



**HAL**  
open science

## A review of the socioecological causes and consequences of cyanobacterial blooms in Lake Victoria

Mark Olokotum, Veronica Mitroi, Marc Troussellier, Ronald Semyalo, Cecile Bernard, Bernard Montuelle, William Okello, Catherine Quiblier, Jean-François Humbert

### ► To cite this version:

Mark Olokotum, Veronica Mitroi, Marc Troussellier, Ronald Semyalo, Cecile Bernard, et al.. A review of the socioecological causes and consequences of cyanobacterial blooms in Lake Victoria. *Harmful Algae*, 2020, 96, pp.101829. 10.1016/j.hal.2020.101829 . mnhn-02635416

**HAL Id: mnhn-02635416**

**<https://mnhn.hal.science/mnhn-02635416v1>**

Submitted on 24 Sep 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License

1 A review of the socioecological causes and consequences of cyanobacterial  
2 blooms in Lake Victoria

3

4 Mark Olokotum<sup>1,2</sup>, Veronica Mitroi<sup>3</sup>, Marc Troussellier<sup>4</sup>, Ronald Semyalo<sup>5</sup>, Cécile Bernard<sup>6</sup>,  
5 Bernard Montuelle<sup>7</sup>, William Okello<sup>2</sup>, Catherine Quiblier<sup>6,8#</sup>, Jean-François Humbert<sup>3#</sup>

6

7 <sup>1</sup>Makerere University, Institute of Environment and Natural Resources, Kampala, Uganda

8 <sup>2</sup>National Fisheries Resources Research Institute (NaFIRRI), Jinja, Uganda

9 <sup>3</sup>INRAE-Institute of Ecology and Environmental Sciences of Paris (iEES), Sorbonne

10 University, Paris, France

11 <sup>4</sup>UMR MARBEC, CNRS-University of Montpellier-IRD-IFREMER, Place Eugène Bataillon,

12 Montpellier, France

13 <sup>5</sup>Department of Zoology, Entomology and Fisheries Sciences, Makerere University, Kampala,

14 Uganda

15 <sup>6</sup>UMR 7245 Molécules de Communication et Adaptations des Microorganismes (MCAM),

16 CNRS-MNHN, Muséum National d'Histoire Naturelle, Paris, France

17 <sup>7</sup>INRAE-UMR CARTELE, Thonon, France

18 <sup>8</sup>University of Paris, France

19

20

21

22 # Corresponding authors

23

24

25 **Abstract**

26 Africa is experiencing high annual population growth in its major river basins. This growth  
27 has resulted in significant land use change and pollution pressure on the freshwater  
28 ecosystems. Among them, the Lake Victoria basin, with more than 42 million people, is a  
29 unique and vital resource that provides food and drinking water in East Africa. However,  
30 Lake Victoria (LV) experienced a progressive eutrophication and substantial changes in the  
31 fish community leading to recurrent proliferation of water hyacinth and cyanobacteria. Based  
32 on an extensive literature review, we show that cyanobacterial biomasses and microcystin  
33 concentrations are higher in the bays and gulfs (B&Gs) than in the open lake (OL), with  
34 *Microcystis* and *Dolichospermum* as the dominant genera. These differences between the  
35 B&Gs and the OL are due to differences in their hydrological conditions and in the origins,  
36 type and quantities of nutrients. Using data from the literature, in this paper we describe the  
37 multiple ways in which the human population growth in the LV watershed is connected to the  
38 increasing occurrence of cyanobacterial blooms in the OL and B&Gs. We also described the  
39 already documented consequences of cyanobacterial blooms on food resources and fishing  
40 and on direct water use and water supply of local populations, with their potential  
41 consequences on the human health. Finally, we discuss the actions that have been taken for  
42 the protection of LV. Although many projects have been implemented in the 15 past years in  
43 order to improve the management of waste waters or to reduce deforestation and erosion, the  
44 huge challenge of the reduction of cyanobacterial blooms in LV by the control of  
45 eutrophication seems far from being achieved.

46

47 **Keywords:** Cyanobacteria; Lake Victoria; Eutrophication; East Africa; Potential toxicity;  
48 Socioecological analysis; Consequences of cyanobacterial blooms

49

## 50 **1. Introduction**

51 Numerous studies have been conducted in the past 20 years with the goal of improving our  
52 knowledge of the causes and consequences of cyanobacterial blooms. Taranu et al. (2015)  
53 have shown that the increasing occurrence of cyanobacterial blooms is clearly associated with  
54 the increasing impact of human activities on freshwater ecosystems during the Anthropocene,  
55 and it is well established that the main cause of cyanobacterial blooms is the nutrient  
56 enrichment of phosphorus (P) and nitrogen (N) (O’Neil et al., 2012, Huisman et al., 2018).  
57 Recently, several papers also suggested that climate change might directly or indirectly  
58 promote cyanobacterial blooms (e.g., Moss et al., 2011; Paerl et al., 2016; Ho et al., 2019).  
59 Blooms are also well known to have multiple impacts on the ecological functioning of  
60 freshwater ecosystems (e.g., Paerl et al., 2016; Huisman et al., 2018, Escalas et al., 2019) and  
61 on the goods and services (G&S) they provide (e.g., Dodds et al., 2009). Finally, many papers  
62 deal with the production of harmful toxins by cyanobacteria and the sanitary risks associated  
63 with them (e.g., Briand et al., 2003; Merel et al., 2013; Meriluoto et al., 2017).

64         Among these previous studies, few papers have focused on developing countries, with  
65 the exception of a few countries such as Brazil and China (Merel et al., 2013). In particular,  
66 the issue of cyanobacterial blooms has been poorly investigated on the African continent, as  
67 illustrated recently by Svircev et al. (2019). When looking in this review at the distribution of  
68 cyanotoxins worldwide, it appears that data on cyanotoxins are available only for 14 of the 54  
69 African countries and for 76 ecosystems on the continent. Among these ecosystems, Lake  
70 Victoria (LV) is the most studied, probably because it is the second largest lake in the world  
71 and provides goods and services (G&S) to millions of people (Downing et al., 2014; El-  
72 Noshokaty, 2017). Moreover, LV has experienced rapid water quality degradation that has led  
73 to eutrophication, which is considered a major threat to the ecological function of the lake  
74 (Hecky et al., 1994; Juma et al., 2014) as it results in the recurrent proliferations of aquatic  
75 weeds (e.g., water hyacinth) and cyanobacteria (Lung’ayia et al., 2000; Opande et al., 2004,

76 Juma et al., 2014). The proliferation of water hyacinth has been more or less controlled since  
77 the end of the 1990s with biological, mechanical or physical strategies (Opande et al., 2004;  
78 Wanda et al., 2015), but cyanobacteria blooms persist in LV, particularly in the bays and gulfs  
79 (B&Gs) (Haande et al., 2011; Sitoki et al., 2012; Mbonde et al., 2015).

80 The LV basin has one of the highest population densities in Africa, with several large  
81 cities located along the banks of the large bays and gulfs (B&Gs) (e.g., Kampala in Uganda,  
82 Kisumu in Kenya, and Mwanza in Tanzania) (Figure 1). An understanding of the interplay of  
83 ecological and socioeconomic processes acting directly or indirectly on the lake is of primary  
84 interest. In this context, we address the state of knowledge on (i) the distribution of  
85 cyanobacterial blooms and cyanotoxins in LV; (ii) the social and environmental factors and  
86 processes potentially explaining the occurrence of cyanobacterial blooms, with a particular  
87 emphasis on changes that have occurred in its watershed during the last 50 years; (iii) the  
88 consequences of these blooms on the ecosystem G&S provided by the lake and (iv) the  
89 management practices implemented with the goal of reducing nutrient loads and consequently  
90 the cyanobacterial blooms.

91  
92 **Figure 1.** The Lake Victoria catchment area with major land use occupation. Land use data  
93 obtained from the ESA Climate Change Initiative - Land Cover project 2017, accessed June  
94 2019.

95

## 96 **2. Study site: the Lake Victoria basin**

97 The LV catchment area has a surface area of 184,200 km<sup>2</sup> and is shared between five  
98 countries (Burundi, Kenya, Rwanda, Tanzania and Uganda). As shown in Figure 1, the  
99 catchment is dominated by cropland and grassland, with major build-up areas (for example  
100 Kampala, Kisumu, Musoma and Mwanza) located on the shorelines of the B&Gs. LV is  
101 located 1,100 meters above sea level in East Africa and is the source of the White Nile. The

102 lake is shared between the three countries of Kenya (6%), Tanzania (51%) and Uganda  
103 (43%). LV has a shoreline of 3,500 km with many B&Gs and a 68,000 km<sup>2</sup> surface area,  
104 making it the world's second largest freshwater lake and the largest lake in the intertropical  
105 area (Dobiesz et al., 2010). The maximum depth of the lake is 80 m, the average depth is 40  
106 m, and the residence time of the water is 23 years. As shown by Talling (1966), Lake Victoria  
107 is monomictic, the overturn period occurring between May and August, while early thermal  
108 stratification occurs between September and December and persistent thermal stratification  
109 from January to April (Muggide et al. 2005).

110         Depending on the areas, the general climate of the Lake Victoria basin ranges from a  
111 modified equatorial type characterized by heavy rainfall throughout the year to a semiarid  
112 type characterized by intermittent drought periods. Overall, there are two rainfall periods  
113 (long rains, March-May, and short rains, October-December) with variations ranging from  
114 870 -1,561 mm in Uganda and from 400-2,736 mm in Tanzania. (Kizza et al.,2009). Water  
115 temperature recorded at the surface of the lake range from 23°C to 29°C throughout the year  
116 (Muggide et al., 2005).

117

### 118 **3. Historical and current status of cyanobacteria and cyanotoxins in Lake Victoria**

#### 119 *3.1. Historical and current status of cyanobacterial blooms*

120 **Recent evolution of the LV phytoplankton community.** As shown from paleolimnological  
121 data by Verschuren et al. (2002), the phytoplankton production in LV has increased since the  
122 1930s. Though there is insufficient nutrient data for this time period, it appears that the  
123 phosphorus concentrations increased (from 1.1 to 2.9  $\mu\text{moles L}^{-1}$  between the 1960s and  
124 1990s) and that eutrophication manifested towards the end of the 1980s (Hecky, 1993; Hecky  
125 et al., 2010). The increasing nutrient content led to an increase in the phytoplanktonic  
126 biomasses and shifts in the diatom community, from the dominance of *Aulacoseira* to the

127 dominance of *Nitzschia* (Stager et al., 2009) and in the total phytoplankton community, from  
128 the dominance of green algae (Chlorophyta) and large diatoms (Bacillariophyta) to the  
129 dominance of cyanobacteria (Lehman and Branstrator, 1994; Ochumba and Kibaara, 1989;  
130 Kling et al. 2001; Verschuren et al., 2002; Hecky et al., 2010). This dominance of  
131 cyanobacteria in phytoplankton communities is now frequently found in the three countries  
132 bordering the lake (Kenya, Tanzania and Uganda), particularly in the numerous B&Gs  
133 (Figure 2).

134

135 **Figure 2.** Cyanobacteria blooms in Uganda, Murchison Bay (A); Kenya, Nyanza Gulf (B);  
136 Tanzania, Mwanza Gulf (C) (© Photos: J.F. Humbert, INRAE)

137

138 **Differences in the phytoplankton biomasses and community compositions of the B&Gs**  
139 **and the OL.** As noted by Talling (1987), the physicochemical conditions and microbial  
140 communities of the open lake (OL) are quite different from those of the B&Gs. In the B&Gs,  
141 phytoplankton biomasses are often  $>30 \mu\text{g Chl-a L}^{-1}$ , with cyanobacteria often comprising  
142 more than 60% of the total phytoplanktonic biomass and frequently comprising more than  
143 80% (Table 1). The rest of the phytoplanktonic community is mainly composed of  
144 Chlorophyta, Cryptophyta, Dinophyta and Euglenophyta (e.g., Haande et al., 2011; Sitoki et  
145 al., 2012).

146 In the OL, the phytoplanktonic biomass is generally less than  $20 \mu\text{g Chl-a L}^{-1}$ , and  
147 changes from a dominance of diatoms to a dominance of cyanobacteria are frequently found  
148 (Table 1). The works of Lung'ayia et al. (2000) and Sitoki et al. (2012) in the Nyanza Gulf  
149 and the OL in Kenya suggest that these changes could be partly driven by the alternation of  
150 dry and rainy seasons.

151 Irrespective of the season, cyanobacteria were dominant in the B&Gs, while diatoms

152 were clearly dominant in the OL during the dry season and represented  $\leq 50\%$  of the  
 153 phytoplanktonic biomass during the rainy season. In the latter case, cyanobacteria were the  
 154 second most dominant group of phytoplankton. Interestingly, Mbonde et al. (2015) have  
 155 shown in a comparative study performed in 16 closed and open bays that the degree of  
 156 connectivity of these bays to the OL greatly impacts their phytoplankton communities. The  
 157 average phytoplankton biovolumes were much higher in the closed bays than in the open  
 158 bays, and the same finding was found when considering only the cyanobacterial biovolumes  
 159 (Supplemental Fig. 1).

