Total Mercury (THg) Concentration in Indian Scad (*Decapterus russelli*) and Torpedo Scad (*Megalaspis cordyla*) from Southern Waters of Binuangeun, Banten

Suratno[1*], Zahriza Purnadayanti[2], Hilda Novianty[1], and Selvia Oktaviyani[3]

[1]*Research Division for Natural Product Technology, Indonesian Institute of Sciences, Jl. Jogja-Wonosari Km 31.5, Gading, Yogyakarta 55861, Indonesia*

[2]*Department of Fisheries and Marine Science, Brawijaya University, Jl. Veteran, Ketawanggede, Malang 65145, Indonesia*

[3]*Research Center for Oceanography, Indonesian Institute of Sciences, Pasir Putih I, Ancol Timur, Jakarta 14430, Indonesia*

*** Corresponding author:**

tel: +62-274-392570
email: nanosan80@gmail.com

Received: June 17, 2020
Accepted: July 24, 2020

DOI: 10.22146/ijc.56967

Abstract: *The high level of fish consumption was the main factor in the vulnerability of Hg exposure to the human body. The preliminary information of the total mercury (THg) concentration of Indian scad (*Decapterus russelli*) and Torpedo scad (*Megalaspis cordyla*) from Binuangeun fish auction in Lebak, Banten, Indonesia, was presented in this research. The objective of this research was to understand the distribution of THg in each organ of* D. russelli *(muscle, gut tissues, gonad, and eggs) and* M. cordyla *(muscle, liver, and gut contents). The results showed that THg in all samples were below the National Regulation limit from the National Agency of Drug and Food in mg/kg ww. THg gonad from* D. russelli *was showed highly significant ($P < 0.01$) lower compare THg in muscle, gut tissues, and eggs. Pearson's correlation from THg in each organ of* D. russelli *compare to total weight and total length showed that concentration of THg in gonad highly significantly ($p < 0.01$) correlated with total body weight ($r^2 = 0.97$) and total length ($r^2 = 0.96$).* M. cordyla *was showed no correlation of THg in muscle compare to total length and total weight. The present study showed that* D. russelli *could accumulate higher mercury compare to* M. cordyla *and need caution while consuming this fish.*

Keywords: Decapterus russelli; Megalaspis cordyla; *total mercury concentration*

INTRODUCTION

Fishes are an essential source of protein, providing essential fatty acids, such as docosahexaenoic acid and eicosapentaenoic acid, which aid in reducing cholesterol levels and incidence of heart disease [1]. Although fish is beneficial to human health, human exposure to Hg can occur primarily through the consumption of fish and is a public health concern worldwide [2]. Human activities such as all activity related industries have significantly increased the input of heavy metals into the aquatic organism and may be further transferred to the trophic level [3].

Mahaffey states that in addition to fish consumption [4], it is suitable for humans, but fishes might also expose the human body to mercury (Hg). About 95% of methyl mercury (MeHg) from fish consumed will be absorbed in the human bloodstream within 4 to 14 h [5]. Maycock and Benford [6] explained that organic mercury (MeHg/EtHg) could easily pass through the plasma membrane compared with inorganic mercury. In the case of pregnant women, MeHg can directly transfer to the fetus through the placenta. The high level of fish consumption produced by fisheries was a factor in the vulnerability of Hg exposure to the human body. The threshold concentration of Hg in fish permitted by the National Agency of Drug and Food Control from the Indonesian Government [7] and JECFA [8] was 0.5 mg/kg wet weight and 1.0 mg/kg wet weight for predatory fish such as tuna, sharks and marlin.

One of the fisheries food products that are very popular in Indonesia was "pindang" (steamed fish), which used *Decapterus russeli* or *Decapterus kuroides* as the main ingredient of the product. In the production, generally, the organs have not been removed from the body of fishes. Besides, people commonly consumed the scad fish group, such as *Megalaspis cordyla,* as a source of protein for daily needs and then processed to be fried, grilled, or smoked fish. So far, information about total mercury (THg) concentration in fish consumed in Indonesian waters is still limited, especially from the Southern Java Sea. Therefore, to fill the information gap, this study has the aim to measure the total concentration of Hg (THg) in organs of *D. russelli* and *M. cordyla* from the Southern Waters of Binuangeun, Banten, Indonesia. Measurements were specified in the gut tissue, gonads, eggs, and muscle/meat of *D. russelli*, while for *M. cordyla*, the extraction of total mercury was in its muscle, liver, and gut content. The result was expected to be a piece of essential information to determine the potential of risk human consumption of these seafood products.

