Pollution 2021, 7(4): 923-932
DOI: 10.22059/POLL.2021.325185.1111

RESEARCH PAPER

The Effect of Monsoon on Chemical Composition and Bioaccumulation of Heavy Metals in *Scomberomorus commerson*, Lacepede 1800, from Oman Sea

Asma Esmaeilzade Ashini, Parvin Sadeghi* and Mohammad Mansoor Tootooni

Department of Marine Biology, Faculty of Marine Science, Chabahar Maritime University, Chabahar, Iran

Received: 01 June 2021, Revised: 02 August 2021, Accepted: 18 September 2021

ABSTRACT
This study was performed to determine the chemical compositions and heavy metals in the muscle of *Scomberomorus commerson* from the Oman Sea, during the two seasons, pre-monsoon and post-monsoon in 2018. The protein, fat, moisture, and ash contents were determined by AOAC (Association of Official Analytical Chemists) methods. Heavy metal (Zn, Cu, and Pb) analyses were performed by atomic absorption spectrophotometer after acid digestion. There were significant differences between protein, fat, moisture, and ash values in muscle tissue in two seasons ($P< 0.05$). The highest content of protein (22.53±2.09%) and fat (4.15±1.25%) was recorded in pre-monsoon. The mean concentrations of heavy metals (µg g^{-1}dw) in muscle tissue were 0.08-0.05 for Zn, 0.04-0.02 for Cu, and 0.02-0.01 for Pb in the pre and post-monsoon, respectively. The accumulation of heavy metals in muscle followed the Zn>Cu>Pb. The amounts of Zn, Cu, and Pb were below maximum permissible limits (MPL) recommended by international standards (FAO, FAO/WHO, and MAFF). Results revealed that estimated daily and weekly intakes of Zn, Cu, and Pb were far below the permissible tolerable daily intake (PTWI) recommended by FAO/WHO. Therefore, consumption of *S. commerson* in the pre and post-monsoon has no risks for human health in the Oman Sea.
Key words: mackerel, protein, pollutant, monsoon, Oman Sea.

INTRODUCTION

Fish has a high nutritional value with having 99% of protein and essential fats, essential amino acids, vitamins, and essential minerals. Fish has long been considered as one of the most critical foods in terms of nutritional and medicinal value (FAO, 2010; Mziray & Kimirei, 2016). Fish muscle is a unique source of easily digestible nutrients and protein. The main chemical constituents of fish meat are water, protein, fat, carbohydrates, vitamins, and minerals, which vary depending on the species, sex, type of nutrition, living environment, age, puberty, season, as well as different parts of the muscle (Oliveira et al., 2003; Pyz-Lukasik et al., 2020). The chemical body compositions (such as protein, fat, ash, and moisture) are appropriate indicators of the physiological health status of the fish (Saliu et al., 2007). Aquatic ecosystems receive large amounts of pollutants such as heavy metals, pesticides, hydrocarbons, radioactive materials, and organic matter resulting from domestic, industrial, mineral, and agricultural wastewater (Canli & Atli, 2003; Resma et al., 2020). The presence of heavy metals over the standards defined in aquatic ecosystems causes environmental effects for animals and humans (Sadeghi et al., 2020). Heavy metals effects on biological functions of aquatic organisms (Bonsignore et al., 2018). On the other hands, fish

* Corresponding author E-mail: parvin.sadeghi@gmail.com

species are bioindicators of environmental pollutant evaluation (Kortei et al., 2020). Heavy metals enter the fish body by absorbing water directly through the gills or skin and eating contaminated food or inedible particles. Then, metals enter the blood of fish and penetrate tissues and accumulate, transmitted through the food chain to consumers and eventually humans, causing chronic and deadly diseases (Kaneko & Ralston, 2007). Fish tissues such as gill, liver, and muscle tissues, due to their different roles in the respiratory, process of metal storage, and their potential in the human diet, are mainly used as biomarkers to analyze metal contaminants in fish (Mziray & Kimirei, 2016). The monsoon phenomenon is caused by temperature changes in the central part of Asia and the Indian Ocean, affecting the Indian region up to parts of the Strait of Hormuz in the Persian Gulf (Goswami & Xavier, 2004). Typically, monsoons via seasonal floods cause turbulence in the aquatic environment and changes in the bottom structure and habitat of benthic organisms (Gaonkar et al., 2013), biological productivity (Malik & Bharti, 2012), spawning of aquatic species (James, 1992), fish diversity (Tremain & Adams, 1995) and heavy metal pollution (Chandra & Garg, 2017).

