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Trace Element Accumulation and Tissue Distribution in the Purpleback Flying Squid *Sthenoteuthis oualaniensis* from the Central and Southern South China Sea

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Abstract *Sthenoteuthis oualaniensis* is a species of cephalopod that is becoming economically important in the South China Sea. As, Cd, Cr, Cu, Hg, Pb, and Zn concentrations were determined in the mantle, arms, and digestive gland of *S. oualaniensis* from 31 oceanographic survey stations in the central and southern South China Sea. Intraspecific and interspecific comparisons with previous studies were made. Mean concentrations of trace elements analyzed in arms and mantle were in the following orders: Zn > Cu > Cd > Cr > As > Hg. In digestive gland, the concentrations of Cd and Cu exceed that of Zn. All the Pb concentrations were under the detected limit.

Keywords Cephalopods · The South China Sea · Trace element · Bioaccumulation

Introduction

The central and southern South China Sea is a vast area located off coasts of the Philippines, Vietnam, and Malaysia. With more than 600 reefs, islets, atolls, cays, and islands [19], it is abundant in the variety of marine species [32]. The fishery of this area is economically important to the surrounding countries like China, Vietnam, and the Philippines [35, 57]. However, there have been few papers concerning about the marine environment of the South China Sea, especially trace element accumulation in the living organisms at present.

Cephalopods have been of great interest worldwide. As an important ecosystem component, cephalopods influence not only their higher predators, such as sea birds, cetaceans, seals, and other top predators [4, 9, 12, 24, 59], but also their own prey, such as fish, crustaceans, and cephalopods themselves [3, 56, 71]. Embracing their functions as consumers, providers, and transporters of various chemicals and energy [10], cephalopods are significant in marine trophic chains. Cephalopods are sensitive to environment changes [45]. In addition, they have relatively shorter life span but higher concentration of trace elements compared with other marine species [34, 62].

Previous studies have also demonstrated the large influence of environmental factors on cephalopods, i.e., habitat and diet which would influence the trace element absorption and accumulation. Hence, cephalopods have been viewed as reliable biomonitor species in their marine environment [15, 23, 44, 46, 47].

In the South China Sea lives the purpleback flying squid *Sthenoteuthis oualaniensis*, which is an oceanic squid of the Ommastrephidae family [38, 58]. It is widely distributed in the Pacific and Indian Ocean [38, 53, 70], which is often caught by hook and line with light during the night. Its life span is as short as 0.5–1 year [39, 40, 65].

This study is the first to investigate trace elements (As, Cd, Cr, Cu, Hg, Pb, and Zn) in the mantle, arms, and digestive gland of *S. oualaniensis* from the central and southern South China Sea and to compare the concentrations of these trace elements in these squids with those in squids of the same family from other waters around the world.

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Materials and Methods

Sampling

Thirty-one oceanographic survey stations were distributed from 5° to 16° N latitude and from 110° to 117° E longitude as shown in Fig. 1.

Specimens were captured during cruises aboard the "NANFENG" RV in March–April, June, and October 2013, initiated by the South China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences. More than five individuals were caught at each station with dip nets and hand lines with jigs. Once captured, the squids were immediately frozen in individual plastic bags and kept at −20 °C until later analysis to minimize the mobilization of trace elements among tissues [29]. The specimens were thawed, measured (length and weight of the mantle), and dissected. Mantle (without skin and inner membrane), arms (with skin and suckers), and digestive gland were separated, weighted, freeze-dried, and homogenized. Normally, samples were pooled for squids of similar size from each station. Mantle length and captured date of purpleback flying squid from 31 survey stations of central and southern South China Sea are shown in Table 1.