160

161 **Table 1.** Overview of the published phytoplankton biomass (either as biovolume, cells mL<sup>-1</sup>,  
 162 or chlorophyll-a estimates), the occurrence and abundance of cyanobacteria, the dominant  
 163 species and the cyanotoxin microcystins in Lake Victoria. f.w.: fresh weight. w.w.: wet  
 164 weight. MC: microcystins. Nd: not determined. NzG, Nyanza Gulf (Kenya), MB, Murchison  
 165 Bay (Uganda); NG, Napoleon Gulf (Uganda); MG, Mwanza Gulf (Tanzania) (see the  
 166 Supplemental Fig. 1 for the location of these sites ) \**Dolichospermum* genus name is used  
 167 instead of *Anabaena*.

168

169 **Main cyanobacterial genera found in Lake Victoria.** A great diversity of cyanobacterial  
 170 taxa, including both nitrogen fixing taxa such as *Dolichospermum*,  
 171 *Cylindrospermopsis/Raphidiopsis* or *Anabaenopsis* and nonnitrogen fixing taxa such as  
 172 *Microcystis*, *Planktolyngbya*, *Merismopedia*, *Cyanodictyon* or *Aphanocapsa*, is often found in  
 173 B&Gs and the OL (Table 1). An underlying dominance of *Dolichospermum* spp. or  
 174 *Microcystis* spp. cyanobacteria has been observed in the literature depending on the location,  
 175 year and month of sampling considered. For example, Gikuma-Njuru et al. (2013a) observed  
 176 a dominance of *Dolichospermum* and small cyanobacteria such as *Cyanodictyon* and  
 177 *Aphanocapsa* between March 2005 and March 2006 in the Nyanza Gulf (Kenya), while Sitoki  
 178 et al. (2012) found that *Microcystis* was clearly the most dominant cyanobacteria in the same



179 area from July 2008 to September 2009. In Murchison Bay (Uganda), *Microcystis* dominance  
180 was noted by Poste et al. (2013), whereas the dominance of *Dolichospermum* was found in  
181 Murchison Bay and the Napoleon Gulf by Okello and Kurmayer (2011) and Okello et al.  
182 (2010a). Similar observations and alternations between a dominance of *Dolichospermum* and  
183 a very diversified cyanobacterial community were also observed by Haande et al. (2011),  
184 depending on the date and the sampling station within Murchison Bay. In Tanzania,  
185 Sekadende et al. (2005) found a dominance of diatoms and cyanobacteria belonging to the  
186 *Planktolyngbya* genus in the Mwanza Gulf between May and August 2002. Several years  
187 later, Mbonde et al. (2015) observed a dominance of *Dolichospermum* and *Microcystis* in the  
188 different B&Gs of Tanzania, including the Mwanza Gulf, between November and December  
189 2009.

190         There is no clear explanation for these spatial and temporal variations in the dominant  
191 cyanobacterial genera, but it is known that variations in nutrient concentrations can influence  
192 the composition of cyanobacterial communities. For example, it has been proposed that high  
193 proportions of N-fixing cyanobacteria such as *Dolichospermum* sp. could be linked to a  
194 nitrogen limitation in the lake (Mugidde et al., 2003; Gikuma-Njuru and Hecky, 2005). In the  
195 same way, many studies have shown that *Microcystis* sp. is the most common bloom-forming  
196 species in freshwater ecosystems with high phosphorus concentrations (e.g., Poste et al.,  
197 2013).

198

### 199 3.2. Cyanotoxin production

200 *Microcystis* and *Dolichospermum* genera are well known as the main potential producers of  
201 cyanotoxins of the microcystins (MC) family, but *Dolichospermum* is also known to produce  
202 several families of cyanotoxins including anatoxin-a (ATX) (Bernard et al., 2017). To our  
203 knowledge, all studies in LV have focused on MC, and only one study performed in the

204 Nyanza Gulf (Kenya) focused on ATX (Kotut et al., 2006). Although *Dolichospermum* was  
205 dominant and *Microcystis* was marginal, ATX was undetectable in both environmental  
206 samples and in the isolated strains. During the same study period, the estimated MC  
207 concentration was approximately  $1 \mu\text{g eqMC-LR.L}^{-1}$  (Krienitz et al., 2002; Kotut et al., 2006).  
208 Some of these cyanobacteria are also known to potentially produce other cyanotoxins such as  
209 the amino acid variant  $\beta$ -methyl-amino-L-alanine (BMAA) and saxitoxins, but these  
210 cyanotoxins have not been investigated in LV.

211 Numerous studies have dealt with the detection of MC in LV (Table 1). The first study  
212 reporting the presence of MC was that of Krienitz et al. (2002) and was performed in the  
213 Nyanza Gulf (Table 1). After this first study, MC occurrence was recorded in different parts  
214 of the lake, mainly in the B&Gs but also in the OL in some cases (Sekadende et al., 2005;  
215 Sitoki et al., 2012) (Table 1). Highly variable concentrations of MC were found in LV, from  
216 less than  $1 \mu\text{g.L}^{-1}$  in Murchison Bay (Uganda) (Semyalo et al., 2010) up to  $81 \mu\text{g.L}^{-1}$  and  $>2$   
217  $\text{mg.L}^{-1}$  in Nyanza Gulf (Kenya) (Sitoki et al., 2012; Simiyu et al. 2018, respectively), the  
218 highest concentrations being found in scums or at the surface of the lake (Table 1). A positive  
219 correlation between the MC concentrations and *Microcystis* abundance was found by Okello  
220 et al. (2010a, b), Sitoki et al. (2012) and Mbonde et al. (2015). Finally, Okello et al. (2010b)  
221 observed during a one-year monitoring study (May 2007-April 2008) that the proportions of  
222 the *mcyB*<sup>+</sup> genotypes (potentially producing MC) in *Microcystis* populations varied from  
223 3.3% to 39.2% in Murchison Bay and from 12.9% to 59.3% in the Napoleon Gulf.

224 So far, 240 MC variants have been described in the world (Spoof and Catherine,  
225 2017), but only a few studies have investigated the MC variant composition in the  
226 cyanobacterial blooms from LV (Table 1). Nevertheless, up to seven different variants have  
227 been identified by Okello and Kurmayer (2011) and up to 31 variants have been identified by  
228 Miles et al. (2013). However, the most common variants detected in the lake are MC-LR,

229 MC-RR and MC-YR (e.g., Okello and Kurmayer, 2011, in Murchison Bay and the Napoleon  
230 Gulf; Sitoki et al., 2012, in the Nyanza Gulf; Mbonde et al., 2015, in the Mwanza Gulf). The  
231 proportions of all these MC variants were highly variable depending on the sampled area. For  
232 example, the average estimated proportions of the MC-LR variant in the Murchison Bay and  
233 the Napoleon Gulf (May 2007 - April 2008) were  $12.4\pm 2\%$  and  $0.5\pm 0.3\%$ , respectively,  
234 according to Okello and Kurmayer (2011) but reached  $50\pm 6\%$  in the Nyanza Gulf (July 2008  
235 - Sept 2009) (Sitoki et al., 2012). The small standard deviations associated with these  
236 proportions seem to express low temporal variations for a given area in LV. However, higher  
237 variations are sometimes reported in the literature, as shown for example by the large standard  
238 deviation found in the mean proportion ( $31\pm 52\%$ ) of the MC-YR in the Nyanza Gulf (Sitoki  
239 et al. 2012).

240

241

#### 242 **4. Linking demographic changes with the increasing occurrence of cyanobacterial** 243 **blooms**

244 From the analysis of the data available in the literature on the causes of cyanobacterial blooms  
245 in LV, we built a flow diagram (Figure 3) describing the multiple ways in which the human  
246 population growth in the LV watershed is connected to the increasing occurrence of  
247 cyanobacterial blooms in the OL and B&Gs.

248

249 **Figure 3.** Links between the increase in the human population density around Lake Victoria  
250 and the occurrence of cyanobacteria blooms in the open lake and in the bays and gulfs.

251 OM: Organic matter; P: Phosphorus; N: Nitrogen

252

253 As summarized in Figure 3, the increase in the populations density in the LV basin,  
254 such as everywhere in the world, has resulted in increasing food, housing and product  
255 demands (FAO, 2016). All these demands have many consequences on land use in the  
256 watershed, including farming and fishing activities, as well as formal and informal  
257 urbanization and industrial and commercial activities. All these processes are described in  
258 section 4.1. Then, as developed in section 4.2, the changes occurring in anthropogenic  
259 activities and land use have led to increasing nutrient pollution in the OL and B&Gs through  
260 three main processes: the aerial deposition of phosphorus and nitrogen, the discharge of  
261 mineral and organic nutrients by rivers and a decrease in natural purification due to wetland  
262 degradation. Finally, section 4.3 shows why the B&Gs are more polluted than the OL and the  
263 processes leading to the decrease in water quality.

264

#### 265 *4.1. Determinism and consequences of human population growth in the LV watershed*

266 **Demographic data on the LV watershed.** The African continent continues to experience a  
267 high annual population growth estimated at 2.6% per year in its major river basins (World  
268 Population Prospects, 2017). The population density in the LV basin almost doubled over the  
269 past 20 years from 27.2 million to ca. 42 million inhabitants (Bremer et al., 2013), which is  
270 considered the largest human population in the watersheds of the great lakes of the world  
271 (Dobiesz et al., 2010). This population increased by 2.4 – 3.2% annually (> 6% in some urban  
272 areas such as Kampala, Uganda; McDonald et al., 2014), a growth rate that is higher than that  
273 observed in the rest of the African continent (UNEP, 2006). The data from the Center for  
274 International Earth Science Information Network - CIESIN - Columbia University (2018)  
275 indicates that the population density in major cities has increased from a max of 100 persons  
276 per km<sup>2</sup> to over 23,000 persons per km<sup>2</sup> in the last two decades. A strong and similar  
277 exponential population increase has been observed since the 1960s in Kenya, Tanzania and

278 Uganda (Supplemental Figure 2). On the other hand, Burundi and Rwanda, which  
279 experienced civil war in the 1990s and do not have direct access to the lake, have seen much  
280 lower population growth.

281  
282 **Causes of this population growth in the LV watershed.** A recent report of the International  
283 Institute for Sustainable Development (Dazé and Crawford, 2016) pointed out that migration  
284 in the Great Lakes Region in East Africa is due partly to both voluntary decisions to migrate  
285 and forced migration.

286       Concerning the voluntary migration, many people have migrated towards the lake  
287 basin to take advantage of the economic benefits linked to the fisheries in the basin (Awange  
288 and Obiero, 2006; Odada et al., 2009). As reported in Mkumbo & Marshall (2015), more than  
289 1,200,000 people are directly or indirectly employed in fisheries, and income from fisheries  
290 supports approximately 4 million people. This makes LV the world's largest host for inland  
291 freshwater fisheries (Simonit and Perrings, 2011).

292       On the other hand, forced migrations have resulted from armed conflicts and violence  
293 in Rwanda and Burundi (from 1993 to 2005) and in the Democratic Republic of Congo (from  
294 1996 to 2002). Many of these migrants are located in rural areas (Dazé and Crawford, 2016).

295  
296 **Consequences of population growth on land use, urbanization and anthropogenic**  
297 **activities.** As established in the diagnostic analysis performed by the Lake Victoria  
298 Environmental Management Project (LVEMP), more than 87% of the inhabitants living in the  
299 LV basin are from the rural populations in Burundi, Kenya, Rwanda and Tanzania (see also  
300 Figure 1), while in Uganda, 94% of the inhabitants living in the LV basin are urban (LVEMP,  
301 2007). Meanwhile, as already observed in the developing world (Montgomery, 2008), the  
302 three countries with direct access to the lake and with livelihoods that rely on the lake have

303 also experienced rapid urbanization that has led to the development of large cities located on  
304 the B&Gs, such as Kampala (>2 million inhabitants) on Murchison Bay (Uganda), Kisumu  
305 (approximately 1 million inhabitants) on the Nyanza Gulf (Kenya) and Mwanza (>400,000  
306 inhabitants) on the Mwanza Gulf (Tanzania) (Supplemental Fig 3).

307         The main consequence of increasing population densities in rural areas is a change in  
308 land use, particularly to cropland (see Figure 1). The agricultural development involves ca. >  
309 80% inhabitants' that depend on small-scale mixed farming operations, thus, influencing the  
310 land use. As highlighted in the LVEMP report (LVEMP, 2007), agricultural development  
311 includes wetland destruction and/or degradation, livestock overgrazing, bush burning, land  
312 fragmentation, and deforestation. Deforestation (for settlement and agriculture development)  
313 is spreading at an alarming rate, e.g., in Uganda between 2000 and 2015, the deforestation  
314 rate was 3.3% annually, which is higher than that in other countries of the watershed (0.2%  
315 for Burundi, 0.3% for Kenya, 1.7% for Rwanda and 0.8% for Tanzania) (FAO, 2015). This  
316 deforestation rate has increased from 1990-2015 in Uganda (from 2.0% in 1990-2000 to 3.3%  
317 in 2000-2010, reaching 5.5% in 2010-2015). In typical developing countries, both rural and  
318 urban populations depend heavily on the forest environment and products, such as building  
319 materials, crafts, firewood, charcoal, food, flavoring, and traditional medicine, for their  
320 livelihood (UNEP, 2008; Mwavu & Witkowski, 2008).