Scomberomorus commerson, Lacepede 1800, narrow-barred Spanish mackerel, is a species of the family Scombridae and is distributed in vast areas of tropical waters, from 10 to 70 m depth (Pauly et al., 1996). *S. commerson* feeds on fish, shrimp, and squids (Kuiter & Tonozuka, 2001).

This species is one of the most commercially important fish caught in the Persian Gulf and Oman Sea. *S. commerson* has economic value and high consumption by the local people around Oman Sea. Also, this fish is one of the most important species used in canneries in this region.

Keeping the above fact in mind, the present study aimed to investigate the changes in chemical composition (fat, protein, moisture, and ash) and the bioaccumulation of heavy metals (Zinc, Copper, and Lead) in muscle tissue of *S. commerson* at pre and post-monsoon in the Oman Sea. Heavy metal levels in fish muscle were compared with maximum permissible limits (MPL) according to international standards. On the other hand, estimated daily intake (EDI) and estimated weekly intake (EWI) of heavy metals for the consumer was calculated and compared with Permissible tolerable daily intake (PTWI) according to the FAO/WHO (2004).

MATERIALS AND METHODS

The Oman Sea is located in the southeast of Iran and the northwest of the Indian Ocean (Fig 1.). The Oman Sea is a marginal and open Sea that connects the Persian Gulf to the Indian Ocean. Therefore, that is important in terms of fisheries, shipping, and military in Iran. Passage of fishing boats and commercial ships, canneries, shipbuilding, and desalination industries causes enter the pollutants into this area (Sadeghi et al., 2015; 2019). On the other hand, the Oman Sea is typically influenced by the two monsoons of the southwest in summer and northeast in winter. Forty specimens of *S. commerson* were caught by local fishermen during the two seasons pre-monsoon (June) and post-monsoon (November) in 2018 from the Oman Sea (around Konarak, Ramin and Beris harbors). The fish were immediately transferred to the laboratory by storage in a cool box with ice powder. The total weight (g) and total length (cm) of each sample were measured (Table 1), then samples of dorsal white muscle were removed and stored at -20°C until chemical analysis.

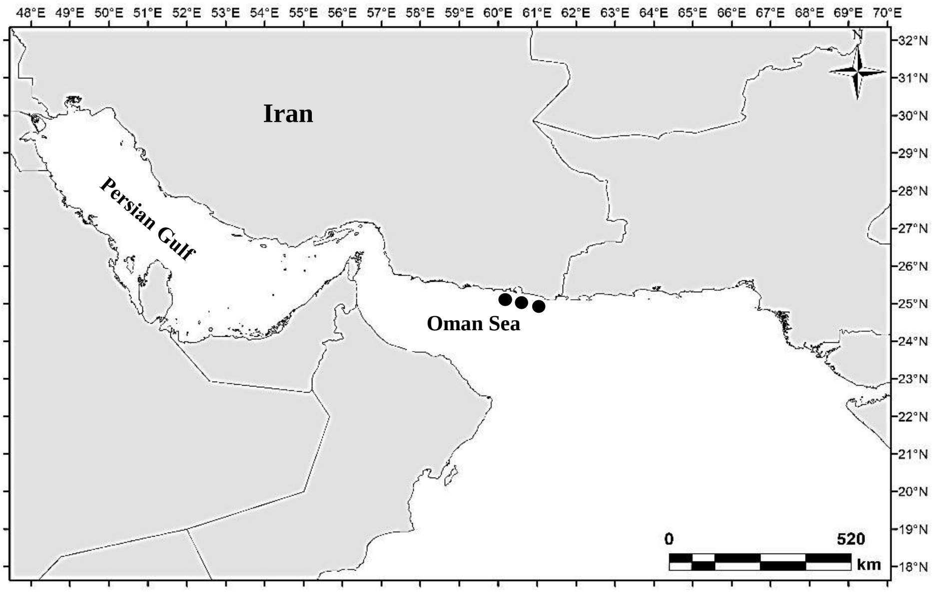

Fig. 1. Sampling site on the Oman Sea

To measure, the muscle protein, 1 g of the sample was placed in filter paper without ash, then placed inside the tube of digestive apparatus. 5 g selenium reagent mixture and 20 cc sulfuric acid were added to tubes and placed inside the Automatic Kjeldahl Distillation Unit (UDK 149, VELP Scientifica). After digestion, the tubes were placed in a distillation apparatus for 5 minutes. The collected liquid was titrated with 0.1 N sulfuric acid. Finally, the protein percentage was calculated from the following equations: (AOAC, 2005)