EXPERIMENTAL SECTION

Materials

Fish samples were obtained from the Binuangeun Fish Auction (latitude: -6.838101°, longitude: 105.883637°) in Lebak, Banten, in September 2019. Fifteen individuals of *D. russelli* and thirty individuals of *M. cordyla* were rinsed using clean water to remove dirt and directly placed in a zip-lock plastic bag and freeze until further analysis. In this study, the samples analyzed were meat, gonad, liver, eggs, digestive content, and digestive tract in the fish sample. The samples were taken to Biogeochemistry Laboratory at Research Center for Oceanography, Indonesian Institute of Sciences (RCO-LIPI). All reagents used were of analytical-reagent grade. The solutions prepared using ultra-pure water (Milli-Q). Mercury Standard solution 1.000 mg/L (Merck) and L-Cysteine from Nacalai Tesque Inc. Japan.

Instrumentation

Morphometric measurement was performed by a digital caliper and Sartorius BP 210 S analytical balance. Heraeus Oven Instrument was used to dry the samples and percentage of moisture content, mortar, pestle, spatula, petri dish, and Mercury Analyzer NIC MA-3000.

Procedure

Preparation samples

Measurement of total length (TL) have done using a digital caliper, while the measurement of total weight (TW) of fishes used a digital scale with the accuracy of two digits behind the comma (0.01 g). Each fish was separated from meat (muscle after the head of the fishes or near first dorsal fin), eggs, gonad, and digestive tract for *D. russelli* and muscle, liver, and digestive contents for *M. cordyla.* The fish samples were then dried at 60 °C for 24 h to obtain samples with a homogenous matrix [9].

Furthermore, the samples were mashed using a mortar to form a homogenous powder and stored in a desiccator until mercury analysis was performed. Measurement of moisture content has done by drying the sample at 105 °C for 24 h [10]. Water content was needed to convert the THg concentration from dry weight to wet weight.

Mercury analysis

The THg concentration was analyzed using the mercury analyzer (NIC-3000), Nippon Instrument Corporation, Japan at RCO-LIPI, in Jakarta. The main principle of mercury analyzer was thermal decomposition, amalgamation, and atomic absorption, according to USEPA 7473 [11]. Three replicates of dried organs from each sample were weighed less than 20 mg and directly inserted in the sample boat, and analyzed with a mercury analyzer for THg. Three replicates of Certified Reference Materials (DORM-4) have been used to check the recovery of the methods. The Hg concentration in the sample was displayed in µg mercury per kg of the sample's dry weight. The use of DORM4 as a control of the Hg measurement method showed 98.73% of the recovery.

Data analysis

Data analysis was performed by converting the THg concentration from dry weight to wet weight and changing its concentration unit from µg/kg dry weight (µg/kg dw) to mg/kg wet weight (mg/kg ww). All graphical plots based on the R program and statistical analysis expressed a p-value of less than 0.05, indicating a statistically significant difference.

■ RESULTS AND DISCUSSION

During the study, a total of 15 individuals of Indian Scad (*D. russelli*) and 30 individuals of Torpedo Scad (*M. cordyla*) were collected from Binuangeun Fish Auction, Banten. The total length of the Indian Scad ranged from 25.0–30.5 cm and 16.2–21.7 cm for Torpedo Scad. The total weight ranged from 124.74–235.57 g and 48.58–86.68 g for Indian Scad and Torpedo Scad, respectively (Table 1). All specimens of Indian Scad were mature or adult fish. According to Pralampita and Chodriyah [12], *D. russelli* achieve adults for males in a total length of 21.2 cm and females at 18.97 cm. Meanwhile, it different for Torpedo Scad, which had a total length lower than the size at maturity, which indicates that all species were immature or maturing fish. Based on Rahmayani [13], females M. *cordyla* mature in total length 28.0–28.4 cm and male at total length 32.1–32.6 cm.