321         The drivers of deforestation identified in the LV watershed can be classified into two  
322 broad categories (Waiswa et al., 2015). The direct human uses of forest resources (Geist &  
323 Lambin, 2002; Mwavu & Witkowski, 2008) include the unplanned spread of agricultural  
324 areas over forest areas, firewood and timber harvesting, clearing forestland for human  
325 settlement, sand mining and brickmaking. The indirect drivers concern the underlying  
326 sociopolitical factors impacting human practices, such as unclear land tenure and/or property  
327 rights, lack of forest monitoring and the noninvolvement of users in forest maintenance,

328 conflicts of interest, political interference, and negative perceptions about planning policies  
329 (Place & Otsuka, 2000; Mwavu & Witkowski, 2008).

330

#### 331 *4.2. Relationships between land use changes and the eutrophication of LV*

332 As shown in Figure 3, various processes associated with land occupation changes and  
333 activities have led to the eutrophication of the OL and B&Gs. Numerous studies have focused  
334 on identifying the different processes that lead to nitrogen and phosphorus pollution in LV,  
335 and four main processes have been identified. These processes include (i) the discharge of  
336 rivers from heavily polluted catchments (Verschuren et al., 2002; Musungu et al., 2014;  
337 Fuhrimann et al., 2015; Jovanelly et al., 2015); (ii) atmospheric deposition, in particular of  
338 phosphorus (P) (accounting for 55% of the total phosphorus input in LV) (Tamatamah et al.,  
339 2005); (iii) the biological fixation of atmospheric dinitrogen (N<sub>2</sub>), which seems to greatly  
340 exceed the contributions of atmospheric N deposition and river N inputs (Mugidde et al.,  
341 2003); and to a lesser extent, (iv) nutrient recycling and release from the sediments (Gikuma-  
342 Njuru et al., 2010).

343 The two first nutrient pollution pathways for LV water are directly linked to human  
344 population growth and activities. First, changes in land use patterns have contributed to  
345 enhanced erosion. In Uganda and Tanzania, the presence of settlements on the LV shoreline  
346 zone were associated with high soil erosion estimates of between 17 and 87 ton. ha<sup>-1</sup>.yr<sup>-1</sup>  
347 (Isabirye et al., 2010). The rate of soil loss in the LV basin also appears to depend on the land  
348 use system (tree plantation versus grassland) (Bamutaze et al., 2017). Other human-induced  
349 disturbances, such timber harvesting and soil compaction by cattle, also increase the risk of  
350 soil erosion (Karamage et al., 2017). Similarly, TP and TN atmospheric deposition mainly  
351 seem to result from burnt biomass, windblown dust and industrial and domestic activities (see  
352 the review of Cheruiyot and Muhandiki, 2014).

353           Second, due to the urban human population growth, increasing quantities of solid and  
354 liquid waste originate from (i) the human populations living in the large cities located near the  
355 B&Gs and (ii) industrial activities such as the activities of large manufacturers of steel  
356 construction materials, factories that produce batteries, soap, paint, metal, plastics, corrugated  
357 iron sheets, or pharmaceuticals, and breweries, tanneries, former copper smelters and abattoirs  
358 (Muwanga and Barifaijo, 2006). Moreover, as shown by Cockx et al. (2019) in Tanzania, the  
359 urbanization of the rural population results in changing food demands, which include  
360 increasing consumption of high-sugar foods and drinks. These changes in the demand for  
361 food have led for example to the installation of bottling factories in the three main cities  
362 located around the lake (Kampala, Mwanza and Kisumu). For Kampala (Uganda), only ca.  
363 8% of all wastes (domestic and industrial) are collected and treated (Matagi, 2002), and the  
364 efficiency of the sewage treatment plants is poor, with up to ca. 89% frequency of  
365 noncompliance with the national standard for BOD<sub>5</sub> (LVEMP, 2005). In the same way,  
366 Oguttu et al. (2008) have shown that point source effluents due to increasing industrial  
367 activities in the Jinja area have contributed to the increasing nutrient loads in the Napoleon  
368 Gulf.

369           Finally, the progressive reduction and degradation of wetlands has played a major role  
370 in the degradation of water quality. This degradation is due to housing, industrialization,  
371 infrastructure development and agriculture (Kansiime & Nalubega, 1999; Fuhrmann et al.,  
372 2015). In the Kampala Metropolitan Area (Uganda), the proportion of severely degraded  
373 wetlands increased from 13% in 1993 to 46% by 1999 (Nyakaana et al., 2007). In particular,  
374 Nakivubo wetlands experienced a 62% loss in wetland vegetation between 2002 and 2014,  
375 mainly due to crop cultivation (Isunju, 2016), despite their high estimated economic value of  
376 between US\$ 760,000-1,300,000 (Schuijt, 2002). Similar observations have been made for the  
377 Nyanza Gulf in Kenya by Juma et al. (2014). In Tanzania, Musamba et al. (2011), showed



378 that an increase in the anthropogenic activities in the Musoma urban area was associated with  
379 the degradation of wetland coverage at the average rate of 6.5 ha yr<sup>-1</sup> between 2001 and 2008.  
380 Knowing that wetlands are located at the mouths of the major rivers and in the inshore areas  
381 of the lake (Okeyo-Owuor et al., 2012) and that they play a major role in waste removal and  
382 water purification (Raburu et al., 2012), their degradation contributes to the decrease in water  
383 quality in the B&Gs.

384 The consequences of all these processes acting on the nutrient load in Lake Victoria is  
385 that high concentrations in soluble elements (SRP, NO<sub>3</sub> and NH<sub>4</sub>) have been recorded in the  
386 twenty past years in the Lake Victoria (Supplemental Table 1). The average TN:TP ratios are  
387 almost double in B&Gs (14.5) than in OL (8.1) (Muggide et al., 2005). This suggests that there is  
388 a global N limitation in Lake Victoria, which is more pronounced in offshore area.

389

#### 390 *4.3. Why do the bays and gulfs of LV have more cyanobacteria blooms than the open lake?*

391 Two main kinds of processes seem to be involved in the greater amount of eutrophication  
392 observed in the B&Gs compared to the OL.

393 First, several big towns are located on the banks of the B&Gs, such as Kampala on the  
394 Murchison Bay, Kisumu on the Nyanza Gulf and Mwanza on the Mwanza Gulf. As shown by  
395 Akurut et al. (2017) for the Murchison Bay (Uganda), the exponential deterioration of the  
396 water quality between 2001 and 2014 was largely due to increasing quantities of waste  
397 generated in Kampala City and discharged in the bay. Similar observations were made by  
398 Cornelissen et al. (2014) for the Mwanza Gulf (Tanzania). Several B&Gs also receive water  
399 from rivers carrying high nutrient loads resulting from agricultural farmland in the catchment.  
400 This contribution has been shown for example for the Nyanza Gulf (Kenya) by Gikuma-Njuru  
401 et al. (2013b). As already described in paragraph 3.2, the decrease in the natural depuration in  
402 the wetlands located in the B&Gs contributes to their hyper eutrophication.

403           Second, the hydrodynamic conditions experienced by the B&Gs favors cyanobacteria  
404 blooms. In the closed B&Gs (e.g., Murchison Bay, the Nyanza and Mwanza Gulfs)  
405 experiencing limited exchange with the OL, the water residence time is long, and the high  
406 nutrient load from their watersheds promote and sustain the development of cyanobacterial  
407 blooms. Moreover, the majority of the B&Gs are very shallow, as illustrated by the Nyanza  
408 Gulf, which has a mean depth of <10 m (<5 m in the eastern part of the gulf). Typically, at  
409 shallow depths, all water is mixed daily and there is thermal stratification during high  
410 insolation periods (Gikuma-Njuru, 2008). Consequently, the alternation of mixing and  
411 stratified periods can potentially promote the release of nutrients from the sediments, which  
412 can then sustain cyanobacteria growth (see for ex. Cao et al., 2016). In addition to the mixing  
413 and stratification that occurs at shallow water depths, the high turbidity occurring in these  
414 shallow and mixed B&Gs (Silsbe et al., 2006; Loiselle et al., 2008 & 2010) could promote the  
415 development of bloom-forming cyanobacteria such as *Microcystis* spp. or *Dolichospermum*  
416 spp., which are able to occupy the top of the water column where light is available for their  
417 growth, due to their gas vesicles (Gikuma-Njuru, 2008; Ssebiyonga et al., 2013).

418

#### 419 *4.4. Other processes involved in the increasing occurrence of cyanobacterial blooms in LV*

420 **Role of changes in the fish community.** Nile perch and several tilapiine species (Nile tilapia:  
421 *Oreochromis niloticus* L.; *O. leucostictus*; *Tilapia zillii*) were introduced into the lake in the  
422 1950s and became dominant (Ogotu-Ohwayo, 2004; Awange and Obiero, 2006).  
423 Consequently, Marshall (2018) discussed the possibility that the changes in the fish  
424 community composition during the 1960s could have aggravated the symptoms of  
425 eutrophication and the proliferations of cyanobacteria in the lake. Although Goldschmidt et al.  
426 (1993) emphasized the importance of endemic phytoplanktivorous and detritivorous  
427 haplochromine species in the littoral and sublittoral areas of LV before the 1980s, these

428 species were victims of Nile perch predation, that led to a dramatic decrease in their  
429 biomasses (Marshall, 2018). Thus, in the context of eutrophication, Batjakas et al. (1997)  
430 suggested that the replacement of endemic phytoplanktivorous species by predatory Nile  
431 perch could have facilitated the proliferation of cyanobacterial blooms. Moreover, as  
432 suggested by Marshall (2018), cyanobacteria could have been favored by the decrease in the  
433 population of large phytoplankton grazers from the zooplanktonic community due to their  
434 consumption by juvenile Nile perch. **The other main introduced fish species (Nile tilapia,**  
435 ***Oreochromis niloticus*) is well-known to ingest a diversity of prey items including**  
436 **phytoplankton (e.g. Bwanika et al. 2006). In LV, many authors have reported that the diet of**  
437 ***O. niloticus* often have large proportion of phytoplankton dominated by cyanobacterial**  
438 **species (Semyalo et al, 2011, Rumisha & Nehemia, 2013, Jihulya, 2014). Cyanobacteria has**  
439 **also been shown to contribute to the bulk of the diet of *O. niloticus* in other tropical aquatic**  
440 **ecosystems (Teferi et al. 2000, Turker et al. 2003, Lu et al. 2006, Torres et al. 2016, Zakaria et**  
441 **al. 2019). However, new data on the quantitative predation of cyanobacteria by *O. niloticus***  
442 **are needed before concluding that this species may play a significant top-down role on the**  
443 **dynamics of cyanobacteria.**

444         Since 2005, the stock of Nile perch in LV has rapidly decreased by approximately  
445 50%, mainly due to overfishing (Matsuishi et al. 2006, Mkumbo et al. 2007; Mkumbo and  
446 Marshall, 2015) but also because of the degradation of the water quality (e.g. anoxia). During  
447 the same period, the biomasses of other species such as Nile tilapia, catfishes or *Protopterus*  
448 biomasses have increased because they are less susceptible to degraded water quality  
449 (Kolding et al., 2008). The recent decrease in Nile perch stocks also favored an increase in  
450 haplochromine prey species, although their biomass and diversity remains low compared to  
451 the pre Nile perch era (Marshall, 2018). It is difficult to predict the consequences for  
452 cyanobacterial blooms to all these changes occurring in fish communities of LV knowing that

453 the grazing rates of both fish and zooplankton always have always been low in Lake Victoria,  
454 particularly since the 1980's (Witte et al., 2012).

455 In addition to the changes occurring in capture fisheries, the recent increases in cage  
456 culture farms in the B&Gs (Aura et al., 2018; Opiyo et al., 2018; Musinguzi et al., 2019)  
457 constitutes an additional threat for the lake. It is well known that aquaculture can contribute  
458 significantly to the nutrient enrichment of freshwater ecosystems (Zhang et al., 2006). In  
459 Napoleon Gulf (Uganda), Egessa et al. (2018) observed organic matter and nutrient  
460 enrichment in the sediment due to cage fish farming. In Shirati Bay (Tanzania), an increase in  
461 nutrient concentrations was observed after cage farming establishment (Kashindye et al.  
462 2015), while in Kenya, Njiru et al, (2018) reported increasing eutrophication in shallow areas  
463 due to aquaculture waste feeds. These areas are only small portions of LV where caged fish  
464 farming has occurred, but farming has begun to spread among the various B&Gs of the lake.  
465 Thus, additional data are needed to study this issue and its related consequences on water  
466 quality.

