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Bioaccumulation of Zinc by Mantis Shrimp (*Harpiosquilla Raphidea*) in Seawater: The Application of Nuclear Technique Using Radioactive Metal

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ABSTRACT

Zinc (Zn) is a heavy metal that, in certain amounts, can be toxic to aquatic organisms and humans. Mantis shrimp (*Harpiosquilla raphidea*) is a source of seafood for humans, but can accumulate heavy metals. This study investigated the ability of *Harpiosquilla raphidea* (*H. raphidea*) to accumulate Zn metal at various concentrations, salinity levels, and weights (wet basis) using ⁶⁵Zn as a radioactive tracer. Radioactive tracer techniques offer quicker and more accurate results while minimizing the use of organisms. The tested Zn concentrations ranged from 0.5 to 2.0 ppm, salinity varied from 25 to 31 ppt, and weights ranged from 15 to 40 grams. The values observed were uptake constant (k_u), elimination constant (k_e), bioconcentration factor (BCF) and biological half-life ($t_{b1/2}$). In experiments with concentration variations, increasing concentration increased k_u , k_e , and BCF , but decreased $t_{b1/2}$. While in experiments with salinity variations, increasing salinity decreased k_u , k_e , and BCF , but increased $t_{b1/2}$ values. Experiments with variations in *H. raphidea* weight, increasing body weight decreased k_u and k_e , but increased BCF and $t_{b1/2}$. In short, changes in Zn concentration, salinity, and biota weight affect Zn bioaccumulation in *H. raphidea*.

Keywords: Bioaccumulation, radiotracer, ⁶⁵Zn, mantis shrimp (*Harpiosquilla raphidea*).



INTRODUCTION

Jakarta Bay is one of the important marine product sources for Jakarta and its surroundings. Nevertheless, Jakarta Bay is also contaminated by biological and chemical pollutants from the land since it is the estuary of 13 rivers carrying various waste from human activity [1] and enter the marine ecosystem, disrupting the sustainability of marine resources. One pollutant class that has contaminated this estuary is heavy metals, which are persistent and harmful to organisms. In determining the concentration of heavy metals in Jakarta Bay sediments, the average Zn concentration was $58.53 \mu\text{g.g}^{-1}$, with the highest concentration being $195 \mu\text{g.g}^{-1}$ [2].

Heavy metals are naturally found in seawater and some of which, at low level, are essential (Fe, Mg, Cu, Zn, etc.) for metabolic processes [2]. Such Essential elements are needed to maintain the formation of the framework structure, regulate acid-base balance, and maintain the colloidal system in human body. In addition, this element also crucial in forming key enzymes, protein structures, and hormones, for example, zinc as component of more than 300 enzymes, and iron for hemoglobin construction [3].

Zinc (Zn) is one of heavy metals that its concentration in the environment is predicted to rise significantly due to human activity. Many industries, including batteries and smelting, use Zn extensively, resulting in significant amount of contamination in industrial wastewater. Therefore, Zn accumulation in human body might occur due to frequent consumption of food containing Zn with a high concentration. Zn toxicity in human might cause several symptoms, such as depression, lethargy, neurological signs and increased thirst [4].

Mantis shrimp are members of the class Malacostraca, order Stomatopoda, which has five super families, with around 400 species, some of which can grow up to 38 cm long [5], one of which is *Harpiosquilla raphidea* [6]. *H. raphidea* are commonly found mainly in river mouths. This species is a predator that feeds different other biota, such as fish, crustaceans, mollusks, [7]. In some areas, *H. raphidea* is considered a delicacy with a high economic value [8], making it a potential vector of pollution to humans.

In Asia, Mantis shrimp are a fishery resource and a favorite food [9]. Mantis

shrimps are fierce, territorial, and opportunistic predators[10], which makes a burrow in a flat surface and is used to wait for the time to catch its prey[11]. Because increasing pollution in coastal areas and growing metal contamination in the sea cause a decline in environmental quality and marine ecology and pose a risk to aquatic organisms, which can affect humans through the food chain [12], it is necessary to investigate Zn bioaccumulation.

