Heliyon 5 (2019) e01875

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.heliyon.com

Mercury and cadmium distribution in yellowfin tuna (*Thunnus albacares*) from two fishing grounds in the Indian Ocean near Sri Lanka

B.K.K.K. Jinadasa [a,*], G.S. Chathurika [a], G.D.T.M. Jayasinghe [a], C.D. Jayaweera [b]

[a] *Analytical Chemistry Laboratory (ACL), National Aquatic Resources Research & Development Agency (NARA), Colombo-15, Sri Lanka*
[b] *Department of Chemistry, University of Sri Jayewardenepura, Nugegoda, Sri Lanka*

ARTICLE INFO

Keywords:
Toxicology
Food science
Food contamination
Food safety
Mercury
Cadmium
Yellowfin tuna
Catching location

ABSTRACT

Mercury (Hg) and cadmium (Cd) are contaminants of great environmental concern due to their natural and anthropogenic origin, their ability of bioaccumulate through the food chain and their harmful effects on human health. In this study, the Hg and Cd accumulation in the muscle of 65 yellowfin tuna (*Thunnus albacares*) collected from two different catching sites of the Indian Ocean near Sri Lanka were evaluated. The samples were mineralized using microwave accelerated digestion, and the metals were detected by atomic absorption spectroscopy (AAS). The metal levels were not significantly different between the two sites ($p > 0.05$), and the average Hg and Cd concentrations were 0.48 ± 0.35 mg/kg and 0.017 ± 0.024 mg/kg, (wet weight basis) respectively. Only 6 (9.2%) and 2 samples (3.1%) exceeded the European Commission limits for Hg (1 mg/kg) and Cd (0.01 mg/kg), respectively. A comparatively strong positive correlation was observed between the THg concentration and the weight of the fish. However, there was no clear relationship between the concentration and size for Cd. These findings provide an understanding of the Hg and Cd distribution in yellowfin tuna in two fishing grounds in the Indian Ocean near Sri Lanka.

1. Introduction

Yellowfin tuna (YFT, *Thunnus albacares*) is a large epipelagic, cosmopolitan species found mainly in the tropical and subtropical oceanic waters of the three major oceans, including the Indian Ocean, where it forms large groups (schools). Sri Lanka is one of the oldest and most important YFT producing nations in the Indian Ocean, accounting for 39,600 t in 2016 (NARA, 2016; Dissanayake et al., 2008). The stock structure of the Indian Ocean YFT is assumed to consist of two major (western and eastern) and two minor (far western and far eastern) populations (Nishida, 1992). YFT are predominantly caught by purse seines, long lines, gillnets, handlines, poles, and lines (Lan et al., 2013). This species is one of the major targets of the industrial fisheries in the Indian Ocean and hence it is necessary for them to comply with national and international standards regarding public health concerns (Jinadasa et al., 2014a).

YFT is a top predatory, slow-growing, long-lived migratory fish species in the marine food web; they are often used to biomonitor nonessential trace metals such as mercury (Hg) and cadmium (Cd) in the marine environment (Bocher et al., 2003; Schindler et al., 2002). These metals enter the marine environment due to natural (weathering and meteorization of rocks, degasification of the earth's crust, terrestrial sources, and volcanism) and anthropogenic activities (mining, fossil fuel burning, industrial and agriculture activities) (Ordiano et al., 2011). There are a number of intrinsic factors (size, sex, migratory pattern, origin) and extrinsic factors (salinity, water temperature, catching location, etc.) that can contribute to elevated levels of toxic metals in the fish (Nicklisch et al., 2017). YFT have high metabolic rates and thus they consume a high volume of food, which results in a high load of pollutant accumulation (Storelli et al., 2005). In many aspects, the Indian Ocean has unique characteristics than other tuna harvested oceans. Further, the surface waters of the northern Indian Ocean are extremely productive and have a complex bathymetry; dividing the Indian Ocean into various separate basins creates a pronounced oceanographical asymmetry, unrivaled by the other oceans (Saager, 1994).