Analysis of Trace Elements

Approximately, 500 mg of the dry tissue was digested with 8 mL high-purity HNO_3 (Guangzhou Chemical Reagent Factory, Guangzhou, China) and microwaved (CEM, MARS 5, USA) at 800 W for 15 min. After cooling down to room temperature, the acid was removed from the samples by evaporation and the residues (1–2 mL) diluted in Milli-Q water. All labware was cleaned with HNO_3 and rinsed with Milli-Q water. Concentrations of Cr, Cu, Zn, Cd, and Pb were determined either by flame atomic absorption spectrometry (AA240FS, Varian, USA) or by graphite furnace atomic absorption spectrometry (AA240Z, Varian, USA), depending on the trace element concentrations. Analysis of As and Hg were determined by AFS-9230 dual-channel atomic fluorescence spectrophotometer (Jitian, China). To evaluate the accuracy and precision of the analytical methodology, national certificate standards (GBW10024 (scallop), China) and blanks were run in parallel with the samples. Obtained values and certified values did not differ significantly at 95 % confidence level (Table 2). Detection limits for Cr, Cu, Zn, total As, Cd, total Hg, and Pb were 0.05, 0.07, 0.05, 0.05, 0.007, 0.01, and 0.012 μg g^{-1}, respectively.

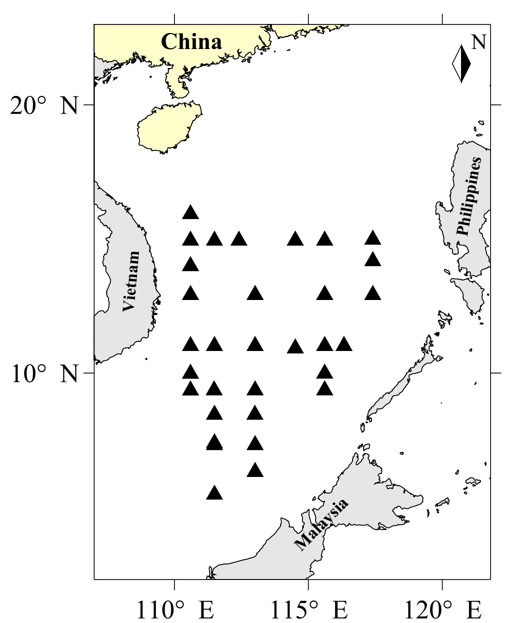

Fig. 1 Locations of oceanographic survey stations in the central and southern South China Sea

Statistical Analysis

Statistical analysis was performed using SPSS 19.0 (IBM, USA). Trace element concentrations were transformed in dried weight as mean ± standard deviation. One-way ANOVA was used to assess significant differences of the target tissues, the specimen length, weight, and the season on the concentration of various trace elements. The Pearson correlation coefficient was used to estimate the strength of association between trace element concentrations in each tissue and concentrations of each trace element in the three tissues.

Result and Discussion

The mantle length and total weight of *S. oualaniensis* captured in the 31 oceanographic survey stations of the central and southern South China Sea ranged within the intervals 70.0–228.5 mm and 35.07–405.91 g, respectively. Concentrations of As, Cd, Cr, Cu, Hg, and Zn in mantle, arms, and digestive gland of *S. oualaniensis* captured in the central and southern South China Sea have been detected. The concentration of Pb is not presented because all samples displayed values below the limit of detection.

Cephalopods are an important source of food for humans, especially for people who live in coastal areas. Trace element levels in cephalopods have attracted pervasive interest these years. Numerous researches have demonstrated the ability of cephalopods to accumulate high concentrations of trace elements in their tissues, especially the high Cd concentration in the digestive gland [17, 48, 64, 66]. Thus, the squid can be a significant source of trace element, essential or toxic, for human beings.