Samples of *D. russelli* were separated into four parts of organs and labeled as meat/muscle, digestive tract/gut tissues, gonad, and eggs. Mercury concentration in muscle ranged from 0.120 to 0.431 mg/kg ww, gut tissues from 0.036 to 0.253 mg/kg ww, gonad ranged from 0.025 to 0.107 mg/kg ww, and eggs ranged from 0.068 to 0.227 mg/kg ww. The THg concentration in *D. russelli* muscle ($p < 0.05$) and gonad ($p < 0.01$) were showed statistically significant differences compared with other organs (gonad and eggs).

Samples of *M. cordyla* were divided into three parts of organs and labeled as muscle, liver, and gut contents. Mercury concentration in muscle ranged from 0.042 to 0.090 mg/kg ww, liver ranged from 0.012 to 0.051 mg/kg ww, and gut contents ranged from 0.007 to 0.054 mg/kg ww. The THg concentration in *M. cordyla* muscle shows a higher concentration ($p < 0.01$) compared to gut content ($p < 0.01$) and showed statistically significant differences compared to other organs (Fig. 1).

The THg concentration of D. *russelli* in gonad have shown a correlation with total length (TL) and total weight (TW) with statistically significant level $p < 0.01$, and THg concentration in the digestive tract (gut) shows statistically

Table 1. Morphometric of samples *D. russelli* and *M. cordyla* from Binuangeun Fish Auction in Banten

Local name/Common name	N	Scientific name	Total Weight (g)	Total length (cm)	Main food/Feeding habit/TL*)
Layang/Indian Scad	15	*Decapterus russelli*	124.74–235.57 (166.50 ± 28.79)	25.00–30.50 (26.97 ± 1.56)	Small fishes, zooplankton, zoobenthos/carnivorous/3.7*)
Selar Tetengkek/Torpedo Scad	30	*Megalaspis cordyla*	48.58–86.68 (70.92±10.60)	16.20–21.70 (20.08 ± 1.27)	Small fishes and crustacean, zooplankton, zoobenthos, detritus/carnivorous/4.4*)

*) based on Frose and Pauly (2019) [14], Tropic level (TL) based [2], mean ± SD from Total Weight (TW) and Total Length (TL)

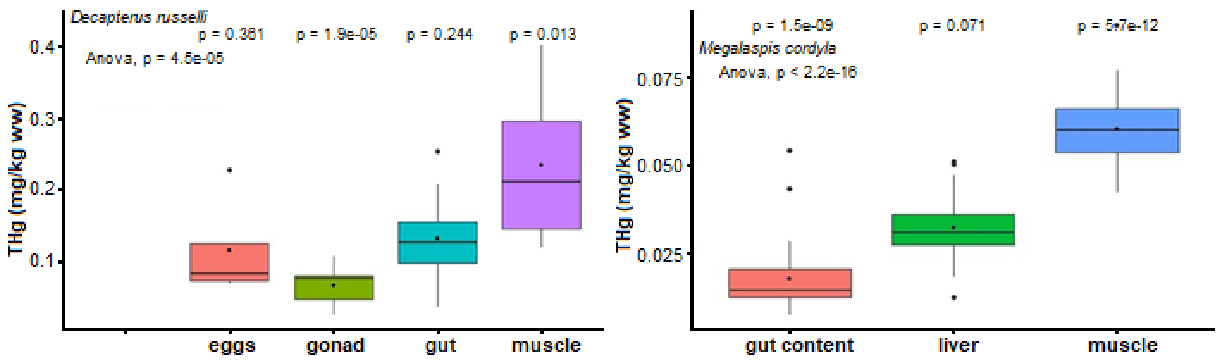

Fig 1. THg concentration (mg/kg ww) on *D. russelli* and *M. cordyla* organs. ● in the center of boxplot graphs indicate mean of THg in each organ

correlation with a total weight (TW) with significant level $p < 0.05$ (Fig. 2). Based on Fig. 2, THg concentration in the muscle of *D. russelli* from Binuangeun does not correlate with TL and TW.

