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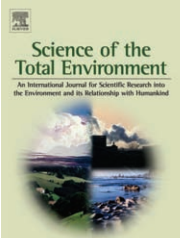

Mercury biomagnification in the food web of Lake Tanganyika (Tanzania, East Africa)

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ABSTRACT

Lake Tanganyika is a globally important lake with high endemic biodiversity. Millions of people in the lake basin depend on several fish species for consumption. Due to the importance of fish consumption as an exposure route of mercury to humans, we sampled Lake Tanganyika in 2000 to assess total mercury concentrations and biomagnification of total mercury through the food web. Stable nitrogen and carbon isotope analyses of food web structure indicate a complex food web with overlapping omnivory with some specialist fish species. Stable nitrogen isotope analyses further confirm that mercury is biomagnifying through the Tanganyika food web at rates similar to those seen in Lakes Malawi and Victoria, the other two African Great Lakes. Most collected fish species and all invertebrate species had mercury concentrations below 0.2 μg Hg/g wet weight. However, several fish species, *Ctenochromis horei* (average 0.15 μg/g ww), *Neolamprologus boulengeri* (0.2 μg/g ww) , *Bathybates* spp.spp. (0.21 μg/g ww), *Mastacembelus cunningtoni* (0.22 μg/g ww) and *Clarias theodorae* (0.22 μg/g ww) approached or slightly exceeded the World Health Organization (WHO)'s recommended guideline of 0.2 μg Hg/g for vulnerable populations with high rates of fish consumption. Two individuals of the piscivorous fish species *Lates microlepis* (0.54, 0.78 μg/g ww) and a *Polypterus congicus* (1.3 μg/g ww) exceeded the international marketing limit value of 0.5 μg/g ww. Because *C. theodorae* and *L. microlepis* are also important market fish species, there is a need to monitor mercury concentrations in internationally marketed fish from Lake Tanganikya to ensure that those fish do not present a risk to human consumers.

1. Introduction

Lake Tanganyika, a globally important Great Lake, is the second deepest lake in the world (~1.5 km) and is a global hotspot of endemic biodiversity (Leveque, 1995). It is also an important resource of water and fish dietary protein to millions of people living in the four countries, Tanzania, Burundi, Zambia and the Democratic Republic of Congo which share the lake (Fig. 1). Fish can be a primary source of dietary methylmercury (MeHg), which constitutes at least 90% of the total mercury (THg) burden in fish muscle (Bloom, 1992). Methylmercury is a neurotoxic chemical to humans worldwide with frequent fish consumers, pregnant women and young children being particularly vulnerable. As such, it is essential to monitor mercury (Hg) concentrations in fish from regions where human reliance on fish protein is high.

Because Hg biomagnifies rapidly, leading to high concentrations in top predators in aquatic ecosystems, the concen-

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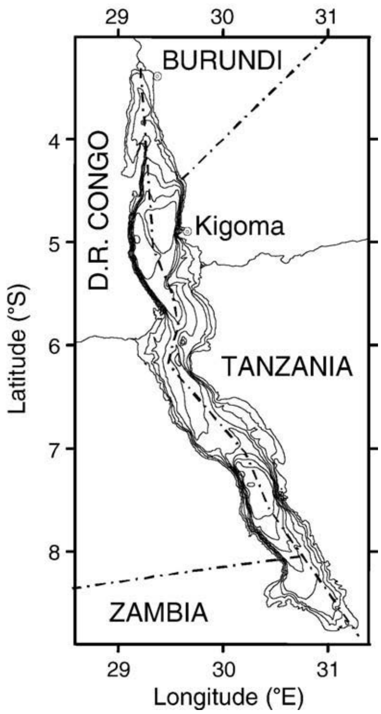

Fig. 1 – Map of Lake Tanganyika. The location of Kigoma, where all sampling took place, is indicated.

trations of mercury in fish is strongly influenced by food web structure (Kidd et al., 2003) and food chain length (Cabana and Rasmussen, 1994). We analysed stable nitrogen (δ^{15}N) and carbon (δ^{13}C) isotopes in fish and their food, a standard technique that has been successfully applied to aquatic ecosystem research globally (Campbell et al., 2003a,b; Kidd et al., 2003). Typically, δ^{15}N values have been used to characterize relative trophic position within the food web while δ^{13}C values have been used to determine the sources and flow of carbon transferred from prey to predator (Cabana and Rasmussen, 1994; Hecky and Hesslein, 1995). Here, we present the first information on biomagnification of mercury in the littoral aquatic food web of Lake Tanganyika.