467  
468 **Potential impact of climate change.** The potential impact of climate change on  
469 eutrophication in LV and consequently on cyanobacterial blooms has been poorly  
470 investigated. Lehman et al. (1998) suggested that the eutrophication of LV may have been  
471 accelerated by climate change, particularly by increased water temperature and reduced  
472 vertical mixing, which are two processes that are known to influence the population dynamics  
473 of cyanobacteria.

474 Recently, Tariku and Gan (2018), modeled the impacts of climate change on the  
475 extreme precipitation indices and temperature of the River Nile Basin and indicated that the  
476 extreme precipitation indices are projected to increase in the second part of this century.  
477 Similarly, Thiery et al. (2016) projected that LV will be a hotspot for heavy thunderstorm

478 events in a future with warmer climate scenarios. These changes might have dramatic  
479 consequences on LV because extreme rain events contribute to runoff and soil erosion, which  
480 enhance the eutrophication of aquatic ecosystems (e.g., Moss et al., 2011) and consequently  
481 the occurrence and intensity of cyanobacterial blooms (e.g., Michalak et al., 2013).

482

## 483 **5. Consequences of cyanobacterial blooms on the different uses of the lake**

### 484 *5.1 Consequences on food resources and fishing*

485 Fishing is an important food resource for approximately 1.5 million people living on the lake  
486 shores as well as for the 42 million inhabitants in the watershed of LV. In this context,  
487 cyanobacterial blooms have two main impacts on the fish communities: (i) the changes in the  
488 environmental conditions of the fish due to the blooms, with potential negative impacts on the  
489 abundance and diversity of the LV fish community, and (ii) the accumulation of cyanotoxins  
490 in the fish and the associated risks for the human populations consuming those fish.

491         It has been shown in numerous water bodies worldwide (e.g., Padmavathi & Veeraiyah,  
492 2009; Lehman et al., 2010) that severe cyanobacterial blooms impact fish populations, mainly  
493 through changes induced in environmental parameters such as dissolved oxygen  
494 concentrations. Indeed, severe anoxia is recorded at the bottom of deep lakes or throughout  
495 the water column in shallow lakes due to the high respiration activity of bacteria degrading  
496 organic matter produced by cyanobacteria. In LV, several studies have linked water quality  
497 degradation to eutrophication and the changes occurring in the fish communities. For  
498 instance, Kundu et al. (2017) reported significant differences in the fish community structure  
499 in the Nyanza Gulf, where severe cyanobacterial blooms are frequently observed, and just  
500 outside of the gulf where better water quality occurs. Furthermore, Kolding et al. (2008)  
501 examined the relationship between the deterioration of water quality and the decline of Nile  
502 perch in the lake. They hypothesized that the low oxygen concentrations at the bottom of the

503 lake resulting from the degradation of phytoplanktonic organic matter may be the cause of the  
504 decline in Nile perch. However, this hypothesis is still in debate, as discussed by Mkumbo &  
505 Marshall (2015).

506 The second impact of cyanobacterial blooms on fish communities is associated with  
507 the potential accumulation of cyanotoxins in the fish and their subsequent potential  
508 consequences on human health. Based on laboratory and field studies in several countries, it is  
509 known that MC can accumulate in fish tissues (e.g., Jiang et al., 2012; Nchabeleng et al.,  
510 2014). In LV, three studies (Semyalo et al., 2010; Poste et al., 2011 and Simiyu et al., 2018)  
511 have shown the accumulation of MC in several fish species. The extent of MC accumulation  
512 displayed considerable variability (from 0.5 to 90  $\mu\text{g}\cdot\text{kg}^{-1}$  wet weight) among the fish species.  
513 For the highest toxin concentrations, the estimated daily exposure to MC could exceed the  
514 tolerable daily intake (TDI) proposed by the WHO for chronic exposure from fish  
515 consumption (i.e., TDI of 0.04  $\mu\text{g}$  MC-LR per kg body weight per day) (Ibelins and Chorus,  
516 2007), especially for *Haplochromis* spp. and *Rastrineobola argentea* (Silver fish), which are  
517 consumed whole. With the growing cage aquaculture in the B&Gs of LV and the incidence of  
518 increasing nutrient loading from aquaculture, cultured fish could accumulate cyanotoxins, but  
519 no data are available. Consequently, all these data suggest that the consumption of fish from  
520 LV could significantly contribute to the chronic exposure of human populations to MCs.

521

## 522 *5.2 Consequences of direct water use and water supply*

523 As shown in Table 1, the MC concentrations in the LV water frequently exceed 1  $\mu\text{g}\cdot\text{L}^{-1}$ ,  
524 which is the threshold proposed by the WHO (Chorus and Bartram, 1999) for drinking water,  
525 and sometimes exceed 10  $\mu\text{g}\cdot\text{L}^{-1}$ , which is the lowest threshold set by the sanitary authorities  
526 from the northern countries for recreational activities (Chorus et al., 2012). Consequently, as  
527 emphasized by Kotut et al. (2006), these MC concentrations in the B&Gs are now a real

528 challenge for local water authorities. However, regular monitoring of the MC concentrations  
529 in the lake water and in the treated water produced by the plants located in the B&Gs is not  
530 regularly performed. Moreover, there is no information on the sanitary risks for people  
531 directly using lake water for domestic activities, including cooking and washing, or for  
532 recreational activities during bloom events.

533         In addition to the potential threat of cyanobacterial blooms to human populations  
534 through the consumption of raw or treated water or contaminated fish, these blooms have  
535 direct and indirect consequences on the price and quantity of drinking water produced by the  
536 treatment plants. In Uganda, Oyoo (2015) showed that cyanobacterial blooms impacted the  
537 price of the water in different ways. First, a clarification stage was added to the oldest water  
538 treatment plant (Gaba I) to improve the water quality. Second, the dosage of aluminum sulfate  
539 used in the plants increased three times from 1993 to 2008 due to the increasing prevalence of  
540 cyanobacterial blooms, and prechlorination was introduced to enhance coagulation and  
541 settling (Olokotum, 2017). Third, the cyanobacteria blooms in Murchison Bay have forced the  
542 water supply authorities and institutions to establish a new water treatment plant outside of  
543 the bay at Katosi (Damba channel), which will incur additional costs due to the construction  
544 of a long pipeline to carry the treated drinking water to the Kampala metropolitan area.

545         In addition to the increasing costs of water treatment due to cyanobacterial blooms,  
546 Oyoo (2015) reported the impacts of cyanobacterial blooms on the availability of water to  
547 local populations. The increased frequency of backwashing to avoid clogging of the sand  
548 filters during water treatment at Gaba I & II in Kampala decreases the runtime of the  
549 machinery, which consequently decreases the quantity of water produced by the plants for  
550 populations. The costs of production and the availability of treated water are very important in  
551 developing countries because when the price increases and/or the availability decreases, the  
552 local populations tend to use alternative water resources that are not safe for their health (Moe

553 and Rheingans, 2006).

554 Finally, from all these data, Figure 4 shows the potential health impacts of  
555 cyanobacterial blooms for human populations living around LV. Concerning the health  
556 impacts of cyanotoxins, limited data demonstrates their real adverse effects on human  
557 populations. However, due to the high recorded MC concentrations and the potentially high  
558 exposure of humans to these toxins (in comparison to populations from developed countries),  
559 these impacts on human health should be seriously considered. This hypothesis is supported  
560 by the recent paper of Roegner et al. (2020) showing that the health of peri-urban fisher  
561 communities in the area of Kisumu is threatened by the consumption and use of lake water  
562 contaminated with MCs and other HAB components. Moreover, in addition to the  
563 disturbances caused by cyanobacteria during the production of drinking water, human  
564 populations can also consume nontreated water from the lake or poorly treated water with  
565 potential exposure to fecal pathogens associated with waterborne diseases.

566

567 **Figure 4.** Potential impacts of cyanobacterial blooms on human health in Lake Victoria

568 LW: Lake water; DW: Drinking water

569

## 570 **6. Efforts to reduce eutrophication and the occurrence/intensity of cyanobacterial** 571 **blooms**

572 Knowing that it is well established that the eutrophication of freshwater ecosystems promotes  
573 cyanobacterial blooms, the reduction of external nutrient inputs in the lakes is the main  
574 sustainable strategy to reduce cyanobacterial blooms (e.g. Huisman et al., 2018). LV is a very  
575 complex socioecological ecosystem, and there is limited documented knowledge (and  
576 understanding) regarding the social and ecological dynamics and interactions involving LV.  
577 However, based on existing knowledge, we provide arguments for the eutrophication



578 trajectory of LV and the necessity to carry out ambitious and sustainable management  
579 measures to address this major problem. The modeling approach developed by Downing et al.  
580 (2014) shows that controlling eutrophication is key to the protection and restoration of LV  
581 and its ecosystem functions and G&S. This finding is shared by many scientists as well as the  
582 local and international authorities in charge of the management of LV. Over the past 10 years,  
583 many actions have been taken to restore LV under the authorities of the East African  
584 Community (EAC), Lake Victoria Fisheries Organization (LVFO), Lake Victoria  
585 Environment Management Program (LVEMP), and Nile Basin Initiative (NBI) (Kayombo  
586 and Jorgensen, 2006).

587         We have attempted to differentiate the issues affecting the B&Gs and the OL resulting  
588 from population growth and human activity because (i) the B&Gs are more polluted than the  
589 OL and (ii) the main sources of pollutants affecting these areas are different. The pollution of  
590 the B&Gs is largely due to the discharge of (i) solid and liquid wastes/pollutants originating  
591 from big cities located on their banks and (ii) sediments and nutrients from the intensive  
592 agricultural farmland. Consequently, efficient wastewater collection and treatment of these  
593 domestic and industrial pollutants are critical in reducing the hyper eutrophication of the  
594 B&Gs. In Murchison Bay (Uganda), most of the influxing nutrients are carried by the  
595 Nakivubo channel (Fuhrimann et al., 2015), comprising mainly the rainwater and the  
596 domestic and industrial wastewater of Kampala (Matagi, 2002; Kayima et al., 2008). With  
597 this goal in mind, the Kampala Capital City Authority (KCCA) launched the Green Industry  
598 Campaign in 2016 with the goal of improving wastewater treatment (KCCA, 2018). Recently,  
599 the KCCA also piloted a new action plan to improve fecal sludge collection and transport  
600 from household pit latrines, which are common in Kampala suburbs (KCCA, 2017). Finally,  
601 the construction of a new wastewater treatment plant in Kampala (Bugolobi/Nakivubo sewage  
602 plant) should increase the sewage treatment capacities of the National Water and Sewerage

603 Corporation (NWSC), which oversees water sanitation in Uganda. Similar approaches have  
604 also been implemented for Kisumu located near the Nyanza Gulf in Kenya and for Mwanza  
605 located near the Mwanza Gulf in Tanzania in the framework of the Lake Victoria Water  
606 Sanitation Projects (LVWATSAN), which were first launched in 2004 but still continue to  
607 support actions for the improvement of solid and liquid waste management  
608 (<https://unhabitat.org/the-lake-victoria-water-and-sanitation-project/>).

609 All these actions are very important for the protection of the B&Gs of LV, but  
610 estimating their “real” impacts on the improvement of the water quality in the B&Gs remains  
611 difficult. Indeed, in urban areas, the wastewater collection networks are still limited, which  
612 results in the treatment of a small proportion of sewage, and with the predicted increased  
613 population growth rate (2 – 5% annually), sewerage production will increase.

614 In addition to improving wastewater collection and treatment, the protection and  
615 restoration of the numerous wetlands that are associated with the B&Gs is also important. As  
616 discussed before, many wetlands have been degraded due to the pressures linked to  
617 population growth. Consequently, several projects in the three riparian countries around LV  
618 focused on the rehabilitation of natural wetlands and the construction of artificial wetlands.  
619 These programs are aimed at securing and maintaining the hydrological and ecological  
620 integrity of wetlands (MWE, 2018). This initiative requires active involvement and  
621 participation of the local communities living in these areas, as shown in Kenya by Raburu et  
622 al. (2012) and in Uganda by Wacker et al. (2016).

623 Concerning the OL, it has been shown that in addition to river discharge, aerial  
624 depositions are the main source of nutrient inputs in the lake (e.g., Tamatamah et al., 2005;  
625 Kayombo & Jorgensen, 2006). Therefore, a reduction of these inputs would be associated  
626 with an integrated approach for the protection of the catchment area, including better soil  
627 cover management and improved land use patterns (Okungu & Opango, 2005; Vuai et al.,

628 2013). To adequately protect the watershed, deforestation needs to be halted and forests need  
629 to be restored; this constitutes a much greater challenge due to the complexity of the drivers  
630 of this phenomenon (Masese et al., 2012; Waiswa et al., 2015). These authors also note the  
631 absolute need to involve local communities in all these processes.

