is high fresh biomass of water hyacinth. All the same, the rot of water hyacinth biomass as any of other dead bodies of plants and animals contributing organic matter over time and may contribute for blooming[17].

Management Strategies from Literature

1. An immediate solution

The utilization of tilapia tainted with muddy flavor due to geosmin can be promoted by applying certain preservation and processing techniques. Deep-frying, smoking after a certain pre-treatments, and marinating in acetic acid solutions at certain durations were found to be effective in reducing and/or masking the muddy flavor in tilapia[24]. Salting and drying in combination can also reduce the off-flavor slightly. Flushing very well Nile tilapia in clean water for two weeks and immersing in Lemmon juices before eating are somehow helpful[32].

2. Research needs

I. Management options distinct depending on lake nutrient sources and hence the source of the problem should be clearly identified and the questions mentioned below should be sought answer

- Is Tana Lake dominated by point source or non-point source nutrients during the nuisance season? How much phosphorus actually Rivers delivered? How much phosphorus is derived from Point sources?
- How much phosphorus Mud/sediment contributes to the lake phosphorus load?

II. Detailed study on cyanotoxins bioaccumulation and its amount within fish tissue, and the concentration of the toxin and taste and odor compounds in the lake should be made using high tech like employing HPLC. Hence, appropriate epidemiology and risk assessment should be undertaken so that an acceptable tolerable daily intake (TDI) and appropriate risk management decisions can be made for human consumption of fish which are harvested from cyanobacterial blooms that contain cyanotoxins.

III. For effective and fruitful lake management a model that predicts nutrient loading and impacts of eutrophication should be developed for the whole Lake Tana ecosystem and its drainage basin

3. Policy and Development needs

Lake Tana is the largest freshwater body we have, being the source of the Blue Nile River, the hot spot of biodiversity, harbor historical places of our identity, multipurpose role water and yet identified as a growth corridor in the country, its sustainable management in general calls planners, developers and policy makers with resource users come to in table to develop a participatory management approach involving the community from the grass root level up to catchment scale. Polices and guidelines practically that compromise development vs conservation ultimately that stops recession agriculture, minimizes fertilizer application, that delineates buffer zone of the lake and prevents the destruction of wetlands should be ratified and implemented soon.

4. Eutrophication management options

Human activities have been turned freshwater lakes into eutrophic condition within only some couple of years, but studies suggest their recovery may take a thousand years under the best environmental conditions. The procedure of handling the impacts of eutrophication by reducing nutrient levels is expensive, incurring costs of up to millions of dollars for an individual lake[33]. We should learn from elsewhere that facing the pain of eutrophication experiences practically and we should not duplicate the history again in our aquatic ecosystems; because now the problem/eutrophication is low and can be addressed at an infant stage, merely with an increasing tendency. If we realize the problem early and adopt appropriate management correction measures we can invert the situation at minimum capital and ecosystem costs. Otherwise, removal of phosphorus, once larger reservoir in sediments build up, would be a challenging task. Therefore, the following management strategies are forwarded: Firstly, a workshop should be prepared and presented to decision makers, policy makers, users, planners and other stakeholders to awareness about the magnitude of the problem and the social, economical and ecological damage of eutrophication and the way forward. Secondly, in order to control eutrophication and restore water quality the best long term solutions are reducing phosphorus inputs and soil erosion practicing: immediate enforcing wastewater treatment for point sources of contamination; agricultural practices that minimize runoff and reduce phosphorus applications to land surface; ending deforestation and fostering afforestation in the catchmentsoil prevent soil erosion and restoring wetlands that act as buffers between fields and lakes, which would eventually help to decrease runoff of excess nutrients from the sources. Finally, individual strategy could not be efficient in curtailing the source of nutrients. Therefore, we propose that an integrated strategy focusing on nutrient input restrictions should be followed.

CONCLUSION

Though further studies are required in terms of detail analysis of the feeding ecology of Nile tilapia and checking additional sources of Geosmin and MIB, it is possible to conclude that Geosmin ($C_{12}H_{22}O$) and MIB (2-Ethylisoborneol) produced by cyanobacteria are the cause for "muddy" or "musty" flavor in Nile Tilapia of Lake Tana. The excessive growth of Cyanobacteria in the investigated area could be caused by cultural eutrophication due to nutrient enrichment most likely added up from the recession agriculture on the shore areas of the Lake Tana and generally from nutrient loads of Rib and Gumara rivers. The nutrient loads in Gumara and Rib rivers and generally from major tributaries of Lake Tana basin sourced also from the diffused and improperly and unsustainable managed agricultural catchment remain to be a threat also in the future[17]. The problem is currently confined to the northeastern portion of the lake where most commercial fish production is harvested and the unique flock *Labeobarbus* fish spp. and others breed, reproduce and provide nursery sites for the small ones. Additionally, the refusal incidence/low acceptance of tilapia fish by consumers and restaurants due to cyanobacteria contamination has been dramatically increased. Hence, the fishers have been compelled to shift catching other fish species such as *Labeobarbus* and catfishes. Clearly, the combination of these effects causes an intensive pressure on the population of the endemic Barbus fish species of Lake Tana which aggravate the already declined and exploited resources[34]. The problem shall not be awaited there; it will spread over other corners of the lake and probably cover the whole lake within a few years time as long as participatory management and planning practices is not soon implemented. If the eutrophication continue to happen, non selective, the massive fish kill will follow. The support of more than 30 thousand fishers and their family that depend on these resources will say goodbye to their livelihood if this situation persists, and the fishery industry would eventually be gone. The ecosystem of the lake is also disrupted and other consequence that we cannot expect will happen.

Figure 3: Cyanobacteria blooming at Wolela wetland 5.5 km far from Lake Tana shore, has hydrorological connection with Lake Tana

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