NUSANTARA BIOSCIENCE
Vol. 16, No. 1, pp. 13-22
May 2024

ISSN: 2087-3948
E-ISSN: 2087-3956
DOI: 10.13057/nusbiosci/n160102

Metal concentrations in Silver pomfret *Pampus argenteus* (Euphrasen, 1788) and its risk assessment in Malaysia

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Manuscript received: 8 November 2023. Revision accepted: 11 May 2024

Abstract. *Shukri SM, Setyawan AD, MD Naim D. 2024. Metal concentrations in Silver pomfret* Pampus argenteus *(Euphrasen, 1788) and its risk assessment in Malaysia. Nusantara Bioscience 16: 13-22.* Fish consumption is one of the most important sources of protein in Malaysia. Nevertheless, anthropogenic sources release contaminants, such as metals, which have the potential to accumulate within marine organisms via the food chain. Hence, ingesting fish polluted with metals can be potentially hazardous to human health. This study aimed to ascertain the levels of metal concentrations in the edible tissues of *Pampus argenteus* (Euphrasen, 1788) inhabiting Malaysian waters to evaluate potential health hazards associated with their use. This study examines the levels of three metals, specifically Cd, Ni, and Pb, in *P. argenteus*. The samples underwent microwave digestion in a closed vessel to extract metals, which were subsequently analyzed using ICP-OES. The study revealed that the quantities of metals in *P. argenteus* were primarily Pb, with Ni and Cd following suit. These values ranged from 0.651 mg/kg to 0.001 mg/kg when measured on a dry weight basis. Notably, the samples collected from the Straits of Malacca exhibit a greater concentration of metals than those obtained from the South China Sea region. The tolerable daily intake of *P. argenteus* from all populations in this study was below the FAO/WHO oral reference dose. The risk assessment results showed that all populations' target hazard quotient was below 1.0. The results indicate that exposure to the metals studied poses a low non-carcinogenic risk and is considered safe for human consumption. This research offers baseline data for evaluating food safety and developing risk management recommendations concerning *P. argenteus*.

Keywords: ICP-OES, metals, *Pampus argenteus*, Reference Dose (RfD), target hazard quotient

INTRODUCTION

Nutritionists widely recognize marine fish and shellfish as significant contributors to high-quality protein, constituting approximately 17% of animal protein intake and accounting for approximately 6% of human dietary intake (Iimtiaz and Naim 2018; Salam et al. 2019). These aquatic organisms also contain essential minerals and fatty acids, particularly omega-3. However, despite the numerous health benefits associated with seafood consumption, it is imperative to consider the potential health hazards that arise from the prevalence of metals in marine fish and seafood. This is particularly relevant for seafood consumers (Rajeshkumar et al. 2018).

Metals refer to a toxic element that can lead to toxicity in the human body, generating harmful species and potentially causing damage and chronic illnesses. Based on the research conducted by (Sankhla et al. 2016; Rehman et al. 2018), it is evident that consuming toxic metals poses numerous health hazards to humans. These risks encompass a range of conditions, including dermatological diseases, skin cancer, and various internal cancers, such as those affecting the liver, kidney, lung, and bladder. Additionally, the ingestion of toxic metals has been related to the expansion of cardiovascular disorders, diabetes, and anemia. Furthermore, these metals can also adversely impact the human body's reproductive, developmental, immunological, and neurological processes.

The escalating demand for fish stocks has caused increased pollution of the local environment, a substantial rise in trawling and culturing activities in the South China Sea, and the intensified human presence in the vicinity of marine culture (Amirah et al. 2013; Zhu et al. 2014). Consequently, this phenomenon poses a direct threat to marine organisms. Fish serve as reliable indicators of metal contaminations in water ecosystems caused by their ability to occupy various trophic levels and exhibit diverse sizes and ages (Cordeli et al. 2023). Fish can accumulate metals within their tissues via absorption mechanisms, which poses a potential risk to humans exposed to these metals through the food chain. The ingestion of contaminated fish has immediate and long-term impacts on human health. For example, high exposure to Ni intake by humans can cause some side effects such as nausea, vomiting, diarrhea, giddiness, lassitude, headache, cough and shortness of breath, lung fibrosis and respiratory tract cancer are some of the conditions/diseases related to the respiratory system (O'Neal and Zheng 2015). Cd is considered to be another carcinogenic hazardous element that can cause hypertension, renal tubular damage or Acute Tubular Necrosis (ATN), and pancreatic, breast, and prostate cancers (Schwartz and Reis 2000; Tamele and Vázquez 2020). Elevated Pb contamination can cause neurological damage (cognition, decreased IQ), kidney disease, an endocrine disorder, elevated blood pressure, decreased total sperm count, increased abnormal sperm frequencies, and cancer (Kumar et al. 2020).