Table 1 Mantle length, total weight, and captured date of 31 dates from central and southern South China Sea

Station number	Mantle length (mm)	Total weight (g)	Date of sampling	Latitude(°N)	Longitude(°E)
1	95.0 ± 2.1	127.5 ± 9.6	March 6, 2013	16° 33′ 0	110° 12′ 4
2	78.0 ± 1.3	90.6 ± 7.2	March 8, 2013	14° 12′ 3	110° 11′ 9
3	82.0 ± 3.2	113.0 ± 7.1	March 9, 2013	9° 45′ 7	110° 23′ 7
4	72.0 ± 2.2	53.4 ± 10.6	March 11, 2013	10° 31′ 6	111° 12′ 3
5	84.5 ± 5.1	69.7 ± 9.1	March 13, 2013	9° 22′ 1	110° 10′ 7
6	91.3 ± 2.6	156.9 ± 24.1	March 15, 2013	9° 24′ 5	111° 13′ 5
7	163.0 ± 23.1	280.7 ± 59.3	March 16, 2013	8° 33′ 4	110° 09′ 3
8	86.5 ± 11.0	150.9 ± 70.1	March 18, 2013	10° 30′ 8	110° 06′ 1
9	90.0 ± 3.9	167.2 ± 49.1	March 20, 2013	5° 23′ 9	111° 15′ 7
10	225.5 ± 6.7	377.6 ± 29.7	March 21, 2013	6° 22′ 7	111° 13′ 9
11	165.0 ± 10.9	257.3 ± 57.1	March 22, 2013	7° 46′ 4	112° 21′ 1
12	92.0 ± 5.6	106.7 ± 26.7	March 23, 2013	8° 37′ 8	113° 39′ 0
13	88.0 ± 2.6	49.6 ± 31.0	March 24, 2013	9° 49′ 7	112° 22′ 9
14	79.0 ± 4.5	86.9 ± 12.3	March 26, 2013	11° 22′ 4	116° 15′ 7
15	95.0 ± 2.8	159.1 ± 37.2	March 28, 2013	11° 26′ 7	114° 23′ 4
16	218.0 ± 13.1	376.0 ± 29.2	March 30, 2013	11° 12′ 5	113° 32′ 1
17	91.0 ± 3.7	126.3 ± 63	April 4, 2013	13° 56′ 0	117° 11′ 1
18	79.5 ± 5.4	46.8 ± 26.3	April 5, 2013	15° 11′ 1	117° 13′ 0
19	88.0 ± 3.4	51.7 ± 5.7	April 7, 2013	14° 23′ 2	115° 21′ 4
20	213.5 ± 23.6	386 ± 18.4	April 9, 2013	15° 19′ 6	114° 45′ 7
21	209.5 ± 11.3	370.9 ± 35.0	April 11, 2013	15° 34′ 7	112° 17′ 4
22	67.6 ± 2.4	29.6 ± 5.5	April 14, 2013	15° 33′ 9	111° 11′ 3
23	80.0 ± 3.5	95.3 ± 46.2	June 3, 2013	11° 25′ 6	116° 17′ 9
24	225.0 ± 13.9	340.2 ± 40.9	June 6, 2013	14° 43′ 7	110° 12′ 2
25	149.5 ± 12.5	220.6 ± 31.6	June 9, 2013	15° 16′ 4	111° 12′ 0
26	87.5 ± 10.6	150.9 ± 56.3	October 10, 2013	14° 38′ 7	110° 17′ 7
27	208.2 ± 20.3	357.9 ± 38.6	October 16, 2013	14° 42′ 5	115° 24′ 3
28	153.0 ± 6.7	240.6 ± 64.2	October 19, 2013	15° 41′ 6	114° 23′ 4
29	92.0 ± 5.1	109.3 ± 26.4	December 5, 2013	6° 21′ 9	111° 11′ 2
30	115.2 ± 8.7	200.4 ± 34.9	December 9, 2013	7° 32′ 9	112° 19′ 3
31	89.6 ± 6.9	67.3 ± 16.9	December 15, 2013	9° 51′ 1	112° 18′ 6

However, there are few research papers concerned on the trace element levels of cephalopods *S. oualaniensis* in the South China Sea, while the commercial application of the squid is thriving. Thus, it is important to know the trace element levels in *S. oualaniensis* in the South China Sea.