$$\%\text{Nitrogen content} = \frac{\text{Normalite of acid} \times 100 \times 0.014 \times \text{consumed acid}}{\text{weight of sample}} \quad (1)$$

$$\%\text{Crude protein} = \text{Nitrogen content} \times 6.26 \quad (2)$$

To measure fat percentage, the beakers were rinsed and dried in the oven at 105 ° C for 24 h. After cooling, beakers were weighed (W1). The sample was weighed (W) and placed into beakers. 80 cc of solvent was poured into beakers. The sample and solvent were transferred to a Soxtec (Avanti 2055, Sweden) and boiled at 30° C for 45 min. washing with solvent was performed twice to collect residual fat in the sample and heated for 30 min. The beakers were removed and cooled in the desiccator. Finally, the weight of the beakers was measured (W2). Fat percentage was calculated from the following equation (AOAC, 2005).

$$\%\text{Fat} = \frac{W2 - W1}{W} \times 100 \quad (3)$$

Moisture percentage of muscle was calculated as hot air oven standard method according to the following formula (AOAC, 2005):

$$\%\text{Moisture content} = \frac{W2 - W3}{W1} \times 100 \quad (4)$$

Weight of the empty crucible = W0 (g)
Weight of the sample = W1 (g)

Weight of the empty crucible+ wet sample = W2 (g)
Weight of the empty crucible + dry sample = W3 (g)

To measure the ash percentage, the samples were placed in a furnace at 550 ° C, and the percentage of ash was calculated based on the following formula (AOAC, 2005):

$$\%\text{Ash} = \frac{\text{W2} - \text{W}}{\text{W1}} \times 100 \tag{5}$$

Weight of the empty crucible = W (g)
Weight of the sample before ashing = W1 (g)
Weight of the empty crucible + sample after ashing = W2 (g)

To determine the heavy metals, muscle tissue was dried in an oven (105 °C). After drying, 1 g of sample was homogenized and digested with 10 mL of HNO_3-$HCLO_4$ (4:1 v/v) at 150 °C on a hot plate for 4 hours. After cooling the liquid at room temperature, samples were filtered through a Whatman No. 42 paper filter and diluted to 25 mL with double distilled water. Concentrations of zinc (Zn), copper (Cu), and lead (Pb) were measured by using atomic absorption spectrophotometer (GBC-932 Australia). The heavy metal concentration of the muscle samples was determined in triplicate and expressed as μg/g dry weight.

Estimated daily intake (EDI) and estimated weekly intake (EWI) were determined according to the following equation (USEPA, 1989). According to the Iran Fisheries Organization (IFO), the average food daily consumption (FDC) by fish muscle for an adult 70 kg (BW) is 33.15 g per day (IFO, 2018). MC (μg/g) is the mean metal concentrations in muscle tissue.

$$\text{EDI} = \frac{\text{MC} \times \text{FDC}}{\text{BW}} \tag{6}$$

$$\text{EWI} = \text{EDI} \times 7 \tag{7}$$

For quality control and quality assurance, all used containers were acid-washed with 10% nitric acid for 48 hours. Then, they were rinsed with double distilled water and placed in an oven at 150° C for drying. Blank and standard solutions were prepared from stock solutions (Merck, Darmstadt, Germany). The analytical quality for fish was checked with DORM-2 from the National Research Council Canada. The recovery rates of heavy metals were 98.7% (Zn), 102.1% (Cu), and 99.2% (Pb). Limits of detection (LOD) were 0.01 μg/g for Zn and 0.05 μg/g for Cu and Pb.

Statistical tests were performed using the SPSS software version 22. Normalization of data was checked using the Kolmogorov test. Significant differences between metal concentrations and chemical compounds in muscle tissue of two seasons were determined using Student's t-test. Pearson test was also used to determine the correlation. The significance level was set at $P < 0.05$. All data were expressed as means± standard deviation (SD).