The establishment of a Provisional Tolerable Weekly Intake (PTWI) by the Joint Expert Committee on Food Additives (JECFA 2004) of the Food and Agriculture Organisation of the United Nations and the World Health Organisation (FAO/WHO) aims to safeguard consumers from the toxicological effects related with the ingestion of metals via fish consumption. The PTWI refers to the established threshold for the maximum daily exposure to a contaminant that an individual can sustain over their lifetime without incurring any adverse health effects related to food consumption. This definition is supported by the FAO/WHO and the research conducted by Peycheva et al. (2016). These limits may vary across species, as the metal accumulation process is subject to variations in developmental rates and metabolism among different organisms (Zaza et al. 2015). The United States Environmental Protection Agency (USEPA 2000) has established the Reference Dose (RfD) to assess the potential health risk associated with exposure to the contaminant. The RfD is a quantitative assessment of the daily oral intake of a contaminant that is expected to pose negligible risks of adverse effects on human health over a lifetime (USEPA 2000). Hence, it is of utmost significance to precisely quantify the levels of heavy metals in silver pomfret fish (*Pampus argenteus* ((Euphrasen, 1788)). This is imperative to ascertain its current and future safety for consumption while also serving as an indicator to alert Malaysian society if the metal concentrations surpass the established thresholds.

The *P. argenteus* primarily inhabits marine and pelagic environments ranging from 1 m to 100 m. Its widespread distribution spans the East China Sea to Southeast Asia, the Indian Ocean, the Arabian Gulf, and the North Sea (Mohitha 2016). The species is significant in Malaysian fishery sectors and has great value and demand as a protein source. Many inquiries undertaken in Malaysia have unequivocally recorded the existence of metals within fish (Kamaruzzaman et al. 2011; Alipour et al. 2021). However, the majority of these studies have primarily concentrated on examining the precise geographical areas where specific metals are present, as well as the particular fish species that are affected. Therefore, the current research was conducted to determine the concentrations of metals in consumable tissues of *P. argenteus* in Malaysia and the waters encircling it, as well as to assess the health risks associated with such substances.

MATERIALS AND METHODS

Sites and samples' description

Samples of *P. argenteus* were obtained from 13 landing sites around Malaysian waters (Figure 1). A total of 20 individuals were sampled from each sampling site. The samples were appropriately labeled to represent each respective sampling area, as indicated in Table 1, and the sampling period spanned from March to December 2018. All mature *P. argenteus* ranging from 18 to 28 cm long were collected. The specimens were examined to discover metal concentrations present in this species within the region of Malaysia.

All specimens were delivered to the School of Biological Science, Universiti Sains Malaysia, using a cool box and appropriate measures for the remaining transit process. Upon arriving at the laboratory, the samples underwent a running water cleaning process. Subsequently, the muscle tissue of the samples was excised using a sterile knife and kept separately in a designated icebox. All specimens were appropriately labeled and identified (Table 1).

Preparation of samples

Drying process

The drying procedure followed the approach outlined by Radojevic et al. (1999) and Feldsine et al. (2002), with slight adjustments to the procedural steps. The samples were homogenized and divided into two equal portions to facilitate the duplicate procedure. Subsequently, the samples underwent oven drying at 105°C. The dried samples were pulverized into fine powder and promptly placed into appropriately labeled containers for digestion.

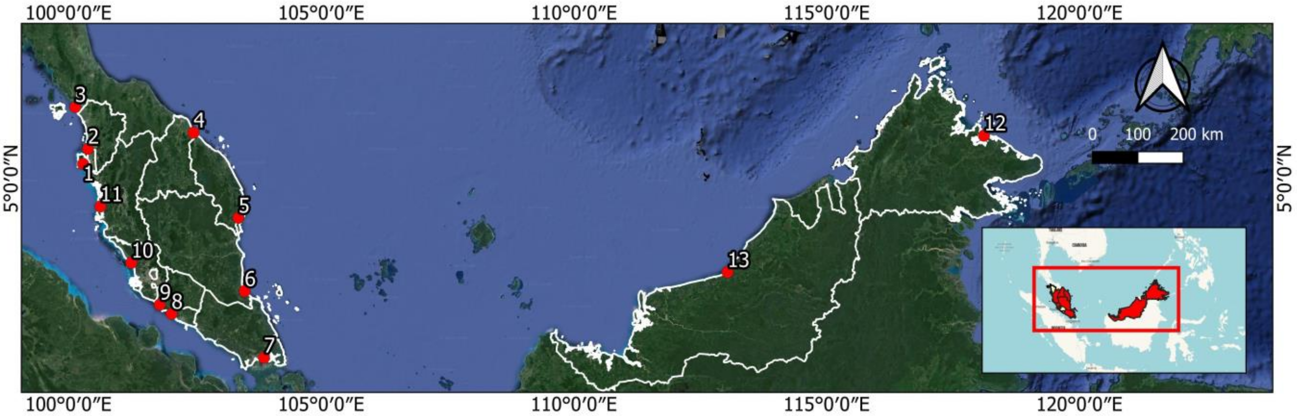

Figure 1. Sampling location of *P. argenteus* around Malaysian waters. 1. Batu Maung, Penang, 2. Kuala Muda, Kedah 3. Kuala Perlis, Perlis 4. Tok Bali, Kelantan 5. Kuala Kemaman, Terengganu 6. Kuala Rompin, Pahang 7. Kuala Benut, Johor 8. Kuala Sungai Baru, Melaka 9. Kuala Lukut Port Dickson, Negeri Sembilan 10. Sg. Yu Kuala Selangor, Selangor 11. Teluk Melintang (Teluk Intan), Perak 12. Sandakan, Sabah 13. Bintulu, Sarawak