Furthermore, according to previous studies, the concentration of trace elements in cephalopods is influenced by not only endogenous (biological) factors but also exogenous (environmental) ones. In addition, different elements may have different pathways within the organisms [6, 20, 25, 48].

Trace Element Concentrations in the Tissues

Among the detected elements, Cu and Zn were the most abundant ones; the values of Cu and Zn generally exceeded, in one to five orders of magnitude, the values obtained for As, Cr, and Hg. Mean concentrations of trace elements analyzed in

Table 2 Concentrations of trace element (μg g^{-1} dry weight) in scallop (GBW10024) obtained in the present study and certified values

		As	Cd	Cr	Cu	Hg	Zn
GBW10024	Obtained	3.4 ± 0.3	0.96 ± 0.10	0.25 ± 0.02	1.16 ± 0.04	38.5 ± 4.5	72.6 ± 1.7
	Certified	3.6 ± 0.6	1.06 ± 0.10	0.28 ± 0.07	1.34 ± 0.18	40 ± 7	75 ± 3

arms and mantle were in the following orders: Zn > Cu > Cd > Cr > As > Hg. In the digestive gland, the concentration of Cu and Cd exceeds that of Zn.

As for the sampled tissues, the digestive gland contained the statistically ($P<0.05$) highest concentration of Zn (50.32–186.17 μg g^{-1}), Cu (20.22–358.22 μg g^{-1}), Cd (18.7–409.1 μg g^{-1}), and As (0.07–0.18 μg g^{-1}) but the lowest concentration of Cr (0.05–0.62 μg g^{-1}). The concentration of Hg showed no significant differences among the muscular parts (mantle and arm) and digestive gland. The arms possessed moderate concentration of trace element compared with the mantle and digestive gland. However, the concentrations of Zn, Cu, and Cd in the arms were statistically higher than those in the mantle. With regard to the concentration of As, the arms and the mantle showed no significant difference. Moreover, the mantle usually exhibited the lowest concentration of trace element, except for the highest Cr concentration among the three studied tissues.

The vital role of the digestive gland to absorb, assimilate, store, and detoxify trace elements has been confirmed by numerous studies [7, 43, 52, 55]. Cd, Cu, and Zn were found to be concentrated greatly in the digestive gland in all the studied species of cephalopods so far [23, 50, 52]. The significantly highest concentration of Cd, Cu, and Zn in the digestive gland in the purpleback flying squid from central and southern South China Sea was in accordance with these former studies (Table 3).

Referring to Hg, the concentrations were of the same order of magnitude among the three studied tissues. No significant differences were found. This is in accordance with other studies in which Hg concentrations are similar among tissues [30, 45, 52]. It was reported in cuttlefish *Sepia officinalis* [27] that inorganic Hg accumulated from seawater was first stored mainly (>70 %) in the muscular part and then transferred toward the digestive gland for detoxification. While accumulated from food, it was mainly located in the digestive gland, indicating that the digestive gland was the target organ where the Hg detoxification and depuration happened. Similar mechanisms are likely to happen in other cephalopod species. Thus, it offers explanations to the distribution of Hg in squid *S. oualaniensis* that the average distribution of Hg could be affected by both seawater and food sources.

In general, according to Miramand and Bentley [33], the ratio between the concentration of trace element in the digestive gland and that in the muscle would reveal the pattern of concentration. In line with their study, Cr, Zn, As, and Hg were poorly concentrated with a ratio smaller than 10. Cu is moderately concentrated with the ratio between 10 and 50 (Table 4). It is worth mentioning that in this study, Cd is only moderately concentrated with a ratio of 27, presumably due to its relatively low concentration in the digestive gland of *S. oualaniensis* compared with those in other studies.