The Government Agency for Toxic Substances and Disease Registry of the United States ranked Hg as the 3rd substance on their substance's priority list in 2017 and the World Health Organization categorized Hg as one of the top ten chemicals or groups of chemicals of major public health concern (ATSDR, 2017; WHO, 2017). Moreover, ATSDR categorized Cd as number seven on that list and the International Agency for Research on Cancer (IARC) categorized Cd and its compounds as human group 1

* Corresponding author.
E-mail address: jinadasa76@gmail.com (B.K.K.K. Jinadasa).

https://doi.org/10.1016/j.heliyon.2019.e01875
Received 1 February 2019; Received in revised form 2 April 2019; Accepted 29 May 2019

carcinogens (IARC, 2018). Ingestion is one of the major routes for human exposure to Hg and Cd and several health risks have been reported such as neurotoxicity disorders, delayed fetal and brain development, stomach irritation, vomiting, and diarrhea while long-term exposure causes kidney diseases, cancer, and fragility at birth (Nicklisch et al., 2017; Corguinha et al., 2015).

Although fish is a very good source of beneficial high-quality proteins, minerals and omega-3 polyunsaturated fatty acids (Obaidat et al., 2015), contaminated fish are a major route of human exposure to nonessential trace metals, especially Hg (Jinadasa et al., 2013; Damiano et al., 2011; Bella et al., 2017). Moreover, fish represent a powerful model for risk-benefit analysis (Bella et al., 2015). There are a number of studies on the Hg and Cd levels in YFT and their relationship to body size (Jinadasa et al., 2014a; Kojadinovic et al., 2007b). Further, few studies have been reported on the Hg and Cd levels of yellowfin tuna in different places in the Indian Ocean such as the Western Indian Ocean (Bodin et al., 2017; Kojadinovic et al., 2006) and the Southern Indian Ocean (Tri et al., 2019). Moreover, some studies have revealed the THg concentration in yellowfin tuna samples collected from Sri Lankan fishery harbors, fish processing factories and the market (Jinadasa et al., 2014a, 2014b). However, no literature is available about the THg and Cd levels and their association with the capture location in the fish catching grounds in the Indian Ocean around Sri Lanka.

In this study, we analyzed the total mercury (THg) and Cd levels in the muscle tissues of YFT caught in two YFT fishing grounds in the Indian Ocean around Sri Lanka and evaluated their relationship with capture location and body size (length and weight).

2. Materials and methods

2.1. Sample collection

The YFT were collected from a commercial seafood exporter. Their catching location was taken from the fisheries logbook and the data were confirmed with a satellite-based vessel monitoring system (VMS). The coordinates were fed into Google map software to identify the fish catching ground. The length-weight data were measured, and 100 g of an edible muscular sample was taken from each fish and transported to the laboratory under chilled conditions and frozen at −20 °C until further analysis.

2.2. Sample preparation

Before use, all glassware and polypropylene containers were soaked for 24 hrs in 10% HNO_3 and washed several times with deionized water and dried.

The samples were thawed in the refrigerator (4 °C) overnight, skin and inedible parts were removed, and each sample was homogenized in a domestic food blender and digested with 10 mL conc. HNO_3 in closed vessels in a microwave accelerated system (CEM, Mars 6, USA) using the following microwave program: pressure, 800 psi; ramp time, 15 min; temperature, 200 °C; holding time, 10 min; maximum power, 800 W. After cooling, the residues were transferred to a 50 mL flask and diluted with deionized water. Reagent blank and quality control samples were prepared in the same manner and all samples were treated in duplicate.

2.3. Sample analysis

Samples were analyzed using an Atomic absorption Spectrophotometer (Varian 240 FS, Mulgrave, Australia). THg was analyzed using the cold vapor generation accessory (Varian VGA-77) and Cd was analyzed with the support of a graphite tube atomizer (Varian GTA-120). Standard solutions were prepared from 1000 mg/L stock solutions (Fluka, Switzerland) with appropriate dilution. All of the instrumental parameters were set according to the manufacturer's recommended procedure.