632 In the framework of the Lake Victoria Environmental Management Project phases I  
633 and II (LVEMP I and II), several soil conservation and afforestation projects were  
634 implemented to limit soil erosion and the aerial deposition of nutrients in the lake. The impact  
635 of these projects on the water quality of the OL has not been estimated. However, considering  
636 the size of the watershed and the increasing population density, soil conservation projects will  
637 require considerable concerted efforts by the five countries before expecting “significant  
638 changes” in the water quality of the main lake.

639 In interaction with LVEMP projects, national management plans have also been  
640 implemented in the countries belonging to the LV watershed. In Kenya for example, a master  
641 plan for the conservation and sustainable management of water catchment areas was proposed  
642 in 2012 by the Ministry of Environment and Mineral Resources (MEMR, 2012). Sub  
643 catchment management plans have been implemented, for example for the Awach Kano,  
644 leading to reduced deforestation, water pollution, gully erosion, etc. (Nyanchaga and Openji,  
645 2017). In Tanzania, similar catchment-based actions have been implemented for the  
646 protection of LV in the framework of Integrated Water Resources Management and  
647 Development (IWRMD) plans (Domasa, 2019).

648

## 649 **7. Conclusion**

650 Due to the demographic growth and the rising concentration of the population into urban  
651 areas in Africa (United Nation, 2018), we may fear that in the next decades, eutrophication of  
652 freshwater ecosystems and associated cyanobacterial blooms will continue to increase in LV

653 and also in many other African lakes. Knowing that all these lakes provide numerous  
654 ecosystem G&S and are vital for the water and food supply, the high microcystin  
655 concentrations recorded in water and fishes of LV and the data of Roegner et al. (2020)  
656 suggest that cyanobacteria and their toxins constitute a serious health concern for local  
657 populations. The same is probably true in many countries of the intertropical area in Africa.  
658 Consequently, it is becoming urgent in Africa (i) to implement long term monitoring  
659 programs of cyanobacteria and cyanotoxins in lentic freshwater ecosystems, (ii) to define  
660 water policies and rules for cyanobacteria and cyanotoxins and to inform human populations  
661 about sanitary risks and (iii) to take actions for reducing the exposure of human populations to  
662 cyanotoxins knowing that among these actions, the provision of affordable and easily  
663 available treated-water is an urgent priority.

664 In a longer-term perspective, the battle against eutrophication will be one of the great  
665 challenge of African countries. As shown in this review, the three main axes in this battle will  
666 concern (i) the wastewater treatment and management in urban areas knowing that currently  
667 available treatment methods might not be used in Africa due for example, to the lack of  
668 appropriate structure (Wang et al., 2014), (ii) the promotion of a sustainable agriculture, such  
669 as conservation agriculture, allowing to provide foods to a growing population whilst  
670 minimizing environmental impacts (Giller et al., 2015) (iii) the protection and restoration of  
671 wetlands, which can play a very important role in nutrient retention and reduction, even for  
672 great lakes (Watson et al., 2016) .

673 As already experienced in developed countries, all these actions for reducing the  
674 exposure of human populations to cyanotoxins and the eutrophication will be very costly and  
675 consequently require international financial cooperation. There is also need for international  
676 collaborative research programs involving scientists and people from local institutions

677 working in the water domain. Finally, the involvement and participation of the local  
678 communities will be also a key factor for their successful development.

679

680

681

682

683

684 **Acknowledgement**

685 This review paper has been prepared in the framework of the WaSAf program, which is  
686 funded by the French Facility for Global Environment (Fonds Français pour l'Environnement  
687 Mondial, FFEM).

688

689

690

691

692 **References**

- 693 Akurut, M., Niwagaba, C.B., Willems, P., 2017. Long-term variations of water quality in the  
694 Inner Murchison Bay, Lake Victoria. *Environ. Monit. Assess* 189(1), 22.
- 695 Aura, C. M., Musa, S., Yongo, E., Okechi, J. K., Njiru, J. M., Ogari, Z., Wanyama, R., Charo-  
696 Karisa, H., Mbugua, H., Kidera, S., Ombwa V., Oucho, V., 2018. Integration of  
697 mapping and socio-economic status of cage culture: Towards balancing lake-use and  
698 culture fisheries in Lake Victoria, Kenya. *Aquacult. Res.* 49(1), 532-545.
- 699 Awange, J.L., Obiero, O., 2006. *Lake Victoria-Ecology, Resources, Environment.*  
700 Heidelberg. Springer Berlin.
- 701 Bamutaze, Y., Wanyama, J., Diekrugger, B., Meadows, M., Opedes H., 2017. Dynamics of  
702 surface runoff and soil loss from a toposequence under varied land use practices in  
703 Rwizi catchment, Lake Victoria Basin. *J. Soil Water Cons.* 72, 480-492.
- 704 Batjakas, I.E., Edgar, R.K., Kaufman, L.S., 1997. Comparative feeding efficiency of  
705 indigenous and introduced phytoplanktivores from Lake Victoria: Experimental  
706 studies on *Oreochromis esculentus* and *Oreochromis niloticus*. *Hydrobiologia* 347, 75-  
707 82.
- 708 Bernard, C., Ballot, A., Thomazeau, S., Maloufi, S., Furey, A., Mankiewicz-Boczek, J.,  
709 Pawlik-Skowronska, B., Capelli, C., Salmaso, N., 2017. In book: *Handbook of*  
710 *Cyanobacterial Monitoring and Cyanotoxin Analysis*, Edition: 1st, Chapter:  
711 *Cyanobacteria associated with the production of cyanotoxins*, Publisher: Wiley,  
712 Editors: Jussi Meriluoto, Lisa Spoo, Geoffrey Codd, pp. 501 – 525.
- 713 Bremer, J., Lopez-Carr, D., Zvoleff, A., Pricope, N., 2013. Using new methods and data to  
714 assess and address population, fertility, and environment links in the Lake Victoria.  
715 XXVII IUSSP International Population Conference.  
716 [https://iussp.org/sites/default/files/event\\_call\\_for\\_papers/IUSSP\\_paper\\_JBremner\\_et\\_al\\_0.pdf](https://iussp.org/sites/default/files/event_call_for_papers/IUSSP_paper_JBremner_et_al_0.pdf).  
717
- 718 Briand, J.F., Jacquet, S., Bernard, C., Humbert, J.F., 2003. Health hazards for terrestrial  
719 vertebrates from toxic cyanobacteria in surface water ecosystems. *Vet. Res.* 34, 361-  
720 377.
- 721 Bwanika, G.N., Chapman, L.J., Kizito, Y., Balirwa, J., 2006. Cascading effects of introduced  
722 Nile perch (*Lates niloticus*) on the foraging ecology of Nile tilapia (*Oreochromis*  
723 *niloticus*). *Ecol. Freshw. Fish*, 15, 470-481.
- 724 Cao, X., Wang, Y., He, J., Luo, X., Zheng, Z., 2016. Phosphorus mobility among sediments,  
725 water and cyanobacteria enhanced cyanobacteria blooms in eutrophic Lake Dianchi.  
726 *Environmental Pollution* 219, 580-587.
- 727 Cheruiyot, C. Muhandiki, V., 2014. Review of estimation of pollution load to Lake Victoria.  
728 *J. Environ. Earth Sci.* 4, 113-120.
- 729 Chorus, I., 2012. Current approaches to Cyanotoxin risk assessment, risk management and  
730 regulations in different countries. Edited by Section II Drinking Water and Swimming  
731 Pool Water Hygiene, Federal Environment Agency, Germany Eds, 151pp.
- 732 Chorus, I., Bartram, J., 1999. *Toxic cyanobacteria in water : A guide to their public health*  
733 *consequences, monitoring and management.* E&FN Spon, London & New York.
- 734 Center for International Earth Science Information Network - CIESIN - Columbia University,  
735 2018. *Gridded Population of the World, Version 4 (GPWv4): Population Density,*  
736 *Revision 11.* Palisades, NY: NASA Socioeconomic Data and Applications Center  
737 (SEDAC). Retrieved from: <https://doi.org/10.7927/H49C6VHW>. Thursday 13th June  
738 2019.
- 739 Cockx, L., Colen, L., De Weerd, J., Gomez, Y., Paloma, S., 2019. Urbanization as a driver of  
740 changing food demand in Africa: Evidence from rural-urban migration in Tanzania.

- 741 JCR Technical Reports, 51 p. (doi:10.2760/515064).
- 742 Cornelissen, I.J.M., Silsbe, G.M., Verreth, J.A.J., van Donk, E., Nagelkerke, L.A.J., 2014.  
743 Dynamics and limitations of phytoplankton biomass along a gradient in Mwanza Gulf,  
744 southern Lake Victoria (Tanzania). *Fresh. Biol.* 59, 127-141.
- 745 Dazé, A., Crawford, A., 2016. Human migration and ecosystems: Insights from the Great  
746 Lakes Region of East and Central Africa. IISD Report, 20 p.
- 747 Dobiesz, N.E., Hecky, R.E., Johnson, T.B., Sarvala, J., Dettmers, J.M., Lehtiniemi, M.,  
748 Rudstam, L.G., Madenjian, C.P., Witte, F., 2010. Metrics of ecosystem status for large  
749 aquatic systems - A global comparison. *J. Great Lakes Res.* 36(1), 123-138.
- 750 Dodds, W.K., Bouska, W.W., Eitzmann, J.L., Pilger, T.J., Pitts, K.L., Riley, A.J., Schloesser,  
751 J.T., Thornbrugh, D.J., 2009. Eutrophication of US freshwaters: Analysis of potential  
752 economic damages. *Environ. Sci. Technol.* 43(1), 12-19.
- 753 Domasa, S., 2019. How can we best protect Lake Victoria's ecosystem? The Niles. Retrieved  
754 from <https://www.theniles.org/en/articles/politics/20625/>
- 755 Downing, A.S., van Nes, E.H., Balirwa, J.S., Beuving, J., Bwathondi, P.O. J., Chapman,  
756 L.J., Cornelissen, L., Cowx, I.G., Goudswaard, K.P.C., Kecky, R.E., Janse, J.H.,  
757 Janssen, A.B.G., Kaufmann, L., Kische-Machumu, M.A., Kolding, J., Ligtvoet, W.,  
758 Mbabazi, D., Merdard, M., Mkumbo, Malponi, E., Munyaho, A.T., Nagelkerke,  
759 N.A.J., Ogutu-Ohwayo, R., Ojwang, W.O., Peter, H.K., Schindler, D.E., Seehausen,  
760 O., Sharpe, D., Silsbe, G.M., Sitoki, L., Tumwebase, R., Tweddle, D., van de  
761 Wolfshaar, K.E., van Dijk, H., van donk, E., van Rijssel, J.C., van Zwieten P.A.M.,  
762 Wanink, J., Witte, F., Mooij, W.M., 2014. Coupled human and natural system  
763 dynamics as key to the sustainability of Lake Victoria's ecosystem services. *Ecol. Soc.*  
764 19(4), 31. doi.org/10.5751/ES-06965-190431.
- 765 Egessa, R., Pabire, G.W., Ocaya, H., 2018. Benthic macroinvertebrate community structure in  
766 Napoleon Gulf, Lake Victoria: effects of cage aquaculture in eutrophic lake. *Environ.*  
767 *Monitoring and Assessment*, 190(3), 112.
- 768 El-Noshokaty, D., 2017. Big Lakes, Big Problems. Is There Still Time to Secure the Water  
769 Resources Lake Victoria Provides? International Reports of the Konrad-Adenauer-  
770 Stiftung. 11p.
- 771 Escalas, A., Catherine, A., Maloufi, S., Cellamare, M., Hamlaoui, S., Yéprémian, C.,  
772 Louvard, C., Troussellier, M., Bernard, C., 2019. Drivers and ecological consequences  
773 of dominance in periurban phytoplankton communities using networks approaches.  
774 *Wat. Res.* 163, 114893.
- 775 Food and Agricultural Research Organisation-FAO, 2015. The state of food insecurity in the  
776 World. doi.org/http://www.fao.org/.
- 777 Food and Agricultural Research Organisation-FAO, 2016. Economic analysis of food supply  
778 and demand in sub-Saharan Africa up to 2022 – special focus on fish and fishery  
779 products, by Trond Bjørndal, Alena Lappo, Madan Dey, Audun Lem and Anna Child.  
780 Fisheries and Aquaculture Circular No. 1101. Rome, Italy.
- 781 Fuhrmann, S., Stalder, M., Winkler, M.S., Niwagaba, C.B., Babu, M., Masaba, G.,  
782 Kabatereine, N.B., Halage, A.A., Schneeberger, P.H.H., Utzinger, J., Cissé, G., 2015.  
783 Microbial and chemical contamination of water, sediment and soil in the Nakivubo  
784 wetland area in Kampala, Uganda. *Environ Monit. Assess.* 187:475. DOI  
785 10.1007/s10661-015-4689-x
- 786 Geist, H., Lambin, E., 2002. Proximate causes and underlying driving forces of tropical  
787 deforestation. *Biosci.* 52, 143-150.
- 788 Gikuma-Njuru, P., 2008. Physical and biogeochemical gradients and exchange processes in  
789 Nyanza gulf and main Lake Victoria (East Africa). PhD Thesis, University of  
790 Waterloo, Waterloo.