Trace element correlations among the tissues of *S. oualaniensis* are shown in Table 5. Generally, the concentrations of these detected trace elements in the three tissues have good correlations, except for Cd, whose concentration has no correlation within arm, mantle, and digestive gland of the squid, which might be explained by the highly concentrated Cd in the digestive gland. It suggested that different trace elements have different pathways of absorption, accumulation, and/or detoxification in the squid *S. oualaniensis*.

Trace Element Distribution in Tissues

The proportions of the body burden of trace elements in *S. oualaniensis* were calculated as the product of concentrations and dry weight of individual tissues (Fig. 2). Despite the relatively highest trace element levels in the digestive gland, the digestive gland only ranked the top in the distribution of Cd for the total body burden, with 72.18 ± 6.47 %. In other species, the digestive gland usually took up more than 90 % of Cd [5, 6]. The highest distribution had been reported to be 99 ± 1 % in the giant squid *Architeuthis dux* from Iberian waters [8]. However, the comparatively low Cd proportion concentrated in digestive gland in *S. oualaniensis* resulted from the low proportion of the digestive gland to the total body weight

Table 3 Concentrations of trace element (μg g^{-1} dry weight) in the tissues of purpleback flying squids from the central and southern South China Sea

Elements	Mantle			Arm			Digestive gland		
	n	Mean ± SD	range (CV)	*n*	Mean ± SD	range (CV)	*n*	Mean ± SD	range (CV)
As	24	0.06 ± 0.01b	0.05–0.10 (18.6)	18	0.07 ± 0.02b	0.05–0.08 (22.38)	22	0.10 ± 0.03a	0.07–0.18 (29.7)
Cd	31	5.96 ± 5.12c	0.3–21.9 (85.9)	30	15.03 ± 12.64b	0.61–39.85 (118.9)	31	164.75 ± 113.70a	18.7–409.1 (69)
Cu	31	13.13 ± 7.63c	2.1–32.4 (58.1)	31	47.85 ± 22.2b	8.21–93.16 (46.4)	31	186.57 ± 87.24a	20.22–358.22 (46.8)
Cr	27	2.64 ± 1.30a	0.01–4.9 (49.2)	28	0.51 ± 0.42b	0.16–1.58 (82.3)	29	0.09 ± 0.14c	0.05–0.62 (162.8)
Hg	25	0.03 ± 0.03a	0.01–0.10 (83.87)	17	0.03 ± 0.02a	0.01–0.06 (55.2)	20	0.03 ± 0.01a	0.01–0.06 (44.4)
Zn	31	45.85 ± 20.01c	14.07–85.57 (43.64)	31	71.29 ± 25.36b	20.70–121.71 (35.57)	31	111.12 ± 39.35a	50.32–186.71 (35.4)

Different letters indicate significant difference ($P<0.05$) of trace element concentration

n numbers of samples, *CV* coefficient of variation (%)

Table 4 Ratio of trace element in the digestive gland and that in the muscle in purpleback flying squid from central and southern South China Sea

Element	As	Cd	Cr	Cu	Hg	Zn
Ratio	1.67	27	0.03	14.21	0.33	2.42
Pattern of concentration	Poorly concentrated	Moderately concentrated	Poorly concentrated	Moderately Concentrated	Poorly concentrated	Poorly concentrated

(2.21–4.8 %), while in other cephalopod species, the digestive gland occupies about 6–12 % of the total body weight [20, 33, 41]. Due to the fact that the mantle takes up about 75 % of the whole body weight, the distribution of trace elements is merited high in it, with 78.39 ± 12.54 % As, 94.92 ± 4.15 % Cr, 39.62 ± 8.06 % Cu, 82.67 ± 10.37 % Hg, and 72.24 ± 11.01 % Zn. This is in accordance with the same species found in Japan [20]. Besides, Pernice et al. [43] suggested in their study the relatively high proportion of excreting tissues (i.e., renal and pericardial appendages) to accumulate As, Pb, and Cr. They mentioned that the accumulation in such organs may be due to the microorganisms' activities [42].

