Mercury Concentrations in Fish Species from Can Gio Mangrove Reserve and Implications for Human Health Risk

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Abstract

Mercury (Hg) exposure in humans primarily occurs through fish consumption, making fish an important indicator of potential health risks. This study represents one of the first efforts to assess Hg levels in edible marine fish from Can Gio Mangrove Reserve (CGMR), Vietnam, providing essential baseline data for evaluating potential health risks to consumers. A total of 75 fish specimens were analyzed for mercury concentrations in their muscle tissue. Hg levels ranged from 0.02 to 0.61 mg.kg^{-1} dry weight, with an average concentration of 0.16 mg.kg^{-1} dry weight. Among the species studied, the large-eye croaker (Johnius plagiostoma) had the highest average mercury level (0.19 mg.kg^{-1} dry weight), followed by Reeve's croaker (Chrysochir aureus) at 0.14 mg.kg^{-1}, and Cynoglossus bilineatus with the lowest level at 0.12 mg.kg^{-1}. A positive correlation was observed between mercury concentrations and body size in the large-eye croaker (R^2= 0.54, P< 0.04). Despite this variation, the mercury levels in all three species were below the Provisional Tolerable Weekly Intake (PTWI) recommended by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Based on these findings, the study recommends that these fish should not be consumed more than 10 times per month, assuming a meal size of 0.227 kg, to ensure that mercury intake remains within safe limits and does not pose a health risk. The relatively low mercury levels in the fish sampled from CGMR suggest that the ecosystem is not currently a significant source of mercury contamination. However, the study highlights the importance of ongoing monitoring to detect potential changes in mercury levels, particularly in the face of increasing human activities in the region in future.

Keywords: *fish, mercury, safety level, consumption, coastal water*

Introduction

Mercury (Hg) is a toxic metal of global concern due to its potent neurotoxic effects, which can impact the brain, liver, and kidneys, and cause developmental disorders in children. Hg is released into the environment from both natural and anthropogenic sources. Recently, the increase in anthropogenic Hg emissions from human activities has become a significant concern. Due to long-range atmospheric transport and deposition, elevated levels of Hg are being observed even in remote and pristine habitats (Chen *et al*., 2013; Fitzgerald *et al*., 1998; Lebreton *et al*., 2018; Wolswijk *et al*., 2020).

The dominant input of mercury to the ocean is through atmospheric deposition (Mason and Sheu, 2002). Hg sinks in surface sediments of the pelagic ocean and riverine inputs from coastal areas can result from human activities (Fu *et al*., 2010), making it the main route for Hg to enter aquatic ecosystems (US EPA, 1997). Hg can be taken up by plankton or benthic fauna and tropically transferred to higher trophic organisms in marine food webs (Chen *et al*., 2013; Le *et al*., 2017), resulting in elevated Hg levels in apex animals, such as carnivorous fish, sharks, sea mammals, and even humans.

Although fish provide vital protein sources for a healthy diet, Hg contamination poses a serious health risk to consumers since most of the mercury content in fish is in the form of methylmercury, which is highly toxic to the brain and nervous system (Fitzgerald *et al*., 1998). Thus, fish have been broadly used as sentinels to assess the potential health risks associated with fish and seafood consumption of Hg worldwide (Sheehan *et al*., 2014).

Vietnam is among the Southeast Asian countries that have experienced rapid economic growth and industrialization in recent decades. The expansion of ferrous production, coal combustion

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(mainly from coal power plants), and landfills of industrial and municipal wastes are likely to increase anthropogenic Hg emissions and deposition, particularly in megacities like Ho Chi Minh City.

Can Gio Mangrove Reserve (CGMR), located downstream from Ho Chi Minh City, the largest industrial city in Vietnam, spans over 60,000 hectares and serves as a vital habitat for a diverse range of invertebrates and fish. These species are essential natural resources for the local communities, supporting their livelihoods. However, the reserve has been impacted by substantial wastewater discharge from Ho Chi Minh City, including pollutants from urban, industrial, and aquaculture activities (Dung *et al*., 2019). As a result, seafood safety has become a growing concern. Despite its importance, there is limited information available regarding mercury (Hg) concentrations in fish and seafood, as well as the associated health risks from consumption, particularly in the Mekong region and within the CGMR.

The hypothesis is that mercury concentrations in fish species from CGMR will vary by species and size, with some species potentially exhibiting levels that exceed safe consumption limits for humans. This study aims to assess mercury levels in fish species from CGMR to determine whether they are safe for local consumption. Additionally, it seeks to establish the maximum quantity of fish containing mercury that can be consumed weekly without exceeding the recommended safe intake levels for the general adult population.

