Benefit-Risk Assessment of Fish And Shrimp Consumption From A Large Eutrophic Freshwater Lake, Southeastern China

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Abstract

Obtaining beneficial nutrients meanwhile ingesting hazardous contaminants through freshwater fish consumption remains a concern for inland residents in China. In this study, contents of fatty acids, essential trace elements (Fe, I, Zn, Se, Cu, Mo, Cr) and non-essential trace elements (As, Cd, Hg, Ni, Pb) were quantified in nine fish and two shrimp species from large eutrophic Chaohu Lake, southeastern China. Benefit-risk assessment for fish and shrimp consumption was conducted on basis of nutrients and contaminants. Total fat acids in the samples were 104.2-2405.2 mg/100g, included which DHA+EPA were 29.0-238.6 mg/100g. Mean content of essential trace elements (μg/g) in fish and shrimp species followed the order of Fe (10.3)>Cu (9.9)>Zn (7.7)> >Cr (1.42)>Se (0.337)>Mo (0.285)>I (0.023). The As, Cd, Hg, Ni, Pb content in the samples were nd-218, 14-97, 3-47, 4200-11300 and 144-1127 μg/kg, respectively, which was below the national maximum limit with the exception of Pb content in several samples. Though no obvious bioaccumulation pattern was found among species, species living in the demersal layers or with higher trophic levels tend to accumulate more trace elements. To achieve the recommended 250 mg of DHA+EPA daily intake, results of benefit-risk assessment indicated that fish and shrimp consumption can be major source of Se, Cu, Mo and Cr intake, whereas fish consumption was potential non-carcinogenic risk exposure for Ni and microcystins. Benefit-risk assessment contributed to the identification of main benefits and hazards of freshwater fish and shrimp consumption for inland populations around the large eutrophic lake.

1. Introduction

Fish is an important dietary source of not only nutrient intake including protein and micronutrients but also contaminant exposure for humans (Geng et al., 2015). Particularly, fish is the main source of essential omega-3 polyunsaturated fatty acids, i.e. docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), which is incorporated into membrane phospholipids that beneficial for human health including early cognitive and retinal development as well as cardiovascular diseases prevention (Sardenne et al., 2020). Trials have demonstrated that high content of DHA and EPA in marine oily fish could reduce blood triglycerides to protect cardiovascular function (Du et al., 2012). Daily intake 250–2000 mg of DHA + EPA has been recommended by World Health Organization (WHO) and several national health and nutrition organizations (Balshaw et al., 2012; Chinese Nutrition Society, 2016; EFSA, 2012). Besides, fish also contains trace elements such as selenium, molybdenum, and iodine, which are essential for the healthy function of human body (Du et al., 2012; Neff et al., 2014). Therefore, fish consumption included in a balanced diet is regularly recommended.

However, rapid urbanization and industrialization throughout the world have resulted in widespread water contamination, as a consequence of which fish is prone to accumulate toxic levels of environmental contaminants such as persistent organic pollutants (POPs) and heavy metals (HMs) that is detrimental to human health so as to decrease the health benefits of unsaturated fatty acids and essential trace elements (Cui et al., 2018). For example,mercury, in particular the most toxic form methyl-Hg, is related to IQ loss or impaired neurodevelopment in vulnerable population including fetuses and offspring (Cardoso et al., 2018). However, the formation of inert Hg-Se complexes that diminishing MeHg accumulation could counteract the toxic effect of Hg, thus the Hg-Se molar ratio in fish has been proposed and widely used to evaluate Hg potential toxicity (Albuquerque et al., 2020; Grgec et al., 2020; Strandberg et al., 2016). Therefore, benefit-risk assessment should be performed with respect to the global increasing trend of fish consumption and widespread contaminants, consequently consumption of fish species those are high in fatty acids whereas low in environmental contaminants needs to be encouraged.

In recent years, a number of researchers have focused on the benefit-risk assessment of fish consumption for human health (Balshaw et al., 2012; Cui et al., 2018; Gladyshev et al., 2020). Various approaches, either deterministic or probabilistic, such as the benefit-risk quotient (BRQ) (Gladyshev et al., 2009), probabilistic exposure assessment based on the extreme value theory (Cardoso et al., 2015), hazard quotient method (Sardenne et al., 2020; Strandberg et al., 2016), *de minimus* ratios (Laird et al., 2018), IQ dose-response equations (Cressey et al., 2020; Wang et al., 2020), net risk/benefit for adult coronary heart disease and infant visual recognition memory (Jing et al., 2021; Wang et al., 2020), have been carried out in benefit-risk assessment of fish consumption in specific areas. Overall, fish consumption and associated benefit-risk effects differ substantially around the world due to the different amount and species consumed as well as the variable cultural traditions of fish consumption (Cardoso et al., 2015; Cui et al., 2018; Grgec et al., 2020).

Nutrients and contaminants in fish from marine or freshwater, wild or farmed may be different (Du et al., 2012; Geng et al., 2015; Jing et al., 2021; Wang et al., 2020). Previous studies have been more concerned with marine fish (Cressey et al., 2020; Cui et al., 2018; Grgec et al., 2020; Wang et al., 2020); however, less attention has been paid to freshwater fish (Jing et al., 2021; Xia et al., 2019; Zhang et al., 2012a, b). As a matter of fact, many Chinese prefer to freshwater lean fish in comparison with marine oily fish which are burdened with more environmental pollutants (Du et al., 2012). Or equal amounts of marine fish and freshwater fish consumption is encouraged in healthy diet (Du et al., 2012; Geng et al., 2015). Freshwater fish, although contain lower DHA and EPA compared with marine fish, have much lower fat content that decreases the dietary intake of total fat to prevent cardiovascular diseases (Geng et al., 2015). Freshwater fish is frequently consumed in China (Jiang et al., 2018) and plays a significant role in the food systems of inland residents. However, rather limited investigations have been conducted on the benefit-risk assessment of freshwater fish consumption (Zhang et al., 2012a, b). Furthermore, more efforts have been made to characterize the beneficial effects of polyunsaturated fatty acids and Se (Grgec et al., 2020; Strandberg et al., 2016), whereas relatively less information on the other essential elements (e.g. Fe, I, Zn, Cu, Mo, Cr) in fish and shrimp, which can have detrimental effects on humans if consumed in excessive quantities, is present (Halder et al., 2020). Therefore, a full benefit-risk assessment on basis of fatty acids, trace elements, POPs, etc., should be performed with regard to freshwater fish consumption.

Chaohu Lake, ranking as the fifth largest freshwater lake in China, is located in the middle of Anhui Province that surrounded by the capital Hefei City. It plays important roles in drinking water supply, shipping, fishery, irrigation and flood control. However, due to rapid development of industrialization and urbanization in recent decades, large amounts of industrial wastewater and domestic sewage have been discharged into the lake that aggravating water quality deterioration (Liu et al., 2012a). The lake has been stressed by harmful contaminants such as POPs (Lyu et al., 2021; Tang et al., 2019; Wu et al., 2019) and heavy metals (Fang et al., 2017, 2019a, b; Zhang et al., 2019). Potential threat has been posed on the ecosystems including biota and flora even the health of residents (Fang et al., 2017, 2019a). The geographical position of Chaohu Lake, i.e. situated on the flood plain between the Yangtze River and the Huaihe River, made it representative to investigate the effects of water contamination on human health through consumption of aquatic species. To date, no benefit-risk analysis including the nutritional value in accompany with the non-carcinogenic and carcinogenic health effects through freshwater fish and shrimp consumption has been conducted for local residents.