Correlations of Trace Element Concentrations Within Tissues

The correlations among the trace elements within the arms, mantle, and digestive gland are shown in Table 6. Correlations were limited to four detected trace elements, except As and Hg; Zn shows good correlation with Cr in arm ($P < 0.05$), mantle ($P < 0.001$), and digestive gland ($P < 0.05$), Cd and Cu exhibit good relationship in the mantle, while in the digestive gland, Cu and Zn are in good relationship (Table 6). Cd is often correlated with Cu and Zn accumulation, in which those elements were reported to be linked to high and low molecular weight proteins in digestive gland [18, 29]. Good relationships were observed between Cd and Cu/Zn in lower molecular weight fractions [49]. It was also reported that Cd would substitute Cu and Zn in the metalloproteins in the digestive gland of squids [60]. In this study, Cu was found to be positively related with Cd in the mantle ($P < 0.001$) and with Zn in the digestive gland ($P < 0.001$). Moreover, Zn and Cr are of the same trace element class and have a similar ionic index [37]. Le Pabic et al. [28] studied the influences of Zn on other trace elements and metalloid concentrations, which suggest substitution of these elements (i.e., Mn, Ag, Cd, Cu) by Zn in cuttlefish *S. officinalis*.

Table 5 Trace element correlations among the tissues of *Sthenoteuthis oualaniensis*

Trace element	Correlations
As	+ Mantle and arm*
Cd	–
Cr	+ Digestive gland and arms**
Cu	+ Mantle and arm*
Hg	+ Digestive gland and mantle and arms*
Zn	+ Mantle and arm**

+ means positively correlated

*$P < 0.05$, **$P < 0.001$

Intraspecific and Interspecific Comparisons

Trace element concentrations in tissues of *S. oualaniensis* caught from the central and southern South China Sea were compared with those of *S. oualaniensis* from other waters as well as other species of the same family of Ommastrephidae around the world (Table 7).

For the specimens used in this study, trace element concentrations in the analyzed tissue did not vary significantly with the mantle length of *S. oualaniensis*. Despite the limited range of mantle length of our samples, there are many studies claiming no significant differences between trace element concentrations with different mantle length, total weight, and/or sex [5, 23, 25, 30, 47, 50, 54]. However, *S. oualaniensis* studied in Okinawa (Japan) exhibited higher concentrations of Zn, Cd, and Pb in the digestive gland of adult squids than that in juvenile ones [20]. It can be explained by the possible difference of food intake between the adults and juveniles. Shchetinnikov [56] reported different prey for *S. oualaniensis* of various mantle lengths in the eastern Pacific. However, data concerning on the species in the South China Sea is limited to the habitat rather than life stages [3]. Moreover, in all the studied habitats, *S. oualaniensis*

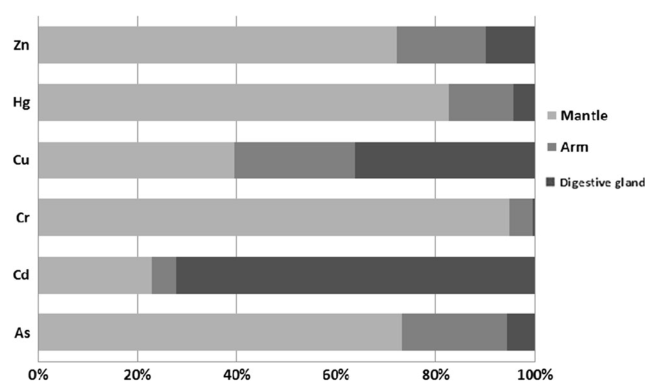

Fig. 2 Total body burden of As Cd, Cr, Cu, Hg, and Zn in the arm, mantle, and digestive gland of *Sthenoteuthis oualaniensis* captured in the central and southern South China Sea

Table 6 Correlations between trace element within the tissues of *Sthenoteuthis oualaniensis*