Duplicate sample analysis and certified Quality Control Samples (CQM) were used to verify the analytical method. Canned fish offal, T/07243, and canned crab meat, T/07279QC from the Food Analysis Performance Assessment Scheme, FAPAS, Sand Hutton, York, UK were used, and the results are given in Table 1. The Limit of Quantification (LOQ) was 0.07 mg/kg and 0.006 mg/kg wet weight for THg and Cd, respectively. In the THg and Cd analysis, the precision is expressed as the relative standard deviation of three replicate samples and the value was maintained at less than 10%.

Table 1
Obtained ±SD and certified concentrations (μg/kg, wet weight) in certified quality control materials (CQM).

CQM		THg	Cd
T/07243	Certified	707 (469–946)	800 (535–1065)
	Obtained	722.55 ± 50.58	782.40 ± 70.41
T/07279	Certified	106 (59–152)	7.55 (5.76–9.33)*
	Obtained	107.48 ± 6.45	7.40 ± 0.59*

* mg/kg, SD – standard deviation.

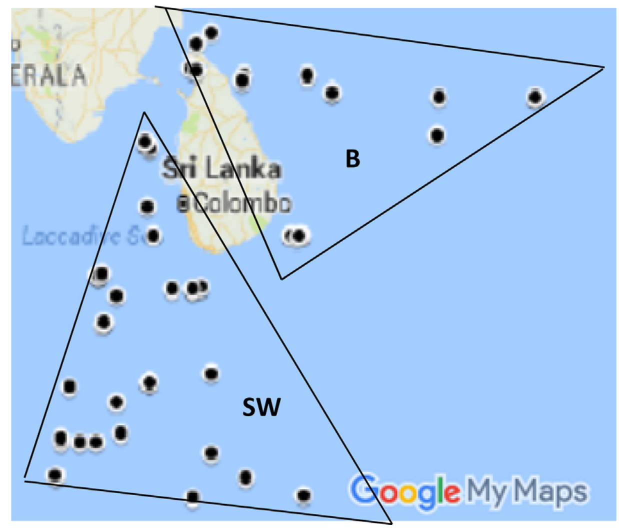

Fig. 1. Locations of sampling; B-Bay of Bengal Sea area, SW-South West Indian Ocean area.

2.4. Statistical analysis

SPSS 17 and curve expert 1.4 software were used for statistical

Table 2
Sample number, weight (kg), length (cm) of YFT and THg (mg/kg) and Cd (mg/kg) on a wet weight basis. The last column shows the results from one-way ANOVA tests on the differences between the fish from the Bay of Bengal and the South West Indian oceans.

Parameter	Bay of Bengal	SW Indian Ocean	Both areas	Comparison by site (*p*-value)
Number of samples	18	47	65	
Weight (kg)	50.9 ± 16.5 (32.0–91.6)	43.9 ± 12.4 (25.5–76.7)	45.9 ± 13.9 (25.5–91.6)	$p > 0.05$
Length (cm)	134 ± 30 (68–170)	120 ± 34 (64–180)	124 ± 33 (64–180)	$p > 0.05$
THg (mg/kg)	0.49 ± 0.33 (ND-1.35)	0.47 ± 0.37 (ND-1.60)	0.48 ± 0.35 (ND-1.60)	$p > 0.05$
Cd (mg/kg)	0.012 ± 0.008 (ND-0.033)	0.019 ± 0.027 (ND-0.134)	0.017 ± 0.024 (ND-0.134)	$p > 0.05$

The values are given as the mean ± SD (range), LOQ for Hg; 0.07 and Cd; 0.006 mg/kg, w/w.

Table 3
Comparison of the mean/range of THg (mg/kg) and sample information for YFT in the present study in comparison to other studies.