RESULTS AND DISCUSSION

The chemical composition of muscle tissue in *S. commerson* is shown in Table 1. The highest mean protein in fish muscle was recorded 22.53±2.09% in the pre-monsoon. The protein content in the muscle of *S. commerson* in the post-monsoon was less than pre-monsoon (16.45±0.6%). There was significant differences between protein content in muscle tissue in the pre and post-monsoon (P< 0.05). The amount of protein content had reversely correlated with length (r=-0.80, P<0.01) and weight (r=-0.70 P<0.01) in two seasons. The results indicated that fat content was ranged between 4.15±1.02-3.08 ±1.01 % in two seasons. There were no significant differences between the values of fat in the pre and post-monsoon (P> 0.05). Change in the amount of lipid in muscle showed reversely correlated with length (r=-0.50, P<0.01) and weight (r=-0.60, P<0.01) of fish in the pre and post-monsoon. Analysis of chemical compositions in the muscle of the *S. commerson* showed that the mean ash was 0.14±0.04 and 0.48±0.24% in the pre-monsoon and post-monsoon, respectively, and there was a significant difference between values of ash in two seasons (P <0.05). The major component in the muscle of *S. commerson* was moisture. The highest moisture content of fish muscle (79.94±0.4%) was recorded in the post-monsoon. Also, the lowest moisture content (73.19±0.06%) was shown in the pre-monsoon. There were significant differences between moisture content in muscle tissue in two seasons (P< 0.05). The results showed that the chemical compositions of the fish body were different between the pre-monsoon and post-monsoon. Physiochemical factors of water, such as temperature and salinity, affect the chemical composition in fish species (Bandarra et al., 1997). The difference in the amount of chemical compounds can be depended on the quality of water, type of feeding, time of capture, fish life cycle, and farming system (Oliveira, 2003; Pyz-Lukasik et al., 2020). According to Eder & Lewis (2005), fish do not eat food during spawning seasons. Therefore, they use fat and protein storage for the required energy. In the present study, protein and fat percentage were less in the post-monsoon (autumn), which can be related to the reproduction time of this species because fish consume more energy (Siddeek, 1995). Gokce et al. (2004) have found that protein and fat in the muscle of *Solea solea* were higher in spring than in autumn, which is agreement with the results of the present study. Catch season and environmental condition effect on protein and fat content in fish muscle (Pyz-Lukasik et al., 2020). Some authors reported similar results for reducing protein and fat levels with the change of seasons (Oliveira, 2003; Nargis, 2006; Usydus et al., 2012; Saeed, 2013; Pradhan et al., 2015). The amount of fat and moisture in fish muscle are inversely related (FAO, 1999), which was also recorded in the present study.

Table 1. Chemical composition in muscle of *Scomberomorus commerson* collected in pre and post-monsoon.

Season	Weight(g)	Total (cm) length	Protein%	Fat%	Moisture%	Ash%
Pre-monsoon	363.05±2.60	38.58±5.1	22.53±2.09^{a}	4.15±1.02^{a}	73.19±0.06^{a}	0.14±0.04^{a}
Post-monsoon	960.04±8.40	54.05±1.96	16.45±0.6^{b}	3.08 ±1.01 ^{b}	79.94±0.4^{b}	0.48±0.24^{b}

Different letters in superscript show significant difference among two seasons (P < 0.05).

The results of mean concentrations of lead, zinc, and copper in muscle tissue of *S. commerson* at different seasons are shown in Table 2. The results showed that the highest concentration of heavy metals was recorded in the pre-monsoon. The highest average of heavy metals in the muscle of *S. commerson* was observed for Zn in the pre-monsoon (0.08±0.01 μg/g). Also, the lowest concentration of heavy metals was obtained for Pb in post-monsoon (0.01±0.004 μg/g). Comparison of heavy metals in the muscle of *S. commerson* showed a significant difference for Zn between the pre and post-monsoon (P <0.05). There were no significant differences between Pb and Cu concentrations in muscle tissue in the pre and post-monsoon (P> 0.05). Changes in the accumulation of heavy metals can be due to environmental conditions (such as temperature, runoff and rainfall), nutritional factors, fish life cycle, and physicochemical conditions in different seasons that these factors can be involved in the absorption of heavy metals (Kojadinovic et al., 2007; Ersoy & Celik, 2009; Hossain et al., 2021). The mean concentration of heavy metals in fish tissue followed the descending order of Zn > Cu > Pb. This pattern of heavy metals in our study was in agreement with the results of Sadeghi et al. (2020) on three species of the Scombridae family of the Oman Sea. The Zn concentration in the muscle tissue of *S. commerson* (0.05-0.08 μg/g) was lower than the value reported by Ahmed (2013) (3.17-9.43 μg/g) and Hosseini et al. (2018) (1.35-4.25 μg/g). The Zn content of *S. commerson* was obtained 2.10-2.23 μg/g by Al-shwafi (2002) in the Gulf of Aden and Red Sea of Yemen, Which was higher than the amount of zinc in the present study. The concentration of Cu in the muscle tissue of *S. commerson* was ranged 0.02-0.04 μg/g. Cu content was lower than the studies previously reported by Saei-Dehkordi & Fallah, 2011 (0.158-0.289 μg/g), Ahmed et al., 2015 (2.78-5.52 μg/g), and Yasmeen et al., 2016 (0.189±0.045 μg/g). The mean value of Pb in muscle tissue of *S. commerson* was detected 0.1-0.02 μg/g. Comparing present results to those reported by Sadeghi et al., 2015 (1.53-1.95 μg/g) and Pilehvarian et al., 2015 (208.91 ± 35.64 μg/g), it can be concluded that Pb contents in the muscle of this species are higher than our data.

