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Mercury levels and tolerable weekly intakes (TWI) of tuna and tuna-like species from the Southern Indian Ocean (Indonesia): Public health perspective

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Abstract. *Handayani T, Maarif MS, Riani E, Djazuli N. 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.* Tuna and tuna-like species are essential sources of protein for much of the world and provide employment in areas where fishing and processing are concentrated, as well as their value are confirmed as extremely valuable. However, their benefits may be overshadowed by the presence of mercury. The main objectives of the study were to analyze mercury content in tuna and tuna-like caught from Southern Indian Ocean related to its correlation with the weight of fish. The method used was linear regression and tolerable weekly intake (TWI) calculation. Mercury levels in yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) indicated significant variations with the level that ranged from 0.049 to 0.654 mg/kg across individual fish weight, while for tuna-like ranged from 0.014 to 1.908 mg/kg. All mercury levels in tuna not exceeded 1.0 mg/kg, while for tuna-like 7.3% (30 kg up), 27.3% (51 kg up) and 34% (51 kg up) for oilfish (*Lepidocybium flavobrunneum*), marlin (*Makaira indica*) and swordfish (*Xiphias gladius*) were exceeded of 1.0 mg/kg respectively. TWI calculation indicates that people who are not in high-risk categories (most adult and adolescents) may consume about 1,000 g of tuna a week and less than for tuna-like.

Keywords: Linear regression; mercury; tolerable weekly intake; tuna and tuna-like species

INTRODUCTION

Fish provide a healthful of dietary protein and are relatively low in cholesterol and high in omega-3 (n-3) fatty acid (USDA 2010). Fish consumption is known to have a beneficial effect on human health due to its nutrients, e.g., log chain n-3 polyunsaturated fatty acids that have beneficial effects on the neurodevelopment of children (Daniels et al. 2004; Mahaffey 2011). Tuna and tuna-like are considered comprised of many species, such as some species of tuna, swordfish, marlin including oilfish that are considered to be highly valuable. They support a large number of industries in many nations and generate more than the US $ 40 billion a year for the global economy from the total production of almost 5 million metric tons (Galand et al. 2016). In 2012, the volume of landed tuna worldwide rose to 4.6 million metric tons, consist of 71% from the Pacific Ocean, 18% and 10% are from Indian and Atlantic Ocean respectively (PARM 2016). Tuna and tuna-like play an important role in Indonesia economy, generate foreign exchange and provide protein intake for the coastal community. Export of tuna and tuna-like from Indonesia in 2014 was 206,555 ton in volume with almost 700.000 US$ (Galand et al. 2016).

Tuna fisheries are an important source of protein for most of the world. On the other hand, many studies have shown that mercury is bio amplified in the food chain, with high-tropic-level predatory species having higher mercury than herbivorous species (Nicklisch et al. 2017; Lacerda et al. 2017). Moreover, many studies advise that pregnant or soon to be a pregnant woman, infants and small children should limit eating tuna and tuna-like (EFSA 2015).

European Union Rapid Alert System for Food and Feed (EU RASFF) had reported tuna and tuna-like rejection due to mercury content yearly of which from 2014-2017 there are 99, 85, 98 and 133 cases of rejection respectively (EU Commission 2017). Tuna and tuna-like will be rejected if the total mercury content higher than 1.0 mg/kg. In 2001, the US FDA issued consumption advisory, based on mercury, that pregnant woman and women of childbearing age who may become pregnant should avoid eating four species of saltwater fish: shark, swordfish, king mackerel and tilefish (FDA 2001). However, study also shown that there is evidence of variation of mercury levels among oceans and countries, probably related to the source of the fishery, species and fish weight (Storelli et al. 2006; Lavoie et al. 2018).