2. Methods

All fish were purchased in the months of July and August of 2000 at fish landings near the city of Kigoma (Fig. 1; Table 1). All fish came from the north-eastern region of Lake Tanganyika, specifically, from the Ujiji fish landing (04° 55.394′S, 029° 40.371′ E), and from two fishing villages, Katonga (04° 54.884′S, 029° 36.720′E) and Kibirizi (04° 51.559′S, 029° 37.365′E). After collection, fish lengths and weights were recorded. All fish were filleted, and the skin-on fillets wrapped in aluminium foil and frozen until arrival in Canada. Within the same time period as the fish collections, freshwater shrimps (genus *Macrobrachium*) and zooplankton were collected with plankton nets from the Tanzania Fisheries Research Institute (TAFIRI) research ship (04° 51.302′S, 29° 34.707′E), while the other invertebrates and detritus were collected at shallow depths (<12 m) by SCUBA, all from Jacobsen Beach, a tourist beach in Kigoma. *Tiphobia horei* were opportunistically collected from two fishermen's nets from the Ujiji fish landing on July 24 and July 30, 2000.

All invertebrate and fish samples were frozen and transported to Canada on ice for analyses, and subsamples taken from thawed samples for drying. For both mercury and stable isotope analyses, skin-free dorsal muscle samples from all fish were analysed. Most invertebrates were dried and ground whole, with the exception of snails (*T. horei*), which were removed from their shells and crabs (*Platytelphusa* spp.) which only had muscle tissue dissected from their largest claw for analyses. There was sufficient mass from each individual sample for both stable isotope and mercury analyses so no samples were pooled. (However, there was insufficient sample mass left after the stable isotope analyses of two *Macrobrachium* spp., so only 11 samples were analysed for mercury, while 13 samples were analysed for stable isotopes.)

Total Hg (THg) analyses on skin-free fish and invertebrate samples were performed in the clean-room laboratory of the Dorset Research Centre, Ontario Ministry of the Environment, Dorset, Ontario (Campbell et al., 2003a). Methylmercury (MeHg) was not analysed due to unavailability of equipment. Ultra-clean protocols were employed throughout the processing (Ontario Ministry of Environment, 1999). The Hg concentration in each biotic sample was determined via atomic fluorescence spectroscopy using the purge-and-trap procedure (Ontario Ministry of Environment, 1999). Samples were dried, weighed and hot-digested in a nitric-sulphuric acid mixture. Also included were the National Research Council (Canada) certified reference materials, DORM-2 ($n=12$, 4.64±0.26 mg Hg/kg, recovery, 110 to 125%) and DOLT-2 ($n=12$, 2.14±0.28 mg Hg/kg, recovery, 97 to 120%), as well as blanks (<0.5 pg total). The detection limit was 10 pg total Hg per sample. Replicate samples (bulk homogenized Lake Victoria *Lates niloticus* and *Oreochromis niloticus*) were included in every run to determine between-run variation, which was 2–7%. The results reported here were not corrected for recovery, and were converted to wet weight assuming 80% moisture content in order to confirm to international guidelines for mercury in fish for human consumption. Invertebrate Hg data were also adjusted, assuming 80% moisture for consistency, although the actual moisture content may have varied. (It was not possible to assess accurately the moisture content from thawed samples.)

To determine food web structure and biomagnification rates, stable nitrogen (δ^{15}N) and carbon (δ^{13}C) isotope values were analysed using dried and homogenized sub-samples following the same methods used for the analyses of the Lake Victoria food web (Campbell et al., 2003b). Briefly, δ^{15}N and δ^{13}C values of each sample were measured concurrently using a Micromass VG-Isochrom Continuous Flow Isotope Ratio Mass Spectrometer (CF-IRMS) at the Environmental Isotope Laboratory, University of Waterloo. The ratios of stable nitrogen isotopes (^{15}N:^{14}N) were measured against those in nitrogen gas (N_2) in ambient air, as a reference, while stable carbon isotope ratios (^{13}C:^{12}C) were measured relative to a PeeDee belemnite (CO_2) equivalent standard. The delta notation (δ) is used to indicate the part per thousand (‰) differences in the isotopic ratio of the sample from the reference standard. Analytical standards were inserted in

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Table 1 – List of sampled species, their numbers and codes used in subsequent figures and tables

