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# Lacustrine Cyanobacteria, Algal Blooms and Cyanotoxins in East Africa: Implications for Human and Ecological Health Protection

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## SUPPLEMENTARY FILES

**Table S1.** Phytoplankton composition and cyanotoxins in East African Community lakes

Water resource (Country)	Trophic status	Chlorophyll <i>a</i> ( $\mu\text{g L}^{-1}$ )	Phytoplankton group <sup>1</sup>	Major genera or species	MCs ( $\mu\text{g MC-LR eq L}^{-1}$ )	MCs congeners	Reference(s)
<b>1. Democratic Republic of Congo</b>							
Lake Tanganyika	OT	0.5 to 2.0	CYB (UDT)	<i>Anabaena</i> , <i>Nitzchia</i> , <i>Dolichospermum</i>	UDT	UDT	[1, 2]
Lake Kivu	OT	2.11	CYB (UDT), diatoms (UDT)	<i>Synechococcus</i> , <i>Planktolyngbya limnetica</i> , <i>Nitzchia</i> , <i>Fragilaria</i>	UDT	UDT	[3]
<b>2. Tanzania</b>					UDT	UDT	
Lake Big Momela, Lake Embagai, Lake Manyara	ET	137 to 2,615	CYB (>50%)	<i>Anabaenopsis elenkenii</i> , <i>A. fusiformis</i> , <i>Spirulina platensis</i> (L. Big Momela). In L. Embagai, <i>A. fusiformis</i> , <i>Oscillatoria</i> , <i>Hantzschia</i> . For L. Manyara, <i>Oscillatoria jenensis</i> , <i>Pseudoanabaena terebriformis</i> , <i>A. fusiformis</i> , <i>Spirulina laxissima</i> , <i>Anabaenopsis</i>	UDT	UDT	[4-6]
Momela Lakes and Lake Natron	ET	UDT	CYB (UDT)	<i>A. fusiformis</i>	0.1–4.5 $\mu\text{g mL}^{-1}$ of scum (L. Natron), BDL (Momela Lakes)	MC-LR, -YR and -RY	[7]
Lake Reshitani	ET	UDT	CYB (UDT)	<i>A. fusiformis</i> , <i>Spirulina laxissima</i>	UDT	UDT	[6]
<b>3. Kenya</b>							
Lakes: Bogoria, Nakuru, Oloidien and Elmenteita	ET	<100 to 8300	CYB (>97%)	<i>A. fusiformis</i>	16 to 155 (L. Bogoria), 130 to 4593 (L. Nakuru)	UDT	[8-12]
Lake Elmenteita	ET	UDT	CYB	<i>Anabaenopsis</i> , <i>Nitzschia</i>	UDT	UDT	[6]
Crater lakes: Sonachi and Simbi	UDT	UDT	CYB (>94%)	<i>A. fusiformis</i> (L. Sonachi), <i>A. fusiformis</i> and <i>Anabaenopsis abijatae</i> (L. Simbi)	1.6 to 12.0 (L. Sonachi), 19.7 to 39.0 (L. Simbi)	MC-RR (L. Sonachi), MC-LR, -RR, -LA and -YR (L. Simbi)	[12-17]
Lake Nakuru	ET	100 to 8300	CYB (UDT)	<i>A. fusiformis</i> , <i>Spirulina laxissima</i> , <i>Anabaenopsis</i>	UDT	UDT	[6, 18]
Lake Baringo	ET	20,000	CYB (UDT)	<i>Microcystis</i>	0.08 to 3.25	UDT	[12, 19]
Lake Naivasha	ET	361	CYB (UDT), diatoms (UDT)	<i>Microcystis</i> , <i>Planktothrix</i> , <i>Dolichospermum</i> , <i>Aulacoseira</i> and <i>Synedra</i>	0.075, 0.06 to 1.3, 0.001 to 0.041 and 0.1 to 0.3	MC-LR, -RR, -YR, -LA	[12, 20-22]
Lake Magadi	ET	UDT	CYB (UDT)	<i>Microcystis</i> , <i>Synechocystis</i> , <i>Synechococcus</i>	UDT	UDT	[23]
<b>4. Uganda</b>							
Crater Lakes: Nyabikere, Nyinambuga, Mwamba	ET	UDT	CYB (UDT)	<i>Microcystis</i> , <i>Anabaena</i> , <i>Cylindrospermopsis</i>	UDT	UDT	[24]
Lake Kachera	ET	181.9	CYB (UDT)	<i>Microcystis</i> and <i>Anabaena</i>	UDT	UDT	[25]
Lake: Kasenda	ET	36.8 to 167	CYB (78%), green algae (17%)	<i>Anabaena</i> , <i>Aphanothecae</i> , <i>Cocconeis</i> , <i>Dictyosphaerium</i> , <i>Microcystis</i>	UDT	UDT	[26]
Lake Edward	HT/ET	21.3	CYB (44-60%), diatoms (25%)	<i>Microcystis</i> , <i>Planktolyngbya</i> , <i>Anabaenopsis</i> and <i>Raphidiopsis</i>	0.1 to 5.81	MC-RR, [Asp <sup>3</sup> ]MC-YR, [Asp <sup>3</sup> ]MC-RR, -RY, [Asp <sup>3</sup> ]MC-RY	[27-29]
Lake George	HT	124.7	CYB (62%)	<i>Microcystis</i> , <i>Planktolyngbya</i> , <i>Anabaena</i> , <i>Anabaenopsis</i> , <i>Aphanocapsa</i> , <i>Aphanizomenon</i> , <i>Lyngbya</i>	BDL to 8.54	MC-RY, MC-RR, [Asp <sup>3</sup> ]MC-RY	[27, 30, 31]
Lake Saka	ET	133.8	CYB (1.7-18.3%)	<i>Planktothrix</i> and <i>Microcystis</i>	0.5 to 61.2	MC-RR, [NMeSer <sup>7</sup> ]MC-YR, [Asp <sup>3</sup> ]MC-YR, -RY, -LR, Unknown	[24, 29, 31]
Lake Mburo	HT/ET	68.5 to 150.5	CYB (10.5-21.5%)	<i>Microcystis</i> and <i>Anabaena</i>	0.5 to 3.5	MC-RR, -LR, -YR, -RY, [Asp <sup>3</sup> ]MC-YR, [NMeSer <sup>7</sup> ]MC-RY, Unknown	[25, 29, 31]
Lake Nkuruba	MT	7.9	CYB (79%), chlorophytes	<i>Planktolyngbya</i>	0.24	UDT	[29]
Lake Kyaninga	OT	3.49 to 9.27; 1.1 to 2.3	CYB (33-92.7%)	<i>Planktolyngbya limnetica</i> , <i>Cylindrospermopsis raciborskii</i> , <i>Aphanizomenon</i> , <i>Aphanocapsa</i> and <i>Aphanothecae</i>	UDT	UDT	[24, 26, 32]
Crater lakes: Munyayange, Kikorongo, Maseche, Murumuli, Bundayampa, Katwe, Bagusa, Nyamunuka	UDT	UDT	CYB (UDT)	<i>A. fusiformis</i> , <i>Planktolyngbya</i>	UDT	UDT	[33]
Lake Albert	MT/ET	19.2	CYB (UDT)	<i>Anabaena</i> , <i>Microcystis</i> , <i>Cylindrospermopsis</i>	UDT	UDT	[29, 34]
Lake Karolero	OT	2.5 to 3.1	CYB (59-85%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Kerere	OT	2.5 to 5.3	CYB (29-57%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Kacula	OT	4.5 to 5.0	CYB (79-93%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Mwengenyi	OT	5.1 to 5.8	CYB (79-95%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Kyerbwato	OT	5.9	CYB (86%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Katanda	MT	6.4 to 12	CYB (62-76%)	<i>Planktolyngbya</i> , <i>Anabaena</i>	UDT	UDT	[24, 26]
Lake Kanyamukali	MT	11.2	CYB (39-67%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Nkugute	MT	10.6 to 23.9	CYB (53-79%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Kyanga	MT	11.2 to 16.7	CYB (64-91%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Mirambi	MT	11.2-28.9	CYB (75-82%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Nyanswiga	MT	12.8	CYB (88%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Kitere	MT	14.7	CYB (79%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Chibwera	MT	16.4 to 32.3	CYB (79-93%)	<i>Planktolyngbya</i>	UDT	UDT	[26]