Table 1. Description of sampling locations and sample size for each locality

Sampling Site	Geographical Location	Marine Region	Coordinate Latitude; Longitude	Sample Size (n)
Batu Maung, Penang (PNG)	NC	SM	5°17'5.0994"N, 100°17'14.9"E	20
Kuala Muda, Kedah (KD)	NC	SM	5°34'59.99"N, 100°22'59.99"E	20
Kuala Perlis, Perlis (PS)	NC	SM	6°23'52.44"N, 100°7'50.52"E	20
Tok Bali, Kelantan (K)	EC	SCS	5°53'51.36"N, 102°28'26.4"E	20
Kuala Kemaman, Terengganu (T)	EC	SCS	4°14'1.68"N, 103°21'49.6"E	20
Kuala Rompin, Pahang (P)	EC	SCS	2°48'2.16"N, 103°29'9.96"E	20
Kuala Benut, Johor (J)	SC	SM	1°30'1.03"N, 103°52'2.08"E	20
Kuala Sungai Baru, Melaka (M)	WC	SM	2°21'25.92"N, 102°2'21.12"E	20
Kuala Lukut Port Dickson, Negeri Sembilan (N9)	WC	SM	2°32'13.85"N, 101°48'20.56"E	20
Sg. Yu Kuala Selangor, Selangor (S)	WC	SM	3°21'17.29"N, 101°14'30.4"E	20
Teluk Melintang (Teluk Intan), Perak (PK)	NC	SM	4°27'20.52"N, 100°37'43.68"E	20
Sandakan, Sabah (SB)	BI	SS	5°50'21.84"N, 118°7'1.92"E	20
Bintulu, Sarawak (SR)	BI	SCS	3°10'16.68"N, 113°2'30.84"E	20
Total				260

Note: North Coast of Peninsular Malaysia (NC), East Coast of Peninsular Malaysia (EC), South Coast of Peninsular Malaysia (SC), West Coast of Peninsular Malaysia (WC), Borneo Island (BI), South China Sea (SCS), Straits of Malacca (SM), Sulu Sea (SS), n: sample size

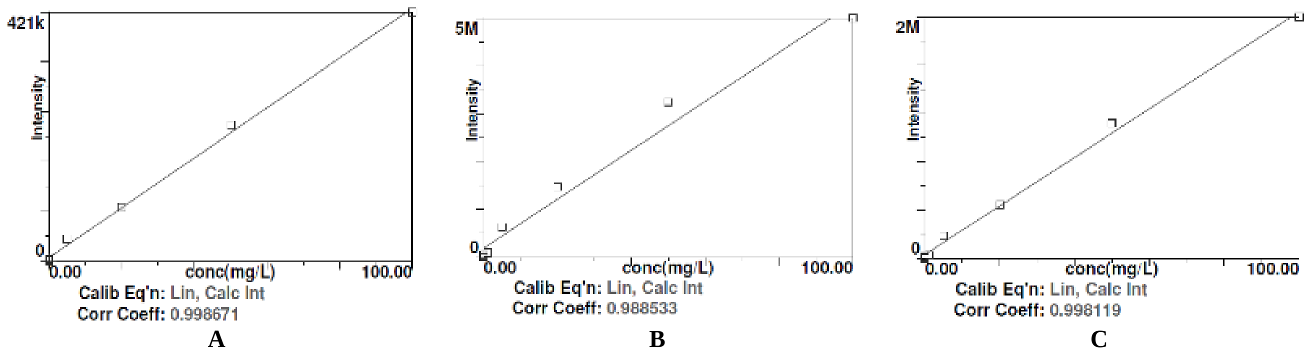

Figure 2. Calibration curve for standard used in the current study. A. Pb, B. Cd, C. Ni

Digestion process

The digestion process is a fundamental requirement technique for transforming the solid sample into a liquid state. This study employed the microwave digestion technique due to its recognized efficacy as a sample preparation method across various sample matrices. The evaluation of analytical quality was carried out by utilizing certified reference materials (CRM-DORM4) obtained from the National Research Council Canada. The dogfish muscle samples were used as a reference in CRM to confirm that all elements were within the designated range, as described by Willie et al. (2012). The observed recoveries of all elements in DORM4 were determined to vary between 80% and 130% of the declared value.

Next, 0.5g of dried samples and DORM4 were added to a Teflon vessel containing 10 ml of 70% nitric acid (HNO_3). The samples underwent digestion using a closed-vessel microwave digestion system (Milestone model Start D, Italy). The samples were filtered for future analysis.