Fig. 3 describes the mean of THg concentration in muscle, the average concentration of *D. russelli* was 0.21 mg/kg ww and *M. cordyla* 0.07 mg/kg ww and a highly statistically significant level $p < 0.001$. Based on this average, the concentration of THg in the muscle of *D. russelli* and *M. cordyla* were below the limit of the guidelines from the National Agency of Drug and Food Control, Indonesia (NADFC) [7] and JECFA/WHO [8] with the maximum value of 0.5 mg/kg ww THg; thus, was permitted for fish and fisheries products. According to Monperrus et al. [15], there is active transport of mercury within different organs, and the muscle is transferred in the last. Bridges and Zalups [16] and Mela et al. [17] explained that dietary mercury would be conveyed through a portal system after uptake in the intestine to the liver organ. Meanwhile, the concentration on fish's gonad and egg is related to maternally transfer of Hg that may impact survival, behavior, and development milestones of the embryo-larval stages of fish [18].

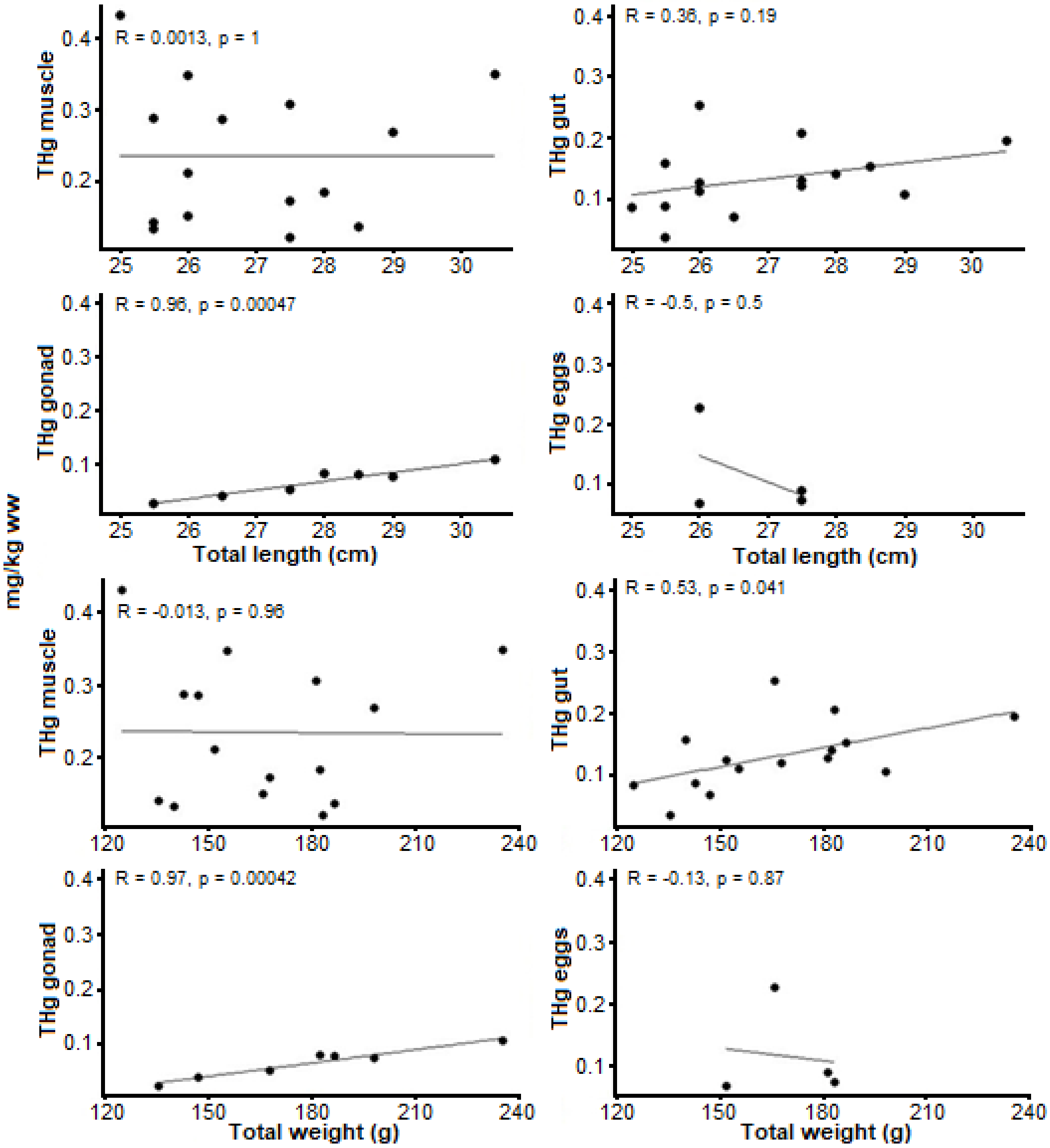

Fig 2. Relationship between total weight (TW) and total length (TL) vs THg (mg/kg ww) in *D. russelli* organs