Water resource (Country)	Trophic status	Chlorophyll <i>a</i> ( $\mu\text{g L}^{-1}$ )	Phytoplankton group <sup>1</sup>	Major genera or species	MCs ( $\mu\text{g MC-LR eq L}^{-1}$ )	MCs congeners	Reference(s)
Lake Lugembe	MT	24.1 to 27.8	CYB (86-98%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Nyanswiga	MT	25.1	CYB (92%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Kamweru	MT	25.6 to 34.2	CYB (90-96%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Nahiryia	MT	33.2 to 52.9	CYB (89-93%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Nyabikere	ET	35.0 to 164.0	CYB (35-83%)	<i>Planktolyngbya</i>	UDT	UDT	[24, 26]
Lake Kyasanduka	ET	42 to 203.0	CYB (79-91%)	<i>Planktolyngbya</i>	UDT	UDT	[24, 26]
Lake Kifuruka	MT	8.6 to 53.6	CYB (94-95%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Wandakara	ET	89 to 98.3	CYB (89-93%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Nyamusigire	ET	135 to 181	CYB (79-96%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Nyungu	MT	16 to 23	CYB (99%)	<i>Planktolyngbya</i>	UDT	UDT	[26]
Lake Katinda	MT	23 to 31	CYB (94-100%)	<i>Planktolyngbya</i>	UDT	UDT	[24, 26]
<b>5. Lake Victoria (Lentic)</b>							
Lake Kanyaboli (a satellite lake, Kenya)	ET/HT	24.1	Chlorophyceae (42.3%), CYB (26.93%)	<i>Tetraspora</i> , <i>Protococcus</i> , <i>Selenastrum</i> , <i>Eudorina</i> , <i>Monoraphidium</i>	UDT	UDT	[35]
Nyanza Gulf (Open Lake)	ET	UDT	CYB (UDT)	UDT	BDL to 21.4	UDT	[36]
27 islands of Ukerewe district, Tanzania	ET	UDT	CYB (UDT)	UDT	0.0028 to 0.0102	MC-RR, -LR, -YR	[37]
Kisumu Bay	ET	1.46 to 2673.74	CYB (35%), diatoms (30%)	<i>Microcystis</i> , <i>Merismopedia</i> , <i>Dolichospermum</i> <sup>2</sup>	0.549 to 0.794	MC-LR, -YR	[38]
Nyanza Gulf	ET	10 to 30	CYB (70-90%)	<i>Microcystis</i> , <i>Planktolyngbya</i> , <i>Dolichospermum</i>	2 to 5; patch 80 to 2000	MC-YR, -LR, unknown MCs with <i>m/z</i> 1052 and 1002	[39]
Some Satellite Lakes	ET	UDT	CYB (UDT)	<i>Microcystis</i> , <i>Planktolyngbya</i> , <i>Dolichospermum</i>	UDT	UDT	[40]
Shirati Bay	ET	7.57 to 69.14	CYB (44.83%), bacillario-phytes (44.72%)	<i>Nitzchia</i> , <i>Dolichospermum</i> , <i>Microcystis</i> , <i>Lyngbya</i>	UDT	UDT	[41]
Several bays and Gulfs, Tanzania	ET	10	CYB (82%)	<i>Dolichospermum</i> , <i>Microcystis</i> , <i>Planktolyngbya</i>	BDL to 13	MC-LR, -RR, -YR, -AR, di-demethyl-MC-RR	[42]
Tanzania (open bays)	ET	12-40	CYB (44%), diatoms (36%)	<i>Microcystis</i> , <i>Nitzschia</i>	BDL	UDT	
Nyanza Gulf	ET	10-45	CYB (72%)	<i>Cyanodictyon</i> , <i>Aphanocapsa</i> , <i>Dolichospermum</i>	UDT	UDT	[43]
Open lake (Kenya)	ET	2-19	CYB (54%), diatoms (43%)	<i>Aphanocapsa</i> , <i>Planktolyngbya</i> , <i>Pseudanabaena</i> , <i>Nitzschia</i> , <i>Dolichospermum</i>	UDT	UDT	