Analysis of metals

Metals were determined on an ICP–OES model Optima 5300 DV (Perkin Elmer, USA). Certificate Recovery Material (CRM) - DORM4 standards were added to the samples to test the reliability of the approach, and their recovery rates were calculated. The results of the element recovery tests are presented in Table 2. The calibration curves were generated by graphing the absorbance readings against the corresponding concentrations using optimized instrument conditions. The calibration curve for each metal is depicted in Figure 2, demonstrating a high degree of correlation (R_2 = 0.999) between absorbance and concentration, indicating that the instrument yielded dependable outcomes.

Recovery tests

The recoveries of Pb, Ni, and Cd were found to be 88%, 90%, and 82.5%, respectively, thus fell within the acceptable range of 80 to 130%, as outlined in a previous study by Buhari and Ismail (2016), indicating a high level of accuracy (Table 2). The recovery values of the metals were determined using ICP-OES, as described in Equation 1. This finding provides initial validation for the calibration techniques employed in the ICP-OES instrument.

Equation 1: Recovery (%) = Observed concentration (mg/kg) / Published concentration (mg/kg) X 100

Table 2. Measured and certified values of metal concentrations (mg/kg DW) utilizing ICP-OES

Elements detected	Obtained conc.	CRM – Dorm4 (published conc. value) (Willie et al. 2012)	Percentage (%) recovery
Cd	0.26	0.299±0.018	88
Ni	1.29	1.34±0.14	90
Pb	0.33	0.404±0.062	82.5

Determination and calculation of metals concentration

The concentration of Pb, Ni, and Cd in triplicate was resolved by utilizing regression equations derived from a plot of absorbance readings of standards against their respective concentrations. This was performed based on the ICP-OES analysis results obtained, utilizing Equation 2.

Equation 2: Actual concentration (mg/kg) = Digested concentration (mg/L) x Volume digested (L) / Weight of dried sample digested (kg)

The metal concentrations that were acquired were then compared to the Estimated Daily Intake (EDI) for human consumption as established by the Malaysian Food Act (MFA) (1983), USEPA (2000), and FAO/WHO (2014).

Statistical analysis

A one-way analysis of variance (ANOVA) was conducted on the experimental data, and the means were compared using Tukey's test with SPSS software (version 22). This analysis aimed to determine if there were significant differences in the concentrations of metals among various sampling sites ($P < 0.05$).

Health risk assessment

To determine the human health risk associated with metal contaminations of *P. argenteus* inhabited in Malaysian waters, the Target Hazard Quotient (THQ) and allowable daily consumption (CR_{lim}) were calculated.

Target Hazard Quotient (THQ)

The Target Hazard Method (TH) is a measurement tool to assess the potential risk to human health from metal exposure (Taweel et al. 2013). The TH can be measured as Target Hazard Quotient (THQ) = (EF x ED x FIR x C/RFD x WAB x TA) x 10^{-3}, where EF = exposure frequency (from 52 days/year for people who eat *P. argenteus* once a week to 365 days/year for people who eat *P. argenteus* seven times a week); ED = exposure duration (70 years) equivalent to the average of a lifetime; FIR = fish ingestion rate (fish: 160 g/day/person) (Idriss and Ahmad 2015); C = element concentration in the muscle (edible part of fish) (mg/kg); RfD = oral reference dose (USEPA 2000; FAO/WHO 2014); WAB = average body weight (64 kg; the references weight were derived from numerous local Malaysian studies (Ismail al. 2018); and TA = average exposure time for non-carcinogens (365 days/year x ED). If the Hazard Quotient >1.00, there is potential risk related to study metals (Khan et al. 2008).

According to USEPA (2000) and FAO/WHO (2014), RfD for Cd = 0.5 mg/kg body wt./day, Pb = 2 mg/kg body wt./day, and Ni = 0.4 mg/kg body wt./day. Therefore, including the metals (Pb, Ni, and Cd) in assessing health risks associated with the consumption of *P. argenteus* is imperative in providing supplementary information on the potential health implications of consuming this fish.

Calculation of the allowable daily consumption (CR_{lim})

The equation presented herein was employed to compute the permissible daily fish consumption of *P. argenteus*. The daily permissible quantity of fish was quantified in kilograms per day (kg/day). This assumption posited that the diet exclusively consists of fish, with no other Cd, Ni, or Pb sources. Maximum safe daily intake is CR_{lim} = RfD x (BW / C_m) x 10^{-3}, where CR_{lim} = maximum safe daily consumption rate of *P. argenteus* (kg/day) (Moreau et al. 2007); RfD = oral reference dose for each metal concentrations (mg/kg/d) (USEPA 2000; FAO/WHO 2014); BW = average consumers body weight (kg); C_m = measured concentration of DW in fish (edible part) (mg/kg). USEPA determines RfD and estimates a safe amount, expecting no adverse effect on human health (USEPA 2000).