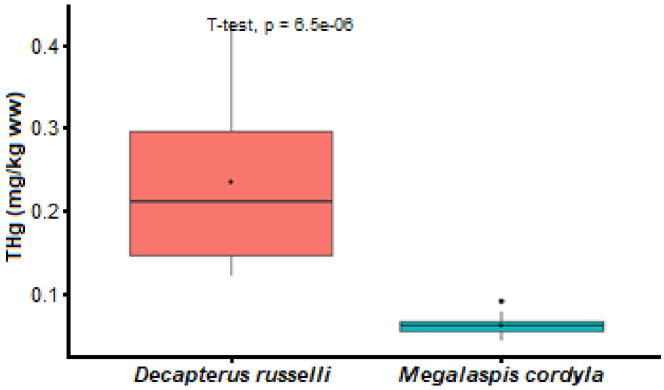

Fig 3. THg concentration (mg/kg ww) on *D. russelli* and *M. cordyla* from Binuangeun, Banten. ● indicates the mean of THg

The data from this study is reverse with previous studies [19-20] where the mercury concentration in fish with higher trophic levels (*M. cordyla*) were significantly lower than in fish with lower trophic levels (*D. russelli*) [2] (Fig. 3). The factor that relevant for mercury has found to be the bioaccumulation process based on its bioavailability and speciation of mercury ion, rate uptake [21] physiological and behavior of feeding habit differences between fish species [22], the biological activity of fishes, wetland runoff/source of pollution [23], habitat and season [24] and also their specific prey [25]. Both species were pelagic species found in inshore waters in-depth, not exceeding 100 m [26-27]. However, Pauly et al. [28] reported that *D. russelli* was also found in up to 275 m depth.

The origin of fish and migration patterns was also relevant factors for mercury to bioaccumulate in fish tissues [29]. The main factors were showed in this study probably a combination of specific prey (*M. cordyla* gut contents were *Stelephorus* sp. while *D. russelli* did not indicate specific prey in their gut tissues) and ages (*M. cordyla* was juvenile compare to *D. russelli* that already in adult size) of the samples were responsible for the differences of THg in this study compared to previous results (Table 2). Besides, Agah et al. [30] and Astani et al. [31] stated that trace concentration of mercury compounds in the fish body related to their concentration in the environment and fish condition, for instance, their size, age, sex, reproductive condition, diet, and trophic level.

Fig. 4 described that THg has a positive relationship, with the size (TW and TL) of all samples were indicating that THg will increase over time during the growth of fishes; bigger and longer fishes usually indicate a higher concentration of Hg [4,29,33-34]. The results have indicated a positive correlation between THg concentration and total weight (R^2: 0.77, $p < 0.01$) and total length (R^2: 0.78, $p < 0.01$) of fish samples from Binuangeun, Banten. The THg concentration in *D. russelli*

Table 2. Previous research publication of THg in *D. russelli* and *M. cordyla* outside Binuangeun area

Species and Σ samples (N)	Location	THg concentration	Reference
M. cordyla (3)	West Peninsular Malaysia	Muscle (0.207 ± 0.089 mg/kg ww)	[20]
D. russelli (1)	West Peninsular Malaysia	0.073 mg/kg ww	[20]
D. russelli (10)	Peninsular Malaysia	0.078-0.304 (0.195) mg/kg dw	[19]
M. cordyla (20)	Peninsular Malaysia	0.202-0.913 (0.319) mg/kg dw	[19]
M. cordyla	Palu Bay, Indonesia	Gills (0.033 mg/kg ww) Muscle (0.028 mg/kg ww) Liver (0.073 mg/kg ww)	[32]
M. cordyla (30)	Binuangeun, Banten	Muscle (0.060 ± 0.011 mg/kg ww) Liver (0.032 ± 0.008 mg/kg ww) Gut contents (0.017 ± 0.010 mg/kg ww)	This study
D. russelli (15)	Binuangen, Banten	Muscle (0.235 ± 0.097 mg/kg ww) Gut tissues (0.132 ± 0.056 mg/kg ww) Gonad (0.066 ± 0.028 mg/kg ww) Eggs (0.115 ± 0.075 mg/kg ww)	This study