Open lake (Tanzania)	ET	UDT	CYB (15-50%)	<i>Nitzschia</i> , <i>Planktolyngbya</i> , <i>Aphanocapsa</i>	BDL to 3	[Asp <sup>3</sup> ]MC-RR	[44]
Mwanza Gulf	ET	25	CYB (UDT)	UDT	UDT	MC-RR, [MSer <sup>7</sup> ]-YR, [MSer <sup>7</sup> ]MC-LR, -LR, -RA, -RF, -RY	[45]
Murchison Bay and Napoleon Gulf	ET	12.3 to 47.6	CYB (UDT)	<i>Microcystis</i> , <i>Dolichospermum</i> , <i>Planktolyngbya</i> , <i>Oscillatoria</i> , <i>Pseudanabaena</i> , <i>Raphidiopsis</i>	0.2-0.7, 0-1.6 and 0.2-15	MC-RR, -YR, [MSer <sup>7</sup> ]-MC-YR, [NMSer <sup>7</sup> ]MC-LR, -LR, -RF, -RY	[46-48]
Nyanza Gulf	ET	UDT	CYB (50-95%)	<i>Microcystis</i> , <i>Dolichospermum</i>	BDL to 81.0	[Asp <sup>3</sup> ]MC-RR, -RR, [NmeSer <sup>7</sup> ]MC-YR, [Asp <sup>3</sup> ]	
Open lake (Kenya)	ET	UDT	CYB (6-50%), diatoms (40-75%)	<i>Synedra</i> , <i>Nitzschia</i> , <i>Microcystis</i> , <i>Dolichospermum</i>	0.01 to 3.1	[Asp <sup>3</sup> ]MC-RR, MC-RR, [NmeSer <sup>7</sup> ]MC-YR, [Asp <sup>3</sup> ] MC-YR, -YR, -LR	[49]
ET	101 and 24	CYB (UDT)	UDT	7.3 and 1.5	UDT	[D-MeAsp <sup>3</sup> , Mda <sup>2+</sup> ]-MC-RR, [Asp <sup>3</sup> ]-MC-RY, [MeAsp <sup>3</sup> ]-MC-RY	[50]
Murchison Bay and Napoleon Gulf	ET	8 to 23	CYB (> 70%)	<i>Dolichospermum</i> , <i>Aphanocapsa</i> , <i>Microcystis</i>	1.3-93	[Asp <sup>3</sup> ]-MC-RR, -RR, [Asp <sup>3</sup> ]-MC-YR, -YR, LR, [Asp <sup>3</sup> ]-MC-RY, -RY	[31]
ET	30 to 98 and 8 to 47	CYB (> 70%)	<i>Microcystis</i> , <i>Dolichospermum</i> , <i>Planktolyngbya</i>	0 to 1.6, 0 to 0.5, respectively	UDT	[Asp <sup>3</sup> ]-MC-RR, -YR, -AR, -RF, -RY	[51]
Murchison Bay	ET	15 to 60	CYB (20 to 85%)	<i>Microcystis</i> , <i>Dolichospermum</i> , <i>Nitzschia</i> , <i>Aulacoseira</i>	UDT	UDT	[52]
ET	28 to 37	CYB (UDT)	UDT	0.2-0.7	MC-RR, -YR, -LR	[53]	
ET	UDT	CYB (5 to 80%)	<i>Nitzschia</i> , <i>Planktolyngbya</i> , <i>Aphanocapsa</i>	UDT	UDT	[44]	
Nyanza Gulf	ET	UDT	CYB (> 95%)	<i>Dolichospermum</i>	1.1 and 1.065	MC-RR, -LR, -LA, -LF	[12, 54]
Napoleon Gulf, Open Lake (Uganda)	ET	71 and 13.5	CYB (UDT)	UDT	UDT	UDT	[55]
Several bays and Gulfs, Tanzania	ET	16	CYB (UDT)	UDT	UDT	UDT	[56]
Open lake (Tanzania)	ET	5		<i>Nitzschia</i> , <i>Cyclotella</i> , <i>Microcystis</i> , <i>Dolichospermum</i> , <i>Lyngbya</i>			
Nyanza Gulf	ET	UDT	CYB (> 60%)	<i>Microcystis</i> , <i>Dolichospermum</i> , <i>Anabaenopsis</i> , <i>Anabaena</i>	UDT	UDT	
Open lake (Kenya)	ET	9 to 71	CYB (20-85%)	<i>Microcystis</i> , <i>Dolichospermum</i> , <i>Anabaenopsis</i>	UDT	UDT	[12, 57]
Napoleon Gulf, Nyanza Gulf, Murchison Bay, Mwanza Gulf	ET	8-78	CYB (UDT)	<i>Microcystis</i> , <i>Dolichospermum</i>	UDT	UDT	[58]
Open water (Uganda, Kenya, Tanzania)	ET	4-12	CYB (53%), diatoms (33%)	<i>Microcystis</i> , <i>Dolichospermum</i> , <i>Cylindrospermopsis</i> , <i>Nitzschia</i>	UDT	UDT	[59]

