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Mercury in fish from three rift valley lakes (Turkana, Naivasha and Baringo), Kenya, East Africa

L.M. Campbell[a,*], O. Osano[b], R.E. Hecky[a], D.G. Dixon[a]

[a]University of Waterloo, 200 University Avenue, Waterloo, ON, Canada N2L 3G1
[b]The School of Environmental Studies, Moi University, PO Box 3900, Eldoret Kenya

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"Capsule": *Mercury concentrations in Kenyan fish vary with tropic position but, in general, do not pose an unacceptable risk to human consumers of wildlife.*

Abstract

Total mercury (THg) concentrations were measured for various fish species from Lakes Turkana, Naivasha and Baringo in the rift valley of Kenya. The highest THg concentration (636 ng g^{-1} wet weight) was measured for a piscivorous tigerfish *Hydrocynus forskahlii* from Lake Turkana. THg concentrations for the Perciformes species, the Nile perch *Lates niloticus* from Lake Turkana and the largemouth bass *Micropterus salmoides* from Lake Naivasha ranged between 4 and 95 ng g^{-1}. The tilapiine species in all lakes, including the Nile tilapia *Oreochromis niloticus*, had consistently low THg concentrations ranging between 2 and 25 ng g^{-1}. In Lake Naivasha, the crayfish species, *Procambrus clarkii*, had THg concentrations similar to those for the tilapiine species from the same lake, which is consistent with their shared detritivore diet. THg concentrations in all fish species were usually consistent with their known trophic position, with highest concentrations in piscivores and declining in omnivores, insectivores and detritivores. One exception is the detritivore *Labeo cylindricus* from Lake Baringo, which had surprisingly elevated THg concentrations (mean = 75 ng g^{-1}), which was similar to those for the top trophic species (*Clarias* and *Protopterus*) in the same lake. Except for two *Hydrocynus forskahlii* individuals from Lake Turkana, which had THg concentrations near or above the international marketing limit of 500 ng g^{-1}, THg concentrations in the fish were generally below those of World Health Organization's recommended limit of 200 ng g^{-1} for at-risk groups.

Keywords: Mercury; Africa; Nile perch; Nile tilapia; Freshwater fish

1. Introduction

The lakes in the eastern rift valley of Africa are diverse, ranging from the large alkaline Lake Turkana in northern Kenya to small lakes such as freshwater Lake Baringo and Lake Naivasha and saline Lake Nakuru in central Kenya. However, the contaminant concentrations and distribution in fish from these lakes are not well studied, especially the potent human neurotoxicant methylmercury (MeHg), which normally constitutes at least 90% of the total mercury (THg) burden in fish (Bloom, 1992). Since MeHg biomagnifies through food webs, concentrations in top predator fish can be three orders of magnitude higher than those in the ambient water (Morel et al., 1998). As such, it is important to determine THg concentrations in fish from regions where human reliance on fresh fish protein is high. We present the first data on THg in fish from three eastern Rift Valley lakes, Turkana, Baringo and Naivasha, all with locally important fisheries and very different environments (Table 1).

2. Methods

2.1. The lakes

Lake Turkana is located at the north of the eastern rift valley, with its northernmost tip stretching into Ethiopia. It is an alkaline lake situated in a arid and hot environment (Table 1). The fisheries are mostly inshore

* Corresponding author. Present address: Canada Centre for Inland Waters, PO Box 5050, 867 Lakeshore Road, Burlington, ON, Canada L7R 4A6, Fax: +1-905-336 4699.
E-mail address: linda.campbell@cciw.ca (L.M. Campbell).