Trace element	Arm	Mantle	Digestive gland
Zn	+ Cr*	+ Cr**	+ Cu*, + Cr*
Cd		+ Cu**	

+ means positively correlated

*$P < 0.05$, **$P < 0.001$

mainly preyed on fish and cephalopods. In addition, *S. oualaniensis* reaches its maturity at the length of about 90–120 mm near the equator [61]. Thus, squids of the same mantle length can be of different stages of maturity. That is to say, the stage of maturity may be the only biological parameter that affects the concentration of trace element in *S. oualaniensis* from the South China Sea. But whether the feed pattern changes with the life stage needs to be known.

Moreover, comparing these biological parameters with the trace element concentrations in other studies, it can be deduced that the exogenous (environmental) factors might have mitigated the effect of the size and/or gender on trace element accumulation occasionally.

Essential elements like Zn and Cu did not vary greatly within the family; they were the most abundant trace elements in *S. oualaniensis*, as well as other cephalopod species [22, 63]. Those elements are required by various metal-dependent enzymes [11] and are essential in several cell functions [1]. The soluble copper-containing hemocyanin is used as respiratory pigment in cephalopods and has oxygen-carrying function; free copper is associated with a number of molecules, including peptides and amino acids [13, 14]; and zinc is a key component of carbonic anhydrase [51, 68], required for the activity of various kinds of enzymes [31] and plays a significant role in reproduction [2]. Hence, these trace elements are required in large concentrations in all species of cephalopods.

However, as regards concentrations of Cd, As, and Hg, statistics obtained in this study exhibited relatively lower level of concentrations: the concentration of As in the digestive gland was two orders of magnitude lower than that of *S. oualaniensis* from Japan and one to two orders of magnitude lower than that of other species reported. The concentration of Hg in the three studied tissues was also one order of magnitude lower than that of others. Moreover, Cd is the most studied trace element in various species of squid due to its toxicity and high accumulation in cephalopods, especially in their digestive gland. Cd concentrations in *S. oualaniensis* have been reported several times, among which the highest concentration was reported by Murthy et al. [36]. In their study, the Cd concentration in the edible part (muscle) of samples from northwest coast of India surpassed the maximum levels allowed by European regulations [16]. Besides, the Cd concentrations in the liver of *S. oualaniensis* observed by Martin and Flegal [29] and Ichihashi et al. [20] were both one order of magnitude higher than the data obtained in this study. In addition to environmental factors, biological factors might also have played a part here. Murthy et al. [36] confirmed in his study that the Cd concentration is significantly higher in the larger specimens. In fact, those specimens were even larger (about 300 mm) than other studied *S. oualaniensis*. Koyama et al. [26] and Bustamante et al. [7] assumed in their studies that food played a more important source of Cd compared with seawater. The low Cd concentration found in *S. oualaniensis* in the central and southern South China Sea may as well reflect low Cd exposure. To be more specific, data concerning Cd concentrations on water and sediment is needed.

It is unexpected that the concentration of Cr is extremely high (one order of magnitude) in the mantle of *S. oualaniensis* compared with what has been found in previous studies. Slight enrichment of Cr has been reported in the Beibu Gulf of South China Sea [69], and Cr in sediment in Hainan (northern South China Sea) is rather high [67]. Environment contamination is a possible explanation of the high concentration of Cr in this study. Since little had been discussed about the exact function of Cr in squids, more work has to be done to find out the explanation.

Conclusion

This study provides new data on seven trace element concentrations and distributions in the edible parts (arms and mantle) and the digestive gland of purpleback flying squid *S. oualaniensis* from the central and southern South China Sea. Results showed that Cu and Zn were the most abundant trace element as they were in other cephalopod species. The digestive gland got the highest concentrations of most trace elements, while the mantle got the lowest concentrations, which was in accordance with the familiar trace element accumulation patterns. However, Hg was similarly accumulated among the three tissues. Furthermore, intraspecific and interspecific comparisons indicated that *S. oualaniensis* from the central and southern South China Sea had relatively low concentrations of most trace elements. This study also highlighted the specialty of Cr in the squid. Its concentration was highest in the mantle and lowest in the digestive gland, and in general, the squid showed a relatively higher Cr level compared with other squids.