Table 2. Mean (±SD) concentration of heavy metals (μg/g dw) in muscle of *Scomberomorus commerson* from Oman Sea collected in pre and post-monsoon.

Season	Zn	Cu	Pb
Pre-monsoon	0.08±0.01[a]	0.04±0.007[a]	0.02±0.006[a]
Post-monsoon	0.05±0.005[b]	0.02 ± 0.005[a]	0.01±0.004[a]

Different letters in superscript show significant difference among two seasons ($P < 0.05$).

The results revealed that the bioaccumulation of heavy metals in the muscle of *S. commerson* is higher pre-monsoon than post-monsoon. During the monsoon phenomenon, due to the strong currents, the bottom composition is disturbed and causes possible contamination away from the bed. In the pre and post-monsoon periods, the intensity of the currents is lower, and the pollutants have a greater chance of accumulating in the sediment and benthic organisms. This may explain the low levels of contaminants in the post-monsoon compared to pre-monsoon. It is well known that Zn and Cu are important and essential elements with known roles in biological processes. On the other hand, Pb is non-essential metal and could be toxic at low concentrations. The concentration of Zn, Cu, and Pb in muscle tissues of *S. commerson* in the present study compared with the MPL (maximum permissible limits) for human consumption established by FAO, FAO/WHO, and MAFF (Table 3). For comparison, dry weight data in this study with other data metal concentrations

Table 3. Comparison of heavy metal levels in muscles of *Scomberomorus commerson* (μg/g ww) with maximum permissible limits (MPL) according to international standards.

Standard	Zn	Cu	Pb	References
FAO[1]	30	30	0.5	FAO, 1983
FAO/WHO[2]	40	30	0.5	FAO/WHO, 2011
MAFF[3]	50	20	2	MAFF, 2000
Pre-monsoon	0.024±0.01	0.012±0.007	0.006±0.006	current study
Post-monsoon	0.015±0.005	0.006±0.005	0.003±0.004	current study

1. Food and Agriculture organization of the United Nations
2. World Health Organization
3. Ministry of Agriculture, Fisheries and Food

were converted to wet weight by converting factor 0.3 (According to Khodabux et al. (2007), the moisture content in the muscle tissue of the Scombridae family is about 70%). Amounts of Zn, Cu, and Pb were below MPL recommended by FAO (1983), FAO/WHO (2011), and MAFF (2000) in *S. commerson* of Oman Sea.

The EDI and EWI for an adult by 70 kg are shown in Table 4. According to the data, the EDI and EWI of Zn, Cu, and Pb in this study are below the permissible tolerable daily intake recommended by FAO/WHO, 2004, which can be suggesting that consumption of *S. commerson* in the pre/post-monsoon has no risks for human health in the Oman Sea. Similarly, consumption of tuna species from the Western Indian Ocean (Kojadinovic et al., 2007), western Pacific (Ordiano- Flores et al., 2011), Ecuadorian coast (Araujo & Cedeno-Macias, 2016), and Oman Sea (Sadeghi et al., 2020) were found to be safe for human consumption without no threat to health.

Table 4. The estimated daily and weekly intakes (µg/kg bw) of zinc, copper and lead of the *Scomberomorus commerson* from the Oman Sea.