Origin	n	Length or weight	THg range (mg/kg)	THg, mg/kg (Mean ± SD)	Reference
Atlantic Ocean	13	96–145 cm	0.166–0.531	–	Besada et al. (2006)
Gulf of California	15	59–136 cm	<DL-0.23	0.03 ± 0.06	García et al. (2007)
Pacific Ocean (Baja California Sur)	68	54.6–94.2 cm	–	0.51 ± 0.33	Ordiano et al. (2011)
Pacific Ocean (Equatorial zone)	200	61.4–145.9 cm	–	0.98 ± 0.68	Ordiano et al. (2011)
Indian Ocean	10	97.07 ± 2.32 cm	–	0.245 ± 0.055	Nicklisch et al. (2017)
South Atlantic Ocean	14	29.0–50.8 kg	0.45–1.52	0.77	Bosch et al. (2016)
western-central Indian Ocean	5	133 ± 13 cm	–	0.375 ± 0.166	Bodin et al. (2017)
Ecuador	44	74–163 cm	0.005–6.0	1.4 ± 1.3	Araújo and Cedeño (2016)
Indian Ocean	140	64–173 cm	<0.07–0.98	0.30 ± 0.18	Jinadasa et al. (2014a)
Oman	346	–	0.01–0.570	0.0326 ± 0.087	Al-Busaidi et al. (2011)
Italy	61	–	0.254–0.430	0.35	Galimberti et al. (2016)
Indian Ocean (Mozambique Channel)	20	22 kg	–	0.13 ± 0.09	Kojadinovic et al. (2007a)
Indian Ocean (Reunion Island)	19	24 kg	–	0.21 ± 0.15	Kojadinovic et al. (2007a)
Indian Ocean (Bay of Bengal and South West Indian oceans)	65	64–180 cm	<0.07–1.60	0.48 ± 0.35	This study

SD – standard deviation.

analysis. Linear regression analysis and Pearson correlation coefficients were applied to measure the correlation between THg and Cd content with the length and weight of SF. The metal content among the different locations was found using one-way analysis of variance (ANOVA) followed by Levene's test.

3. Results and discussion

The accuracy of the capture coordinates (latitude and longitude) were assessed using a satellite-based vessel monitoring system (VMS) and the two main yellowfin tuna catching areas were identified as the Bay of Bengal area and the South West Indian Ocean area (Fig. 1).

Eighteen samples from the Bay of Bengal sea area and 47 samples from the South Western Indian Ocean area were collected for the study. The characteristics of morphological data of the YFT from both ocean areas are presented in Table 2. The average length and weight of YFT from the Bay of Bengal area (134 cm and 50.9 kg) were larger than the South West Indian Ocean area (120 cm and 43.9 kg), but the difference was not found to be statistically significant ($p > 0.05$).

The THg and Cd concentration in the dorsal white muscle of YFT was analyzed in the present study, since this tissue will provide the most accurate and robust estimate for the whole fish (Balshaw et al., 2008) and it represents the portion that is used for human consumption (Nicklisch et al., 2017).

The average and range of THg and Cd levels on a wet weight basis of the YFT samples are shown in Table 2. Mercury was detected in 60 samples but in the others the THg was below the detection limit (0.07 mg/kg). In the Bay of Bengal area, THg varied from ND-1.35 mg/kg (average THg, 0.49 ± 0.33 mg/kg), while in the South West Indian Ocean area the THg concentration varied from ND-1.60 mg/kg (average THg, 0.47 ± 0.37 mg/kg). The results revealed that the THg concentration was not significantly different ($p > 0.05$) between the sampling areas.

The THg concentration in the YFT indicated that the fish samples contained a high amount of THg in their muscle tissues. At the same time, a higher value for the coefficient of variation, 74.33%, indicates a higher variability, suggesting that many individuals have low levels of THg. The concentration of THg in the muscle of YFT for most of the individuals was below the permissible intake level, 1 mg/kg, as established by the European Commission Regulation 1881/2006. Among the analyzed samples, 5 individuals (7.7%) exceeded the 1 mg/kg value, 23 individuals (35.4%) were contaminated at 0.50–1.00 mg/kg, and only 19 individuals (29.2%) were below 0.25 mg/kg. A comparison of the THg values in YFT found in the present study with those found in the literature for the same species showed they were consistent, as demonstrated in Table 3.