A joint Expert Committee on Food Additives constitute has recommended provisional tolerable weekly intakes (PTWI) of mercury concentrate of 5,0 µg/kg of body weight (FAO/WHO 2014), of which an adult who weighs to 60 kg, maximum consumption of mercury about 300 µg in a week. Furthermore, study carried out by Okyere et al. (2015), found that highest mercury concentration obtained from tuna of 0.2 µg/g and an adult must consume about 1,500 g of tuna per week in order to accumulate 300 µg of mercury in a week which is the limit set by the Joint Expert Committee on Food Additives (FAO/WHO 2014). Although there are several published reports of mercury in fish, most studies have not distinguished between species tuna and tuna-like, as well as between weights within the same species from a trading or commercial perspective. The amount of mercury in fish is related to the age of fish and the position of the fish species within the food chain, predatory fish and older fish having a higher concentration than others (Mahaffey 2011; Sackett 2013). Thus, assessing the levels of mercury in tuna and tuna-like with different weight related to commercial and business as well as its PTWI of consumption is important from trading or commercial as well as public health perspective. The objectives of the study were to analyze mercury content in tuna and tuna-like related to the maximum level of rejection and its correlation with the weight of fish, as well as the calculation of provisional tolerable weekly intake (PTWI).

MATERIALS AND METHODS

Source of mercury levels data

The data were gathered from seven processing plants of tuna and tuna-like located in Jakarta Fishing Port-Jakarta, and Benoa-Bali, Indonesia where the tuna and tuna-like landed were caught from the Southern Indian Ocean. Those fish factories were processed tuna and tuna-like for export purposes mostly to US and EU countries in the form of loin, steak as well as a whole fish. Since those processing plant exported to EU and USA, the Indonesian competent authority required them to do monitoring of harmful substances, e.g. total mercury regularly, as requirements for hazard analysis critical control point (HACCP) implementation, EU approved establishments and HC issued. The sample taken shall be at random based on species, and weight of fish and mercury was analyzed in the ISO 17025 certified laboratory, equipped with atomic absorption spectrophotometer (AAS) analyzer.

Data analysis

Mercury concentration monitoring data from seven processing plants were gathered from 2012 to 2017, of which 758 total data were collected consists of 167 data, 126, 150, 150 and 165 for yellowfin tuna (*Thunnus albacares)*, bigeye tuna (*Thunnus obesus*), oilfish (*Lepidocybium flavobrunneum*), swordfish (*Xiphias gladius)* and marlin (*Makaira indica*) respectively. The weight of fish divided into two groups based on market and trading specification, for tuna (yellowfin and bigeye) and tuna-like (swordfish and marlin) were 1-10 kg, 11-30 kg, 31-50 kg, 51-100 kg and 100 kg up, while for oilfish were 1-5 kg, 6-10 kg, 11-15 kg, 16-30 kg and 30 kg up. The data were tabulated based on the classification of weight for each species and average (mean) of mercury level per processing factory to measure the correlation between mercury level and weight of fish; linear regression analysis was applied (Walpole 1982). PTWI values of mercury by an adult of 5 µg/kg body weight or equivalent to 300 µg of 60 kg body weight (recommend by FAO/WHO 2004) were calculated using the average value of mercury by each fish species. PTWI calculated using the formula : maximum accumulated mercury per week (300 µg) divided by a mean concentration of mercury of fish species.

RESULTS AND DISCUSSION

Total mercury content in tuna and tuna-like gathered from seven processing establishments located in Jakarta Fishing Port-Jakarta and Benoa-Bali consists of 167 data of yellowfin tuna and 126 of bigeye, while mercury content for tuna-like were 150, 150 and 165 data for oilfish, swordfish, and marlin respectively. The data were collected from monitoring mercury required by Indonesian Competent Authority carried out by processing plants from the year 2012-2017. The total mercury content gathered were classified analyzed based on the weight of fish used in trading and commercial practices. Based on data of total mercury collected could be divided into two categories which are total mercury in tuna (yellowfin and bigeye) and tuna-like (oilfish, swordfish, marlin, and mahi-mahi).

Total mercury in tuna

The mean concentration of mercury in a different weight of yellowfin are shown in Table 1. The mean mercury levels ranged from the lowest of 0.085 mg/kg to the highest of 0.654 mg/kg. There was a weak relationship between mercury content and weight of yellowfin tuna. The higher weight are not followed by the higher Hg concentration, of which the Hg contents fluctuated. Indeed, the fish with the highest concentration of 0.654 ppm had found from B weight (11-30 kg) of yellowfin, while for the highest weight E of yellowfin (100 up) the highest concentration was 0.408 mg/kg. The grand mean of mercury level of yellowfin weight was 0.175 mg/kg; 0.301 mg/kg; 0.247 mg/kg; 0.331 mg/kg and 0.298 mg/kg for A, B, C, D and E weight respectively. The rejection level of 1.0 mg/kg for tuna set by EU-FVO was no data exceeded the rejection level from 167 data gathered for yellowfin tuna.