Element	PTWI[a]	PTWI[b]	PTDI[c]	EDI[d]		EWI[e]	
				Pre-monsoon	Post-monsson	Pre-monsoon	Post-monsson
Zn	7000	490000	70000	0.0378	0.0236	0.2646	0.1652
Cu	3500	245000	35000	0.0189	0.0094	0.1323	0.0658
Pb	25	1750	250	0.0094	0.0047	0.0658	0.0329

a Provisional tolerable weekly intake (µg /week/kg body weight).
b Provisional tolerable weekly intake for an adult person (µg /week/70 kg body weight).
c Permissible tolerable daily intake (µg /day/70 kg body weight) (FAO/WHO, 2004).
d Estimated daily intake (µg /day/70 kg body weight).
e Estimated weekly intake (µg /week/70 kg body weight).

CONCLUSION

This study assessed variation in the chemical composition and heavy metal bioaccumulation in the muscle of *Scomberomorus commerson* during pre and post-monsoon in the Oman Sea. There were significant differences between protein, fat, moisture, and ash content in the muscle tissue in the pre and post-monsoon .The results indicated that the highest bioaccumulation of Zn, Cu, and Pb in the muscle of *S. commerson* was recorded in the pre-monsoon. The mean concentrations of heavy metals in muscle of this spices were lower than the standard limits established by FAO, FAO/WHO, and MAFF. The estimated daily and weekly intake of Zn, Cu, and Pb were far below the permissible tolerable daily intake. Therefore, consumption of *S. commerson* in pre and post-monsoon can be entirely safe for human health.

ACKNOWLEDGEMENTS

The authors thank the anonymous referees, who significantly contributed to improving the contents and style of the manuscript.

GRANT SUPPORT DETAILS
The present research has been financially supported by Chabahar Maritime University (grant No. 2951-95199201).

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Ahmed, Q. (2013). Determination of Heavy metals in Indian Mackerel Fishes (Family- *Scombridae)* from Karachi Coast. Ph.D. thesis. Department of Zoology University of Karachi.

Al-Shwafi, N.A.A. (2002). Heavy Metals Concentration Levels in some Fish Species in the Red Sea and Gulf of Aden-Yemen. Qatar Univ. Sci. J., 22; 171–176. http://hdl.handle.net/10576/9621

AOAC (Association of official analytical chemists). (2005). Official methods of analysis, 18th edn. Association of Official Analytical Chemists, Gaithersburg

Araujo, C.V.M. and Cedeno-Macias, L.A. (2016). Heavy metals in yellowfin tuna (*Thunnus albacares*) and common dolphin fish (*Coryphaena hippurus*) landed on the Ecuadorian coast. Sci. Total. Environ., 541; 149–154.

Bandarra, N. M., Batista, I., Nunes, M. L., Empis, J. M. and Christie, W. W. (1997). Seasonal changes in lipid composition of sardine (*Sardina pilchardus*). J. Food Sci., 62; 40–42.

Bonsignore, M., Salvagio Manta, D., Mirto, S., Quinci, E.M., Ape, F., Montalto, V., Gristina, M., Traina, A. and Sprovieri, M. (2018). Bioaccumulation of heavy metals in fish, crustaceans, molluscs and echinoderms from the Tuscany coast. Ecotox. Environ. Safe., 162; 554–562.

Canli, M. and Atli, G. (2003). The relationship between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. Environ. Pollut., 121; 129-136.

Chandra, S. and Garg, S.K. (2017). Pre and Post-monsoon Seasonal Variation of some Heavy Metal Pollution in Sediments of river Gomti in the Vicinity of Lucknow City, India. J. Appl. Sci. Environ. Manage., 21 (3); 593-599.

Eder, E.B. and Lewis, M.N. (2005). Proximate composition and energetic value of demersal and pelagic prey species from the SW Atlantic Ocean. Mar. Ecol. Prog. Ser., 291; 43-52.

Ersoy, B. and Çelik, M. (2009). Essential elements and contaminants in tissues of commercial pelagic fish from the Eastern Mediterranean Sea. J. Sci. Food Agric., 89; 1615–1621.

FAO. (1983). (Food and Agriculture Organization), Compilation of legal limits for hazardous substances in fish and fishery products, FAO Fishery Circular No. 464, pp: 5–100.

FAO. (1999). World production of fish, crustaceans and mollusks by major fishing areas. Fisheries Information Data and Statistics Unit (FIDI), Fisheries Department, FAO Rome, p. 33.

FAO. (2010). Yearbook of Fishery Statistics 2004 (Vol. 1/2). Food and Agriculture Organization of the United Nations, Roma.

FAO/WHO Expert Committee on Food Additives. (20110. Evaluation of certain food additives and contaminants: Seventy-third report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series; No 960 (228 pp.).