Therefore, the objective of the present study was to (1) quantify the fatty acids and trace elements in the main fish and shrimp species from Chaohu Lake, southeastern China; (2) conduct a benefit-risk assessment for consumers to ensure adequate essential intakes meanwhile minimizing non-essential exposure, basing on content of DHA + EPA, trace elements (essential and non-essential), and microcystins from previous related studies (Jiang et al., 2017). The overall health effects of fish and shrimp consumption could provide scientific and practical consumption recommendation for general inland population in China, especially those residing in middle and lower reaches of the Yangtze River that relying heavily on freshwater fish as a subsistence food source.

2. Materials And Methods

2.1. Study site and sample collection

Lakes distributed in the Yangtze River basin have been burdened with rapid industrialization, urbanization and agricultural intensification in recent decades. Therein, Chaohu Lake, covering a surface area of ~ 760 km^2 with a mean depth of ca. 3 m, is one of the five largest freshwater lakes meanwhile one of the three most polluted freshwater lakes in China, which is situated on the flood plain between the Yangtze River and the Huaihe River (Fig. 1). Since the 1980s, the lake has suffered from serious pollution originating from industrial wastewater and domestic sewage (Liu et al., 2012a).

Fish and shrimp were collected during fishery resource survey in Chaohu Lake in November 2019. In total, nine fish and two shrimp species were obtained, including silver carp (*Hypophthalmichthys molitrix*, HyM), bighead carp (*Aristichthys nobilis*, ArN), common carp (*Cyprinus carpio*, CyC), crucian carp (*Carassius auratus*, CaA), Wuchang bream (*Megalobrama amblycephala*, MeA), topmouth culter (*Culter alburnus*, CuA), *Hemibarbus maculates* (HeM), icefish (*Neosalanx taihuensis*, NeT), lake anchovy (*Coilia ectenes*, CoE), white shrimp (*Palaemon modestus*, PaM) and shrimp (*Macrobrachium nipponense*, MaN), which were important species in Chaohu Lake. Samples were packed in ice chest and immediately transported to the laboratory after collection. Fish length and weight were measured with caliper and weighing balance in the laboratory.

2.2. Sample preparation and analysis

Skinned dorsal muscle was dissected from large-sized individuals. Besides, small-sized fish such as icefish and shrimp were homogenized as pooled samples respectively. Finally, a total of 125 individual and/or composite samples covering nine fish and two shrimp species were obtained for present study (Table S1). Water content was determined gravimetrically to convert concentrations from wet weight (ww) to dry weight (dw) when necessary. Approximately 2 g of wet weight sample were taken and dried to constant weight at 105°C in an oven.

2.2.1. Fatty acids analysis

Thirty-seven samples, including fish muscles and the whole bodies of small fish and shrimp species, were selected for fatty acids analysis, which was implemented using an acid hydrolysis method according to Chinese national standard (Determination of Fatty Acids in Foods, GB 5009.168–2016). Briefly, approximate 10.0 g of individual sample was weighed into 250 mL flat-bottomed flask. Pyrogallic acid, zeolites, 95% ethyl alcohol and Milli-Q ultrapure water were added and mixed. The mixture was then hydrolyzed with hydrochloric acid and extracted with diethyl ether-petroleum ether mixture. Then, fatty acids methyl esters (FAMEs) were prepared under alkaline conditions. FAMEs were determined using a gas chromatography in a GC 2010 plus analyzer (Shimadzu, Japan). Analytical accuracy was checked by the internal standard (10-Hydroxy-2-Decenoic Acid, ANPEL Laboratory Technologies, Shanghai, China). Results were in the range of the certified values. Content of fatty acids were expressed in mg/100g of wet weight.

2.2.2. Trace elements analysis

Trace element analysis was conducted by means of wet digestion. Subsamples of 1.5-2 g (ww) were weighed and digested in a mixture of 5 mL concentrated nitric acid (GR, 65.0 ~ 68.0%) and 2 mL perchloric acid (GR, 70.0 ~ 72.0%) on a hot plate at a temperature range of 120–160°C. Digested solution was transferred to polypropylene tubes and diluted to 15 mL with ultrapure water. Concentrations of Hg, As, Se in the digested samples were determined by atomic fluorescence spectrometer (AFS; AFS-230a) and Cr, Fe, Ni, Cu, Zn, Mo, Cd, I, Pb was quantified by inductively coupled plasma mass spectrometry (ICP-MS; Thermo Fisher Scientific, X Series 2). Quality assurance and quality control (QA/QC) were applied throughout the analysis using reagent blanks, duplicates, and standard reference materials. Certified reference materials (GBW10018 and GBW10024) obtained from the National Center of Standard Materials of China was processed simultaneously during sample analysis. Rhenium was used as internal standard in ICP-MS determination. The determined results were in good accordance with the certified values and the recovery of metals was within the range of 80%-120%. Besides, the standard deviation of duplicate samples was within 10%. All contents were expressed in μg/g of wet weight except for As, Cd, Hg, Ni, Pb that was presented as μg/kg ww.

2.3. Data processing and analysis

Benefit-risk quotient (BRQ) was adopted to evaluate the benefit-risk effect of fish and shrimp consumption. The assessment was conducted on basis of the recommended daily intake of nutrients, reference dose, tolerable daily intake, and cancer slope factor of toxins. Non-carcinogenic and carcinogenic benefit-risk quotients were calculated according to Eqs. (1) and (2) (Geng et al., 2015; Gladyshev et al., 2009), respectively.

$$BRQ_{NC}=\frac{R_{EFA}\times c}{C_{EFA}\times BW\times RfD}$$

1

$$BRQ_{C}=\frac{R_{EFA}\times CSF\times c}{C_{EFA}\times BW\times ARL}$$

2

where R_{EFA} (mg/d) was the recommended daily intake of essential fatty acids, i.e. DHA + EPA; c (mg/g) was the mean content of a certain contaminant in fish or shrimp species; C_{EFA} (mg/g) was the mean content of DHA + EPA in fish or shrimp species; BW was the body weight, 60 kg for an adult; RfD was the reference dose (mg/kg/d), which was an estimate of daily exposure to human population that was likely to be without an appreciable risk of deleterious effects during a lifetime, US EPA; CSF was cancer slope factor; ARL was the maximum acceptable individual lifetime risk level, 1×10^{-6}. If BRQ < 1, to achieve the recommended daily intake of EPA + DHA, there was no obvious risk to human health through fish consumption, and vice versa (Gladyshev et al., 2009). Generally, 250 mg/d of DHA + EPA was sufficient to prevent from coronary heart disease, thus this daily intake was adopted in present assessment (Cui et al., 2018; Geng et al., 2015).

The contribution of essential trace elements (ETEs) to recommended daily intake was calculated using the following Eq. (3) (Grgec et al., 2020):

$$RDI_{ETE}(\%)=\frac{c\times R_{FA}}{C_{FA}\times RDI}\times 100$$

3

where $RDI_{ETE}\%$ was the contribution of essential trace elements to recommended daily intake from fish and shrimp consumption; c (mg/g), R_{FA} (mg/d), C_{FA} (mg/g) were the same as the aforementioned equations; RDI was the recommended daily intake amount (mg/d) of essential trace elements (WS/T 578.3–2017, China).