The mean total mercury levels of bigeye in different weight are shown in Table 2. Total mercury level means ranged from the lowest of 0.049 mg/kg to the highest of 0.514 mg/kg. A trend of total mercury levels toward weight of bigeye tends to fluctuate and not increased toward the increase of the bigeye weight. The grand mean of mercury levels toward weight of bigeye were 0.096; 0.219; 0.279; 0.155 and 0.327 mg/kg for A, B, C, D and E weight respectively. The rejection level of 1.0 mg/kg for tuna set by EU-FVO was not exceeded by 126 data gathered for bigeye.

Table 1. The average of total mercury in yellowfin tuna (*Thunnus albacares*)

Weight (kg)	The average of total mercury mg/kg/processing plant							Grand mean	Median	N	Std dev
	1	2	3	4	5	6	7				
A (1-10)	0.170	0.108	0.248	0.154	0.204	0.212	0.126	0.175	0.170	31	0.050
B (11-30)	0.274	0.173	0.127	0.471	0.085	0.654	0.324	0.301	0.274	37	0.2033
C (31-50)	0.259	0.186	0.198	0.263	0.229	0.246	0.349	0.247	0.246	34	0.054
D (51-100)	0.163	0.514	0.185	0.376	0.152	0.615	0.312	0.331	0.312	35	0.182
E (100 UP)	0.303	0.261	0.280	0.279	0.408	0.173	0.381	0.298	0.280	28	0.078

Table 2. The average of total mercury in bigeye tuna (*Thunnus obesus*)

Weight (kg)	The average of total mercury mg/kg/processing plant							Grand mean	Median	N	Std dev
	1	2	3	4	5	6	7				
A (1-10)	0.092	0.135	0.060	NA	0.128	0.070	0.092	0.096	0.092	23	0.030
B (11-30)	0.263	0.237	0.172	0.228	0.191	0.186	0.259	0.219	0.228	31	0.037
C (31-50)	0.313	0.171	0.280	0.099	0.368	0.239	0.481	0.279	0.280	32	0.126
D (51-100)	NA	0.049	0.149	0.101	NA	0.271	0.206	0.155	0.149	19	0.087
E (100 UP)	0.514	0.139	NA	0.329	0.268	NA	0.386	0.327	0.329	21	0.139

Total mercury in tuna-like

The mean concentration of total mercury of oilfish in the different weight reis shown in Table 3. Total mercury level means ranged from the lowest of 0.014 mg/kg to the highest of 1,174 mg/kg. Contrarily to bigeye tuna, strong effects were observed when examining the impact of weight on mean mercury levels, where total mercury increased linearly toward the increase of the fish weight. The grand mean of mercury level of oilfish toward oilfish weight were 0.045; 0.121; 0.329; 0.513 and 1.026 mg/kg for A, B, C, D and E weight respectively. The rejection level of 1.0 mg/kg for oilfish set by EU-FVO was exceeded by 11 out of 150 data gathered for oilfish (7.3%).

The mean levels of total mercury of swordfish in the different weight of fish are shown in Table 4. Total mercury level means ranged from the lowest of 0.056 mg/kg to highest of 1.657 mg/kg. A trend of total mercury levels toward the weight of swordfish was increased significantly and linearly against increase of the fish weight. The grand mean of mercury concentrations related to the weight of fish was 0.163; 0.569; 0.723; 1.271 and 1.606 mg/kg for A, B, C, D and E weight respectively. The rejection level of 1.0 mg/kg for swordfish set by EU-FVO was exceeded by 51 (34%) out of 150 data gathered for swordfish.