Materials and Methods

Fish samples were collected the coast water of CGMR by purchasing them from local fishermen who rely on daily fishing for their livelihood. Samples of three species, *Chrysochir aureus, Johnius plagiostoma* and *Cynoglossus bilineatus*, were collected (Figure 1). All samples were kept in labeled polyethylene bags and stored in an icebox before being transferred to the laboratory, where they were stored at −20°C for further analysis.

Fish specimens were identified using the taxonomic key of Matsunuma *et al*. (2011), and their length and weight were measured to the nearest 1 mm and 0.01 g, respectively. The trophic position of each fish species was determined as described by Froese and Pauly (2016) and based on their food preferences

A portion (2-3 g flesh weight) of the dorsal muscle tissue was dissected using acid-cleaned stainless-steel scalpels and forceps to minimize contamination. The samples were placed in pre-cleaned glass containers and dried for 24 h at 60°C in a contamination-free environment. After drying, the samples were finely ground using a mortar and pestle that had been pre-cleaned with nitric acid (10%). The mortar and pestle were thoroughly rinsed between samples to eliminate potential contaminants. The Hg concentrations in the powdered samples were measured using a cold vapor atomic absorption spectrometer (MA-3000; Nippon Instruments Corp., Japan) with a detection limit of 0.001 ng. To prevent

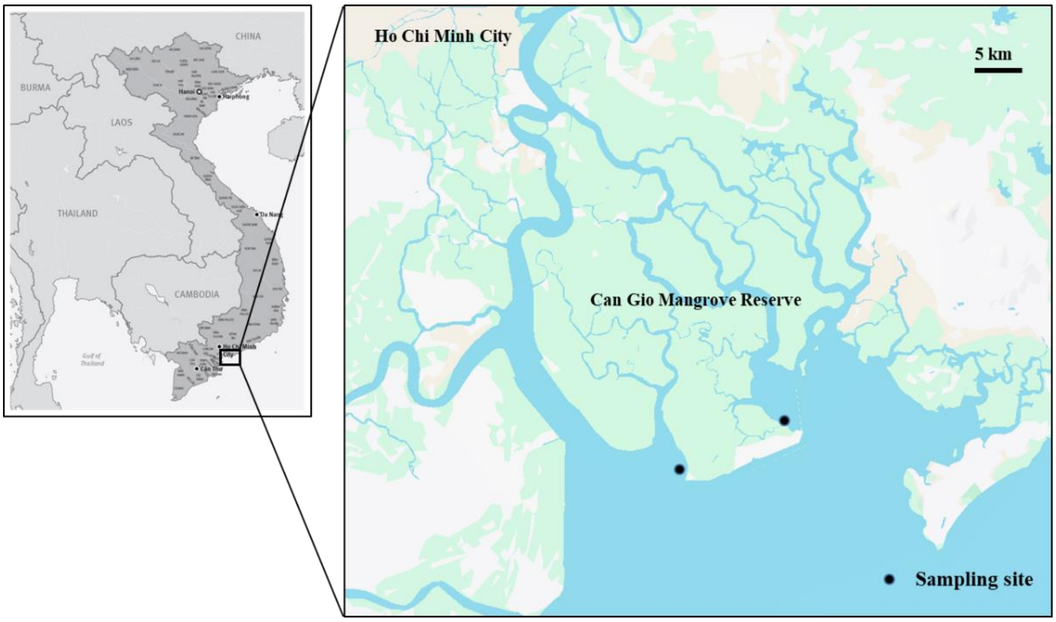

Figure 1. Studying area in Can Gio mangrove reserve

cross-contamination during analysis, all sample handling and weighing were performed in a clean laboratory environment with minimal exposure to airborne contaminants, and work surfaces were regularly wiped with ethanol.

Quality controls for the total Hg measurements included blanks, replicates, Hg standard (L-cysteine) solutions, and a certified reference material (CRM) of NIST-SRM2976 (National Institute of Standards and Technology, USA). All chemicals used were of analytical grade, and the reagents were prepared according to the instructions in NIC-600-2166-03 (Nippon Instruments Corp.). A calibration curve to estimate the Hg concentration (mg.kg^{-1} dry weight) in each fish sample was generated using 0, 0.5, 1.0, and 2.0 ppm standards. The accuracy of the method was assessed based on the recovery rate of 105-110% in the CRM.