Type	N	Code	Taxonomic name	Family name	TL	Wgt	Known feeding	English	Kiswahili
Detritus	1	DET	Detritus	~	~	~	~	Detritus	
Sponge	1	SPO	Porifera	~	~	~	Filters particulate material	Deep water sponge	
Invert	2	ZOO	Cyclopoida and Calanoida	~	~	~	Phytoplankton	Zooplankton	
Invert	2	EPH	Ephemeroptera	~	~	~	Algae, detritus	Mayfly	
Invert	13*	MAC	*Macrobrachium* spp.	Palaemonidae	1.1±4	~	Algae	Shrimp	
Invert	1	PAR	*Platytelphusa armata*	Potamonautidae	2.5	~	Snails	Crab	
Invert	1	PTU	*Platytelphusa tuberculata*	Potamonautidae	2.0	~	Snails	Crab	
Invert	2	THO	*Tiphobia horei*	Thiaridae	~	~	Detritus	Deep water snail	
Fish	1	CSI	*Chrysichthys sianenna*	Bagridae	14	20	Small cichlids, invertebrates		Kanimba
Fish	3	CST	*Chrysichthys stappersi*	Bagridae	23±4	152±69	Crabs, fish, carrion		
Fish	1	CTH	*Clarias theodorae*	Clariidae	44	460	Fish, invertebrates, detritus	African catfish	Kambale Mumi
Fish	3	LMA	*Lates mariae*	Centropomidae	59±25	1500±996	Fish, benthic invertebrates	Bigeye lates	Sangala
Fish	3	LMI	*Lates microlepis*	Centropomidae	65±31	2583±2023	Fish	Forktail lates	Nonzi
Fish	1	LST	*Lates stappersi*	Centropomidae	12	~	Fish, pelagic shrimps	Sleek lates	Mikebuka
Fish	2	BFA	*Bathybates fasciatus*	Cichlidae	20–27	47–153	Clupeids, cichlids		
Fish	1	BGR	*Bathybates graueri*	Cichlidae	18	60	Clupeids, cichlids		
Fish	1	BLE	*Bathybates leo*	Cichlidae	25	96	Clupeids		
Fish	2	BAT	*Bathybates* spp.	Cichlidae	22–27	89–140	Clupeids		
Fish	1	BMI	*Boulengerochromis microlepis*	Cichlidae	29	204	Fish	Giant cichlid	Kuhe
Fish	1	CMA	*Callochromis macrops*	Cichlidae	8	4	Invertebrates		
Fish	1	CPL	*Callochromis pleurospilus*	Cichlidae	9	17	Invertebrates		
Fish	2	CHO	*Ctenochromis horei*	Cichlidae	11–17	17–67	Invertebrates		Mbaramatete
Fish	1	GPE	*Gnathochromis permaxillaris*	Cichlidae	10	13	Invertebrates		
Fish	2	GLE	*Grammatotria lemairei*	Cichlidae	19–21	47–153	Mollusks, diatoms		
Fish	1	HMI	*Haplotaxodon microlepis*	Cichlidae	21	104	Zooplankton		
Fish	2	HEM	*Hemibates stenosoma*	Cichlidae	17–19	49–61	Zooplankton, invertebrates		Limbata
Fish	1	LLE	*Lamprologus lemairii*	Cichlidae	16	59	Fish		
Fish	1	LCU	*Lepidiolamprologus cunningtoni*	Cichlidae	19	75	Fish, invertebrates, zooplankton		
Fish	1	LPE	*Lestradea perspicax*	Cichlidae	19	43	Invertebrates		
Fish	2	LDA	*Limnotilapia dardennei*	Cichlidae	23	130	Algae, detritus, invertebrates		
Fish	1	NBO	*Neolamprologus boulengeri*	Cichlidae	7	~	Invertebrates		
Fish	1	OTA	*Oreochromis tanganicae*	Cichlidae	27	330	Benthic algae, invertebrates	Tilapia	Ngege
Fish	1	PPA	*Plecodus paradoxus*	Cichlidae	16	38	Fish scales	Scale eater	
Fish	1	SDI	*Simochromis diagramma*	Cichlidae	14	39	Benthic algae		
Fish	3	TPO	*Tylochromis polylepis*	Cichlidae	19±2	99±32	Detritus, ostracods, insects, snails		Ndanga
Fish	1	XOC	*Xenotilapia ochrogenys*	Cichlidae	11	15	Insects, algae, fish, zooplankton, snails		
Fish	1	XSI	*Xenotilapia sima*	Cichlidae	10	12	Invertebrates		
Fish	4	STA	*Stolothrissa tanganicae*	Clupeidae	7±1	~	Phytoplankton/zooplankton		Dagaa
Fish	2	ATA	*Acapoeta tanganicae*	Cyprinidae	18–29	51–157	Periphyton		Mbaraga
Fish	2	LTA	*Lamprichthys tanganicanus*	Cyprinodontidae	11–11	8–11	Zooplankton		
Fish	1	MEL	*Malapterurus electricus*	Malapteruridae	29	350	Fish, invertebrates	Electric catfish	Manikwe
Fish	2	MCU	*Mastacembelus cunningtoni*	Mastacembelidae	45–51	233–300	Cichlids	Spiny eel	Gamba nioka
Fish	1	AOC	*Auchenoglanis occidentalis*	Mochokidae	30	310	Mollusks, fish	Giraffe catfish	Karungwe
Fish	2	SMU	*Synodontis multipunctatus*	Mochokidae	12–13	21–26	Zoobenthos		Kajikijiki
Fish	1	PCO	*Polypterus congicus*	Polypteridae	48	660	Fish, invertebrates	Bichir	Munkunga