Data normality was verified by Kolmogorov-Smirnov test. Data was log-transformed before analysis as they were not normally distributed. Principle component analysis (PCA) was adopted to differentiate contents of trace elements in fish and shrimp species among various habitat and feeding habit. Association between fatty acids and subgroups, effect of fish length and weight on trace element accumulation and correlation between trace elements were investigated by Spearman rank correlation analysis. Statistical tests were performed with IBM SPSS Statistics v.22 (IBM Corporation, Armonk, NY, USA). Significance was set as $p < 0.05$.

3. Results And Discussion

3.1. Content and composition of fatty acids

Total fat acids and subgroups including saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), omega-3 and omega-6 fatty acids in fish and shrimp species from Chaohu Lake were summarized in Table 1. Furthermore, the contribution of various subgroups to the total fatty acids and the mean percentage of DHA + EPA in omega-3 PUFAs for different species were depicted in Fig. 2. Total fatty acid contents in fish and shrimp species differed substantially with a mean range of 270.0-2107.5 mg/100g ww. Among species, lake anchovy (CoE) had the highest whereas icefish (NeT) had the lowest fatty acid content. Difference in fatty acid contents might be attributable to the lipid content in various species (Cui et al., 2018; Laird et al., 2018). SFAs, MUFAs, PUFAs contributed 21–28%, 26–55%, 19–48% to total fatty acids, respectively (Fig. 2a). Composition profile of fatty acids in studied species was similar to those species from Taihu Lake, another large eutrophic freshwater lake in China (Zhang et al., 2012a). It seemed MUFAs and PUFAs contributed more than SFAs to the total fatty acids. Divergence in composition of fatty acids might be related to a number of factors including species, feeding habit, ambient temperature, and life stage and age of the fish (Cui et al., 2018; Wang et al., 2020; Zhang et al., 2012a). Moreover, fish and shrimp species had favorable ratios of PUFA/SFA (all > 0.7), which was higher than the recommended nutritional guidelines (minimum value of 0.4–0.5, FAO/WHO, Neff et al., 2014). More importantly, health benefit of fat consumption was closely related to omega-6 and omega-3 PUFAs (Balshaw et al., 2012). Omege-6 PUFAs (e.g. linoleic acid) might counteract the beneficial effects of omega-3 PUFAs, thus the ratio of omega-6 to omega-3 PUFAs was an important nutritional quality index (Jing et al., 2021). The ratios were ranged from 0.4 to 0.9 (Table 1), which was comparable to the ratios reported for fish species from Taihu Lake (0.8–1.2, Zhang et al., 2012a) and much lower than four as recommended by FAO/WHO (Zhang et al., 2012a). Therefore, in view of content and composition of fatty acids, fish and shrimp species from Chaohu Lake were considered healthy food choices for human consumption.

Table 1
Mean content and composition of fatty acids (mg/100g ww) in fish and shrimp species collected from Chaohu Lake, China.

Species	FAs	SFAs	MUFAs	PUFAs	DHA + EPA	omega-3	omega-6	omega-6/omega-3
HyM	857.7	207.2	339.8	305.8	113.8	192.6	86.1	0.4
ArN	621.7	174.7	214.2	239.6	107.4	160.4	61.8	0.4
CyC	371.7	86.3	107.4	178.0	84	102.9	66.2	0.6
CaA	760.5	182.1	325.4	245.6	92.3	129.3	101.6	0.8
MeA	882.9	187.6	384.1	307.0	96.2	164.9	132.3	0.8
CuA	1337.6	335.1	590.8	400.4	154.6	224.7	149.0	0.7
HeM	545.9	130.7	228.0	183.8	82.2	110.0	64.8	0.6
NeT	270.0	76.9	73.6	117.3	70.4	77.6	32.8	0.4
CoE	2107.5	548.4	1151.0	390.2	123.2	195.1	179.9	0.9
PaM	731.1	190.1	186.5	349.3	184.3	226.8	114.4	0.5
MaN	1140.4	237.9	510.9	384.9	185.3	248.1	123.7	0.5

HyM - *Hypophthalmichthys molitrix*; ArN - *Aristichthys nobilis*; CyC - *Cyprinus carpio*; CaA - *Carassius auratus*; MeA - *Megalobrama amblycephala*; CuA - *Culter alburnus*; HeM - *Hemibarbus maculates*; NeT - *Neosalanx taihuensis*; CoE - *Coilia ectenes*; PaM - *Palaemon modestus*; MaN - *Macrobrachium nipponense*. FAs - fatty acids; SFAs - saturated fatty acids; MUFAs - monounsaturated fatty acids; PUFAs - polyunsaturated fatty acids.

Contents of DHA and EPA were the main factor when evaluating the health benefit through fish consumption (Du et al., 2012; Geng et al., 2015). However, data on DHA and EPA content in freshwater fish from China were scarce (Jing et al., 2021; Zhang et al., 2012a, b). Herein, the EPA + DHA contents were 29.0-238.6 mg/100g ww, covering a percentage of 5–31% in total fatty acids and 49–96% in omega-3 PUFAs (Fig. 2b), among which the highest mean value was found in shrimps *Macrobrachium nipponense* (185.3 mg/100g) and *Palaemon modestus* (184.3 mg/100g) whereas the highest percentage was discovered in icefish (NeT), though total FAs for this boneless specie was least but it was abundant in calcium and protein that was much suitable for children. Therefore, greater nutritional values in above-mentioned species enabled them to be identified as optimum choice for human consumption (Balshaw et al., 2012).

When setting those shrimp species aside, it could be found that greater content of omega-3 PUFAs was found in carnivorous topmouth culter (Table 1). It was speculated that feeding habits might be one of the main factors influencing the fatty acid composition (Zhang et al., 2012b). Omnivorous and herbivorous fish were devoted to elongate and desaturate those algae or plants synthesized short chain fatty acids to long chain fatty acids. Further, carnivorous fish, which scavenged on other fish species with no need for chain elongation and desaturation, were typically rich in omega-3 PUFAs (Inhamuns and Franco, 2008). In eutrophic lakes, phytoplankton communities changed and decreased essential fatty acids that eventually affecting the composition of fatty acids in higher trophic level species (Jing et al., 2021; Sardenne et al., 2020). However, Laird et al. (2018) and Wang et al. (2020) deemed that phytoplankton contained high levels of omega-3 PUFAs therefore leading to greater omega-3 PUFAs in omnivorous and planktivorous fish, whereas Kainz et al. (2017) demonstrated that the contents of omega-3 PUFAs were related to total lipid in freshwater fish regardless of feeding sources and trophic positions. Therefore, the reason for discrepancy in fatty acid composition was disputed and needed further research.