For the assessment of potential health risks from human consumption in CGMR, given that most mercury in fish and shellfish tissue is present primarily as methylmercury (MeHg) (Le *et al*., 2009) and the high cost of analyzing for MeHg, total mercury is considered to be present as MeHg. This is because the percentage of methylmercury to total mercury in fish muscle varies from 80% to 100% (Le *et al*., 2010). Additionally, Hg concentrations were converted from (mg.kg^{-1}) dry weight to flesh weight at a ratio of approximately 21% when using the reference dose (RfD) of 0.1 μg.kg^{-1} per day, developed by the United States Environmental Protection Agency (USEPA, 2009). The average Hg concentration was also calculated and evaluated against human health risks from weekly fish intake (Herrman and Younes, 1999). Estimated weekly intake (EWI) values of Hg, based on the calculation of consumption limits for non-carcinogenic effects, were derived from the formula:

$$EWI = \frac{C_m \times IR}{BW}$$

Where IR is the fish intake rate (0.240 kg per week) for Vietnamese individuals (FAO, 2018); C_m is the measured concentration of Hg in a given species of fish (mg.kg^{-1}); and BW is the average body weight of the adult population (50 kg) (Le *et al*., 2009). The EWI estimates were compared with the standard limits of the Provisional Tolerable Weekly Intake (PTWI) of 0.0016 mg.kg^{-1} BW (JECFA, 2010). The risk was estimated using the hazard quotient (HQ) with a probabilistic approach:

$$HQ = \frac{EWI}{PTWI}$$

The PTWI denotes the amount of a substance that can be ingested weekly without any negative health effects. If the calculated HQ is greater than 1, it indicates a potential risk to human health.

The study also calculates the allowable daily consumption (CR_{lim}) of contaminated fish, based on the non-carcinogenic health effects of MeHg (USEPA, 2000), expressed in kilograms of fish per day.

$$CR_{lim} = \frac{RfD \times BW}{C_m}$$

All analyzed and calculated data were expressed as the mean ± standard deviation. A simple linear regression between the Hg concentration in the fish and the fish’s body size was performed. Statistical analyses were conducted using SPSS Statistics 16, Release 16.0.0.0.

Results and Discussion

Mercury concentration in the fish species

A total of seventy specimens from three species were collected and analyzed for total mercury in muscle tissue. The Hg concentrations varied widely among the species and their body sizes, ranging from 0.02 to 0.61 mg·kg^{-1} dry weight, with a mean value of 0.16 mg·kg^{-1} dry weight (Table 1). The highest mean Hg concentration (0.19 mg·kg^{-1} dry weight) was found in the large-eye croaker, *Johnius plagiostoma*, followed by Reeve's croaker, *Chrysochir aureus* (0.14 mg·kg^{-1} dry weight), and the lowest in *Cynoglossus bilineatus* (0.12 mg·kg^{-1} dry weight). The slightly higher Hg concentration in *Johnius plagiostoma* likely reflects its role as a predator of larger prey, leading to greater biomagnification. In contrast, *Cynoglossus bilineatus*, with a diet incorporating more detrital material, exhibited the lowest Hg concentration, suggesting differences in Hg uptake pathways among the species.

The trophic behaviors of the studied species are closely linked to mangrove and estuarine ecosystems, where mercury bioaccumulation is facilitated through sediment-associated food webs. *Chrysochir aureus* and *Johnius plagiostoma* are benthic carnivores that prey on crustaceans, mollusks, and smaller fish, primarily inhabiting shallow coastal waters, estuaries, and mangrove habitats (Sasaki, 2001; Froese and Pauly, 2016). This diet places them at a higher risk of Hg exposure through the consumption of sediment-associated prey, which are often enriched with trace metals, including mercury (Konieczka *et al*., 2022). In contrast, *Cynoglossus bilineatus*, with a more diverse diet comprising invertebrates, detritus, and organic matter, forages on or near sediment surfaces. This behavior similarly facilitates the transfer of mercury from sediment and water into the aquatic food web, albeit through a broader range of dietary sources (Gamboa-García *et al*., 2019). These feeding strategies reflect the trophic pathways through which Hg is bioaccumulated and magnified, underscoring the vulnerability of benthic and detritivorous species to sediment-associated contamination.

This dynamic is further influenced by the properties of mangrove sediments, such as those in CGMR, which act as reservoirs for mercury due to their high organic matter content and fine particle retention (de Oliveira *et al*., 2015). The anoxic conditions prevalent in these sediments promote the microbial conversion of inorganic Hg into methylmercury, a highly bioavailable and toxic form (Hall *et al*., 2008). As benthic species like *C. aureus, J. plagiostoma*, and *C. bilineatus* forage in these sediment-rich environments, they become increasingly susceptible to Hg accumulation, amplifying the risks of mercury exposure throughout the food web.