- 791 Gikuma-Njuru, P., Hecky, R.E., 2005. Nutrient concentrations in Nyanza Gulf, Lake Victoria,  
792 Kenya: light limits algal demand and abundance. *Hydrobiologia* 534, 131-140.
- 793 Gikuma-Njuru, P., 2008. Physical and biogeochemical gradients and exchange processes in  
794 Nyanza Gulf and main Lake Victoria (East Africa). PhD Thesis. University of  
795 Waterloo, Ontario, Canada.
- 796 Gikuma-Njuru, P., Hecky, R.E., Guildford, S.J., 2010. Surficial sediment phosphorus  
797 fractions along a biogeochemical gradient in Nyanza (Winam) Gulf, northeastern Lake  
798 Victoria and their possible role in phosphorus recycling and internal loading.  
799 *Biogeochem.* 97, 247-261.
- 800 Gikuma-Njuru, P., Guildford, S.J., Hecky, R.E., Kling, H.J., 2013a. Strong spatial  
801 differentiation of N and P deficiency, primary productivity and community  
802 composition between Nyanza Gulf and Lake Victoria (Kenya, East Africa) and the  
803 implications for nutrient management. *Freshw. Biol.* 58(11), 2237-2252.
- 804 Gikuma-Njuru, P., Hecky, R.E., Guildford, S.J., Macintyre, S., 2013b. Spatial variability of  
805 nutrient concentrations, fluxes, and ecosystem metabolism in Nyanza Gulf and  
806 Rusinga Channel, Lake Uictoria (East Africa). *Limnol. Oceanogr.* 58(3), 774-789.
- 807 Giller, K.E., Andersson, J.A., Corbeels, M., Kirkegaard, J., Mortensen, D., Erenstein, O.,  
808 Vanlauwe, B., 2015. Beyond conservation agriculture. *Front. Plant Sci.* 6, 870.
- 809 Goldschmidt, T., Witte, F., Wanink, J., 1993. Cascading Effects of the Introduced Nile Perch  
810 on the Detritivorous/Phytoplanktivorous Species in the Sublittoral Areas of Lake  
811 Victoria. *Conserv. Biol.* 7(3), 686-700.
- 812 Haande, S., Rohrlack, T., Semyalo, R. P., Brettum, P., Edvardsen, B., Lyche-Solheim, A.,  
813 Sorensen, K., Larsson, P., 2011. Phytoplankton dynamics and cyanobacterial  
814 dominance in Murchison Bay of Lake Victoria (Uganda) in relation to environmental  
815 conditions. *Limnologica - Ecology and Management of Inland Waters* 41(1), 20-29.
- 816 Hecky, R.E., 1993. The eutrophication of Lake Victoria. *Verhandlungen Des Internationalen*  
817 *Verein Limnol.* 25, 39-48.
- 818 Hecky, R.E., Bugenyi, F.W.B., Ochumba, P., Talling, J.F., 1994. Deoxygenation of the deep  
819 water of Lake Victoria, East Africa. *Limnol. Oceanogr.* 39(6), 1476-1481.
- 820 Hecky, R.E., Muggide, R., Ramsal, P.S., Talbot, M.R., Kling, G.W., 2010. Multiple stressors  
821 cause rapid ecosystem change in Lake Victoria. *Freshw. Biol.* 55(Suppl. 1), 19-42.
- 822 Ho, J.C., Michalak, A.M., Pahlevan, N., 2019. Widespread global increase in intense lake  
823 phytoplankton blooms since the 1980s. *Nature* 574, 667
- 824 Huisman, J., Codd, G.A., Paerl, H.W., Ibelings, B.W., Verspagen, J.M.H., Visser, P.M., 2018.  
825 Cyanobacterial blooms. *Nature Rev. Microbiol.* 16(8). DOI: 10.1038/s41579-018-  
826 0040-1.
- 827 Ibelings, B.W., Chorus, I., 2007. Accumulation of cyanobacterial toxins in freshwater  
828 “seafood” and its consequences for public health: A review. *Environ. Pollut.* 150,  
829 177-192.
- 830 Isabirye, M., Kimaro, D., Semalulu, O., 2010. Sediment production from settlements and  
831 farmlands within Lake Victoria shoreline zone in Uganda and Tanzania. *Tropicultura*  
832 28, 89-95.
- 833 Isunju, J.B., 2016. Spatiotemporal analysis of encroachment on wetlands: hazards,  
834 vulnerability and adaptations in kampala city, Uganda. PhD Dissertation. University of  
835 Stellenbosch, South Africa.
- 836 Jiang, J., Shi, Y., Shan, Z., Yang, L., Wang, X., Shi, L., 2012. Bioaccumulation, oxydative  
837 stress and HSP70 expression in *Cyprinus carpio* L. exposed to microcystin-LR under  
838 laboratory conditions. *Comparative Biochemistry and Physiology Part C: Toxicol.*  
839 *Pharmacol.* 155 (3), 483-490.
- 840 Jihulya, N.J. 2014. Diet and feeding ecology of Nile tilapia, *Oreochromis niloticus* and Nile

- 841 perch, *Lates niloticus* in protected and unprotected areas of Lake Victoria, Tanzania.  
842 Int. J. Sci. Technol. Res. 3, 280–286.
- 843 Jovanelly, T. J., Johnson-Pynn, J., Okot-Okumu, J., Nyenje, R., Namaganda, E., 2015.  
844 Pioneering water quality data on the Lake Victoria watershed: Effects on human  
845 health. J. Wat. Health 13(3), 920-930.
- 846 Juma, D.W., Wang, H., Li F., 2014. Impacts of population growth and economic development  
847 on water quality of a lake: case study of Lake Victoria Kenya water. Environ. Sci. Poll. Res.  
848 21, 5737-5746
- 849 Kabenge, M., Wang, H., Li, F., 2016. Urban eutrophication and its spurring conditions in the  
850 Murchison Bay of Lake Victoria. Environ. Sci. Pollut. Res. Int. 23, 234-241.
- 851 Kampala Capital City Authority-KCCA, 2017. Piloting a mobile sludge transfer tank in 5  
852 parishes of Kampala. [https://www.kcca.go.ug/news/242/Piloting-a-mobile-sludge-  
853 transfer-tank-in-5-parishes-of-Kampala#.XCTz5WIRWM8](https://www.kcca.go.ug/news/242/Piloting-a-mobile-sludge-transfer-tank-in-5-parishes-of-Kampala#.XCTz5WIRWM8)
- 854 Kampala Capital City Authority-KCCA, 2018. What is the Kampala Green Industry  
855 Campaign. <https://www.kcca.go.ug/ptf-gic>
- 856 Kansiime, F., Nalubega, M., 1999. Wastewater Treatment by a Natural Wetland: The  
857 Nakivubo Swamp, Uganda. IHE. <http://edepot.wur.nl/192727>.
- 858 Karamage, F., Zhang, C., Liu, T. Maganda, A., Isabwe, A., 2017. Soil erosion risk assessment  
859 in Uganda. Forests 8, 52.
- 860 Kashindye, B. B., Nsinda, P., Kayanda, R., Ngupula, G. W., Mashafi, C. A., & Ezekiel, C. N.,  
861 2015. Environmental impacts of cage culture in Lake Victoria: the case of Shirati Bay-  
862 Sota, Tanzania. *SpringerPlus*, 4, 475-475. doi:10.1186/s40064-015-1241-y
- 863 Kayima, J., Kyakula, M., Komakech, W., Echimu, S.P., 2008. A study of the degree of  
864 pollution in Nakivubo Channel, Kampala, Uganda. J. Environ. Sci. Appl. Manag.  
865 12(2), 93-98.
- 866 Kayombo, S., Jorgensen, S.E., 2006. Lake Victoria: Experience and Lessons Learned Brief,  
867 In: Lake Basin Management Initiative: Experience and Lessons Learned Briefs (on  
868 CD). International Lake Environment Committee Foundation, Kusatsu, Japan, pp.  
869 431-446.
- 870 Kizza, M., Rodhe, A., Xu, C.Y., Ntale, H.K., Halldin, S., 2009. Temporal rainfall variability  
871 in the Lake Victoria Basin in East Africa during the twentieth century. Theor. Appl.  
872 Climatol. 98, 119-135.
- 873 Kling, H.J., Mugidde, R., Hecky, R.E., 2001. Recent changes in the phytoplankton  
874 community in response to eutrophication. In M. Munawar R.E. Hecky (Eds.), The  
875 Great Lakes of the World (GLOW): Food-web, health and integrity (pp. 44-65).  
876 Leiden, The Netherlands: Backhuys.
- 877 Kolding, J., van Zwieten, P., Mkumbo, O., Silsbe, G., Hecky, R.E., 2008. Are the Lake  
878 Victoria fisheries threatened by exploitation or eutrophication? Towards an ecosystem  
879 based approach to management. In R. Bianchi, & H. R. Skjoldal (Eds.), The  
880 ecosystem approach to fisheries. (pp 309-354). Rome: CABI Publishing.
- 881 Kotut, K., Ballot, A., Krienitz, L., 2006. Toxic cyanobacteria and their toxins in standing  
882 waters of Kenya: implications for water resource use. J. Wat. Health 4(Suppl. 2), 3-18.
- 883 Krienitz, L., Ballot, A., Wiegand, C., Kotut, K., Codd, G.A., Pflugmacher, S., 2002.  
884 Cyanotoxin-producing bloom of *Anabaena flos-aquae*, *Anabaena discoidea* and  
885 *Microcystis aeruginosa* (Cyanobacteria) in Nyanza Gulf of Lake Victoria, Kenya. J.  
886 Appl. Bot. 76, 179-183.
- 887 Kundu, R., Aura, C.M., Nyamweya, C., Agembe, S., Sitoki, L., Lung'ayia, H., Ongore, C.,  
888 Ogari, Z., Werimo, K., 2017. Changes in pollution indicators in Lake Victoria, Kenya  
889 and their implications for lake and catchment management. Lakes Reserv. Res.  
890 Manag. 22(3), 199-214.

- 891 Lake Victoria Environmental Management Project (LVEMP), 2005. Water quality and  
892 ecosystem status. <http://hdl.handle.net/11671/718>
- 893 Lake Victoria Environmental Management Project (LVEMP), 2007. Preparation of National /  
894 Regional Management Framework: Institutional Component for the Lake Victoria  
895 Basin Final National Report. <http://repository.eac.int>.
- 896 Lehman, J.T., 1998. Role of climate in the modern condition of Lake Victoria. *Theor. Appl.*  
897 *Climatol.* 61, 29-37.
- 898 Lehman, J.T., Branstrator, D.K., 1994. Nutrient dynamics and turnover rates of phosphate and  
899 sulfate in Lake Victoria, East Africa. *Limnol. Oceanogr.* 39(2), 227-233.
- 900 Lehman, P.W., The, S.J., Boyer, G.L., Nobriga, M.L., Bass, E., Hogle, C., 2010. Initial  
901 impacts of *Microcystis aeruginosa* blooms on the aquatic food web in the San  
902 Francisco Estuary. *Hydrobiologia* 637, 229-248.
- 903 Loiselle, S.A., Azza, N., Cozar, A., Bracchini, L., Tognazzi, A., Dattilo, A., Rossi, C.,  
904 2008. Variability in factors causing light attenuation in Lake Victoria. *Freshw. Biol.* 53  
905 (3), 535-545.
- 906 Loiselle, S.A., Azza, N., Gichuki, J., Bracchini, L., Tognazzi, A., Dattilo, A.M., Rossi, C.,  
907 2010. Spatial dynamics of chormophoric dissolved organic matter in nearshore waters  
908 of Lake Victoria. *Aquat. Ecosyst. Health Manag.* 13, 1-11.
- 909 Lu, K., Jin, C., Dong, S., Gu, B., Bowen, S.H., 2006. Feeding and control of blue-green algal  
910 blooms by tilapia (*Oreochromis niloticus*). *Hydrobiologia*, 568, 111-120.
- 911 Lung'aya, H.B.O., M'harzi, A., Tackx, M., Gichuki, J., Symoens, J.J., 2000. Phytoplankton  
912 community structure and environment in the Kenyan waters of Lake Victoria. *Freshw.*  
913 *Biol.* 43, 529-543.
- 914 Marshall, B.E., 2018. Guilty as charged: Nile perch was the cause of the haplochromine  
915 decline in Lake Victoria. *Can. J. Fish. Aquat. Sci.* 75(9), 1542-1559.
- 916 Maseke, F.O., Raburu, P.O., Mwasi, B.N., Etiégni, L., 2012. Effects of Deforestation on  
917 Water Resources: Integrating Science and Community Perspectives in the Sondu-  
918 Miriu River Basin, Kenya. *IntechOpen: New Advances and Contributions to Forestry*  
919 *Research*, 3–18. [doi.org/10.5772/2246](https://doi.org/10.5772/2246).
- 920 Matagi, S.V., 2002. Some Issues of Environmental Concern in Kampala, the Capital City of  
921 Uganda. *Environ. Monit. Assess.* 77, 121-138.
- 922 Matsuishi, T., Muhoozi, L., Mkumbo, O., Budeba, Y., Njiru, M., Asila, A., Othina, A., Cowx  
923 I.G., 2006. Are the exploitation pressures on the Nile perch fisheries resources of Lake  
924 Victoria a cause for concern? *Fish. Manag. Ecol.* 13(1), 53-71.
- 925 Mbonde, A.S., Sitoki, L., Kurmayer, R., 2015. Phytoplankton composition and microcystin  
926 concentrations in open and closed bays of Lake Victoria, Tanzania. *Aquat. Ecosyst.*  
927 *Health Manag.* 18(2), 212-220.
- 928 MEMR, 2012. Masterplan for the conservation and sustainable management of water  
929 catchment areas in Kenya. Ministry of Environment and Mineral Resources  
930 ([https://www.preventionweb.net/files/34692\\_conservationmasterplanfinal.pdf](https://www.preventionweb.net/files/34692_conservationmasterplanfinal.pdf)).
- 931 Merel, S., Walker, D.B., Chicana, R., Synder, S.A., Baures, E., Thomas, O., 2013. State of  
932 knowledge and concerns on cyanobacterial blooms and cyanotoxins. *Environ. Internat.*  
933 59, 303-327.
- 934 Meriluoto, J., Blaha, L., Bojadzija, G., Bormans, M., Brient, L., Codd, G. A., Drobac, D.,  
935 Faassen, E.J., Fastner, J., Hiskia, A., Ibelings, B.W., Kaloudis, T., Kokocinsky, M.,  
936 Kurmayer, R., Pantelic, D., Quesada, A., Salmaso, N., Tokodi, N., Triants, T.M.,  
937 Visser, P.M., Svirčev, Z., 2017. Toxic cyanobacteria and cyanotoxins in European  
938 waters – recent progress achieved through the CYANOCOST Action and challenges  
939 for further research. *Adv. Oceanogr. Limnol.* 8(1), 161-178.
- 940 Michalak, A. M., Anderson, E.J., Beletsky, D., Boland, S., Bosch, N.S., Bridgeman, T.B.,