The total fatty acids content in present study (1.04–24.05 mg/g) was within the reported ranges of previous studies (Table S2), i.e. 2.3–3.9 mg/g for freshwater fish from Taihu Lake, China (Zhang et al., 2012a), 13.2–18.1 mg/g for market sold fish from Shanghai, China (Geng et al., 2015), 3.5–7.81 mg/g for freshwater fish from Lake Erie (Neff et al., 2014), and 2.6–87 mg/g for marine fish from the Bohai coast, China (Cui et al., 2018). More data was recorded for DHA, EPA, or DHA + EPA throughout the world. The DHA + EPA content in wild fish in present study were comparable to those from Taihu Lake, China (Zhang et al., 2012a), WJD Reservoir, China (Jing et al., 2021), market sold freshwater fish (Du et al., 2012), boreal lakes, Finland (Strandberg et al., 2016), whereas lower than those from the Dehcho Region (Laird et al., 2018), Lake Erie (Neff et al., 2014) and those from marine environment including the Bohai coast, China (Cui et al., 2018), the Portuguese coast (Cardoso et al., 2015), and New Zealand waters (Cressey et al., 2020). Contents of DHA and EPA tended to be greater in marine oily fish than in freshwater lean fish (Du et al., 2012; Geng et al., 2015). Even so, freshwater fish contained much less fat than most livestock meat (Lescord et al., 2020), thus freshwater fish was healthier alternative food with regard to less fat content as well as low environmental contaminants compared with seafood.

3.2. Content of essential and non-essential trace elements

Statistical description of essential and non-essential trace elements in the studied fish and shrimp species from Chaohu Lake were presented in Table 2. For essential trace elements, Fe was characteristic of the highest mean content being 10.3 μg/g, followed by Cu (9.9 μg/g), Zn (7.7 μg/g), Cr (1.42 μg/g), Se (0.337 μg/g), Mo (0.285 μg/g), I (0.023 μg/g). When in comparison with the maximum limits, it was found that Se content in more than half of the samples exceeded 0.3 μg/g (maximum tolerable level, Brazilian, Albuquerque et al., 2020) and Cr content in four samples was above 2 μg/g (GB 2762 – 2017, China). Indeed, the limit for Se was considered unrealistically low (Albuquerque et al., 2020). The non-essential As, Cd, Hg, Ni, Pb contents were in the range of nd-218, 14–97, 3–47, 4200–11300 and 144–1127 μg/kg, respectively, which was mostly below the maximum limits of the National Standard of China (GB 2762 – 2017) with the exception of Pb content in several samples. Overall, results revealed that non-essential trace elements were within a low content range in the majority of analyzed fish and shrimp samples from Chaohu Lake demonstrating a limited level of environmental exposure. In this case, trace element metabolism was considered to be regulated by homeostatic mechanisms, thus differences among fish species were related to physiological factors and feeding habits to a large extent (Albuquerque et al., 2020; Varol and Sünbül, 2018).

Table 2
Descriptive statistics of trace elements (mean ± sd) in different fish and shrimp species from Chaohu Lake, China (μg/g ww for Fe, I, Zn, Se, Cu, Mo, Cr; μg/kg ww for As, Cd, Hg, Ni, Pb).

Species	**Fe**	**I**	**Zn**	**Se**	**Cu**	**Mo**
HyM	10.8 ± 1.9 6.1–13.3	0.016 ± 0.003 0.009–0.026	5.6 ± 1.1 2.3–7.4	0.259 ± 0.076 0.027–0.416	10.3 ± 2.4 5.9–14.5	0.304 ± 0.056 0.207–0.386
ArN	12.2 ± 1.7 8.8–14.5	0.019 ± 0.015 0.011–0.092	5.8 ± 1.1 2.9–7.4	0.309 ± 0.084 0.025-0.5	12.6 ± 3.5 5.9–17.5	0.342 ± 0.048 0.253–0.426
CyC	9.3 ± 0.3 9.0-9.9	0.026 ± 0.004 0.021–0.033	13.0 ± 3.2 7.8–16.9	0.790 ± 0.298 0.530–1.244	5.3 ± 0.4 4.9–5.9	0.247 ± 0.006 0.238–0.258
CaA	8.2 ± 0.9 6.4–9.1	0.032 ± 0.007 0.023–0.043	15.5 ± 3.0 11.0-19.4	0.459 ± 0.186 0.246–0.751	5.6 ± 0.3 5.2–6.2	0.229 ± 0.019 0.205–0.256
MeA	8.1 ± 1.9 5.4–9.7	0.020 ± 0.003 0.018–0.024	5.5 ± 3.4 1.3-9.0	0.317 ± 0.244 0.004–0.593	7.2 ± 2.2 4.8–9.5	0.206 ± 0.023 0.178–0.229
CuA	8.5 ± 1.0 6.0-9.6	0.018 ± 0.003 0.013–0.024	6.2 ± 0.8 5.2–7.8	0.423 ± 0.085 0.290–0.591	8.1 ± 0.9 7.2–9.7	0.190 ± 0.018 0.163–0.214
HeM	9.2	0.012	8.6	0.471	8.7	0.186
NeT	8.0 ± 2.0 5.8–9.7	0.059 ± 0.013 0.047–0.073	11.3 ± 3.2 7.6–13.2	0.297 ± 0.064 0.230–0.359	6.3 ± 2.4 4.7-9.0	0.275 ± 0.063 0.203–0.318
CoE	8.3 ± 0.6 7.6–8.7	0.022 ± 0.008 0.015–0.030	14.9 ± 1.7 13.7–16.8	0.431 ± 0.171 0.290–0.621	7.8 ± 1.8 5.7-9.0	0.233 ± 0.050 0.201–0.291

[a] inorganic As; short names of fish species were same as in Table 1.

Species	Fe	I	Zn	Se	Cu	Mo
PaM	8.4 ± 1.3 7.0-9.5	0.078 ± 0.027 0.047–0.098	12.3 ± 0.4 11.9–12.7	0.291 ± 0.046 0.252–0.342	14.6 ± 1.0 13.6–15.7	0.269 ± 0.059 0.207–0.324
MaN	6.8 ± 1.4 5.8–7.7	0.125 ± 0.004 0.122–0.128	32.0 ± 12.5 23.1–40.8	0.295 ± 0.020 0.281–0.309	16.9 ± 0.8 16.4–17.5	0.297 ± 0.018 0.284–0.310
maximum limit	**100**		**30**	**0.3**	**30**	
Species	**Cr**	**As**	**Cd**	**Hg**	**Ni**	**Pb**
HyM	1.43 ± 0.28 0.44–2.19	13 ± 6 nd-33	29 ± 10 14–67	7 ± 2 3–13	8443 ± 1446 4665–10286	249 ± 85 157–665
ArN	1.48 ± 0.33 0.44–2.5	15 ± 9 3–42	27 ± 4 21–37	10 ± 5 5–25	9567 ± 1288 6863–11280	251 ± 84 167–651
CyC	1.25 ± 0.07 1.12–1.35	6 ± 2 4–8	32 ± 7 25–44	26 ± 4 20–33	7324 ± 192 7230–7759	271 ± 111 249–521
CaA	1.37 ± 0.21 1.13–1.70	14 ± 6 6–23	39 ± 26 25–97	28 ± 9 20–47	6465 ± 716 4984–7129	350 ± 343 208–1127
MeA	1.23 ± 0.54 0.51–1.67	10 ± 10 2–24	34 ± 5 29–40	10 ± 5 5–17	6363 ± 1490 4238–7590	217 ± 52 144–265
CuA	1.49 ± 0.23 1.02–1.87	12 ± 7 2–27	38 ± 8 28–49	18 ± 7 13–34	6630 ± 777 4759–7538	241 ± 57 181–372
HeM	1.28	7	45	11	7279	226

[a] inorganic As; short names of fish species were same as in Table 1.