The mean concentration of total mercury in the different weight of marlin are shown in Table 5. The average of total mercury levels ranged from the lowest of 0.014 mg/kg to the highest of 1.908 mg/kg. A similar increasing trend of total mercury level with swordfish weight was also observed in marlin, of which total mercury increased significantly towards the increase of the fish weight. The grand mean of mercury levels related to the fish weight of marlin were 0.052; 0.172, 0.702; 1.451 and 1.895 mg/kg for A, B, C, D and E weight respectively. The rejection level of total mercury for marlin fish set by EU FVO was 1.0 mg/kg, where from 165 data gathered, 45 (27.3 %) data were exceeded.

Total mercury levels in yellowfin tuna and bigeye were ranged from 0.085-0.649 mg/kg and 0.49-0.514 mg/kg respectively. On the other hand, the level of total mercury in tuna-like ranged from 0.014-1.174 mg/kg, 0.056-1.657 mg/kg and 0.014-1.908 mg/kg for oilfish, swordfish, and marlin respectively. The mercury levels found in tuna (yellowfin and bigeye) tends to be lower compared to other tuna-like (swordfish, oilfish, and marlin). It is possibly due to differences in feeding habits, growth rate and tropics position (Bosch et al. 2016; Drevnick et al. 2015). Many studies have shown that mercury is bio-amplified in the food chain with high-tropic-level predatory species (such as shark, swordfish, and marlin) having higher mercury (Nicklisch et al. 2017), of which tuna-like are a greedier predator in their eating habits compared to tuna. Differences in feeding habit also dictate Hg levels in fish (Hosseini et al. 2014). According to Gobert et al. (2017), as the top predator, swordfish may be the end reservoir of the bioaccumulation of trace elements in a food chain because they occupy higher trophic levels and are an important food source, causing swordfish to be potentially hazardous to consume. Swordfish is considered apex predator and carry out very intensive metabolic activities that require a continuous supply of energy, and the rate of predation and food consumption is extremely high, which contributes notably to the accumulation of pollutants (Storelli et al. 2005). These data are also parallel with the rejection of fish products due to mercury content in European Union, of which in year 2016-2017, swordfish 71 and 82 cases, marlin 6 and 7 cases, and 1 and 3 cases for yellowfin from 100 and 117 cases fish products rejected respectively (EU Commission 2017).

The National Marine Fisheries Service (1978) measured total mercury in 250 individuals of several species of tuna, yielding a median of 0.12 mg/kg and a maximum of 0.87

mg/kg. However, some studies on total mercury in tuna shown that total Hg was at a higher level, Plessi et al. (2001) reported an average of 0.249 in bluefin tuna, 0.85-1.45 mg/kg in albacore from the Mediterranean (average 1.17 mg/kg) with 78% exceeding 1.0 mg/kg. Storelli et al. (2002) and Dezfouli et al. (2018) reported levels of mercury in canned tuna from the Persian Gulf of 0,074 to 0,311 mg/kg. Moreover, there is evidence of variation among oceans and countries, probably related to the source of the fishery, species and fish weight.

The effect of tuna and tuna-like weight on total mercury levels

To measure the correlation between total mercury levels and the weight of tuna and tuna-like, linear regression analyses were applied. Yellowfin and bigeye ranged in weight from 1-10 kg (A weight) to 100 up kg (E weight), and grand mean of total mercury levels are weakly associated with the weight ($R2 = 0.0839$ and $R2 = 0.0784$), as shown in Figure 1.

The weight of both tuna species did not affect total mercury levels. The grand mean of total mercury in all weight of yellowfin and bigeye were not exceeded 0.5 mg/kg, and 1.0 mg/kg as the maximum permitted a level of mercury in fish (tuna) for safe consumption set by many countries including EU-FVO (EU 2006).

A weak correlation was also found by Nicklisch et al. (2017) that fish ranged in length from 52.32 cm (10.1 kg) to 139.5 cm (186 kg) and methyl mercury levels were weakly associated. A similar weak relationship has been observed between mercury concentration and length of bluefin tuna (Colman et al. 2015). In contrast, a strong effect was observed when examining the impact of mercury level on swordfish and marlin fish weights ranged from A weight (1-10 kg) up to E weight (100 kg up). Total mercury levels were increased significantly and strongly correlated with the increment of the fish weight ($R2 = 0.9602$ and $R2 = 0.9059$) as shown in figure 2. The linear regression equation shows that the weight above of 50 kg (D weight) for swordfish and marlin have mercury levels tends to exceed of 1.0 mg/kg as a maximum permitted level of mercury level set by some countries including EU-FVO.