In regard to the Cd level, no significant difference between the two catching areas was observed ($p > 0.05$). The mean Cd concentration found in fish from the Bay of Bengal area was 0.012 ± 0.08 mg/kg while the value for the other (South West Indian Ocean) area was 0.019 ± 0.027 mg/kg. Table 2 shows the Cd content of the YFT muscle samples. Only 2 samples (3.1%) exceeded the European Commission regulation limit for Cd in YFT (0.1 mg/kg). In general, the Cd concentration in YFT in our study was similar to or lower than the other studies conducted on fish caught in the same area; it was <0.001–0.09 mg/kg in the study of Jinadasa et al. (2014a). The range was 0.25 ± 0.21 mg/kg (d/w basis) in the Mozambique Channel (Indian Ocean) and 0.23 ± 0.20 mg/kg (d/w basis) in a study considering Reunion Island (Indian Ocean) carried out by Kojadinovic et al. (2007a). Araújo and Cedeño (2016) reported an average value of 2.4 ± 5.1 mg/kg Cd (w/w basis) for YFT captured along the Ecuadorian coast. This concentration is nearly 14 times higher than our values.

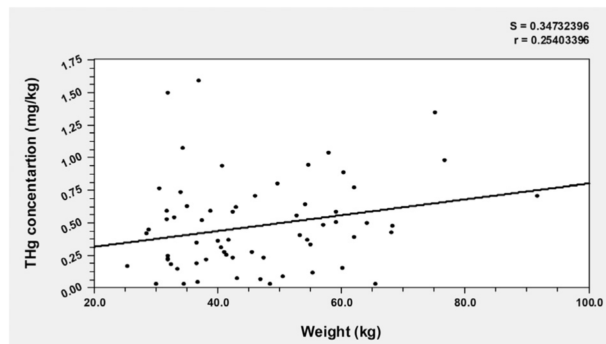

Fig. 2. Relationship between THg (mg/kg) concentration and the weight (kg) of YFT.

The correlations for the THg-length, Cd-length, and Cd-weight were weakly associated. However, a comparatively strong positive correlation was observed between the THg concentration and the weight of the fish. The linear fit model equations $y = a+bx$ ($a = 1.95E\text{-}001$ and $b = 6.08E\text{-}003$) showed a 0.25 correlation between the two parameters (Fig. 2). In a similar study by Bosch et al. (2016), they found a strong positive correlation ($r = 0.79$) between the weight and THg concentration of YFT. However, they only studied 14 samples. Similar results were found by Jinadasa et al. (2015) who analyzed 140 YFT samples from the Indian Ocean around Sri Lanka and reported correlations of 0.53 and 0.41 for weight and length, respectively. The bioaccumulation of nonessential trace metals such as Hg and Cd depends on a number of variables. Most probably, large individual variations can be observed within species-location subgroups (Kojadinovic et al., 2007a). Furthermore, Kojadinovic et al. (2007a) observed that the Cd level did not correlate with the fish length for YFT and the common Dolphin fish.

4. Conclusion

The results revealed that the YFT collected from two areas of the Indian Ocean near Sri Lanka considered for this study did not differ significantly in THg and Cd levels. A comparatively strong positive correlation was observed between the THg concentration and the weight of the fish. However, there was no clear relationship between the concentration of Cd and fish size. Furthermore, we can conclude that YFT from these two areas comply with the European Commission maximum allowable limits for Cd and Hg and that fewer than 10% of the samples exceeded the European Commission regulatory limits for Hg (1 mg/kg) and Cd (0.01 mg/kg).

Declarations

Author contribution statement

B.K.K.K. Jinadasa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

G.S. Chathurika: Conceived and designed the experiments; Performed the experiments.

G.D.T.M. Jayasinghe: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

C.D. Jayaweera: Conceived and designed the experiments; Analyzed and interpreted the data.

Funding statement

This work was supported as part of the annual research project, 2017 of National Aquatic Resources Research and Development Agency (NARA).

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors would like to express gratitude to Tropic Frozen Food (Pvt) Ltd., Ceylon Fresh Seafood (Pvt) Ltd. and Jay Sea Foods Processing (Pvt) Ltd. for providing the facility for sample collection.