Species	Fe	I	Zn	Se	Cu	Mo
NeT	1.21 ± 0.37 0.85–1.60	14 ± 15 5–32	60 ± 17 43–77	9 ± 2 7–12	6296 ± 1678 4457–7744	276 ± 24 252–299
CoE	1.58 ± 0.41 1.20–2.02	27 ± 16 14–45	48 ± 13 33–57	9 ± 1 9–10	6500 ± 399 6041–6765	330 ± 98 223–416
PaM	1.29 ± 0.23 1.16–1.56	85 ± 47 44–137	53 ± 8 44–58	3 ± 1 3–4	6573 ± 1106 5344–7489	235 ± 33 214–272
MaN	1.29 ± 0.17 1.18–1.41	165 ± 76 111–218	78 ± 18 65–90	4 ± 0 4-4.2	5145 ± 1167 4320–5970	268 ± 43 237–299
maximum limit	**2**	**100[a]**	**100**	**500**	**70000–80000**	**500**

[a] inorganic As; short names of fish species were same as in Table 1.

Except for *Macrobrachium nipponense*, in which highest I, Zn, Cu, As, Cd and lowest Fe, Ni, Pb content was found, no obvious bioaccumulation pattern in individual species could be explored, which was different from previous studies that carnivorous and/or omnivorous fish was prone to accumulate more trace elements than planktivorous fish (Albuquerque et al., 2020; Jiang et al., 2018; Xia et al., 2019). Possible reasons for this discrepancy might be the limited sample size and relatively lower contamination level of trace elements in Chaohu Lake (Fang et al., 2017, 2019a, b). Accumulation of trace elements in fish was dependent on multiple factors including elemental type, trophic level, habitat, feeding habit, and ambient environment (Xia et al., 2019). Differences among fish species might be greater when fish was exposed to high environmental levels, which overloaded homeostatic mechanisms in fish (Albuquerque et al., 2020). Although no obvious bioaccumulation pattern was found among species, results of PCA analysis demonstrated that trace elements in fish and shrimp showed different accumulation tendency with various feeding habit and habitat (Fig. S1). It seemed that As, I, Cd, Zn, Pb, Se, Hg, and Cr was more accumulated in fish species living in the demersal layer or in fish species with higher trophic level, whereas the opposite trend was found for Cu, Mo, Fe, Ni. Therefore, non-essential elements in demersal or piscivorous species should be routinely monitored to ensure food safety.

Bioaccumulation of Hg in fish was closely related to the bioavailability of Hg (i.e. chemical speciation) in environment and the methylation efficiency of Hg to MeHg (Strandberg et al., 2016). Although Hg in water

(Fang et al., 2019a) and sediment (He et al., 2016) was reported at levels of environmental concern in study region, Hg contents in fish and shrimp species from Chaohu Lake were much lower than the maximum limit of 500 μg/kg (GB 2762 – 2017, China) that suggested a low exposure across the aquatic ecosystem, which might be attributed to the low bioavailability of Hg in sediment (Fang et al., 2019a) and biodilution of cyanobacteria bloom (Strandberg et al., 2016). Mercury bioaccumulation in fish could be influenced by the structure of the planktonic food web (Signa et al., 2019). In eutrophic lakes, Hg was diluted as higher algal biomass, and low content at the base of the food web led to lower content at higher trophic levels (Strandberg et al., 2016). Besides, fat deposition might also contribute to dilute Hg already present in fish tissues (Cressey et al., 2020). Nevertheless, Jing et al. (2021) found higher Hg content in planktivorous fish in a eutrophic reservoir, which was a consequence of trophic transfer, i.e., planktivorous fish were mainly fed on plankton whereas other species on artificial fish food that experienced short time of Hg/MeHg exposure. Furthermore, fish and shrimp species from this study presented substantial Se content to countervail the toxic effects of Hg/MeHg exposure (Table 2).

Broad comparison was carried out with reported data in worldwide studies (Tables S2). Content of trace elements in fish and shrimp species from Chaohu Lake were within the same order of magnitude as previously reported data. It was noteworthy that Zn content in present study was higher than those quantified in fish from Western Pará (Albuquerque et al., 2020), Keban Dam Reservoir (Varol et al., 2018), northern Ontario (Lescord et al., 2020) and Nenets autonomous region (Sobolev et al., 2019), whereas lower than in fish from Taihu Lake, where denser industries were developed around the lake in past several decades (Fu et al., 2013). Similar to Zn, Cu was much higher in Chaohu aquatic species but close to it in Taihu fish species (Fu et al., 2013). Selenium contents in present study were comparable to those in previous studies, no matter focused on freshwater or marine fish (Lescord et al., 2020; Sobolev et al., 2019). Data for molybdenum was rare in previous publications (Albuquerque et al., 2020) meant this element was overlooked for its dietary intake through fish consumption. Herein, a higher accumulation for Cr and Ni was found, which might be related to the higher background levels in the Chaohu Lake catchment (Fang et al., 2019b; Liu et al., 2012b). Besides, Cd (14–97 μg/kg) and Pb (144–1127 μg/kg) in this study was much higher than farmed fish compiled from markets in big cities, China (Du et al., 2012; Geng et al., 2015). It was stated that farmed fish was fed on commercially formulated diets that reducing the bioaccumulation of toxic elements through trophic transfer (Du et al., 2012). The Hg content of fish and shrimp species in present study was much lower than previous studies, for example, those fishes from the Amazon region where was affected by mining exploitations (Albuquerque et al., 2020). Overall, accumulation of trace elements in freshwater fish was affected by both geographical condition and anthropogenic activities (Xia et al., 2019).

3.3. Relationship among length, fatty acids, and trace elements

Not only nutrients but also contaminants could be bioaccumulated to various degrees in different aquatic species, which was affected by multiple factors, such as the living environment, species, habitat, feeding habit as well as individual size (Cui et al., 2018; Grgec et al., 2020).

Significant positive correlations between total fatty acids and subgroups including SFAs, MUFAs, PUFAs, omega-3 and omega-6 fatty acids, and DHA + EPA were found (Table S3). In view of this, it was speculated fish increase or supplement fatty acids in equal proportions through food or other sources (Balshaw et al., 2012; Wang et al., 2020). The DHA + EPA were well correlated with total fatty acids ($r = 0.711$, $p < 0.01$), indicating that beneficial effects of fish consumption were closely associated with the fatness of fish (Neff et al., 2014; Strandberg et al., 2016). Furthermore, no significant correlation was found between the DHA + EPA contents in samples and habitats as well as feeding habits, which was consistent with previous study that PUFAs were adjusted as total lipid status regardless of feeding sources and trophic positions (Kainz et al., 2017). The relationship between fish length and fatty acids as well as subgroups was not investigated due to the composite samples of small-sized species included in FA analysis.

Correlation between fatty acids together with subgroups and trace elements were analyzed. Among trace elements, only Cu and As was positively correlated with fatty acids and subgroups, albeit the correlation was weak ($r = 0.369–0.593$, $p < 0.05$), indicating most of trace elements were lipophobic and more incorporated in proteins (Sobolev et al., 2019). Conversely, negative relationships were found between omega-3 fatty acids and Hg ($p < 0.05$), omega-6 fatty acids and Mo, Pb ($p < 0.05$), between DHA + EPA and Hg ($p < 0.05$). The negative correlation between fatty acids and Hg was sometimes discovered elsewhere (e.g. in Strandberg et al., 2016), indicating that the risk posed by toxic trace elements such as Hg could counteract the beneficial effects of essential fatty acids.