RESULTS AND DISCUSSION

The metal concentrations in fish

This study encompassed 13 sampling sites across five distinct regions with varying activities and pollution elements. Table 3 presents the recorded concentrations of metals within *P. argenteus* across various geographical locations. The concentrations of metals provided are expressed in terms of DW. Furthermore, regarding mean concentration, the sequence of metals in *P. argenteus* muscle was as follows: Pb > Ni > Cd. The concentration of Ni at the sampling site in S was observed to be the highest, with a value of 0.369 mg/kg, followed by SR, with a concentration of 0.322 mg/kg. Conversely, the remaining sites exhibited concentrations below 0.3 mg/kg. The sample obtained from T exhibited the lowest recorded concentration of Ni, measuring at 0.126 mg/kg. The sampling site of PNG exhibits the highest concentration of Cd at 0.181 mg/kg, surpassing K at 0.069 mg/kg and T at 0.048 mg/kg. The concentration of Cd observed at the other sampling sites was less than 0.04 mg/kg.

In addition, it is noteworthy that the Pb concentration (mg/kg) exhibited the highest value in the sample obtained from J, measuring at 0.651 mg/kg. Subsequently, the sample from T displayed a slightly lower concentration of 0.572 mg/kg, followed by the K sample exhibited a lower concentration of 0.532 mg/kg. The concentrations of Pb at the remaining sampling sites were found to be less than 0.4 mg/kg. Samples collected from M exhibited the lowest concentration of Pb, measuring 0.141 mg/kg.

Analysis of Variance (ANOVA) across sampling sites

Significant variations were observed in Pb, Cd, and Ni concentrations across all sampling locations. ANOVA test reveals statistically significant variations in the concentrations of Cd among all samples obtained. The findings also indicate no statistically significant variations in the levels of Pb among the samples collected from PNG, KD, PK, PS, and S. However, notable distinctions were observed in the samples obtained from the remaining locations. The ANOVA test further reveals no statistically significant variation in the Ni content across the samples obtained from Peninsular Malaysia. Nevertheless, it is noteworthy to mention that significant differences in Ni content were observed exclusively among the samples collected from BI, with a p-value less than 0.005.

Table 3. Metals (mg/kg DW) accumulation based on different sampling sites (mean value ± SD) (n = 20)

Sampling Site	Cd	Ni	Pb	Sig.
PNG	0.181±0.013	0.202±0.004	0.317±0.063	0.000
KD	0.024±0.009	0.206±0.019	0.331±0.037	0.000
PS	0.001±0.002	0.180±0.009	0.277±0.049	0.000
K	0.069±0.029	0.204±0.000	0.532±0.000	0.000
T	0.048±0.005	0.126±0.012	0.572±0.027	0.000
P	0.011±0.003	0.222±0.008	0.231±0.046	0.000
J	0.003±0.020	0.204±0.013	0.651±0.007	0.000
M	0.015±0.01	0.155±0.015	0.141±0.491	0.013
N9	Nd	0.157±0.067	0.221±0.017	0.000
S	Nd	0.369±0.006	0.248±0.025	0.000
PK	0.006±0.000	0.227±0.021	0.239±0.023	0.000
SB	Nd	0.289±0.003	0.243±0.020	0.000
SR	Nd	0.322±0.011	0.245±0.018	0.000

Note: n is the number of samples. Nd: Not detected due to small amount. Values are significantly different at p <0.05. The RfD (Oral reference Dose) for Cd: 0.5, Ni: 0.4, and Pb: 2 mg/kg/day (USEPA 2000; FAO/WHO 2014)

Health risk assessment

Target Hazard Quotient (THQ)

The calculation of the health risk from the consumption of *P. argenteus* for all the metals in this study is shown in Table 4. Pb, Ni, and Cd exhibit THQ values for individuals consuming *P. argenteus* weekly in various regions, ranging from 0.06 to 0.25, 0.29 to 0.4, and 0 to 0.06, respectively. Based on the data, the consumption of *P. argenteus* from all sampling sites at a frequency of five times per week is associated with an elevated health risk. However, it is important to note that this risk remains below the established threshold of risk, which is less than 1.0 (Biswas et al. 2023).

Allowable daily consumption (CR_{lim})

CR_{lim} was calculated and compared with RfD for all regions (Table 5). RfD for Cd, Ni, and Pb are 0.5, 0.4, and 2 mg/kg, respectively (FAO/WHO 2014; USEPA 2000). This study found that Cd exhibited the highest values of CR_{lim} of fish (kg/d) across various regions, including the NC, WC, SC, EC, and BI. Specifically, the calculated values for Cd were 0.744, 1.600, 10.667, 0.627, and 0 kg/d, respectively, surpassing those of the other metals investigated. Table 5 displays the association of Ni with the lowest CR_{lim} of *P. argenteus* across various regions, including the NC, WC, SC, EC, and BI. The CR_{lim} for these regions were recorded as 0.131, 0.126, 0.129, 0.106, and 0.086 kg/d, respectively.