The average total length (TL, cm) and weight (Wgt, g) for each species are noted. For species with *N*=1–2, ranges of sizes are indicated and those with *N*>2, averages±SD are shown. Also listed are the known feeding habits obtained from literature (Hori, 1983, 1997; Konings, 1988; Brichard, 1989; Coulter, 1991) and common English and local Kiswahili names.

*Thirteen subsamples from individually ground *Macrobrachium* spp. samples were each analysed for stable isotopes, but just 11 subsamples from the same individuals were included in the Hg analyses.

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every run, and included International Atomic Energy Agency (IAEA) and in-house walleye, Nile perch and cellulose standards. Standard deviations for the standards averaged from all runs over 3 years of operation were ±0.3‰ for δ^{15}N and ±0.2‰ for δ^{13}C, while standard deviations for replicate samples were ±0.16‰ for δ^{15}N and ±0.24‰ for δ^{13}C. Data analyses were done in JMP version 6 (SAS Institute Inc, Canada), with significance set at $P \leq 0.05$. THg was log-transformed to normalize the data.

3. Results and discussion

Two inshore riverine piscivorous species, *Polypterus* and *Clarias* had highest δ^{15}N values, which may indicate a high trophic level and a diet encompassing both river prey (e.g., amphibians) and lake prey (molluscs, fish) (Fig. 2). This finding of elevated δ^{15}N values were also observed for *Polypterus* spp and *Clarias* spp from Lake Albert in northern Uganda which also exhibited elevated δ^{15}N values relative to other piscivore lake species (Campbell et al., 2005a). In addition, the scale-eating cichlid species *Plecodus paradoxus* also had elevated δ^{15}N values, very likely due to the consumption of scales from higher trophic fish species such as *Lates* spp or *Lamprologus* spp (Nshombo, 1994). Phytoplankton was similar in δ^{15}N (−0.22±0.63 SD, $n=8$) to benthic algae (0.72±0.29SD, $n=12$; P Verburg, unpublished data), therefore differences in δ^{15}N in consumers can be used to indicate differences in trophic level regardless the location of capture around Kigoma. The piscivorous species *Lates mariae* and *L. microlepis* had lower δ^{15}N values (6–8‰), similar to other reported δ^{15}N values for *Lates* spp. near Kigoma (~6–7‰; O'Reilly et al., 2002). The high degree of scatter and overlap among species indicate a high degree of omnivory for many species, which may be opportunistically feeding on available prey. Similar findings of omnivory at higher trophic levels also have been reported for many upper trophic fish species such as *Lates*, Bagridae and upper trophic Cichlidae from other African Great Lakes, Lakes Malawi, Victoria and Albert (Bootsma et al., 1996; Campbell et al., 2003a,b, 2005b). Given that the number of samples per species were limited due to logistics and sampling challenges (often only 1 or 2 samples per species), a detailed description of the food web structure is not possible, although the stable isotope trends observed here for fish adhere closely to those observed for other African lakes with similar