The mercury levels and weights of oilfish ranged from 1-5 kg (weight) up to 30-50 kg (E weight) were correlated as shown in Figure 3. ($R2 = 0.9063$). The higher weight will increase the levels of mercury, although the mercury levels of both species are much lower compare to swordfish and marlin. Mercury levels of the biggest oilfish (30-50 kg) tend to exceed 1.0 ppm as the maximum permitted mercury levels set by some countries including EU-FVO (EU 2006).

Table 3. The average of total mercury in oilfish (*Ruvettus pretiosus*)

Weight (kg)	The average of total mercury mg/kg/Processing plant							Grand mean	Median	N	Std dev
	1	2	3	4	5	6	7				
A (1-5)	0.014	0.014	0.056	0.105	0.043	NA	0.036	0.045	0.040	31	0.034
B (6-10)	0.149	0.116	0.132	0.123	0.112	NA	0.095	0.121	0.120	32	0.018
C (11-15)	0.321	0.336	0.299	0.363	0.359	NA	0.296	0.329	0.329	29	0.029
D (16-30)	0.375	0.556	0.560	0.527	0.410	NA	0.647	0.513	0.542	30	0.102
E (30 UP)	1.174	1.135	0.966	0.865	0.992	NA	NA	1.026	0.992	28	0.127

Table 4. The average of total mercury in swordfish (*Xiphias gladius*)

Weight (kg)	The average of total mercury mg/kg/processing plant							Grand mean	Median	N	Std dev
	1	**2**	**3**	**4**	**5**	**6**	**7**				
A (1-10)	0.156	0.264	0.261	0.098	0.144	0.163	0.056	0.163	0.156	31	0.077
B (11-30)	0.598	0.522	0.679	0.383	0.701	0.785	0.314	0.569	0.598	32	0.173
C (31-50)	0.756	0.696	0.903	0.463	0.795	NA	NA	0.723	0.756	27	0.164
D (51-100)	1.344	1.573	1.657	0.963	1.231	0.963	1.165	1.271	1.231	34	0.273
E (100 UP)	1.592	1.648	1.606	1.593	NA	1.605	1.589	1.606	1.599	26	0.022

Table 5. The average of total mercury in marlin (*Macaira indica*)

Weight (kg)	The average of total mercury mg/kg/processing plant							Grand mean	Median	N	Std dev
	1	**2**	**3**	**4**	**5**	**6**	**7**				
A (1-10)	0.058	0.014	0.048	0.062	0.048	0.042	0.090	0.052	0.048	34	0.023
B (11-30)	0.179	0.149	0.171	0.166	0.174	0.180	0.188	0.172	0.174	40	0.013
C (31-50)	0.842	0.692	0.657	NA	0.682	0.724	0.616	0.702	0.687	35	0.078
D (51-100)	1.682	0.986	1.350	1.854	1.389	1.446	NA	1.451	1.418	32	0.299
E (100 UP)	1.902	1.896	1.908	1.882	NA	1.890	1.889	1.895	1.893	24	0.010

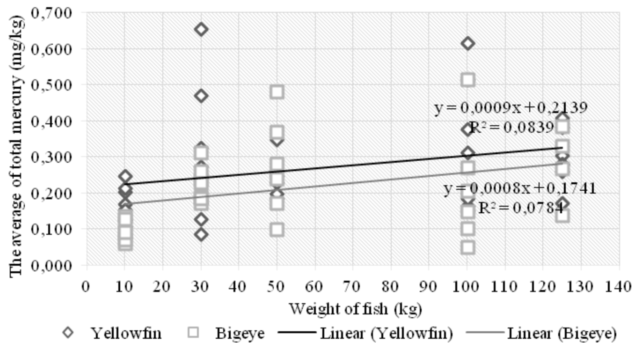

Figure 1. Correlation between mercury concentration and weight of yellowfin and bigeye