References

Al-Busaidi, M., Yesudhason, P., Al-Mughairi, S., Al-Rahbi, W.A.K., Al-Harthy, K.S., Al-Mazrooei, N.A., Al-Habsi, S.H., 2011. Toxic metals in commercial marine fish in Oman with reference to national and international standards. Chemosphere 85, 67–73.

Araújo, C.V.M., Cedeño, M.L.A., 2016. Heavy metals in yellowfin tuna (*Thunnus albacares*) and common dolphinfish (*Coryphaena hippurus*) landed on the Ecuadorian coast. Sci. Total Environ. 541, 149–154.

ATSDR, 2017. ATSDR's Substance Priority List. Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/SPL/. (Accessed 20 December 2018).

Balshaw, S., Edwards, J.W., Ross, K.E., Daughtry, B.J., 2008. Mercury distribution in the muscular tissue of farmed southern bluefin tuna (*Thunnus maccoyii*) is inversely related to the lipid content of tissues. Food Chem. 111, 616–621.

Bella, D.G., Potortì, A.G., Lo Turco, V., Bua, D., Licata, P., Cicero, N., Dugo, G., 2015. Trace elements in *Thunnus thynnus* from Mediterranean Sea and benefit–risk assessment for consumers. Food Addit. Contam. B 8, 175–181.

Bella, G.D., Russo, E., Dugo, G., 2017. Heavy metals and persistent organic pollutants in marine organisms from two Sicilian protected areas: strait of Messina and Cape Peloro lakes. Curr. Org. Chem. 21, 387–394.

Besada, V., González, J.J., Schultze, F., 2006. Mercury, cadmium, lead, arsenic, copper and zinc concentrations in albacore, yellowfin tuna and bigeye tuna from the Atlantic Ocean. Cienc. Mar. 32, 439–445.

Bocher, P., Caurant, F., Miramand, P., Cherel, Y., Bustamante, P., 2003. Influence of the diet on the bioaccumulation of heavy metals in zooplankton-eating petrels at Kerguelen archipelago, Southern Indian Ocean. Polar Biol. 26, 759–767.

Bodin, N., Lesperance, D., Albert, R., Hollanda, S., Michaud, P., Degroote, M., Churlaud, C., Bustamante, P., 2017. Trace elements in oceanic pelagic communities in the western Indian Ocean. Chemosphere 174, 354–362.

Bosch, A.C., O'Neill, B., Sigge, G.O., Kerwath, S.E., Hoffman, L.C., 2016. Mercury accumulation in Yellowfin tuna (*Thunnus albacares*) with regards to muscle type, muscle position and fish size. Food Chem. 190, 351–356.

Corguinha, A.P.B., Souza, G. A. d., Gonçalves, V.C., Carvalho, C. d. A., Lima, W. E. A. d., Martins, F.A.D., Yamanaka, C.H., Francisco, E.A.B., Guilherme, L.R.G., 2015. Assessing arsenic, cadmium, and lead contents in major crops in Brazil for food safety purposes. J. Food Compos. Anal. 37, 143–150.

Damiano, S., Papetti, P., Menesatti, P., 2011. Accumulation of heavy metals to assess the health status of swordfish in a comparative analysis of Mediterranean and Atlantic areas. Mar. Pollut. Bull. 62, 1920–1925.

Dissanayake, D., Samaraweera, E., Amarasiri, C., 2008. Fishery and feeding habits of yellowfin tuna (*Thunnus albacares*) targeted by coastal tuna longlining in the north western and north eastern coasts of Sri Lanka. Sri Lanka J. Aquatic Sci. 13, 1–21.

Galimberti, C., Corti, I., Cressoni, M., Moretti, V.M., Menotta, S., Galli, U., Cambiaghi, D., 2016. Evaluation of mercury, cadmium and lead levels in fish and fishery products imported by air in North Italy from extra-European Union Countries. Food Control 60, 329–337.

García, H.J., Cadena-Cárdenas, L., Betancourt-Lozano, M., García-De-La-Parra, L.M., García-Rico, L., Márquez-Farías, F., 2007. Total mercury content found in edible tissues of top predator fish from the Gulf of California, Mexico. Toxicol. Environ. Chem. 89, 507–522.