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Table 1
Physical and chemical parameters for the Kenyan rift valley lakes

	Turkana	Naivasha	Baringo
Volume	204 km^3 [1]	4.6 km^3 [1]	160 m^3 [6]
Residence time (year)	12.5 [1]	1.5 [1]	
Surface temperature (°C)	27.2–29.4 [2]	19.5–23 [6]	
Secchi depth (m)	0.8–1.2 [3]	0.7–0.9 [5]	0.15 [6]
Number of fish species	47 [4]	5 [8]	7 [8]
PH	9.4–10.0 [3]	~	6.5–7.5 [3]
Conductivity (μS/cm)	2500–3600 [3]	420 [5]	800–1200 [3]
Alkalinity (mg/l $CaCO_4$)	10 [3]	3.2 [5]	450–600 [3]
Chlorophyll (top 1 m, μg/l)	126–146 [3]	72 [5]	29–58 [3]
Surface dissolved oxygen (mg/l)	6.8–8.4 [2]	5.6–8.2 [5]	6.0–8.6 [3]

The superscripts refer to the references from which the information was obtained and the year it was collected (if available). [1] http://www.ilec.or.jp/database/database.html International Lake Committee (2001); [2] 1989, Kolding (1992); [3] Republic of Kenya (1985); [4] Pitcher and Hart (1995); [5] 1991, Harper et al. (1993); [6] Litterick et al. (1979); [7] 1988–89, Patterson and Wilson (1995); [8] Muchiri (1997).

with diverse catches, and there has been a strong decline in commercial fisheries despite the potential in a region of frequent devastating famines (Kolding, 1992). Lake Naivashia, a small freshwater lake fed by groundwater, is surrounded by industrial and agricultural regions (Table 1). The lake has become increasingly hyper-eutrophic in recent times (Abiya, 1996) and local fishermen have reported an increase in both the size and incidence of algal blooms. There are virtually no native fish species in the system, and the introduced aquatic species, especially largemouth bass (locally called black bass) *Micropterus salmoides*, tilapiines and crayfish (*Procamborus clarkii*), support the local fisheries (Muchiri, 1997). Lake Baringo, a tourist destination in central Kenya is a small shallow lake with 10 islands and a possible subterranean outlet (Burnett and Rowntree, 1990). This lake is exceedingly silty with a low organic content, (Patterson and Wilson, 1995) and is surrounded by agricultural and cattle grazing land (Muchiri, 1997)

2.2. Sampling

In July 2000, fish were purchased directly from fishermen at the Kalokol fish landing on L. Turkana (03°33.596′ N, 35°55.079′ E), the Central Landing on Lake Naivasha (00°44.369′ N, 36° 24.133′E), and the Kampi ya Samaki landing on Lake Baringo (00°36.82′ N, 36° 03.469′ E). It should be noted that the Nile tilapia species *Oreochromis niloticus* from Lake Baringo (*O. n. baringoensis*), Lake Turkana (*O. n. vulcani*) and Lake Victoria (*O. n. niloticus*) have been classified as different sub-species (Trewavas, 1983), and have been identified here as such.

2.3. Laboratory analyses

Weight and total length was recorded for each fish. A 10-cm^2 sample of muscle tissue was taken from each fish. For crayfish samples, which form a major portion of the diet of *Micropterus salmoides* in Lake Naivasha, muscle was extracted from the largest claw. Samples were wrapped in aluminium foil and stored on ice until transfer to a freezer. The samples were shipped frozen to Canada. THg analyses on the fish samples were performed in the clean-room laboratory of Dorset Research Centre, Ontario Ministry of the Environment, Dorset, Ontario (Campbell et al., in press-a; Ontario Ministry of Environment, 1999). Concentrations were measured on a dry weight basis and were converted to a wet-weight basis assuming 80% water. The Hg concentration in each biotic sample was determined via atomic fluorescence spectroscopy using the purge-and-trap procedure. Briefly, the samples were dried, weighed and digested in 2 ml of 1:4 nitric–sulfuric acid at 255 °C for 6 h. Also included were the National Research Council (Canada) certified reference materials, DORM-2 (4.64±0.26 mg Hg /kg; recovery, 110–125%) and DOLT-2 (2.14±0.28 mg Hg /kg; recovery, 97–120%), as well as blanks (<0.5 pg total). The detection limit was 10 pg total Hg per sample. Replicate samples were included in every run to determine between-run variation, which was 2–7%. The results reported here were not corrected for recovery. The statistics were calculated using the SYSTAT software (v. 9.0 for Windows, SPSS, 1998).