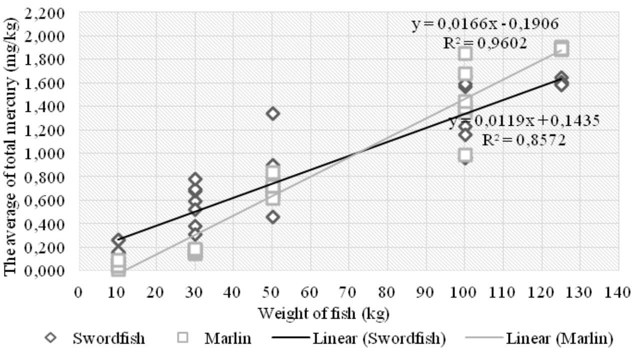

Figure 2. Correlation of between mercury concentration and weight of swordfish and Marlin

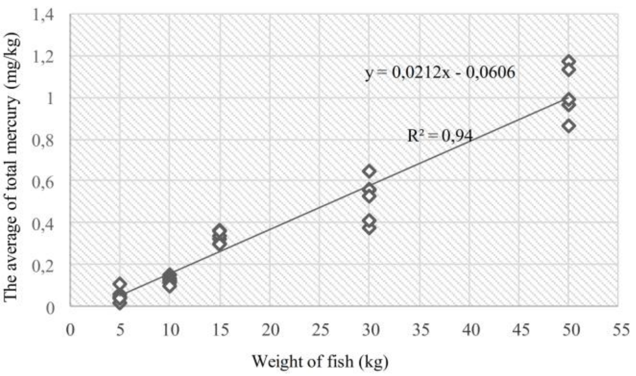

Figure 3. Correlation of between mercury concentration and weight of oilfish

Provisional tolerable weekly intake

A joint FAO/WHO expert committee has recommended a provisional tolerable weekly intake (PPTWI) of mercury at the concentration of 5 µg/kg body weight. For an adult weighing 60 kg, maximum mercury accumulation per week is 300 µg (WHO 2014). The highest mercury levels grand mean of yellowfin and bigeye were 0.331 and 0.327 mg/kg respectively, of which below 1.0 mg/kg as the maximum permitted levels set by many countries including EU-FVO. Tolerable weekly intake (PTWI) for tuna (yellowfin and bigeye) with the highest mercury levels of 0.33 mg/kg, the maximum consumption is about 909 g, with maximum consumption about 714 g per week in order to accumulate 300 µg of mercury in a week which is the limit set by FAO/WHO expert committee on food additive. These mean that for oilfish with weight lower than 30 kg which has lower mercury concentrations, can be consumed more than 714 g per week before exceeding the PTWI. The highest concentrations of oilfish, swordfish, and marlin were 1.026; 1.606 and 1.895 mg/kg respectively, where weight 30 kg up for oilfish and 50 kg up for swordfish and marlin tend to exceed the mercury levels of 1.0 ppm as a maximum level set by many countries.

The grand mean mercury levels of oilfish lower than 30 kg are 0.513 mg/kg and for swordfish and marlin lower than weight 50 kg were 0.723 and 0.702 mg/kg. Maximum consumption of oilfish per week is about 600 g and 400 g for swordfish and marlin and can be higher for fish weight lower than 50 kg before exceeding PTWI.

In conclusions, the meat fish is highly appreciated for being tender and delicious and for the beneficial influence of its nutrient: high-quality protein, n-3 fatty acids, vitamins, and minerals. However, consumption of large predatory fish (tuna and tuna-like) may place an individual at risk of serious illness due to high levels of mercury. It has been shown that mercury level in tuna (yellowfin and bigeye) were substantially lower than in tuna-like (swordfish, marlin, and oilfish), whereas all mercury levels in tuna did not exceed 1.0 mg/kg and the weight of tuna species does not affect mercury contents. These data, particularly for mercury in tuna-like (swordfish, marlin, and oilfish), indicate the desirability of instituting a regular monitoring program for exported and consumed products. PTWI calculation indicates that people who are not in high-risk categories (most adult and adolescents) may consume about 1,000 g of tuna per week and lesser for tuna-like (swordfish, oilfish, and marlin). Pregnant or soon to be pregnant women, infants, and small children should limit tuna-like intake and select tuna rather than tuna-like. It is highly recommended that intensive monitoring program of mercury levels for tuna-like (swordfish, marlin, and oilfish) should be carried out both by processing plants and governments authority for the continuation of trading, industries and in the prespective of public health.

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