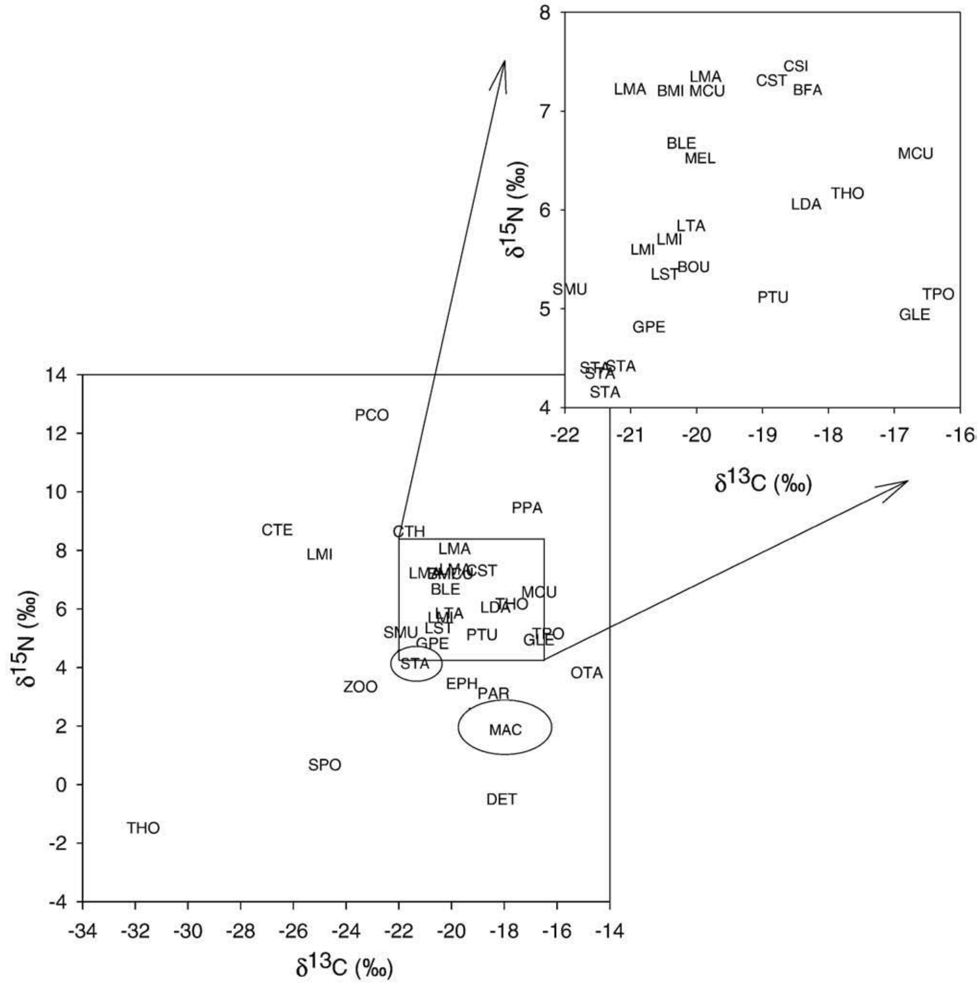

Fig. 2 – Stable isotope diagram of the Lake Tanganyika food web. The circles indicate the range of *Stolothrissa tanganicae* (STA) and *Macrobrachium* spp. (MAC). To allow for clearer view of overlapping datapoints, a portion of the data is shown in the insert graph. See Table 1 for corresponding species codes.

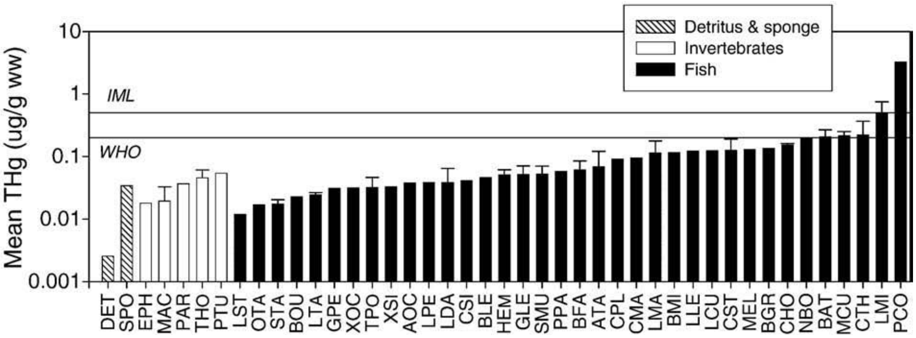

Fig. 3 – Mean THg concentrations (μg/g wet weight) in Tanganyika species (standard deviations bars are indicated where sample numbers are more than 2). Hatched bars indicate detritus and sponge; white bars indicate invertebrates while the solid bars indicate fish. The World Health Organization's recommended guideline for at-risk human fish consumers (WHO) and the international marketing limit (IML), are indicated. See Table 1 for corresponding species codes.

ichthyofauna. For instance, *Lates* spp. occupy a high trophic level in Lake Victoria (Campbell 2003a,b) and Lake Albert (Campbell et al., 2005b), and their stable carbon and nitrogen isotope values indicate a high level of omnivory, similar to those observed for the *Lates* spp. in Lake Tanganyika. The cichlid assemblage in Lake Tanganyika has complex species-food web interactions, which is also reflected for the cichlid assemblage in Lake Malawi (Bootsma et al., 1996).

The crab species, *Platytelphusa* spp., tended to have highest δ^{15}N values of all invertebrates collected, while their δ^{13}C values reflected their littoral origins (Fig. 2). The two individual snails *T. horei* had very different δ^{13}C and δ^{15}N values. This is likely due to the different origins of each snail since the snails were opportunistically collected from commercial deepwater gill nets off the Ujiji fish landing, at two times over two weeks. The gillnets are set out at undisclosed regions across the lake, which could mean the snails came from two different sites. Freshwater littoral shrimp *Macrobrachium* spp. and Ephemeroptera larvae collected from near Kigoma had similar δ^{13}C values, but lower δ^{15}N values than for *Platyelphusa* spp.