3. Results and discussion

Low THg concentrations in fish are characteristic of most African lakes (Campbell et al., in press-*b*), and these Kenyan lakes were not an exception. Overall, the fish from the three lakes had THg concentrations ranging from 3.7 ng g^{-1} for a detritivorous *O. leucostictus* from Lake Naivasha to 636 ng g^{-1} for a piscivorous *Hydrocynus forskahlii* from Lake Turkana. Except for two *H. forskahlii* from Lake Turkana (490 and 636 ng

g^{-1}), THg concentrations in all fish were significantly lower than the international marketing limits of 500 ng g^{-1} (European Economic Community, 16 June 1993), and the World Health Organization limit of 200 ng g^{-1} for at-risk groups (World Health Organization, 1990).

In Lake Turkana, *H. forskahlii* is an important top trophic predator (Kolding, 1993), and, as an adult, can have a diet consisting entirely of fish (Winemiller and Kelso-Winemiller, 1994) which can result in elevated THg concentrations (mean THg = 306 ng g^{-1}; Table 2) in the more piscivorous individuals. In contrast, *L. niloticus*, which consumes both fish and invertebrates (Ogutu-Ohwayo, 1994), has somewhat lower THg concentrations (46–79 ng g^{-1}), which are similar to *Synodontis schall* and *C. gariepinus* (45–123 ng g^{-1}; Table 2). The other fish species in this sample set, including *Citharinus citharinus*, *Distichodus niloticus* and the tilapiines, have low THg concentrations consistent with their detritivore or invertebrate feeding patterns (Table 2).

M. salmoides is a North American fish species introduced to Lake Naivasha along with the crayfish from the southern regions of United States (Muchiri, 1997). As such, there is a large body of mercury literature for this species in North America. Similarly to the N. American *M. salmoides* (Lange et al., 1994; Foster et al., 2000), there is a significant positive correlation between THg concentration and length for *M. salmoides* from Lake Naivasha (THg = 19 + 0.034 (weight), $r^2_{adj} = 0.88$, $P < 0.001$). Lake Naivasha *M. salmoides* tend to have much lower concentrations (52 ± 35 ng g^{-1}; Table 2) than the same species from most sites in North America, which usually have mean THg concentrations between 100 and 600 ng g^{-1} in adults (Castro et al., 1999). The North American sites are usually in or near contaminant pathways and sources such as Maryland or the Florida Everglades (Lange et al., 1994; Foster et al., 2000; Castro et al., 1999). While the catchment of Lake Naivasha is heavily impacted by agricultural activities, the degree of industrialization is low relative to North America and local sources of anthropogenic Hg is limited. A previous study has indicated that the water in Lake Naivasha has low THg concentrations (1–2 ng l^{-1}), while the rivers feeding the lake have THg concentrations ranging from 1 to 12 ng l^{-1} (Bonzongo et al., 1996). In Lake Naivasha, both detritivore groups, crayfish and tilapiines are important to the diet of *M. salmoides* and share similar THg concentrations (4–18

Table 2
Mean (±S.D. with range) THg concentrations and weight (Wt) for fish from Lakes Turkana, Naivasha and Baringo, along with general feeding habits[a]