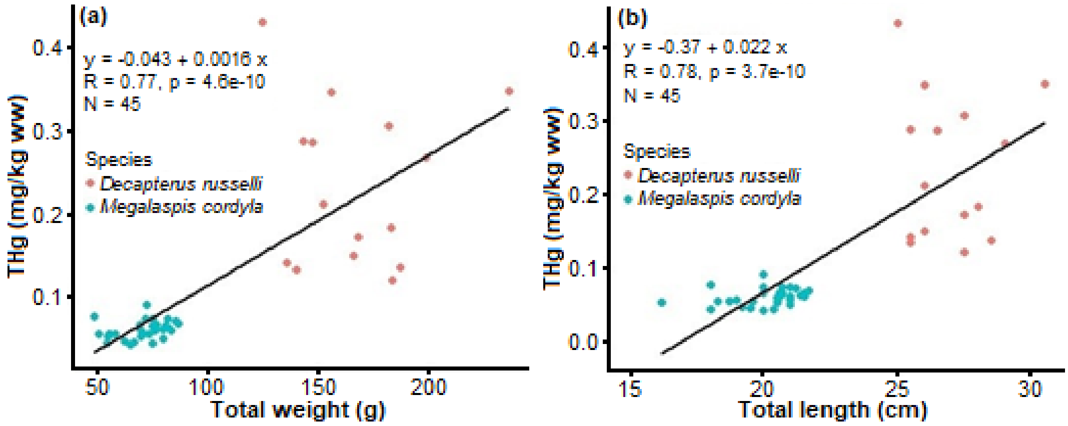

Fig 4. (a) Relationship between THg concentrations (mg/kg ww) on total weight (TW), (b) Relationship between THg vs. total length (TL) of fish samples from Binuangeun, Banten

and *M. cordyla* will contribute toward baseline data on THg in marine fish that are commonly caught and consumed in the Binuangeun area or West Java Sea near the Sunda Strait waters. This study shows lower THg concentration compared to the National Guideline from NADFC, but it would impact human health if the fishes consumed in excessive amounts.

CONCLUSION

This study measured total mercury (THg) in two species of small pelagic fishes from Binuangeun Fish Auction in Banten. The average THg concentration in the muscle (edible portion) of *D. russelli* was 0.21 mg/kg ww and *M. cordyla* 0.07 mg/kg ww. In general, THg concentration in all samples (muscle) was below permissible national and international mercury consumption guidelines (0.5 mg/kg ww for fish and fishery products). This study's results showed that THg in predator fish (*M. cordyla*) is lower than in *D. russelli* with low trophic levels. Further research is needed, which the specimens were analyzed has a large size range in order to assess the life cycle regarding total mercury concentration.

ACKNOWLEDGMENTS

Authors thanks to *Riset Prioritas* COREMAP CTI–LIPI No: B-5849/IPK.2/KP.06/VI/2019 Research Centre for Oceanography, LIPI year fiscal 2019 for funding and this publication was part of research on title Data Collection and Biological Aspects of Sharks and Rays that listed on Appendix CITES and Endangered Species. The authors would like to thank Mr Johan Picasouw (Rest in Peace) for assistance in the preparation sample from the location and laboratory.

AUTHOR CONTRIBUTIONS

S as the main contributor to the concept idea, data analysis, and drafted the manuscript, ZP, HN, and SO executed sample and drafted the manuscript.

REFERENCES

[1] Lim, T.O., Ding, L.M., Suleiman, A.B., Fatimah, S., Siti, S., Tahir, A., and Maimunah, A.H., 2000, Distribution of body weight, height and body mass index in a national sample of Malaysian adults, *Med. J. Malays.*, 55 (1), 108–128.
[2] Stergiou, K.I., and Karpouzi, V.S., 2002, Feeding habits and trophic levels of Mediterranean fish, *Rev. Fish Biol. Fish.*, 11 (3), 217–254.
[3] Reinfelder, J.R., Fisher, N.S., Luoma, S.N., Nichols, J.W., and Wang, W.X., 1998, Trace element trophic transfer in aquatic organisms: A critique of the kinetic model approach, *Sci. Total Environ.*, 219 (2-3), 117–135.
[4] Mahaffey, K.R., 2004, Fish and shellfish as dietary sources of methylmercury and the ω-3 fatty acids, eicosahexanoic acid, and docosahexaenoic acid: Risks and benefits, *Environ. Res.*, 95 (3), 414–428.
[5] Kershaw, T.G., Clarkson, T.W., and Dhahir, P.H., 1980, The relationship between blood levels and a

dose of methylmercury in man, *Arch. Environ. Health*, 35 (1), 28–36.