FAO/WHO. (2004). Summary of Evaluations Performed by the Joint FAO/WHO Expert Committee on Food Additives (JECFA 1956–2003), (First Through Sixty First Meetings). ILSI Press International Life Sciences Institute.

Gaonkar , U.V., Sivadas, S.K. and Ingole, B.S. (2013). Effect of tropical rainfall in structuring the macrobenthic community of Mandovi estuary, west coast of India. J. Mar. Biolog. Assoc. U.K., 93(7); 1727-1738.

Gokçe, M.A.., Taşbozan, O., Çelik, M. and Tabakoğlu, S.S. (2004). Seasonal variations in proximate and fatty acid compositions of female common sole (*Solea solea*). Food Chem., 88(3); 419-423.

Goswami, B. N. and Xavier, P. K. (2004). Dynamics of Internal Inter annual Variability of the Indian Summer Monsoon in a GCM. J. Geophys. Res., 110 (D24); 1-17.

Hossain, M.N., Rahman, A. and Shamsuddin, S.Md. (2021). Comparative seasonal assessment of pollution and health risks associated with heavy metals in water, sediment and fish of Buriganga and Turga River in Dhaka city, Bangladesh. SN Appl. Sci., 3; 509.

Hosseini, M., Naderi, M., Gholami, S. and Hadipour, M. (2018). Toxic metals in the muscle and liver of five main commercially-important fishes from the Persian Gulf, Southern Iran. Casp. J. Environ. Sci., 16(2); 191-198.

Iran Fisheries Organization (IFO). (2018). Annual Iranian Fisheries Statistics 2014 and 2018. Fisheries Design and Program Office, Tehran, Iran. P; 33.

James, P. S. B. R. (1992). Monsoon fisheries of the west coast of India Prospects, problems and management. Bull. Cent. Mar. Fish. Res. Inst., 45; 1-3.

Kaneko, J.J. and Ralston, N.V. (2007). Selenium and mercury in pelagic fish in the central north pacific near Hawaii. Biol. Trace Elem. Res., 119 (3); 242–254.

Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R.P. and Bustamante, P. (2007). Bioaccumulation of trace elements in pelagic fish from the western Indian Ocean. Environ. Pollut., 146; 548–566.

Kortei, N., Heymann, M.E., Essuman, E.K., Kpodo, F.M., Akonor, P.T., Lokpo, S.Y., Boadi, N.O., Ayim-Akonor, M. and Tettey, C. (2020). Health risk assessment and levels of toxic metals in fishes (*Oreochromis noliticus* and *Clarias anguillaris*) from Ankobrah and Pra basins: Impact of illegal mining activities on food safety. Toxicol. Rep., 7; 360-369.

Kuiter, R.H. and Tonozuka, T. (2001). Pictorial guide to Indonesian reef fishes. Part 3. Jawfishes - Sunfishes, Opistognathidae - Molidae. Zoonetics, Australia., P; 623-893.

MAFF (Ministry of Agriculture, Fisheries and Food). (2000). Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1997. in: Aquatic environment monitoring report No. 52. Lowestoft, UK: Center for Environment, Fisheries and Aquaculture Science.

Malik, D.S. and Bharti, U. (2012). Status of plankton diversity and biological productivity of Sahastradhara stream at Uttarakhand, India. J. Appl. Nat. Sci., 4 (1); 96-103.

Mziray, P. and Kimirei, I.A. (2016). Bioaccumulation of heavy metals in marine fishes (Siganus sutor, Lethrinus harak, and Rastrelliger kanagurta) from Dar es Salaam Tanzania. Reg. Stud. Mar. Sci., 7; 72–80.

Nargis, A., 2006. Seasonal Variation in the Chemical Composition of Body Flesh of Koi Fish *Anabas testudineus* (Bloch) (Anabantidae: Perciformes). Bangladesh J. Sci. Ind. Res., 41(3-4); 219-226.

Oliveira, E.R., Agostinho, A.A. and Matsushita, M. (2003). Effect of biological variables and capture period on the proximate composition and fatty acid composition of the dorsal muscle tissue of *Hypophthalmus edentatus (Spix, 1829).* Braz. Arch. Biol. Technol., 46 (1); 105–114.

Ordiano-Flores, A., Galván-Magaña, F. and Rosiles-Martínez, R. (2011). Bioaccumulation of mercury in muscle tissue of yellowfin tuna, *Thunnus albacares*, of the Eastern Pacific Ocean. Biol. Trace. Elem. Res., 144; 606–620.