Lake	Species	General feeding	Code	*N*	Wt (g)	THg (ng g^{-1} ww)
Turkana	*Hydrocynus forskahlii* (Alestiidae)	Fish	H	4	775 ± 581 (200–1300)	306 ± 302 (31.2 - 636)
	Lates niloticus (Centropomidae)	Fish/invertebrates	N	3	5595 ± 9017 (37.5–16000)	93.4 ± 46.2 46.1–132)
	Clarius gariepinus (Clariidae)	Fish/mollusks	I	1	1900	72.6
	Bagrus bayad (Bagridae)	Fish/invertebrates	B	1	450	38.4
	Syndontis schall (Mochokidae)	Mollusks	S	3	133 ± 47 (80–170)	75.5 ± 41.7 (45.1–123.1)
	Alestes baremose (Alestiidae)	Zooplankton/invertebrates	A	2	150–150	13.8–27.3
	Tetraodon lineatus [b] (Tetraodontidae)	Mollusks	T	2	170–195	9.3–9.5
	Citharinus citharus intermedius (Citharinidae)	Detritus, plants	V	4	1062 ± 193 (800–1250)	10.6 ± 4.3 (6.5–14.6)
	Distichodus niloticus (Citharinidae)	Detritus, plants	D	3	1067 ± 652.6 (550–1800)	27.6 ± 16.5 (17.7–46.6)
	Labeo horie (Cyprinidae)	Detritus, plants	E	6	625 ± 295 (250–1100)	12.4 ± 4.2 (8.1–17.8)
	Oreochromis niloticus vulcani (SF Tilapiine)	Detritus	O	8	438 ± 297 (150–1000)	11.6 ± 7.2 (3.3–24.7)
	Sarethorodon galilaeus (SF Tilapiine)	Detrius	G	7	371 ± 278 (150–950)	2.7 ± 0.5 (2.19–3.51)
Naivasha	*Micropterus salmoides* (Centrarchidae)	Fish/crayfish	M	8	960 ± 863 (7–2500)	52.0 ± 34.9 (4.3–94.9)
	Barbus paludinosus [c] (Cyprinidae)	Insects	P	1	3	81.1
	Haplochromine spp. (Cichlidae)	Planktivore	X	1	2	5.6
	Tilapia zilli (SF Tilapiine)	Detritus, macrophytes	Z	7	173.1 ± 44.6 (119–241)	9.3 ± 3.7 (5.7–16.7)
	Oreochromis leucostictus (SF Tilapiine)	Detritus	L	4	473.8 ± 146.4 (295–650)	4.8 ± 1.3 (3.7–6.6)
	Procambarus clarkii (Cambraridae)	Detritus	Y	4	16.9 ± 1.1 (16.1–18.4)	11.7 ± 4.5 (6.6–18.4)
Baringo	*Clarius gariepinus* (Clariidae)	Fish/mollusks	I	5	2330 ± 2167 (350–5500)	62.0 ± 27.9 (43.5–111.3)
	Protopterus aethiopicus (Polypteridae)	Fish/mollusks	F	3	2533 ± 1928 (550–4400)	40.6 ± 12.4 (33.1–54.9)
	Barbus intermedius australis [d] (Cyprinidae)	Insects	Q	3	64.3 ± 42.2 (40–113)	47.2 ± 44.5 (17.9–98.4)
	Oreochromis niloticus baringoensis (SF Tilapiine)	Detritus	O	13	208 ± 85 (103–400)	11.8 ± 3.2 (5.3–15.8)
	Labeo cylindricus (Cyprinidae)	Detritus/plants	R	7	36.3 ± 3.9 (31.0–41.0)	75.0 ± 25.2 (34.3–105.5)

[a] When the sample size (*N*) is < 3, only the ranges, or the single value when *N* = 1, is given. Each species (with the family in brackets) is identified by a letter code used in Fig. 1. The subfamily (SF) Tilapiine is in the family Cichlidae.
[b] Formerly *T. fahaka*.
[c] Formerly *B. amphigramma*.
[d] Formerly *B. gregorii*.