Table 5. Allowable daily consumption (CR_{lim}) (kg/day) for the metals studied from *P. argenteus* muscle (edible part)

Metal	Location	Metal Concentration (mg/kg)	RfD (mg/kg/d)	Allowable Daily Consumption (CR_{lim})(kg/d)
Cd	NC	0.043	0.5	0.744
	WC	0.020		1.600
	SC	0.003		10.667
	EC	0.051		0.627
	BI	0		0
Ni	NC	0.195	0.4	0.131
	WC	0.203		0.126
	SC	0.199		0.129
	EC	0.241		0.106
	BI	0.299		0.086
Pb	NC	0.328	2	0.390
	WC	0.203		0.631
	SC	0.498		0.257
	EC	0.407		0.314
	BI	0.218		0.587

Table 4. Health risk estimates for Pb, Ni, and Cd ingestion from *P. argenteus* from five different regions in Malaysia

Sampling Region	Level of Exposure (DW)	Cd	THQ	Ni	THQ	Pb	THQ
NC	1	0.043±0.069	0.05	0.195±0.018	0.29	0.328±0.574	0.16
WC	1	0.020±0.003	0.02	0.203±0.088	0.3	0.203±0.656	0.06
SC	1	0.003±0.020	0.003	0.199±0.001	0.29	0.498±0.216	0.25
EC	1	0.051±0.051	0.06	0.241±0.136	0.3	0.407±0.155	0.2
BI	1	0	0	0.299±0.017	0.4	0.218±0.030	0.11

Note: The RfD (Oral reference Dose) for Cd: 0.5, Ni: 0.4, and Pb: 2 mg/kg/day (USEPA 2000; FAO/WHO 2014)

Discussion

This research indicates that the average amount of Cd, Ni, and Pb in *P. argenteus* is below the upper limit set by FAO/WHO and health authorities (Table 3). Generally, the average concentration patterns in the muscle of *P. argenteus* are as follows: Pb, Ni, and Cd. This indicates that the species has the potential to function as a bioindicator for monitoring Pb, Ni, and Cd pollution in Malaysian waters. In general, the metal concentrations identified in *P. argenteus* through this investigation were comparatively lower than those documented in studies carried out in China by Han et al. (2021), Pb (0.06 mg/kg) and Cd (0.02 mg/kg); in India by Bepari et al. (2021), Pb (8.45-13.02 mg/kg); and in Iran by Modheji et al. (2023), Ni (0.42 mg/kg) and Cd (0.14 mg/kg).

According to Yousif et al. (2021), various factors contribute to the accumulation of metals in fish tissues, including metal bioavailability, the ability of fish to absorb and remove pollutants, and variation in trophic structure. Malaysia's advanced industrial sector and rapid economic growth and development have increased the coastal water pollution risk. Therefore, when pollutants enter water, they cause significant changes that can affect the ecological balance of the environment either directly or indirectly (Matta et al. 1999). Additionally, due to their high toxicity and cumulative behavior, pollutants have adverse effects on the life and activity of aquatic organisms and can even cause mass death.

Analysis of metal concentrations based on sampling regions shows that the metal levels in the WC, NC, and SC of Peninsular Malaysia representing the SM tend to increase comparatively compared to other geographical areas (EC and BI). Interestingly, BI is moderately polluted with various metals, but the concentration is lower than in Peninsular Malaysia. Specimens collected from PNG show higher concentrations of Cd (0.181±0.013), S shows higher concentrations of Ni (0.369±0.006), and J shows higher concentrations of Pb (0.651±0.007) (Table 3).

Based on the findings of Buhari and Ismail (2016), the Prai industrial area in Penang is home to numerous industries that are supposed to be partly responsible for metal pollution in the marine environment. They revealed a significant contamination of Cd in Prai, Penang. It is important to note that various activities, including households, agriculture, and fishing, may also contribute to the elevated metal concentration levels observed in this area (Ong et al. 2016). These activities have released their waste products into the adjacent sea. The average Cd value obtained in this study (0.001±0.002 - 0.181±0.013 mg/kg) was lower than the findings by Rosli et al. (2018). Their research reported that Cd concentrations in fishes in the T site were 0.39±0.26 mg/kg. Generally, the accumulation of Cd in this research was lower than observed in fishes of Langkawi Island, Malaysia (0.20 to 0.90) (Octavianti and Jaswir 2017); North East Coast of India (0.41 mg/kg) (Kumar et al. 2012) and Miri coast, Sarawak, Borneo (0.41 mg/kg) (Anandkumar et al. 2018).

Additionally, Salam et al. (2021), who studied *P. argenteus* in K and S, discovered that the Cd levels ranged from 0.03 to 0.16 mg/kg. This signifies that the findings of this current study were lower than those of the prior ones. USEPA (2000) and FAO/WHO (2014) have established a regulatory threshold for Cd concentration in fish at 0.5 mg/kg; similarly, MFA (1983) has set a maximum allowable Cd content in fish at 1 mg/kg. The Cd accumulation in this research remains below the upper limit accumulations recommended by MFA (1983) and FAO/WHO (2014).

Besides that, Cd concentration from K (0.069±0.029) and T (0.048±0.005) showed moderately high. The results were substantiated by research conducted by Azmi et al. (2019), which indicated that the Kuantan region, situated on the EC, exhibited a greater concentration of Cd. The study revealed that it is possible to deduce that the EC of Peninsular Malaysia experienced contamination of metals that originated from a singular point source. This contamination occurred despite the area's relatively low levels of human activity. The main anthropogenic sources of Cd include metallurgical industries, municipal effluents, sewage sludge, mine wastes, fossil fuels, and fertilizers (Yao et al. 2015).