- 941 Chaffin, J.D., Cho, K., Confesor, R., Daqloglu, I., DePinto, J.V., Evans, M.A.,  
 942 Fahnenstiel, G.L., He, L., Ho, J.C., Jenkins, L., Johengen, T.H., Kuo, K.C., LaPorte,  
 943 E., Liu, X., McWilliams, M.R., Moore, M.M., Posselt, D.J., Richards, R.P., Scavia,  
 944 D., Steiner, A.L., Verhamme, E., Wirght, D.M., Zagorski, M.A., 2013. Record-setting  
 945 algal bloom in Lake Erie caused by agricultural and meteorological trends consistent  
 946 with expected future conditions. *Proc. Nat. Acad. Sci. USA* 110(16), 6448-6452.
- 947 Miles, C.O., Sandvik, M., Nonga, H.E., Rundberget, T., Wilkins, A.L., Rise, F., Ballot, A.,  
 948 2013. Identification of microcystins in a Lake Victoria cyanobacterial bloom using  
 949 LC-MS with thiol derivatization. *Toxicon* 70, 21-31.
- 950 Ministry of Water and Environment-MWE, 2018. Wetlands Management Department.  
 951 <https://www.mwe.go.ug/dept/wetlands-management-department>.
- 952 Mkumbo, O.C., Marshall, B.E., 2015. The Nile perch fishery of Lake Victoria: Current status  
 953 and management challenges. *Fish. Manag. Ecol.* 22(1), 56-63.
- 954 Mkumbo, O.C., Nsinda, P., Ezekiel, C.N., Cowx, I.G., Aeron, M., 2007. Towards sustainable  
 955 exploitation of Nile perch consequential to regulated fisheries in Lake Victoria. *Aquat.*  
 956 *Ecosyst. Health Manag.* 10(4), 449-457.
- 957 Moe, C. L., Rheingans, R. D., 2006. Global challenges in water, sanitation and health. *J. Wat.*  
 958 *Health* 4(Suppl. 1), 41-58.
- 959 Montgomery, M.R., 2008 The urban transformation of the developing world. *Science* 319,  
 960 761-764.
- 961 Moss, B., Kosten, S., Meerhoff, M., Battarbee, R.W., Jeppesen, E., Mazzeo, N., Havens, K.,  
 962 Lacerot, G., Liu, Z., De Meester, L., Paerl, H., Scheffer, M., 2011. Allied attack:  
 963 climate change and eutrophication. *Inland Wat.* 1(2), 101-105.
- 964 Muggide, R., Hecky, R.E., Hendzel, L.L., Taylor, W.D., 2003. Pelagic nitrogen fixation in  
 965 Lake Victoria (East Africa). *Journal of Great Lakes Research* 29, 76-88.
- 966 Muggide, R., Hecky, R.E., Ndawula, L., 2005. Chapter Eight - Eutrophication of Lake  
 967 Victoria, Uganda. In *Water Quality and Quantity Synthesis Final report, LVEMP*, pp.  
 968 131-148.
- 969 Musamba, E.B., Ngaga, Y.M., Boon, E.K., Giliba, R.A., 2011. Impact of socio-economic  
 970 activities around Lake Victoria: Land use and land use changes in Musoma  
 971 municipality, Tanzania. *J. Hum. Ecol.* 35, 143-154.
- 972 Musungu, P.C., Lalah, J.O., Jondiko, I.O., Onger, D.M.K., 2014. The impact of nitrogenous  
 973 and phosphorus nutrients from selected point sources in Kisumu City on River Kisat  
 974 and Nyalenda Wigwa Stream before their discharge into Winam Gulf, Lake Victoria.  
 975 *Environ. Earth Sci.* 71 (12), 5121-5127.
- 976 Muwanga, A., Barifaijo, E., 2006. Impact of industrial activities on heavy metal loading and  
 977 their physico-chemical effects on wetlands of Lake Victoria basin (Uganda). *Afr. J.*  
 978 *Sci. Tech.* 7, 51-63.
- 979 Musinguzi, L., Lugya, J., Rwezawula, P., Kanya, A., Nuwahereza, C., Halafo, J., Kamondo,  
 980 S., Njaya, F., Aura, C., Shoko, A.P., Osinde, R., Natugonza, V., Ogutu-Ohwayo, R.,  
 981 2019. The extent of cage aquaculture, adherence to best practices and reflections for  
 982 sustainable aquaculture on African inland waters. *J. Great Lakes Res.* 45,1340-1347
- 983 Mwavu, E.N., Witkowski, E.T.F., 2008. Land-Use and Cover Changes (1998- 2002) around  
 984 Budongo Forest Reserve, NW Uganda: Implicationz for Forest and Woodlands  
 985 Sustainability. *Land Degrad. Dev.* 19, 606-622.
- 986 Nchabeleng, T., Cheng, P., Oberholster, P., Botha, A.-M., Smit, W., Luus-Powell, W., 2014.  
 987 Microcystin-LR equivalent concentrations in fish tissue during a post bloom  
 988 *Microcystis* exposure in Loskop Dam, South Africa. *Afr. J. Aquat. Sci.* 39, 459-466.

- 989 Ngupula, G.W, Mbonde, A.S.E, Ezekiel, C.N., 2011. Spatial and temporal patterns of  
 990 phytoplankton abundance and composition in three ecological zones in the Tanzanian  
 991 waters of Lake Victoria. *Afr. J. Aquat. Sci.* **36**,197-206.
- 992 Njiru, J. M., Aura, C. M., & Okechi, J. K., 2018. Cage fish culture in Lake Victoria: A boon  
 993 or a disaster in waiting? *Fisheries Management and Ecology*, *00*, 1-9.  
 994 doi:10.1111/fme.12283
- 995 Nyakaana, J.B., Sengendo, H., Lwasa, S., 2007. Population, urban development and the  
 996 environment in Uganda: the case of Kampala city and its environs. Faculty of Arts,  
 997 Makerere University, Kampala, Uganda.
- 998 Nyanchaga, E.N., Openji, S.O., 2017. Effectiveness of the implementation of the Sub-  
 999 Catchment Management Plan – A case study of Awach Kano water resources users  
 1000 association. *Int. J. Inn. Stu. Sci. Eng. Tech.* *3*, 9-15.
- 1001 O’Neil, J.M., Davis, T.W., Burford, M.A., Gobler, C.J., 2012. The rise of harmful  
 1002 cyanobacteria blooms: The potential roles of eutrophication and climate change.  
 1003 *Harmful Algae* *14*, 313-334.
- 1004 Ochumba, P.B.O., Kibaara, D.I., 1989. Observations on blue-green algal blooms in the open  
 1005 waters of Lake Victoria, Kenya. *Afr. J. Ecol.* *27*, 23-34.
- 1006 Odada, E.O., Ochola, W.O., Olago, D.O., 2009. Understanding future ecosystem changes in  
 1007 Lake Victoria basin using participatory local scenarios. *Afr. J. Ecol.* *47*(Suppl. 1), 147-  
 1008 153.
- 1009 Ogutu-Ohwayo, R., 2004. Management of the Nile perch, *Lates niloticus* fishery in Lake  
 1010 Victoria in light of the changes in its life history characteristics. *Afr. J. Ecol.* *42*, 306-  
 1011 314.
- 1012 Oguttu, H.W., Bugenyi, F.W.B., Leuenberger, H., Wolf, M., Bachofen, R., 2008. Pollution  
 1013 menacing Lake Victoria: Quantification of point sources around Jinja Town, Uganda.  
 1014 *Water S.A.* *34*, 89-98.
- 1015 Okello, W., Portmann, C., Erhard, M., Gademann, K., Kurmayer, R., 2010a. Occurrence of  
 1016 microcystin-producing cyanobacteria in Ugandan freshwater habitats. *Environ.*  
 1017 *Toxicol.* *25*(4), 367-380.
- 1018 Okello, W., Ostermaier, V., Portmann, C., Gademann, K., Kurmayer, R., 2010b. Spatial  
 1019 isolation favours the divergence in microcystin net production by *Microcystis* in  
 1020 Ugandan freshwater lakes. *Wat. Res.* *44*, 2803-2814
- 1021 Okello, W., Kurmayer, R., 2011. Seasonal development of cyanobacteria and microcystin  
 1022 production in Ugandan freshwater lakes. *Lakes Reserv. Res. Manag.* *16*, 123-135.
- 1023 Okeyo-Owuor, J.B, Raburu, P.O., Masese, F.O., Omari, S.N., 2012. Wetlands of Lake  
 1024 Victoria Basin, Kenya: distribution, current status and conservation challenges in  
 1025 Community Based Approach to the Management of Nyando Wetland. *Int. J. Novel*  
 1026 *Res. Hum. Soc. Sci.* *3*(5), 35-40.
- 1027 Okungu, J., Opango, P., 2005. Pollution loads into Lake Victoria from the Kenyan catchment.  
 1028 In: C.A. Mallya (Ed.), *Knowledge and Experiences gained from Managing the Lake*  
 1029 *Victoria Ecosystem* (pp. 90-108). Dar es Salaam. Regional Secretariat, Lake Victoria  
 1030 Environmental Management Project (LVEMP).
- 1031 Olokotum, M., 2017. The occurrence and elimination of cyanobacterial toxins in portable  
 1032 water in Uganda: A case study of Gaba III and Walukuba Waterworks. MSc Thesis.  
 1033 17192. University of Natural Resources and Life Sciences (BOKU), Vienna, Austria.
- 1034 Opande, G.O., Onyango, J.C., Wagai, S.O., 2004. Lake Victoria: The water hyacinth  
 1035 (*Eichhornia crassipes* [MART.] SOLMS), its socio-economic effects, control  
 1036 measures and resurgence in the Winam gulf. *Limnologica* *34*(1-2), 105-109.
- 1037 Opiyo, M.A., Marijani, E., Muendo, P., Odede, R., Leschene, W., Charo-Karisa, H., 2018.  
 1038 Review of aquaculture production and health management practices of farmed fish in