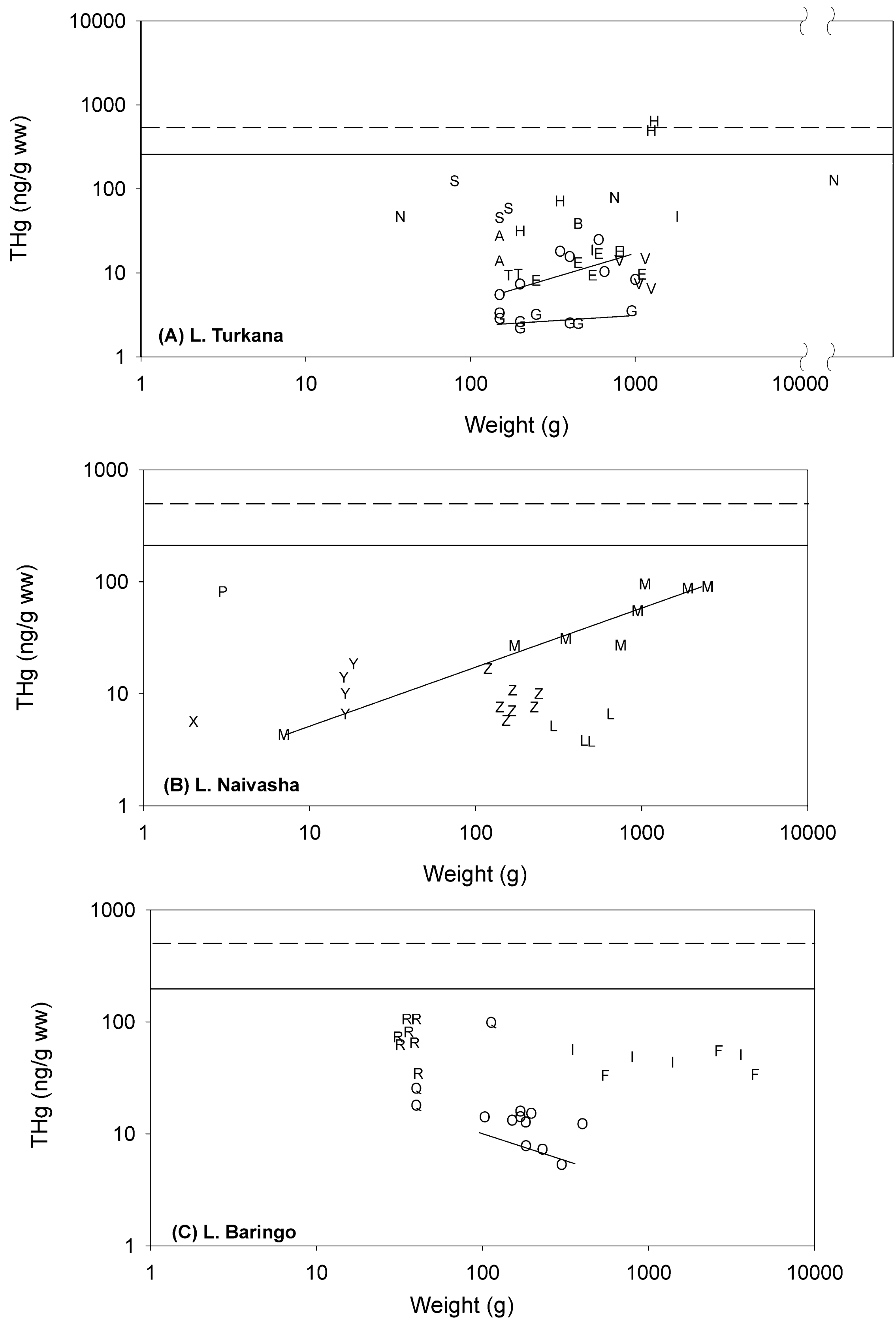

Fig. 1. THg concentrations versus total length for each fish species from Lake Turkana (A), Lake Naivasha (B) and Lake Baringo (C). Dashed horizontal lines indicate European Economic Community (EEC) marketing limit of 500 ng g^{-1} and solid horizontal lines indicate World Health Organization (WHO) limit of 200 ng g^{-1} for at-risk consumers. Fish species codes are listed in Tables 1 and 2. Significant regressions discussed in the text are indicated.

ng g^{-1}; Table 1). The approximate biomagnification ratio of THg concentrations in *M. salmoides* and the crayfish is 5, indicating that THg is being biomagnified through the food web, despite the low concentrations in water and lower trophic biota.