The concentrations of metals varied across different sampling sites or regions, potentially attributed to factors such as untreated sewage, industrial effluents, and variations in geological conditions (Pobi et al. 2019). Moreover, the regions on the EC experience significant impacts from industrial effluents due to the swift expansion of various industries, including chemical, oil and gas, and domestic sectors (Ahmad 2014). Environmental discharge of toxic elements is caused by various factors, including crop and commercial waste, mineral deposits, manufacturing and mining operations, atmospheric dissolution, and unregulated solid waste management (Atamaleki et al. 2019). Furthermore, the EC region is characterized by its urban environment and proximity to petrochemical industries, potentially serving as sources of Cd pollution in the coastal vicinity (Sujaul et al. 2013). This statement is further corroborated by Afshan et al. (2014), who observed that the combustion of fossil fuels and municipal waste is widely acknowledged as a significant factor in releasing Cd emissions into the environment.

Another metal that holds significance for living organisms is Ni. The bioavailability of Ni in the human body is considerable, although it can be substantially diminished when consumed alongside certain foods, such as orange juice, tea, coffee, and milk (Schrenk et al. 2020). The mean Ni values obtained in the present study (0.126±0.012 - 0.369±0.006 mg/kg) were found to be comparatively lower than the similar research conducted on *P. argenteus* from Hara Reserve, Iran (1.42 mg/kg) (Mohammadnabizadeh et al. 2014). Similarly, the results obtained from the metals analysis exhibited that the mean Ni concentration in the muscle tissue of various types of marine fish was as high as that recorded on the southwest coast of India (6.06-13.92 mg/kg) (Rejomon et al. 2010); Iran (49.4054.10 mg/kg) (Hosseini et al. 2015); and Miri, Sarawak, Malaysia (0.85-4.10 mg/kg) (Anandkumar et al. 2018). The southern region of Iran exhibits a higher concentration of Ni (49.40-54.10 mg/kg) due to the major presence of an oil industry. As the petrochemical manufacturing and hydrocarbon industries are significant contributors to the accumulation of metals in the local environment, including Ni, the region's high Ni concentration is not unexpected (Abdolahpur et al. 2013). Based on a report by USEPA (2000), the limit set is 0.4 mg/kg for Ni concentration in fish, which is higher than the Ni concentration obtained in this study.

Pb is a substance that can accumulate in the body over time and has toxic properties. Despite the low bioavailability of Pb in the marine ecosystem, the ongoing bioaccumulation of this element by aquatic organisms, particularly fish, potentially poses a significant risk to human health if consumed (Kamaruzzaman et al. 2011). The accumulation of Pb in this research varied between 0.141 and 0.651 mg/kg in *P. argenteus*. SC showed the greatest accumulation of Pb compared to other locations. The findings were corroborated by Kamaruzzaman et al. (2011), who conducted a study on *P. argenteus* in the SC. Their research indicated that the fish from J exhibited the highest concentration of Pb (0.17±0.087 mg/kg). However, the average concentration of Pb on *P. argenteus* from the J population observed in this study (0.651±0.007 mg/kg) was significantly higher than the values reported by Kamaruzzaman et al. (2011). However, such values were found to be lower compared to findings by Rosli et al. (2018) (0.90±0.10 - 1.00±0.25 mg/kg).

The permissible Pb concentration threshold for fish is 0.5 mg/kg (FAO/WHO 2014). Conversely, USEPA (2000) has stipulated a maximum allowable Pb content of 2 mg/kg. The introduction of Pb into the water ecosystem can be attributed to various factors, including natural activities such as soil erosion, as well as anthropogenic sources like rapid industrialization, the use of fertilizers and pesticides, and agricultural disposal (Agah et al. 2009; Hamada et al. 2018; Shokr et al. 2019). Hence, it is unsurprising that the level of Pb concentration in the SC surpasses that of other regions since it correlates with population density and the prevalence of agricultural practices in the area (Jaji et al. 2018). Using fertilizers and pesticides has resulted in the discharge of waste from rivers into the ocean (Khan et al. 2018).

The most likely explanation for this is that the WC, NC, and SC, particularly the SM, exhibit a significant level of rapid development and are characterized by a significant concentration of human activity (Minhat et al. 2020). However, many additional factors play a role in the pollution of water bodies due to metals. Various natural processes, including soil erosion, geological weathering, atmospheric deposition, and human activities such as household and industrial waste disposal, fertilizer and pesticide use, and agricultural practices, have contributed to the entry of metals into aquatic ecosystems, further affecting the concentration of accumulated metals in the marine environment (Basim and Khoshnood 2016).

However, several factors have affected marine pollution in BI, including domestic waste disposal, tourism and recreational pressure, waste pollution and sedimentation problems due to two oil and gas companies located in Labuan, Sabah (Mokhtar et al. 2012). In addition, several palm oil production, wood processing, and car workshop enterprises have grown in Sarawak's coastal areas (Anandkumar et al. 2018) and ship-building industries in Miri (Nagarajan et al. 2014). The Analysis of Variance (ANOVA) conducted at a 95% confidence level reveals a statistically significant amount of variation across all sampling locations.