IARC. 2018. IARC monographs on the evaluation of carcinogenic risk to human, (Vols. 1–123) https://monographs.iarc.fr/list-of-classifications-volumes/[Online]. [Accessed 2018/12/29.

Jinadasa, B.K.K.K., Edirisinghe, E.M.R.K.B., Wickramasinghe, I., 2014a. Total mercury, cadmium and lead levels in main export fish of Sri Lanka. Food Addit. Contam. B 7, 309–314.

Jinadasa, B.K.K.K., Edirisinghe, E.M.R.K.B., Wickramasinghe, I., 2015. Mercury concentration of muscle tissue and relationship with size of yellowfin tuna, *Thunnus albacares*, of the Indian Ocean. Eur. J. Appl. Econ. 2, 35–40.

Jinadasa, B.K.K.K., Edirisinghe, E.M.R.K.B., Wickremasinghe, I., 2013. Total mercury content, weight and length relationship in swordfish (*Xiphias gladius*) in Sri Lanka. Food Addit. Contam. B 6, 244–248.

Jinadasa, B.K.K.K., Ginigaddarage, P.H., Ariyawansa, S., 2014b. A Comparative quality assessment of five types of selected fishes collected from retail market in Sri Lanka. Adv. J. Food Sci. Technol. 2, 21–27.

Kojadinovic, J., Michel, P., Matthieu, L.C., Richard, P.C., Paco, B., 2006. Mercury content in commercial pelagic fish and its risk assessment in the Western Indian Ocean. J. Sci. Teach. Educ. 366, 688–700.

Kojadinovic, J., Michel, P., Matthieu, L.C., Richard, P.C., Paco, B., 2007a. Bioaccumulation of trace elements in pelagic fish from the Western Indian Ocean. Environ. Pollut. 146, 548–566.

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

Lan, K.W., Evans, K., Lee, M.-A., 2013. Effects of climate variability on the distribution and fishing conditions of yellowfin tuna *(Thunnus albacares*) in the western Indian Ocean. Clim. Change 119, 63–77.

NARA, 2016. Sri Lanka fisheries yearbook. NARA, Sri Lanka. Available online. www.nara.ac.lk.

Nicklisch, S.C.T., Bonito, L.T., Sandin, S., Hamdoun, A., 2017. Mercury levels of yellowfin tuna (*Thunnus albacares*) are associated with capture location. Environ. Pollut. 229, 87–93.

Nishida, T., 1992. Considerations of stock structure of yellowfin tuna (*Thunnus albacares*) in the Indian Ocean based on fishery data. Fish. Oceanogr. 1, 143–152.

Obaidat, M.M., Massadeh, A.M., Al-Athamneh, A.M., Jaradat, Q.M., 2015. Heavy metals in fish from the Red Sea, Arabian Sea, and Indian Ocean: effect of origin, fish species and size and correlation among the metals. Environ. Monit. Assess. 187, 218.

Ordiano, F.A., Galván, M.F., Rosiles, M.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.

Saager, P.M., 1994. The biogeochemical distribution of trace elements in the Indian Ocean. Proc. Indian Acad. Sci. Earth Planet Sci. 103, 237–278.

Schindler, D.E., Essington, T.E., Kitchell, J.F., Boggs, C., Hilborn, R., 2002. Sharks and tunas: fisheries impacts on predators with contrasting life histories. Ecol. Appl. 12, 735–748.

Storelli, M.M., Giacominelli-Stuffler, R., Storelli, A., Marcotrigiano, G.O., 2005. Accumulation of mercury, cadmium, lead and arsenic in swordfish and bluefin tuna from the Mediterranean Sea: a comparative study. Mar. Pollut. Bull. 50, 1004–1007.

Tri, H., Mohamad, S.M., Etty, R., Nazori, D., 2019. Mercury levels and tolerable weekly intakes (TWI) of tuna and tuna-like species from the Southern Indian Ocean (Indonesia): public health perspective. Biodiversitas 20, 504–509.

WHO, 2017. Mercury and Health [Online]. https://www.who.int/news-room/fact-sheets/detail/mercury-and-health. (Accessed 19 December 2018).