[6] Maycock, B., and Benford, D., 2007, Risk assessment of dietary exposure to methylmercury in fish in the UK, *Hum. Exp. Toxicol.*, 26 (3), 185–190.

[7] BPOM, 2018, *Batas Maksimum cemaran logam berat dalam pangan olahan*, Badan Pengawas Obat dan Makanan Republik Indonesia No. 5, Jakarta, 1–15.

[8] Codex Alimentarius, 2016, *General standard for contaminants and toxin in food and feed*, CODEX STAND 193-1995, 1–65.

[9] SNI, 2016, *Cara uji Kimia – Bagian 6: Penentuan kadar logam berat merkuri (Hg) pada produk perikanan*, SNI-01-2354.6, Badan Standardisasi Nasional-BSN, Jakarta, 1–15.

[10] SNI, 2006, *Cara uji Kimia – Bagian 2: Penentuan kadar air pada produk perikanan*, SNI-01-2354.2, Badan Standardisasi Nasional-BSN, Jakarta, 1–12.

[11] USEPA, 1998, *Method 7473: Mercury in solids and solution by thermal decomposition, amalgamation, and atomic absorption spectrophotometry*, https://www.epa.gov/sites/production/files/2015-07/documents/epa-7473.pdf.

[12] Pralampita, W.A., and Chodriyah, U., 2010, Aspek biologi reproduksi ikan laying (*Decapterus russelli*) dan ikan banyar (*Rastrelinger kanagurta*) yang didaratkan di Rembang, Jawa Tengah, *Bawal Widya Riset Perikanan Tangkap*, 3 (1), 17–23.

[13] Rahmayani, 2016, Biologi Reproduksi Ikan Tetengkek *Megalaspis cordyla* (Linnaeus, 1758) di Perairan Selat Sunda, *Undergraduate Thesis*, Institut Pertanian Bogor, Indonesia.

[14] Froese, R., and Pauly, D., 2019, FishBase, *World Wide Web electronic publication*, www.fishbase.org.

[15] Monperrus, M., Pécheyran, C., and Bolliet, V., 2020, Imaging differential mercury species bioaccumulation in glass eels using isotopic tracers and laser ablation inductively coupled plasma mass spectrometry, *Appl. Sci.*, 10 (7), 2463.

[16] Bridges, C.C., and Zalups, R.K., 2010, Transport of inorganic mercury and methylmercury in target tissues and organs, *J. Toxicol. Environ. Health Part B*, 13 (5), 385–410.

[17] Mela, M., Neto, F.F., Yamamoto, F.Y., Almeida, R., Grötzner, S.R., Ventura, D.F., and de Oliveira Ribeiro, C.A., 2013, Mercury distribution in target organs and biochemical responses after sub-chronic and trophic exposure to Neotropical fish *Hoplias malabaricus*, *Fish Physiol. Biochem.*, 40 (1), 245–256.

[18] Bridges, K.N., Soulen, B.K., Overturf, C.L., and Roberts, A.P., 2016, Embryotoxicity of maternally transferred methylmercury to fathead minnows (*Pimephales promelas*), *Environ. Toxicol. Chem.*, 35 (6), 1436–1441.

[19] Ahmad, N.I., Mohd Noh, M.F., Wan Mahiyuddin, W.R., Jaafar, H., Ishak, I., Wan Azmi, W.N.F., Veloo, Y., and Hairi, M.H., 2015, Mercury levels of marine fish commonly consumed in Peninsular Malaysia, *Environ. Sci. Pollut. Res.*, 22 (5), 3672–3686.