- 1039 Kenya. Int. J. Vet. Sci. Med. 6(2), 141-148.
- 1040 Oyoo, R., 2015. Deteriorating water quality in the Lake Victoria Inner Murchison Bay and its  
1041 impact on the drinking water supply for Kampala, Uganda.  
1042 [http://wldb.ilec.or.jp/data/ilec/WLC13\\_Papers/others/3.pdf](http://wldb.ilec.or.jp/data/ilec/WLC13_Papers/others/3.pdf)
- 1043 Padmavathi, P., Veeraiyah, K., 2009. Studies on the influence of *Microcystis aeruginosa* on the  
1044 ecology and fish production of carp culture ponds. J. Biotechnol 8(9), 1911-1918.
- 1045 Paerl, H.W., Gardner, W.S., Havens K.E., Joyner A.R., McCarthy M.J., Newell S.E., Qin, B.,  
1046 Scott, J.T., 2016. Mitigating cyanobacterial harmful algal blooms in aquatic  
1047 ecosystems impacted by climate change and anthropogenic nutrients. Harmful Algae  
1048 54, 213-222.
- 1049 Place, F., Otsuka, K., 2002. Land tenure systems and their impacts on agricultural investments  
1050 and productivity in Uganda. J. Dev. Studies 38(6), 105-128.
- 1051 Poste, A.E., Hecky, R.E., Guildford S.J., 2011. Evaluating Microcystin Exposure Risk  
1052 through Fish Consumption. Env. Sci. Technol. 45, 5806-5811.
- 1053 Poste, A.E., Hecky, R.E., Guildford, S.J., 2013. Phosphorus enrichment and carbon depletion  
1054 contribute to high *Microcystis* biomass and microcystin concentrations in Ugandan  
1055 lakes. Limnol. Oceanogr. 58(3), 1075-1088.
- 1056 Raburu, P.O., Okeyo-Owuor, J.B., Kwena, F., 2012. Community Based Approach to the  
1057 Management of Nyando Wetland, Lake Victoria Basin, Kenya. KDC - VIRED –  
1058 UNDP. Nairobi, Kenya.
- 1059 Roegner, A., Sitoki, L., Weirich, C., Corman, J., Owage, D., Umami, M., Odada, E., Miruka,  
1060 J., Ogari, Z., Smith, W., Rejmankova, E., Miller, T.R., 2020. Harmful algal blooms  
1061 threaten the health of peri-urban fisher communities: A case study in Kisumu Bay,  
1062 Lake Victoria, Kenya. Expos Health, Early access Feb 2020 ([https://doi-  
1063 org.inee.bib.cnrs.fr/10.1007/s12403-019-00342-8](https://doi-org.inee.bib.cnrs.fr/10.1007/s12403-019-00342-8))
- 1064 Rumisha, C., Nehemia, A., 2013. Feeding selectivity of wild and pond-cultured Nile tilapia  
1065 *Oreochromis niloticus* in the lake Victoria basin in Mara, Tanzania. Afr. J. Aquat. Sci.  
1066 38, 55-60.
- 1067 Schuijt, K., 2002. Land and water use of wetlands in Africa: Economic values of African  
1068 wetlands. doi.org/10.1016/j.molcel.2012.05.044.
- 1069 Sekadende, B.C., Lyimo, T.J., Kurmayer, R., 2005. Microcystin production by cyanobacteria  
1070 in the Mwanza Gulf (Lake Victoria, Tanzania). Hydrobiologia 543(1), 299-304.
- 1071 Semyalo, R., Rohrlack, T., Naggawa, C., Nyakairu, G.W., 2010. Microcystin concentrations  
1072 in Nile tilapia (*Oreochromis niloticus*) caught from Murchison Bay, Lake Victoria and  
1073 Lake Mburo: Uganda. Hydrobiologia 628, 235-244.
- 1074 Semyalo, R., Rohrlack, T., Kayiira, D., Kizito, Y.S., Byarujali, S., Nyakairu, G., Larsson, P.,  
1075 2011. On the diet of Nile tilapia in two eutrophic tropical lakes containing toxin  
1076 producing cyanobacteria. Limnologia 41, 30-36.
- 1077 Shayo, S.D., Lugomela, C., Machiwa, J.F., 2011. Influence of land use pattern on some  
1078 limnological characteristics in the south-eastern part of Lake Victorian, Tanzania.  
1079 Aquat. Ecosyst. Health Manag. 14, 246-251.
- 1080 Silsbe, G.M., Hecky, R.E., Guildford, S.J., 2006. Variability of chlorophyll *a* and  
1081 photosynthetic parameters in a nutrient-saturated tropical great lake. Limnol.  
1082 Oceanogr. 51(5), 2052-2063.
- 1083 Simiyu, B.M., Oduor, S.O., Rohrlack, T., Sitoki, L., Kurmayer, R., 2018. Microcystin content  
1084 in phytoplankton and in small fish from eutrophic Nyanza Gulf, lake Victoria, Kenya.  
1085 Toxins 10(7), 1-19.
- 1086 Simonit, S., Perrings, C., 2011. Sustainability and the value of the 'regulating' services:  
1087 Wetlands and water quality in Lake Victoria. Ecol. Econom. 70(6), 1189-1199.
- 1088 Sitoki, L., Kurmayer, R., Rott, E., 2012. Spatial variation of phytoplankton composition,



- 1089 biovolume, and resulting microcystin concentrations in the Nyanza Gulf (Lake  
1090 Victoria, Kenya). *Hydrobiologia* 691, 109-122.
- 1091 Spooof, L., Catherine, A., 2017. Appendix 3 – Tables of Microcystins and Nodularins.. In  
1092 Handbook of Cyanobacterial Monitoring and Cyanotoxin Analysis. Meriluoto J.,  
1093 Spooof L. and Codd G.A. Eds. Hohn Wiley & Sons, Ltd, 526-537.
- 1094 Ssebiyonga, N., Erga, S.R., Hamre, B., Stamnes, J.J., Frette, Ø., 2013. Light conditions and  
1095 photosynthetic efficiency of phytoplankton in Murchison Bay, Lake Victoria, Uganda.  
1096 *Limnologia* 43(3), 185-193.
- 1097 Stager, J.C., Hecky, R.E., Grzesik, D., Cumming, B.F., Kling, H., 2009. Diatom evidence for  
1098 the timing and causes of eutrophication in Lake Victoria, East Africa. *Hydrobiologia*  
1099 636, 463-478.
- 1100 Svircev, Z., Lalic, D., Bojadzija Savic, G., Tokodi, N., Drobac Backovic, D., Chen, L.,  
1101 Meriluoto, J., Codd, G.A., 2019. Global geographical and historical overview of  
1102 cyanotoxin distribution and cyanobacterial poisonings *Arch. Toxicol.* 93, 2429–2481.
- 1103 Talling, J.F., 1966. The annual cycle of stratification and phytoplankton growth in Lake  
1104 Victoria. *Int. Revue ges. Hydrobiol.* 51, 545-621.
- 1105 Talling, J.F., 1987. The phytoplankton of Lake Victoria (East Africa). *Arch. Hydrobiol. Beih.*  
1106 *Ergebn. Limnol.* 25, 229-256.
- 1107 Tamatamah, R.A., Hecky, R.E., Duthie, H.C., 2005. The atmospheric deposition of  
1108 phosphorus in Lake Victoria (East Africa). *Biogeochem.* 73, 325-344.
- 1109 Taranu, Z.E., Gregory-Eaves, I., Leavitt, P.R., Bunting, L., Buchaca, T., Catalan J.,  
1110 Domaison, I., Guilizzoni, P., Lami, A., McGowan, S., Moorhouse, H., Morabito, G.,  
1111 Pick, F.R., Stevenson, M.A., Thompson, P.L., Vinebrooke, R.D., 2015. Acceleration  
1112 of cyanobacterial dominance in north temperate-subarctic lakes during the  
1113 Anthropocene. *Ecol. Lett.* 18(4), 375-384.
- 1114 Tariku, TB., Gan, T.Y., 2018. Regional climate change impact on extreme precipitation and  
1115 temperature of the Nile river basin. *Clim. Dyna.* 51, 3487-3506.
- 1116 Teferi, Y., Admassu, D., Mengistou, S., 2000. The food and feeding habit of *Oreochromis*  
1117 *niloticus* L. (Pisces: Cichlidae) in Lake Chamo, Ethiopia. *SINET: Ethiop. J. Sci.* 23(1),  
1118 1-12.
- 1119 Thiery, W., Davin, E.L., Seneviratne, S.I., Bedka, K., Lhermitte, S., van Lipzig, N.P.M.,  
1120 2016. Hazardous thunderstorm intensification over Lake Victoria. *Nature Comm.* 7,  
1121 12786.
- 1122 Torres, G.S., Silva, L.H., Rangel, L.M., Attayde, J.L., Huszar, V. L., 2016. Cyanobacteria are  
1123 controlled by omnivorous filter-feeding fish (Nile tilapia) in a tropical eutrophic  
1124 reservoir. *Hydrobiologia*, 765, 115-129.
- 1125 Turker, H., Eversole, A. G., Brune, D. E., 2003. Filtration of green algae and cyanobacteria  
1126 by Nile tilapia, *Oreochromis niloticus*, in the Partitioned Aquaculture System.  
1127 *Aquaculture* 215, 93-101.
- 1128 United Nations Environment Program-UNEP, 2006. UNEP 2006 annual report.  
1129 <https://www.unenvironment.org/resources/annual-report/unep-2006-annual-report>.
- 1130 United Nations Environment Program-UNEP, 2008. Africa: Atlas of our changing  
1131 environment. Malta: Progress Press.
- 1132 United Nations, Department of Economic and Social Affairs, Population Division, 2019.  
1133 World Urbanization Prospects 2018: Highlights (ST/ESA/SER.A/421).
- 1134 Verschuren, D., Johnson, T.C., Kling, H.J., Edgington, D.N., Leavitt, P.R., Brown, E.T.,  
1135 Talbot, M.R., Hecky, R.E., 2002. History and timing of human impact on Lake  
1136 Victoria, East Africa. *Proc. Biol. Sci. Royal Soc.* 269(1488), 289-294.
- 1137 Vuai, S.A.H., Ibembe, J.D., Mungai, N.W., 2013. Influence of land use activities on spatial  
1138 and temporal variations of nutrient deposition in Mwanza region: Implication to the

- 1139 atmospheric loading to the Lake Victoria. *Atmosph. Clim. Sci.* 3, 224-234.
- 1140 Wacker, C., Okello, W., Gitau, M.K., Wolf, M., 2016. Participatory wetland management at  
1141 the shoreline of Lake Victoria in Jinja, Uganda. Kampala: Fountain Publishers.
- 1142 Waiswa, D., Stezrn, M.J., Prisley, S.P., 2015. Drivers of deforestation in the Lake Victoria  
1143 crescent, Uganda. *J. Sustain. Forest.* 34, 259-275.
- 1144 Wanda, F.M., Namukose, M., Matuha, M., 2015. Water hyacinth hotspots in the Uganda  
1145 water of Lake Victoria in 1993-2012: implications for management. *Afr. J. Aqu. Sci.*  
1146 40, 101-106.
- 1147 Wang, H., Wang, T., Zhang, B., Li, F., Toure, B., Omosa, I.B., Chiramba, T., Abdel-Monem,  
1148 M., Pradhan, M., 2014. Water and wastewater treatment in Africa – Current practices  
1149 and challenges. *Clean (Weinh)* 42, 1029-1035.
- 1150 Watson, S.B., Miller, C., Arhonditsis, G., Boyer, G.L., Carmichael, W., Charlton, M.N.,  
1151 Confesor, R., Depew, D.C., Höök, T.O., Ludsins, S.A., Matisoff, G., McElmurry, S.P.,  
1152 Murray, M.W., Richards, R.P., Rao, Y.R., Steffen, M.M., Wilhelm, S.W., 2016. The  
1153 re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. *Harmful Algae* 56,  
1154 44-66.
- 1155 Witte, F., Silsbe, G.M., Hecky, R.E., Goudswaard, P.C., Guildford, S.J., Kische-Machumu,  
1156 M.A., Wanink, J.H., 2012. Did the loss of phytoplanktivorous fish contribute to algal  
1157 blooms in the Mwanza Gulf of Lake Victoria? *Hydrobiologia* 679, 283-296.
- 1158 World Population Prospect, 2017. United Nations - DESA/Population Division.  
1159 <https://population.un.org/wpp/>
- 1160 Zakaria, M., Zienab, A., Bakr, A., 2019. Assessment of phytoplankton species in gut and  
1161 feces of cultured tilapia fish in Egyptian fishponds - Implications for feeding and  
1162 bloom control. *Acta Limnol. Brasil.*, 31, e27.
- 1163 Zhang, S., Liu, J., Wei, S., Zhang, K., 2016. Impact of aquaculture on eutrophication in  
1164 Changshou Reservoir. *Chin. J. Geochem.* 25(1), 90-96.
- 1165
- 1166
- 1167
- 1168
- 1169



1170 **Supplemental Table 1.** Dissolved nutrient and chlorophyll-a concentrations in the Lake  
1171 Victoria

1172

1173 **Supplemental Figure 1.** Chlorophyll-a and microcystin concentrations in the main lake and  
1174 in the bays and gulfs of the Lake Victoria

1175

1176 **Supplemental Figure 2.** Population size dynamics in the five countries of the watershed of  
1177 Lake Victoria (data from the “World Population Prospects, The 2017 Revision”, United  
1178 Nations; <https://population.un.org/wpp/Download/Standard/Population/>)

1179

1180 **Supplemental Figure 3.** Geographical distribution of the human population densities in the  
1181 Lake Victoria watershed.

1182