Crustacean gills are the primary site of heavy metal uptake and accumulation when exposed to contaminated water. They also perform several physiological functions, such as gas and ion exchange with the environment, and play a key role in regulating internal homeostasis. Their properties change with changing environmental conditions. Posterior gills may play a more significant role than anterior gills in enhancing metal uptake and toxicity during exposure to contaminated water. [13].

The hepatopancreas contributes functionally to the digestion and absorption of dietary nutrients, as well as the secretion, absorption, and detoxification of heavy metals. Epithelial cells lining the hepatopancreatic tubules display a number of plasma membrane transport proteins that facilitate the transfer of calcium and divalent heavy metals such as copper, cadmium, and zinc between the external and internal environments. Crustaceans possess mechanisms to detoxify heavy metals and reduce their intracellular concentrations by storing them in specific organelles or binding them to cytoplasmic proteins known as metallothioneins. The production of these proteins can be genetically regulated in response to increased xenobiotic levels within the cell. Members of the Zip family increase intracellular zinc activity by transporting zinc into the cell from the environment. Conversely, members of the ZnT family reduce cytoplasmic zinc levels by facilitating zinc efflux from the cell or transferring it to organelles or vesicles. The ZnT2 transporter has been found in acidic intracellular compartments, likely lysosomes, where it may help accumulate zinc. [14]. The main location for the uptake and desorption of metals from waterborne exposure is the gills, and the regulation of hemolymph zinc concentrations depends on the loss of zinc through the gills[15].

Information on trace metal concentrations in stomatopod crustaceans is

still limited. The narrow range of zinc (Zn) concentrations found, and the insignificant differences suggest that *Squilla mantis* may regulate Zn levels in its soft tissues, like what has been observed in the palaemonid decapod *Palaemon elegans* and the crab *Circinus maenas*. While the results are comparable across these species, the mechanisms responsible for Zn homeostasis differ. In *P. elegans*, the rate of zinc uptake matches the rate of zinc excretion. In contrast, *C. maenas* exhibits a meager rate of zinc uptake, even with high zinc availability, resulting in stable zinc concentrations within its body [16]. At low concentrations of environmental zinc (Zn), animals can absorb and retain it for essential functions in their tissues. However, when exposure to zinc increases over time, aquatic animals can regulate their bioaccumulation. Both of these detoxification processes involve binding proteins, such as metallothionein [17]. The important role of metallothionein (MT) is to bind zinc with high affinity, function as an intracellular zinc reservoir, and release free intracellular zinc when needed. Excessive zinc also causes a surge in reactive oxygen species (ROS). ROS and intracellular zinc are interrelated. ROS facilitates the oxidation of zinc-binding proteins and causes zinc release in the cytoplasmic compartment, while extra zinc in the cytoplasm causes an increase in ROS. Increased zinc induces MT expression, and thus, zinc homeostasis is maintained [18].

Aquatic organisms can be exposed to chemical pollutants through two pathways. First, pollutants dissolved in water can be absorbed through the gills and body surface. Second, pollutants in the form of particles or live food can be taken in through the digestive system. Bioaccumulation refers to the accumulation of metals in certain tissues or organisms due to exposure. Bioaccumulation of metals can occur through absorption on surfaces or by certain organisms or tissues and is expressed in wet/dry weight. Metals can bioaccumulate from various environmental sources such as air, water, solids (organic and inorganic in soil and sediment), and food [19].

Jiao et al. reported that the amount of Zn in Japanese mantis shrimp (*Oratosquilla oratoria*) was the highest (21.7 $\mu\text{g g}^{-1}$) compared to other metals [20]. Due to the high Zn content found in Jakarta Bay sediments, it is necessary to study Zn bioaccumulation in *H. raphidea* for safe seafood consumption.