Accumulation levels tended to increase with fish size (Neff et al., 2014). Due to sample size, only *Hypophthalmichthys molitrix* ($N = 56$) and *Aristichthys nobilis* ($N = 26$) were chosen to investigate the effects of fish length and weight on bioaccumulation of trace elements at the species level. Results of Spearman rank correlation analysis were tabulated in Table S4. For *Hypophthalmichthys molitrix*, fish length and weight was significant factor for Fe, Cu, Mo, Hg, and Ni ($p < 0.01$), whereas for *Aristichthys nobilis*, it was positively associated with Cu ($p < 0.01$), Mo ($p < 0.01$), Cd ($p < 0.05$), Hg ($p < 0.01$), Pb ($p < 0.05$). Of note, Cu, Mo, and Hg were size-dependent in both species. Besides, negative association was found for As ($p < 0.05$) in ArN, indicating a dilution with growth and/or stronger detoxification and elimination mechanism of As in larger bighead fishes. Difference in the correlation result was probably related to their different dietary habits and homeostatic regulatory mechanism for trace element metabolism in each species (Albuquerque et al., 2020). Fish length and weight could be used as a basis for predicting those significantly correlated trace elements of individual fish (Cressey et al., 2020). Weak correlations among physiological factors and other trace elements suggested that fish physiological development was not main reason for the variation of these elements in individuals (Albuquerque et al., 2020).

Spearman rank correlation analysis was applied to explore the relationship between various trace elements within each species (Table S5). For HyM, significant positive correlations were found between Fe, Cu, Mo and Ni ($p < 0.01$), whereas strong negative association were discovered including Se-As and Cr-As ($p < 0.01$). And for ArN, significant positive correlations were found between Fe, Cu, Mo, Ni and Pb (either $p < 0.01$ or $p < 0.05$), whereas strong negative association were recorded between Cu, Mo, Ni and As (either $p < 0.01$ or $p < 0.05$). Strong correlation among trace elements reflected either approximate contamination degree or analogous pollution sources (Sobolev et al., 2019). Iodine, Se, and Pb displayed no association with other trace elements for both species, representing their divergent originations or metabolism mechanisms. Selenium was commonly considered to play an important role in Hg cycling and methylation (Grgec et al., 2020), however, in present study, no significant correlation was discovered between Hg and Se whereas the correlation was found between Hg and Cu, Mo, demonstrating that other essential elements might have the potential to relieve Hg toxicity in aquatic ecosystem (Albuquerque et al., 2020).

3.4. Benefit-risk assessment

Fish consumption and the related beneficial and hazardous effects differed to a large extent in specific areas, which was predominantly dependent on the composition of fish species and the amount of fish consumed (Du et al., 2012; Grgec et al., 2020). It should be kept in mind that the health benefit might be diminished by elevated content of environmental contaminants in aquatic species due to natural and anthropogenic activities that dispersing more contaminants into the aquatic ecosystems.

The beneficial effects of fish consumption were primarily ascribed to PUFAs, particularly DHA and EPA. According to the amount of fish and shrimp consumed to obtain enough DHA + EPA, efforts were made to assess the potentiality of fish and shrimp consumption to fulfill the daily requirement of essential trace elements in human body (Halder et al., 2020; WS/T 578.3–2017). To achieve the recommended 250 mg of DHA + EPA daily intake, the daily fish consumption ought to be 134.9-355.1 g (CR_{EFA}, Table 3). Therefore, on basis of the aforementioned amount, the contribution of fish consumption to the recommended daily intake of essential trace elements, i.e. RDI%, was calculated and shown in Table 3. It was found that fish and shrimp consumption could contribute 66–392%, 164–366%, 31–98%, 580–1432% to the recommended daily intake of Se, Cu, Mo, Cr, respectively. Therefore, it could be stated that fish and shrimp consumption to be considerable source of Se, Cu, Mo, and Cr for consumers, which was different from previous study that fish consumption was of little importance in nutrients intake except DHA and EPA (Du et al., 2012). On the other hand, more attention was paid to Cr for its rather high RDI%. It should be noted that Cr content in majority of the samples did not exceed the maximum limit (GB 2762 – 2017, China) with the exception that four samples had Cr content greater than 2 μg/g. However, Cr commonly existed in the trivalent state in natural foods that was non-toxic to human health (Lescord et al., 2020). Otherwise, the non-carcinogenic health effects of Cr was calculated (Table 3) and results showed the BRQ_{NC} for Cr was less than one signifying negligible health risk from Cr.

Table 3
Results of RDI% for essential trace elements calculated on basis of recommended daily intake in China (WS/T 578.3–2017).

Species	DHA + EPA mg/g	CR_{EFA} g/d	Fe	I	Zn	Se	Cu	Mo	Cr	BRQ_{NC}[a]
	RDI (mg/d)	**250**	**12**	**0.12**	**12.5**	**0.06**	**0.8**	**0.1**	**0.03**	
HyM	1.137	219.9	20%	3%	10%	95%	283%	67%	1048%	0.003
ArN	1.074	232.8	24%	4%	11%	120%	366%	80%	1148%	0.004
CyC	0.839	298	23%	6%	31%	392%	196%	74%	1242%	0.004
CaA	0.923	270.9	19%	7%	34%	207%	189%	62%	1237%	0.004
MeA	0.962	259.9	17%	4%	11%	137%	233%	54%	1065%	0.004
CuA	1.546	161.7	11%	2%	8%	114%	164%	31%	803%	0.003
HeM	0.822	304.1	23%	3%	21%	239%	331%	57%	1298%	0.004
NeT	0.704	355.1	24%	17%	32%	176%	277%	98%	1432%	0.005
CoE	1.233	202.8	14%	4%	24%	146%	197%	47%	1068%	0.004
PaM	1.843	135.6	10%	9%	13%	66%	248%	36%	583%	0.002
MaN	1.853	134.9	8%	14%	35%	66%	286%	40%	580%	0.002
HyM	1.137	219.9	20%	3%	10%	95%	283%	67%	1048%	0.003

[a] BRQ_{NC} was calculated for Cr separately for its rather high RDI%.