The majority of collected fish species had mercury concentrations (Fig. 3) below the typical international marketing limit of 0.5 μg Hg/g wet weight fish muscle and below the World Health Organization's recommended guideline (0.2 μg/g wet weight) for vulnerable human consumers, including young children, pregnant women and frequent fish consumers (World

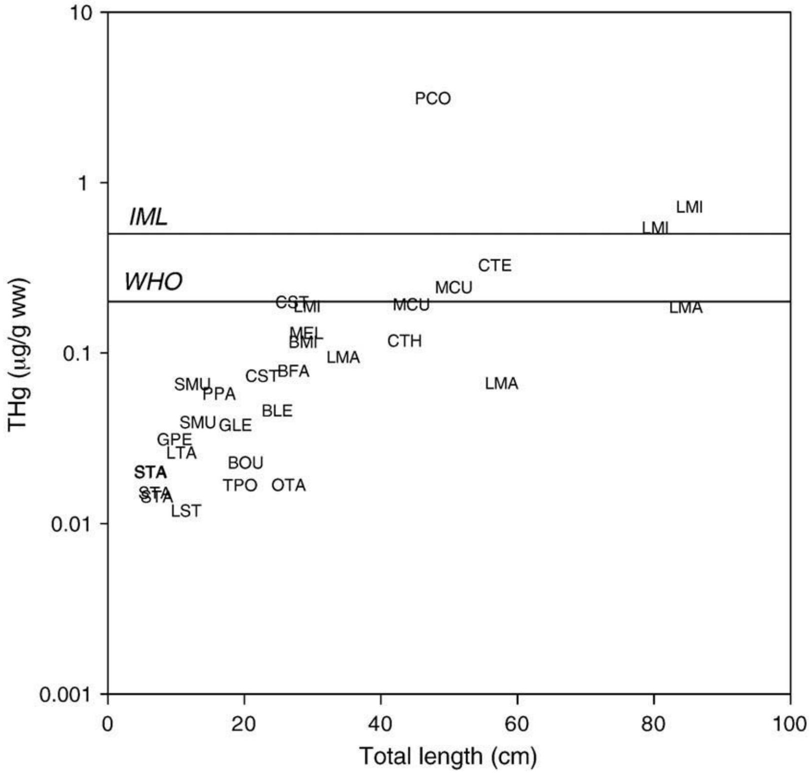

Fig. 4 – Total mercury concentrations versus total length for sampled Tanganyika fish species. The International Marketing Limit (IML) and World Health Organization (WHO) guidelines for mercury in fish are indicated. See Table 1 for corresponding species codes.

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Health Organization, 1990). Overall, the top predatory species, including *Lates* spp., *Clarias theodorae*, *Malapterurus electricus* and *Polypterus congicus*, tended to have elevated mercury concentrations, particularly the largest individuals of each species (Fig. 4). Due to sampling logistics limiting the total number of individuals we were able to collect for each species, we were not able to construct size-mercury relationships for these species. However, in general, fish species larger than 50 cm had mercury concentrations over 0.2 μg/g wet weight (Fig. 4).

Seven fish species had mercury concentrations that approached or exceeded the WHO recommended guidelines (Figs. 3 and 4), including *Ctenochromis horei* (average 0.13±0.1 μg/g ww), *Neolamprologus boulengeri* (0.19 μg/g ww) , *Bathybates* spp. (0.16–0.25 μg/g ww), *Mastacembelus cunningtoni* (0.19–0.24 μg/g ww), *C. theodorae* (0.11–0.33 μg/g ww), *Lates microlepis* (0.48±0.27 μg/g ww) and *P. congicus* (3.23 μg/g ww). Of those seven species, two individuals of the piscivorous fish species *L. microlepis* and the single *P. congicus* sample exceeded the International Marketing Limit (IML) value of 0.5 μg/g wet weight (Fig. 3). Since *L. microlepis* is also an important market fish species, the elevated mercury concentrations suggest that a monitoring program needs to be established to ensure that mercury concentrations in market fish does not present a risk to human consumers, particularly for the at-risk groups, including pregnant women, young children under 15 years and frequent fish consumers for whom the WHO recommended guideline was developed.

There is a clear positive trend between fish size and mercury burden, regardless of species (Fig. 4). Although there were insufficient number of samples to determine the length-mercury concentrations relationship for each species, the larger fish sampled in this study also feed at higher trophic levels, with fish larger than 40 cm having mercury concentrations above the WHO guidelines. Many fishermen and their families around Lake Tanganyika are among the significant fish consumers in the region. However, they tend to consume smaller fish more frequently while reserving the larger and more-profitable fish for the market. Other significant fish consumers should avoid consuming fish over 40 cm on a frequent basis, although a more detailed study is needed to establish consumption guidelines for each market species around Lake Tanganyika.