Bioaccumulation studies of Zn by *H. raphidea* especially in Jakarta Bay have not been carried out. In this research, the bioaccumulation kinetics of Zn metal were studied using a ^{65}Zn radiotracer to accurately, quickly, and in real-time determine the Zn concentration in *H. raphidea*. By using this technique, fewer experimental animals are used. This research aims to explore the effect of Zn concentration, salinity, and body weight of organisms on Zn bioaccumulation in *H. raphidea* through the water pathway.

METHODOLOGY

a. Materials

Aquarium with aquaria system, Zn metal (Merck), ^{65}Zn (PRTRRB-ORTN-BRIN), HCl (Merck), sea water, fish food, fresh water, mantis shrimp (*H. raphidea*) were obtained from fishermen in Jakarta Bay, micro pipette (Eppendorf), measuring glass, measuring pipette, measuring flask, beaker glass (Iwaki), aspirator bulb (VWR).

b. Instrumentation

Mobius ORTECH hybrid gamma spectrometry with an HPGe detector equipped with a Maestro multi-channel analyzer.

c. Methods

The research was carried out following Budiawan et al. (2021) with several modifications. The research location was in the laboratory of the Research Center for Radioisotope, Radiopharmaceutical and Biodosimetry Technology (PRTRRB), National Research and Innovation Agency (BRIN), B.J Habibie Serpong Integrated Science Area. The mantis shrimp *H. raphidea* was acclimatized to the PRTRRB laboratory. The kinetics of Zn bioaccumulation in *H. raphidea* were determined through the following stages.

^{65}Zn preparation

To obtain ^{65}Zn , Zn metal was irradiated in the G. A. Siwabessy multipurpose reactor, where ^{64}Zn metal through the n,γ reaction will produce ^{65}Zn . 500 mg. Zn metal was irradiated in the G. A. Siwabessy multipurpose reactor for 96 hours with a power of 15 MW, Obtained ^{65}Zn of $2.1\text{E}+09$ bq. The target that had been irradiated in the Siwabessy multipurpose reactor was then processed at the National Research and Innovation Agency, Nuclear Energy Research Organization, Research

Center for Radioisotope Technology, Radiopharmaceuticals and Biodosimetry (BRIN-ORTN-PRTRRB). Here the target was dissolved with HCl to obtain a $^{65}\text{ZnCl}_2$ solution. Measurements were carried out using gamma spectrometry consisting of a Mobius ORTEC hybrid high purity germanium (HPGe) detector with a multichannel analyzer and a computer with maestro software. The concentration of radioactivity in the sample was determined by comparing it to a standard phantom containing 822 Bq of ^{65}Zn . Phantoms are standard organisms with the same shape as living organisms and known activity concentrations. Decay measurements were adjusted for radioisotope decay, and a 5% instrument error was considered in the Gamma spectrometer readings.

Acclimatization

Acclimatization is carried out to adapt biota to laboratory conditions and avoid the death of biota during the experiment. Acclimatization is carried out by placing *H. raphidea* in an aquarium containing seawater that has been filtered with a 0.45 μm filter, with a volume of 200 liters, flowing and blowing oxygen continuously, temperature $27^\circ \pm 0.5^\circ\text{C}$, salinity 31 ppt, pH 8.2, and a light-dark cycle of 12;12 hours for seven days.

Zn bioaccumulation

Bioaccumulation of Zn is carried out by preparing twelve aquariums with a capacity of 25 liters filled with 18 liters of seawater. The first four aquariums were filled with sea water with a salinity of 31 ppt. Each aquarium was sequentially added with non-active Zn at a concentration of 0.5; 1.0; 1.5; and 2.0 ppm. After that, ^{65}Zn was added to each aquarium so that the radioactivity of the aquarium water was 14,7 bq.ml⁻¹. Into the second four aquariums, sea water was added successively with a salinity of 31; 29; 27; and 25 ppt. The third four aquariums are filled with sea water with a salinity of 31 ppt. *H. raphidea*, weighing about 15; 20; 30; and 40 grams in a row, was put into the aquarium. Zn was added to each aquarium with variations in salinity and biota weight, so the Zn concentration was 2.0 ppm and spike with ^{65}Zn . After that, two *H. raphidea* were put into each aquarium, and exposure was carried out for seven days for *H. raphidea* with varying concentrations and fourteen days for variations in salinity and body weight of the organism. Measurement of the concentration