Fish consumption poses a potential hazard due to the presence of contaminants, which may result in negative effects on human health. Metals analysis revealed that the concentration of *P. argenteus* posed the least potential health risk to individuals who consumed fish from all sites once a week. This means that *P. argenteus* can be listed among humans' safest fish for ingestion and carries no known hazards. Muscle, the consumable portion of the fish, exhibited lower levels of metals than other fish components such as the gills and liver (Taweel et al. 2013).

Metals can undergo reactions with diffusing ligands, such as iron or molecules, as well as macromolecules. These reactions can result in biomagnification and bioaccumulation within the marine food chain. Consequently, these elements can persist in the environment and induce metabolic anomalies in the consumed organisms.

Anthropogenic sources include mining, refining, and coal-based industries, potentially introducing contaminants into the aquatic environment and reaching the sea through direct deposition (CCREM 2014). Pb contamination of marine species can be attributed to several processes, such as petroleum combustion, wastewater, sludge, metal processing and manufacturing, Pb mineralization, and atmospheric deposition (Singh et al. 2022). Meanwhile, weathering and sediment erosion, non-ferrous metal mining, non-ferrous metal ore smelting, and phosphate fertilizer manufacturing are all possible sources of Cd in the maritime environment (FAO/WHO 2014).

Calculating the THQ is a major method for evaluating long-term risk. According to the results of a risk analysis of *P. argenteus* ingestion, which incorporated an evaluation of multiple metals, the computed THQ value appears to be less than 1 (<1). This indicates that individuals who consume *P. argenteus* from the studied regions do not present a health risk. In contrast, if the THQ value surpasses 1.0, it signifies a potential risk of adverse health effects (Biswas et al. 2023). Recent research by Salam et al. (2021) indicates that *P. argenteus* exhibited a moderate health risk in KD and S and suggests that the consumption of *P. argenteus* acquired from Malaysian waters remains safe for consumers while consumed within the recommended daily intake. Based on these reasons, it is worth noting that *P. argenteus* found in Malaysian waters can still be considered part of an unpolluted ecosystem.

The allowable daily consumption (CR_{lim}) possesses a specific numerical value, and a proposed threshold has been suggested to mitigate potential health hazards for individuals who consume it (Table 5). Human consumption of *P. argenteus* may result in the ingestion of metals, potentially harming individuals' health. Consequently, the daily intake rates for each metal examined were denoted as consumption limits; the consumption limit (kg/d) has been established for certain metals that hold significance for human health. The risk estimation related to the consumption limit of certain metals involved determining the maximum daily intake of contaminated fish that would not harm human health (USEPA 2000). The determination of the daily consumption limit was conducted by employing the aforementioned published formulae, and the calculation was predicated on the concentration of metals found in the edible portion (muscle) of *P. argenteus*.

Moreover, Table 5 revealed that all the metals were within daily permissible consumption value. Similar studies were also described by Singh et al. 2010; Salam et al. 2019 and Salam et al. 2021. The CR_{lim} of *P. argenteus* (kg/d) across various regions is 0.26-0.59 kg/d for Pb, 0.09-0.13 kg/d for Ni and 0-10.67 kg/d for Cd ranges (Table 5). The mean CRlim and THQ were generally lower than the thresholds associated with adverse health effects. This suggests that consuming *P. argenteus* in Malaysian waters does not pose significant health risks concerning the three metals examined.

Understanding the concentrations of metals in fish, particularly in *P. argenteus*, holds significant importance in regulating fish consumption. The *P. argenteus* had Pb's highest mean metal content, followed by Ni and Cd. Furthermore, it has been observed that the specimens collected from the marine region of the SM exhibit elevated accumulation of Ni and Pb in comparison to the specimens obtained from the marine region of the SCS (South China Sea). Furthermore, this current investigation unequivocally demonstrated the reduced toxicity of various metal concentrations in *P. argenteus* inhabiting Malaysian water bodies. All metal concentrations examined are below the maximum recommended concentrations established by MFA (1983) and FAO/WHO (2014). The *P. argenteus* obtained from Malaysian waters is unlikely to induce acute toxicity in humans upon consumption. Therefore, concerning human health, the THQ value suggests that daily consumption of *P. argenteus* does not pose any risk. Besides that, it is critical to consider all data because the absence of some facts would disrupt some crucial concerns and weaken the contents/analyses. This research offers baseline data for evaluating food safety and developing risk management recommendations about *P. argenteus*. Hence, this research offers an assessment of consumer vulnerability and recommendations for local consumers regarding their susceptibility to chronic or acute exposure to metals.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to Universiti Sains Malaysia (USM) and the School of Biological Sciences (SBS), Malaysia for providing opportunities and research facilities for this study. This work was funded by the Fundamental Research Grant Scheme (FRGS Fasa 1/2020), Ministry of Higher Education Malaysia.

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