Pauly, D., Cabanban, A. and Torres Jr., F.S.B. (1996). Fishery biology of 40 trawl-caught teleosts of western Indonesia. p. 135-216. In D. Pauly and P. Martosubroto (eds.) Baseline studies of biodiversity: the fish resource of western Indonesia. ICLARM Studies and Reviews, 23.

Pilehvarian, A.A., Malekirad, A.A., Bolandnazar, N.S. and Rezaei, M. (2015). Heavy metal bioaccumulation in different fish species in the coast of the Persian Gulf, Iran. Toxin. Rev., 34(4); 215–219.

Pradhan, S.C., Patra, A.K. and Pal, A. (2015). Seasonal analysis of the biochemical composition of muscle and liver of *Catla catla* in a tropical climate of India. Comp. Clin. Pathol., 24; 593–603.

Pyz-Lukasik, R., Chalabis-Mazurek, A. and Gondek, M. (2020). Basic and functional nutrients in the muscle of fish: a review. Int. J. Food Prop., 23 (1); 1941-1950.

Resma, N.S., Haque Meaze, A.K.M.M., Hossain, Sh., Khandaker, M.U., Kamal, M. and Deb, N. (2020). The presence of toxic metals in popular farmed fish species and estimation of health risks through their consumption. Phys. Open., 5; 100052.

Sadeghi, E., Mohammadi, M., Sharafi, K. and Bohlouli, S. (2015). Determination and assessment of three heavy metal content (Cd, Pb and Zn) in *Scomberomorous commerson* fish caught from the Persian Gulf. Bulg. Chem. Commun., 47 (D); 220-223.

Sadeghi, P., Loghmani, M. and Afsa, E. (2019). Trace element concentrations, ecological and health risk assessment in sediment and marine fish *Otolithes ruber* in Oman Sea, Iran. Mar. Pollut. Bull., 140; 248–254.

Sadeghi, P., Kazerouni, F., Savari, A., Movahedinia, A., Safahieh, A. and Ajdari, D. (2015). Application of biomarkers in Epaulet grouper (*Epinephelus stoliczkae*) to assess chromium pollution in the Chabahar Bay and Gulf of Oman. Sci. Total. Environ., 15(518-519); 554-561.

Sadeghi, P., Loghmani, M. and Frokhzad, S. (2020). Human health risk assessment of heavy metals via consumption of commercial marine fish (*Thunnus albacares*, *Euthynnus affinis*, and *Katsuwonus pelamis*) in Oman Sea. Environ. Sci. Pollut. Res., 27; 14944–14952.

Saeed, S.M. (2013). Impact of environmental parameters on fish condition and quality in Lake Edku, Egypt. Egypt. J. Aquat. Biol. Fish., 17(1); 101–112.

Saei-Dehkordi, S.S. and Fallah, A.A. (2011). Determination of copper, lead, cadmium and zinc content in commercially valuable fish species from the Persian Gulf using derivative potentiometric stripping analysis. Microchem. J., 98 (1); 156-162.

Saliu, J.K., Joy, O. and Catherine, O. (2007). Condition factor, fat and protein content of five fish species in Lekki Lagoon. Nigeria. Life Sci. J., 4; 54–57.

Siddeek, M. (1995). Review of fisheries biology of Scomberomorous and Acanthocybium species in the western Indian Ocean (FAO, Area 51. WGP) 95/2/32P.

Tremain, D. M. and Adams, D. H. (1995). Seasonal variations in species diversity, abundance and composition of fish communities in the Northern Indian River Lagoon, Florida. Bull. Mar. Sci., 57(1); 171-192.

USEPA-503/8-89-002. (1989). US EPA Office of Marine and Estuarine Protection, Washington, DC.USEPA (Environmental Protection Agency). 1986. Subchronic (90-day) toxicity of thallium (I) sulfate in Sprague-Dawley rats. Prepared by the Midwest Research Institute, Kansas City, MO for the Office of Solid Waste, Washington, DC.

Usydus, Z., Szlifder-Richert, J. and Adamczyk, M. (2012). Variations in proximate composition and fatty acid profiles of Baltic sprat (*Sprattus sprattus balticus*). Food Chem., 130; 97–103.

Yasmeen, K., Mirza, M.A., Khan, N.A., Kausar, N., Rehman, A.U. and Hanif, M. (2016). Trace metals health risk appraisal in fish species of Arabian Sea. Springerplus., 5(1); 859.