Research on mercury concentrations in Vietnamese fish has primarily focused on freshwater species, with limited data available on marine or estuarine fish, especially from mangrove ecosystems (Le *et al*., 2009; Lobus and Komov, 2016). This study's findings, which show moderate Hg concentrations in fish from CGMR, are lower than those reported for carnivorous freshwater species like *Channa striata* and *Mystus* sp. (exceeding 0.3 $mg.kg^{-1}$ dry weight). Compared to heavily polluted mangrove ecosystems, the Hg concentrations in CGMR remain relatively low, indicating that, despite limited marine fish data in the region, the Hg contamination levels in CGMR are not yet a significant concern (Phuong *et al*., 2012).

Relationship between mercury concentration and body size

A positive correlation between THg and body size was found only in *J. plagiostoma* (R^2 = 0.54, $P <$ 0.04) (Figure 2). This result aligns with well-documented bioaccumulation and biomagnification in fish species (Lavoie *et al*., 2013; Le *et al*., 2010; 2017). As fish grow, they accumulate mercury through dietary intake, with larger individuals typically exhibiting higher Hg concentrations due to prolonged exposure and consumption of contaminated prey (Le *et al*., 2009; Siau *et al*., 2021). However, the absence of a similar correlation in *C. aureus* and *C. bilineatus* suggests species-specific variations in feeding habits, metabolic processes, and Hg elimination rates, as previously reported in marine and estuarine ecosystems (Chumchal and Hambright, 2009; Wiener *et al*., 2003). Research on estuarine fish species has shown that benthic feeders with a diet composed of lower trophic-level organisms, such as detritus or invertebrates, may not exhibit clear size-dependent Hg accumulation due to a lower rate of trophic transfer (Baeyens *et al*., 2003; Gamboa-García *et al*., 2019). Additionally, ontogenetic dietary shifts—where fish change their diet as they grow—can influence Hg accumulation patterns. Some carnivorous species shift from consuming lower to higher trophic-level prey as they mature, leading to increased Hg bioaccumulation, while others maintain a consistent diet throughout their lifespan, which may result in weaker size-related trends (Storelli *et al*., 2005).

Implications for human health and ecosystem monitoring

The estimated weekly intake of mercury from these fish species remains below the provisional tolerable weekly intake (PTWI) threshold of 0.0016 $mg{\cdot}kg^{-1}$ body weight, as established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (WHO, 2011). Additionally, the hazard quotient (HQ) is below 1, indicating that regular consumption of these fish does not pose an immediate health risk (Table 2). These findings align with previous studies on marine fish from relatively uncontaminated environments, where Hg exposure remains within safe limits for human consumers (Le *et al*., 2009; Siau *et al*., 2021).

Based on the calculated monthly consumption limits for non-carcinogenic health risks (Table 3), the study recommends limiting consumption of these fish species to a maximum of ten meals per month (assuming a standard meal size of 0.227 kg). This recommendation is in line with guidelines issued for seafood consumption in regions with moderate Hg contamination (Ginsberg and Toal, 2009; FAO/WHO, 2011).

While the current Hg levels in these fish species do not pose an immediate threat, the proximity of CGMR to the Saigon River—a major conduit for urban and industrial runoff—raises concerns about future Hg contamination. The designation of CGMR as a UNESCO biosphere reserve highlights its dual role as a critical habitat and a natural buffer against pollutant inputs. Given the potential for increased Hg deposition from anthropogenic activities, a robust long-term monitoring strategy is essential to track temporal variations in Hg levels and assess emerging risks. This should include periodic sampling across multiple trophic levels, from primary consumers to top predators, to better understand Hg bioaccumulation and biomagnification patterns.

Table 1. Mean concentrations (mg.kg-1 dry weight) of Hg in muscle tissue of fishes

Species	n	TL (cm)	BW (g)	[Hg] (mg.kg-1 dried weight)
Chrysochir aureus	16	26.5±1.8	216.3±41.8	0.14±0.11
Johnius plagiostoma	32	16.2±3.5	57.8±32.5	0.190±0.148
Cynoglossus bilineatus	22	22.8±4.5	84.5±51.1	0.121±0.097