Among the invertebrates, muscle tissue from the crabs *Platytelphusa* spp. and shell-free bodies of the deepwater snail species, *T. horei*¸ tended to have higher THg concentrations relative to whole-body *Macrobrachium* spp. and Ephemeroptera (Fig. 3). The Porifera sample from the littoral site (<10 m) tended to have relatively elevated THg relative to *Macrobrachium* spp. and Ephemeroptera as well as detritus (Fig. 3). In general, invertebrate species that were in closer contact to the bottom sediment tended to contain higher THg loads than more pelagic species, regardless of their feeding habits (filtering, grazing or predation). For Ephemeroptera and *Macrobrachium* spp., it is possible that a portion of their isotopic signature was influenced by their gut contents since we were not able to allow the organisms to clear their guts prior to sampling, so the plankton in their stomach contents may have influenced their average stable isotope and mercury values to a slightly more

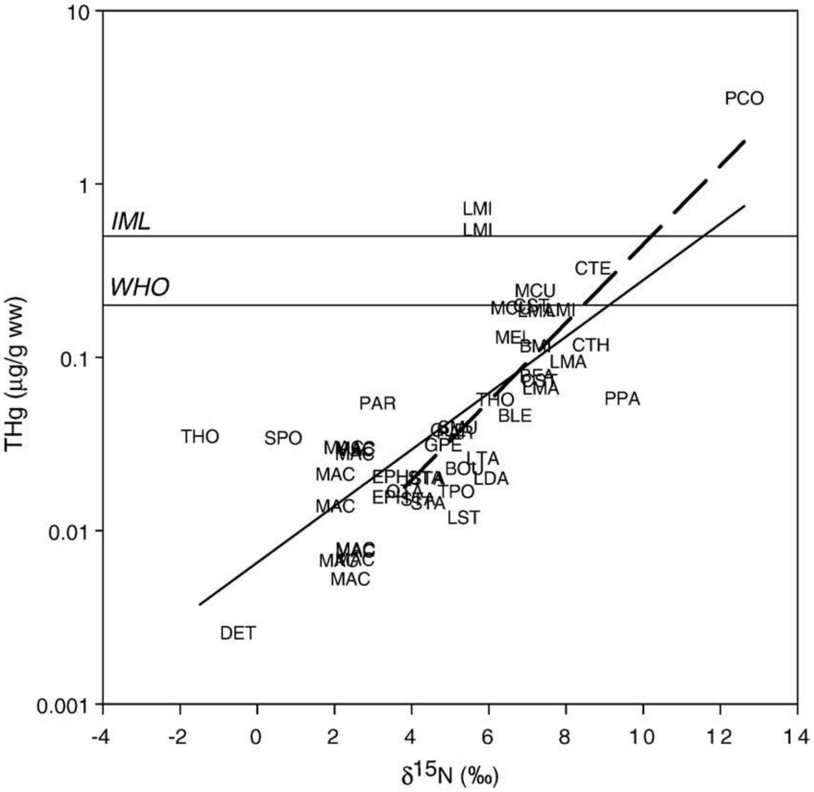

Fig. 5 – Total mercury concentrations versus stable nitrogen isotope values of littoral Tanganyika species. The solid line indicates the linear regression for the whole food web (including both invertebrates and fish) and the dashed line indicates the linear regression for the fish-only food web (see text for equations and explanations). The International Marketing Limit (IML) and World Health Organization (WHO) guidelines for mercury in fish are indicated. See Table 1 for corresponding species codes.

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Table 2 – Published values for total mercury (THg, µg/g dry weight) in fish species (N, total number of samples analysed) from Lake Tanganyika