For non-essential trace elements, the BRQ_{NC} and BRQ_C values were calculated to determine the susceptibility of consumers to the non-carcinogenic and carcinogenic health effects through fish and shrimp consumption (Table 4). The BRQ_{NC} values for As, Cd, Hg, Ni, and Pb was in the range of 0.10–1.24, 0.10–0.36, 0.06–0.81, 0.58–1.86, and 0.13–0.41, respectively. Notably, eight out of the eleven fish and shrimp species had BRQ_{NC} values of Ni exceeded one, warning that consumers were at the risk of non-carcinogenic health effects of Ni. Besides, the BRQ_{NC} value of As for shrimp MaN had the value of 1.24 that was also larger than one. Due to the fact that only As had been provided the cancer slope factor (IRIS, US EPA), thus only the carcinogenic effect of As was evaluated herein. The BRQ_C values of As were ranged from 0.11 in CuA and HeM to 1.11 in MaN. It seemed that As in MaN shrimp might pose non-carcinogenic and carcinogenic risk on consumers. However, As was predominantly in non-toxic organic forms (e.g., arsenobetaine and arsenocholine) in aquatic species (Albuquerque et al., 2020; Gladyshev et al., 2020), in addition, the accumulation of Se might also decrease the As toxicity through antagonistic effect (Halder et al., 2020; Lescord et al., 2020), thus the concern on the deleterious effects of As through shrimp consumption could be eliminated. Even so, the chemical speciation of As in shrimp species needed further investigation. Moreover, in eutrophic lakes, the potential health risk of hepatotoxic microcystins (MCs) should be raised attention in consideration to their potential liver damage in fish and humans (Jiang et al., 2017; Jing et al., 2021). Therefore, contents of MCs in aquatic species from previous study (Jiang et al., 2017) were obtained to investigate the non-carcinogenic effect as to achieve the recommended daily intake of DHA + EPA. It was of note that the non-carcinogenic effects of MCs deserved attention because the BRQ_{NC} values for MCs was close to or higher than one (Table 4). Management strategies should be taken to control the eutrophication in the lake to reduce the MCs accumulation in fish (Jing et al., 2021).

Table 4
Results of integrated benefit-risk assessment for consumption of fish and shrimp species from Chaohu Lake, China.

Species	BRQ_{NC}						BRQ_C
	As	Cd	Hg	Ni	Pb	MCs	As
HyM	0.16	0.11	0.14	**1.55**	0.23	**2.11**	0.14
ArN	0.19	0.10	0.24	**1.86**	0.24		0.17
CyC	0.10	0.16	0.81	**1.82**	0.34		0.09
CaA	0.21	0.18	0.79	**1.46**	0.39	**1.82**	0.19
MeA	0.14	0.15	0.27	**1.38**	0.23	**1.56**	0.13
CuA	0.12	0.10	0.30	0.89	0.16		0.11
HeM	0.12	0.23	0.32	**1.84**	0.29		0.11
NeT	0.28	0.36	0.37	**1.86**	0.41		0.25
CoE	0.30	0.16	0.21	**1.10**	0.28	0.94	0.27
PaM	0.64	0.12	0.06	0.74	0.13		0.58
MaN	**1.24**	0.18	0.06	0.58	0.15		**1.11**

3.5. Uncertainty of the benefit-risk assessment

In this study, benefit-risk assessment was conducted on basis of the recommended daily intake of essential fatty acids (DHA + EPA) and trace elements (Fe, I, Zn, Se, Cu, Mo, Cr), reference dose of non-essential trace elements (As, Cd, Hg, Ni, Pb), tolerable daily intake of microcystins, and cancer slope factor of As. There were uncertainties related to the benefit-risk assessment:

(1) The assessment assumed that inland residents obtained nutrients and contaminants through freshwater fish consumption, i.e. provided a fraction of food consumption, whereas excluding other dietary sources of nutrients and contaminants. Moreover, the assessment presumed that only one fish or

shrimp specie was consumed in diet, yet the benefit and risk would be moderated by consumption of different species (Geng et al., 2015).

(2) For large-sized individuals, only dorsal muscles were investigated, however muscles from other portions (ventral, tail, etc) with different nutrients and contaminants were not included (Cui et al., 2018; Zhang et al., 2012b).

(3) Total content of trace elements were reported and evaluated, however, not all forms of trace elements were toxic to wildlife or humans (Lescord et al., 2020). For instance, arsenobetain and arsencholine were predominant organic-As compounds in freshwater fish (Gladyshev et al., 2020; Sobolev et al., 2019). And for Cr, the trivalent Cr was nutritionally beneficial while the hexavalent Cr was highly toxic and carcinogenic. Fortunately, Cr commonly existed in the trivalent state in natural foods (Lescord et al., 2020). Besides, cooking process might whether or not decrease the contaminant content in food. The bio-accessibility/bio-availability of nutrients and contaminants were not taken into account. Therefore, it was noteworthy that the risk of these elements to fish consumers might be over/under estimated.

(4) Besides non-essential trace elements, fish and shrimp were likely to accumulate other environmental contaminants that needed to be considered (Nostbakken et al., 2021). However, duo to the lack of corresponding RfD and CSF values, these contaminants were not included in present assessment.

(5) The average daily consumption of aquatic products for residents from the whole country, villages, cities and big cities were 29.6 g, 23.7 g, 44.9 g and 62.3 g, respectively (Zhai and Yang, 2006). Besides, it was regarded that a low fish intake of 15–35 g/d could have beneficial effect on heart disease and stroke (Du et al., 2012). However, the amount of fish consuming to fulfill the daily intake of essential fatty acids was 134.9- 355.1 g/d, which was much higher than the statistical consuming amount, thus the practical ingestion of nutrients and contaminants might be much lower for inland residents through freshwater fish and shrimp consumption (Qin et al., 2020). Nevertheless, such integrated benefit-risk assessment was necessary to provide consumers with sufficient information for healthy food choice (Gladyshev et al., 2009).

4. Conclusions

In present study, fatty acids, essential and non-essential trace elements were quantified in fish and shrimp species from large eutrophic Chaohu Lake, China. In view of the content and composition of fatty acids, fish and shrimp species were considered as healthy food choices for human consumption. Both essential and non-essential trace elements were reported within the same order of magnitude of worldwide range. Of the toxic elements, Pb seemed to be of concern for its exceeding beyond the national maximum limit in several samples. Habitat and feeding habits were probably attributed to the bioaccumulation of trace elements in studied species. According to the benefit-risk assessment, fish and shrimp consumption could be a major source of Se, Cu, Mo, and Cr to meet the daily requirement. Nevertheless, it could also be a potential non-carcinogenic exposure for Ni and microcystins that deserved attention. More exhaustive assessment was still needed for ensuring human health through freshwater fish consumption.

Declarations

Availability of data and materials The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Ting Fang, Yangyang Liang, Kun Yang, Xiuxia Zhao, Na Gao and Hui Li. Funding was acquired by Ting Fang, Wenxuan Lu, Kai Cui, Yangyang Liang and Jing Li. The first draft of the manuscript was written by Ting Fang and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Ethics approval I would like to declare on behalf of co-authors that the work described was original research that has not been published previously, in whole or in part.

Consent to participate All the authors listed consent to participate.

Consent for publication All the authors listed have approved the manuscript that is enclosed.