Table 2. The estimation of the weekly intake of Hg in studied fishes

Species	Level	Calculated dose (mg.kg-1 -d)	HQ
Chrysochir aureus	Min	0.01	0.09
	Max	0.09	0.59
	Mean	0.03	0.20
Johnius plagiostoma	Min	0.01	0.06
	Max	0.13	0.88
	Mean	0.02	0.27
Cynoglossus bilineatus	Min	0.004	0.03
	Max	0.08	0.57
	Mean	0.04	0.17

Table 3. Monthly Fish Consumption Limits for Noncarcinogenic Health Endpoint –Methylmercury (Source: U.S. EPA, 2000)

Risk Based Consumption Limit [a] Fish Meals/Month	Noncancer Health Endpoints [b] Fish Tissue Concentrations (mg.kg-1, wet weight)
Unrestricted (>16)	0 - 0.029
16	>0.029 - 0.059
12	>0.059 - 0.078
8	>0.078 - 0.12
4	>0.12 - 0.23
3	>0.23 - 0.31
2	>0.31 - 0.47
1	>0.47 - 0.94
0.5	>0.94 - 1.9
None (<0.5)	>1.9

[a] The assumed meal size is 8 oz (0.227 kg). The ranges of chemical concentrations presented are conservative, e.g., the12-meal-per-month levels represent the concentrations associated with 12 to 15.9 meals; [b] Chronic, systemic effects.

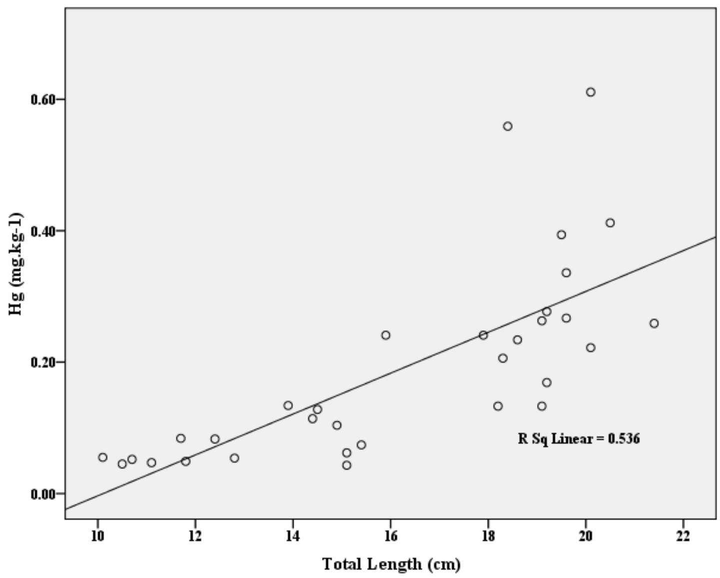

Figure 2. A positive correlation between Hg levels (mg.kg-1) and body size (cm) of large-eye croaker, *J. plagiostoma*

In addition to direct waterborne and sediment sources, atmospheric deposition is another significant pathway through which Hg enters mangrove ecosystems. Airborne Hg can be deposited onto mangrove soils and subsequently incorporated into the food web through microbial methylation and uptake by primary producers (Poissant *et al*., 2004; Costa *et al*., 2012). Monitoring Hg fluxes from atmospheric sources is, therefore, critical for obtaining a comprehensive assessment of contamination risks and long-term trends.

Integrating advanced analytical techniques, such as stable isotope analysis and Hg speciation studies, can further enhance monitoring efforts by distinguishing between natural and anthropogenic Hg sources (Siau *et al*., 2021). Additionally, the establishment of standardized biomonitoring protocols and the use of bioindicator species could improve early detection of Hg pollution trends.

While current Hg levels in the studied fish remain low, their trophic connections to the mangrove ecosystem make them particularly susceptible to future contamination. Strengthening regulatory frameworks and implementing pollution mitigation measures—such as improved wastewater treatment and stricter industrial discharge controls—are crucial for minimizing Hg inputs into the aquatic environment. By adopting a proactive, data-driven approach to Hg monitoring, researchers and policymakers can safeguard both ecological integrity and public health in CGMR and beyond.

Conclusion

This study represents one of the first efforts to assess Hg levels in marine fish from CGMR, providing critical baseline data. The study recommends that these fish should not be consumed more than 10 times per month, assuming a meal size of 0.227 kg. This recommendation aims to ensure that Hg intake remains within safe limits and does not pose a risk to human health. The findings underscore the importance of continued monitoring to detect changes in Hg contamination, particularly in light of escalating human activities. The relatively low Hg levels in *Chrysochir aureus, Johnius plagiostoma*, and *Cynoglossus bilineatus* reflect the moderate contamination of the CGMR and highlight the need for proactive management to preserve this valuable ecosystem.

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