Lake Baringo has a small fishery that is an important source of income to the local fishermen. There are no piscivorous fish species in this lake, although there are fish-eating crocodiles. The highest fish trophic positions are occupied by omnivorous *C. gariepinus* and *P. aethiopicus* (Muchiri, 1997), which also have the highest THg concentrations (33–111 ng g^{-1}; Table 2). *L. cylindricus*, a putative detritivore (Muchiri, 1997), showed higher THg concentrations (75 ng g^{-1}; Table 2) than would be expected on its low trophic position. Why the concentrations in this species are higher than those in *O. n. baringoensis* (12 ng g^{-1}; Table 2) is unknown especially as they share similar feeding patterns. The Baringo fishermen has reported that this rare species, which is not typically consumed by humans, is difficult to find in the lake and usually are caught in areas of dense macrophyte growth. It is possible that increased organic carbon content in the sediments of the macrophyte beds is resulting in enhanced activity by methylating bacteria, a mechanism suggested by Sjöblom et al. (2000), with a parallel increase in exposure of *L. cylindricus* to MeHg.

The Perciformes species, *M. salmoides* and *L. niloticus* are roughly comparable in their feeding ecology, as they consume both macroinvertebrates and fish (Hickley et al., 1994; Ogutu-Ohwayo, 1994). The *L. niloticus* from Lake Turkana and the *M. salmoides* from Lake Naivasha had comparable THg concentrations to those for similarly sized *L. niloticus* (20–60 cm) from Lake Victoria (25–116 ng g^{-1}; Campbell et al., in press-*a*). The tilapiine species have similar feeding habits across Africa, typically relying on phytoplankton and macrophyte detritus (Trewavas, 1983). THg concentrations in the tilapiine species from the Kenyan rift valley lakes are somewhat lower than those for *O. n. niloticus* (20–40 cm) from Lake Victoria (7.8–40 ng g^{-1}; Campbell et al., in press-*a*). *O. n. vulcani* and *S. galilaeus* from Lake Turkana had consistent and significant increase in THg concentrations with size ($P<0.005$; Fig. 1), indicating constant uptake and accumulation. No consistent changes with size were seen for the Lake Naivasha tilapiine species (Fig. 1), but the *O. n. baringoensis* from Lake Baringo had decreasing THg concentrations with size ($P=0.001$; Fig. 1). The unexpected decline of THg with size seems to suggest that after the initial uptake of THg, *O. n. baringoensis* either undergoes growth dilution or depuration.

Tropical contaminant research and ecotoxicology is an emerging field, particularly in Africa where published research is scarce (Lacher and Goldstein, 1997). As reviewed by Campbell et al. (in press-*b*), recent studies have consistently indicated low THg concentrations in *Lake niloticus* and other important fish species from Lake Victoria and other East African lakes. Currently, we are investigating the reasons behind the surprisingly low THg concentrations in fish from East African lakes. Possible hypotheses which has been put forth include: (1) higher rates of evasion to the atmosphere; (2) year-around growth of African fish leading to growth dilution of accumulated THg; (3) the tendency of African lakes to be eutrophic, thereby "diluting" THg by uptake by increased phytoplankton biomass; (4) and tropical biogeochemistry including low sulfate reduction rates (Campbell et al., in press-*a*, b).

In conclusion, the THg concentrations in fish from these three Kenyan lakes are dependent upon their trophic position within the food web and the amount of THg available for uptake. The elevated THg concentrations in *H. forskahlii* from Lake Turkana deserve a closer examination, and are likely due to the tigerfish's high trophic position, its larger size (suggesting older fish) and its highly piscivorous diet. The unexpected results from Lake Baringo, namely the higher THg concentrations in *L. cylindricus* and the decline of THg concentrations with size in *O. n. baringoensis,* suggest that not all Kenyan lakes will have predictable patterns of THg distribution and bioaccumulation. However, with the exception of *H. forskahlii* from Lake Turkana, THg concentrations in fish from Kenyan lakes do not pose unacceptable risk to human consumers nor wildlife accordingly to WHO guidelines.

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