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Figures

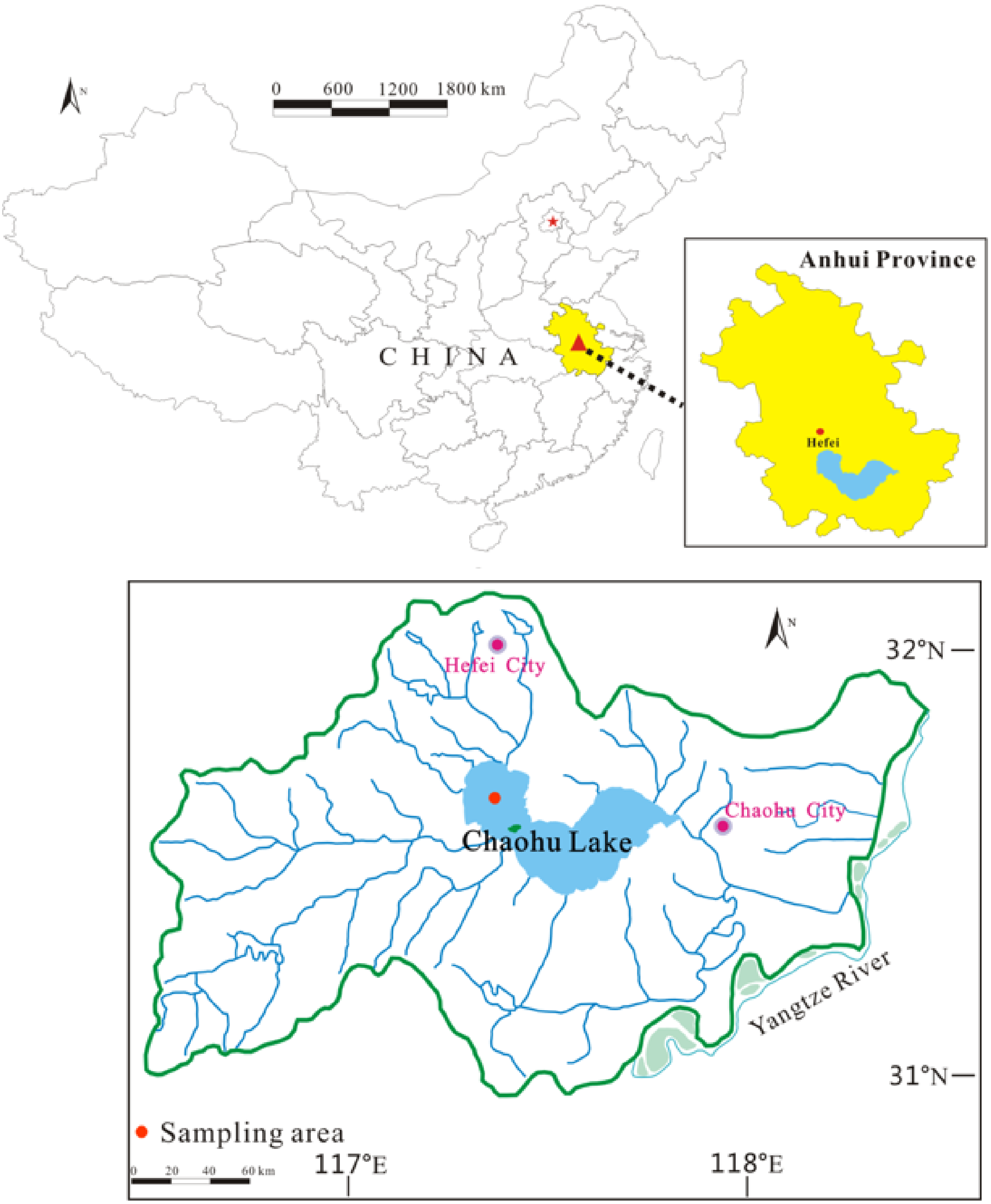

Figure 1

Geographical location of Chaohu Lake and sampling area for present study.

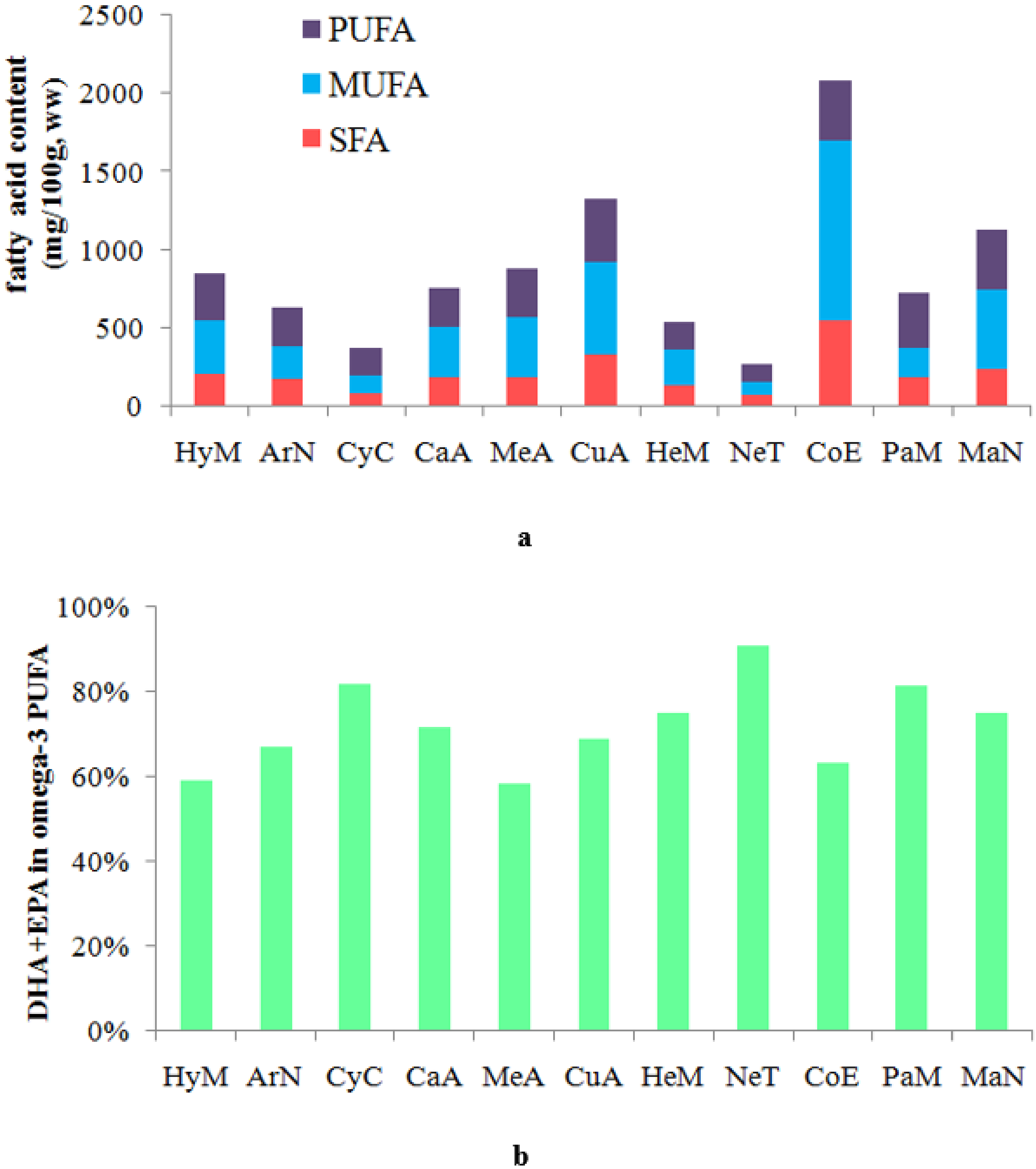

Figure 2

(a) Contributions of different subgroups (saturated fatty acid, SFA; monounsaturated fatty acid, MUFA; polyunsaturated fatty acid, PUFA) to total fatty acid content in fish and shrimp species from Chaohu Lake; (b) Mean percentage of DHA+EPA in omega-3 PUFAs in fish and shrimp species from Chaohu Lake

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