Species	THg (*N*)	Known feeding	Region	Notes	Study
Auchenoglanis occidentalis	0.005–0.034 (5)	Mollusks, fish	Ilagala Market, Burundi	Muscle	2
	0.050 (1)		Ujiji fish landing, Tanzania	Muscle	3
Barbus tropidolepis	0.021–0.033 (4)	Invertebrates, snails	Uvinza, Burundi	Muscle	2
Brycinus rhodopleura	0.025–0.032 (3)	Insects, detritus	Ilagala Market, Burundi	Muscle	2
Clarias gariepinus	0.002–0.042(6)	Fish, invertebrates, detritus	Ilagala Market, Burundi	Muscle	2
Clarias theodorae	0.015 (1)	Fish, invertebrates, detritus	Ujiji fish landing, Tanzania	Muscle	3
Distichodus spp.	0.026 (1)	Detritus, zooplankton, insects	Uvinza, Burundi	Muscle	2
Hydrocynus vittatus	0.02–0.044 (8)	Fish	Ilagala Market, Burundi	Muscle	2
Lates angustifrons	0.011–0.043 (5)	Fish	Ilagala Market, Burundi	Muscle	2
Lates stappersi	0.04 ± 0.02 (50)	Fish, pelagic shrimps	Unspecified, Burundi	Muscle	1
	0.015 (1)		Ujiji fish landing, Tanzania	Muscle	3
Oreochromis tanganicae	0.014–0.074 (4)	Benthic algae, invertebrates	Uvinza, Burundi	Muscle	2
	0.007–0.021 (5)		Ilagala Market, Burundi	Muscle	2
	0.02 (1)		Ujiji fish landing, Tanzania	Muscle	1
Stolothrissa tanganicae	0.06 ± 0.03 (50)	Phytoplankton/zooplankton	Unspecified, Burundi	Whole fish	1
	0.019–0.026 (4)		Ujiji fish landing, Tanzania	Muscle	3

Values are from (1) Sindayigaya et al., 1994; (2) Taylor et al., 2005 or (3) this study. Note that dry weight Hg values are listed here for consistency among studies. (In general, a conversion factor assuming 80% water is used to convert THg values to wet weight values.).

pelagic signature and possibly lower mercury concentrations. However, the contribution of the gut contents relative to the contribution of the overall body mass is relatively small, and would not have significantly shifted the overall isotopic value of the organism.

To determine biomagnification trends of mercury concentrations within this food web, log$_{10}$-transformed THg values were regressed against δ^{15}N values of each fish and invertebrate species (Fig. 5). Including the invertebrates, the regression equation was: Log THg = −1.87 + 0.13 (δ^{15}N), $r^2_{\mathrm{adj}} = 0.53$, $p \ll 0.001$. The slope of the log THg–δ^{15}N regression, which is usually interpreted as indication of biomagnification rate, for both whole food web (0.13) and fish-only food web (0.22) was similar to that seen for the Lake Victoria and Lake Malawi food webs (0.12–0.20), and globally (Bowles et al., 2001; Campbell et al., 2003a, 2005a,b; Kidd et al., 2003). Because the proportion of mercury that is methylmercury is typically more variable in invertebrates (30–100%) compared to fish (90–100%; Bloom, 1992), most food web biomagnification studies looking at total mercury include solely fish for consistency. Including the invertebrates in the food web biomagnification model above resulted in a lower slope, which suggests that the proportion of methylmercury available for uptake by higher trophic predators may be highly variable. Further investigations on mercury trophodynamics in Lake Tanganyika should also incorporate methylmercury analyses where feasible. The biomagnification rate for the fish food web of Lake Tanganyika, as indicated by the slope value of 0.22, is consistent with those found for other aquatic and marine ecosystems worldwide (Campbell et al., 2005b).

To the best of our knowledge, this study is the first to quantify food web interactions and mercury transfer patterns using stable isotope analyses in Lake Tanganyika. Other studies have reported THg concentrations (Table 2) for a selection of fish species in and near Lake Tanganikya (Sindayigaya et al., 1994; Taylor et al., 2005). Similar fish species from our study near Kigoma have shown Hg concentrations comparable to those from Burundi waters at the north end of Tanganyika (Sindayigaya et al., 1994) and in streams leading to Tanganyika (Taylor et al., 2005). This suggests that mercury contamination of northern Lake Tanganyika may be diffuse, with no clear point sources of mercury to the lake. There are a few potential regional sources of mercury to Lake Tanganyika, including the use of elemental mercury in gold ore processing in Burundi and northern Tanzania (Taylor et al., 2005) and atmospheric deposition of mercury from smoke emanating from biomass burnings by farmers across central and eastern Africa, which produces the world's highest volume of biomass smoke (Brunke et al., 2001; Dwyer et al., 2000).

In conclusion, mercury is present and biomagnifying in the food web of Lake Tanganyika food web. While the majority of the fish species in this study do not have concentrations that exceed the international marketing limit, some insectivorous and piscivorous fish species including *Ctenochromis horei*, *N. boulengeri*, *Bathybates* spp.spp., *M. cunningtoni*, *C. theodorae*, *L. microlepis* and *P. congicus* may present a risk to human fish consumers according to World Health Organization and International Marketing Limit guidelines. In particular, two key market species *Lates microlepis* and *C. theodorae* have sufficiently elevated mercury concentrations approaching or exceeding IML guidelines, and it is recommended that important market fish from the higher trophic positions within the Lake Tanganyika food web be monitored for mercury concentrations to reduce risk to fish consumers.

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