Water resource (Country)	Trophic status	Chlorophyll <i>a</i> ( $\mu\text{g L}^{-1}$ )	Phytoplankton group <sup>1</sup>	Major genera or species	MCs ( $\mu\text{g MC-LR eq L}^{-1}$ )	MCs congeners	Reference(s)
6. Rwanda Lake Muzahi	ET	18.1	CYB (47-58%), Chlorococcales (27-32%), diatoms (15%)	<i>Microcystis aeruginosa</i> and <i>Ceratium hirundinella</i>	UDT	UDT	[60]

**Note:** Trophic status: MT/ET = mesotrophic/eutrophic; ET = eutrophic, OT = oligotrophic, and HT = hypereutrophic. The classifications were that chlorophyll-a concentration up to 6  $\mu\text{g/L}$  = OT; upto about 20  $\mu\text{g/L}$  = MT/ET, and then ET/HT at about 60  $\mu\text{g L}^{-1}$ . <sup>1</sup>Expressed as percentage of the total phytoplankton in the samples. Where *Spirulina platensis* was indicated, its synonym (*Arthrospira fusiformis*) is indicated here. CYB: Cyanobacteria; BDL: Undetected; UDT: Undetermined, *m/z* = mass to charge ratio. Nyanza Gulf and Kisumu Bay are in Kenya, Murchison Bay and Napoleon Gulf are in Uganda while Shirati Bay and Mwanza Gulf are in Tanzania. Nnakabirwa et al. [26] found the dominant cyanobacteria to be *Planktolyngbya limnetica* in the crater lakes.



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