[20] Anual, Z.F., Maher, W., Krikowa, F., Hakim, L., Ahmad, N.I., and Foster, S., 2018, Mercury and risk assessment from consumption of crustaceans, cephalopods, and fish from West Peninsular Malaysia, *Microchem. J.*, 140, 214–221.

[21] Burger, J., Gaines, K.F., Boring, C.S., Stephens, W.L., Snodgrass, J., and Gochfeld, M., 2001, Mercury and selenium in fish from the Savannah River: Species, trophic level, and locational differences, *Environ. Res.*, 87 (2), 108–118.

[22] Al-Majed, N.B., and Preston, M.R., 2000, Factors influencing the total mercury and methyl mercury in the hair of the fishermen of Kuwait, *Environ. Pollut.*, 109 (2), 239–250.

[23] Kinghorn, A., Solomon, P., and Chan, H.M., 2007, Temporal and spatial trends of mercury in fish collected in the English–Wabigoon river system in Ontario, Canada, *Sci. Total Environ.*, 372 (2-3), 615–623.

[24] Saei-Dehkordi, S.S., Fallah, A.A., and Nematollahi, A., 2010, Arsenic and mercury in commercially valuable fish species from the Persian Gulf: Influence of season and habitat, *Food Chem. Toxicol.*, 48 (10), 2945–2950.

[25] Eagle-Smith, C.A., Suchanek, T.H., Colwell, A.E., and Anderson, N.L., 2008, Mercury trophic transfer in a eutrophic lake: The importance of habitat-specific foraging, *Ecol. Appl.*, 18 (Sp8), A196–A212.
[26] Smith-Vaniz, W.F., 1999, "Carangidae. Jacks and scads (also trevallies, queenfishes, runners, amberjacks, pilotfishes, pampanos, etc)" in *FAO Species Identification Guide for Fishery Purposes, the Living Marine Resources of the Western Central Pacific*, Vol. 4. Bony Fishes Part 2 (Mugilidae to Carangidae), Eds. Carpenter, K.E., and Niem, V.H., Food and Agriculture Organization of the United Nations, Rome, 2659–2756.
[27] Al Sakaff, H., and Esseen, M., 1999, Occurrence and distribution of fish species off Yemen (Guld of Aden and Arabian Sea), *Naga*, 22 (1), 43–47.
[28] Pauly, D., Cabanban, A., and Torres, Jr., F.S.B., 1996, "Fishery biology of 40 trawl-caught teleost of western Indonesia" in *Baseline Studies of Biodiversity: The Fish Resource of Western Indonesia*, Eds. Pauly, D., and Martusubroto, P., ICLARM, Manila, Philippines, 135–216.
[29] Gochfeld, M., Burger, J., Jeitner, C., Donio, M., and Taryn, P., 2012, Seasonal, locational and size variations in mercury and selenium levels in striped bass (*Morone saxatilis*) from New Jersey, *Environ. Res.*, 112, 8–19.
[30] Agah, H., Leermakers, M., Elskens, M., Fatemi, S.M.R., and Baeyens, W., 2007, Total mercury and methyl mercury concentrations in fish from the Persian Gulf and the Caspian Sea, *Water Air Soil Pollut.*, 181 (1), 95–105.
[31] Astani, E., Vahedpour, M., and Babaei, H., 2016, Organic and total mercury concentration in fish muscle and thermodynamic study of organic mercury extraction in fish protein, *Ecopersia*, 4 (3), 1517–1526.
[32] Paundanan, M., Riani, E., and Anwar, S., 2015, Kontaminasi logam berat merkuri (Hg) dan timbal (Pb) pada air, sedimen dan ikan selar tetengkek (*Megalaspis cordyla* L) di teluk Palu, Sulawesi Tengah, *JPSL*, 5 (1), 161–168.
[33] Seixas, T.G., Moreira, I., Malm, O., and Kehrig, H.A., 2013, Ecological and biological determinants of methylmercury accumulation in tropical coastal fish, *Environ. Sci. Pollut. Res.*, 20 (2), 1142–1150.
[34] Horvat, M., Degenek, N., Lipej, L., Tratnik, J.S., and Faganeli, J., 2014, Trophic transfer and accumulation of mercury in ray species in coastal waters affected by historic mercury mining (Gulf of Trieste, northern Adriatic Sea), *Environ. Sci. Pollut. Res.*, 21 (6), 4163–4176.