Table 7 Concentration of trace elements (μg g^{-1} dry weight) of cephalopods

Species	Tissues	Zn (μg g^{-1} dwt)	Cu (μg g^{-1} dwt)	Cd (μg g^{-1} dwt)	Cr (μg g^{-1} dwt)	As (μg g^{-1} dwt)	Hg (μg g^{-1} dwt)	Mantle length (mm)	Body weight (g)	Location	Source
	Mantle	45.85 ± 20.01	13.13 ± 7.63	5.96 ± 5.12	2.64 ± 1.30	0.055 ± 0.068	0.026 ± 0.026	82.2–225.6	35.07–405.91	The central and southern South China Sea	This study
S. oualaniensis	Arm	71.29 ± 25.36	47.85 ± 22.20	15.03 ± 12.64	0.51 ± 0.42	0.069 ± 0.015	0.022 ± 0.019				
	Digestive gland	111.12 ± 39.35	186.57 ± 87.24	164.75 ± 113.70	0.09 ± 0.14	0.104 ± 0.031	0.027 ± 0.012				
S. oualaniensis[a]	Digestive gland (adult)	255.5	1115.0	394.5	0.32	44.8	0.25	190	412	Japan	Ichihashi et al. [20]
	Digestive gland (juvenile)	45.8	65.50		0.64	37.70	0.3	175.2	380		
S. oualaniensis	Mantle			3.6				300–470		Northwest coast of India	Murthy et al. [36]
	Arm			2.1							
	Digestive gland			1088.05							
S. oualaniensis	Digestive gland	513 ± 288	1720 ± 151	782 ± 255						Monterey bay	Martin and Flegal [29]
Todaropsis eblanae	Mantle			1.55 ± 2.15			0.206 ± 0.201			UK waters	Pierce et al. [45]
	Digestive gland			25.1 ± 25.9			0.128 ± 0.099				
Todarodes sagittatus	Mantle			0.30 ± 0.29			0.425 ± 0.194				
	Digestive gland			65.3 ± 61.1			0.280 ± 0.105				
Dosidicus gigas	Mantle	71–98	3.7–13	0.13–2.4	0.43–2.0	10–33		320–730	900–13,000	Gulf of California	
	Digestive gland	22–333	6.8–560	57–509	0.36–5.0	8.1–20					
Todarodes pacificus[a]	Mantle	75	13.5	0.42	0.365	12.5		166	93	Pacific Ocean	Ichihashi et al. [21]
	Digestive gland	390	55	120	0.75	15					
Todarodes pacificus[a]	Mantle	80	17	0.175	0.14	14.5		196	162	Coastal area of Japan	
	Digestive gland	390	650	95	0.21	24.5					
Todarodes filippovae	Mantle	63.1 ± 7.0	7.20 ± 2.43	0.20 ± 0.14	DL	15.3 ± 3.73	0.75 ± 0.42	447 ± 42.9	2290 ± 881	Tasmania	Kojadinovic et al. [25]
	Digestive gland	88.5 ± 38.8	137 ± 176	98.5 ± 67.2	0.14 ± 0.05	17.1 ± 7.16	0.33 ± 0.22				
	Mantle	55.6 ± 4.1	6.36 ± 1.33	0.93 ± 0.79	DL	14.4 ± 2.54	0.25 ± 0.11	341 ± 48.5	825 ± 394	Amsterdam	
	Digestive gland	94.3 ± 66.1	218 ± 196	246 ± 187	0.27 ± 0.16	11.5 ± 3.07	0.14 ± 0.06				

DL detection limit

[a] Converted to dry weight by a factor of 5 (80 % water content on average)

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