of ^{65}Zn contained in *H. raphidea* was carried out every day. Before measurements, *H. raphidea* was placed in a container containing three liters of ^{65}Zn -free seawater for 30 minutes and fed. Measurement of ^{65}Zn concentration in *H. raphidea* was carried out using a Mobius ORTECH hybrid gamma spectrometry with an HPGe detector equipped with a Maestro multi-channel analyzer. The ability of organisms to take up contaminants through water is called CF (concentration factor), which is the ratio of the concentration of pollutants in the organism (C_t) to that in the water (C_w).

$$CF_t = \frac{C_t}{C_w} \quad (1)$$

In steady-state conditions, the equation becomes;

$$CF_t = CF_{ss} (1 - e^{-k_e \cdot t}) \quad (2)$$

The term " CF_{ss} " refers to the concentration factor under steady-state conditions. Determining the bioaccumulation of biota with unknown equilibrium conditions can be achieved using kinetic modeling, such as a simple one-compartment kinetic model, which can be simulated as follows:

$$dC = k_u \times C_w - k_e \times C \quad (3)$$

Where k_u represents the water absorption rate constant (L/g/h), C_w is the contaminant concentration in water (mg/L), k_e is the efflux rate constant, and C is the accumulation concentration (mg/g).

After integration, the concentration of accumulated contaminants at time t can be described by the following equation:

$$C_t = k_u \times C_w / k_e \times [1 - e^{-k_e t}] \quad (4)$$

In a steady state, when the rate of change of concentration (dC/dt) is zero, the steady state concentration (C_{ss}) can be calculated as;

$$C_{ss} = k_u \times \frac{C_w}{k_e} \quad (5)$$

By knowing k_u , k_e , and C_w , contaminant concentrations at steady-state conditions can be predicted. Since bioconcentration factor (BCF) is;

$$BCF = C_{ss} / C_w \quad (6)$$

BCF can also be calculated using two kinetic parameters.

$$BCF = \frac{k_u}{k_e} \quad (7)$$

While K_u is the slope of CF vs time (t).

Depuration

Depuration was carried out to determine the release constant (k_e) of ^{65}Zn from *H. raphidea*. k_e is obtained from the slope of the percentage (%) of retention against time. Depuration is done by placing *H. raphidea* in an aquarium containing 18 liters of seawater ^{65}Zn free for seven days. To find out how much ^{65}Zn was still present in *H. raphidea*'s body, the concentration of the metal was measured daily. Feeding is done once a day before changing the aquarium water. Depuration was carried out for seven days. The biological half-life of ^{65}Zn in *H. raphidea* can be expressed by;

$$t_{b1/2} = \frac{\ln 2}{K_e} \quad (8)$$

In this experiment, linear equations were used to determine BCF and $t_{b1/2}$ [21][17][22].

RESULTS AND DISCUSSION

Changes in environmental conditions affect the bioaccumulation pattern of Zn metal as seen from the results of the experiments carried out below.

From the bioaccumulation graph, there is an increase in the concentration factor (CF) value simultaneously, which indicates the occurrence of Zn bioaccumulation in *H. Raphidea*, as shown in Figure 1a. In the depuration graph, there is a decrease in the amount of Zn retained by *H. raphidea* from day to day as in Figure 1b. Zn Bioaccumulation and depuration occur efficiently. This can be seen from the increase in the uptake constant (k_u) and the increase in the elimination constant (k_e) of Zn in *H. raphidea* (Figures 2a and 2b). In the experiment to observe the effect of concentration on Zn biokinetics in *H. raphidea*, the bioconcentration factor (BCF)

increased along with the increase in Zn concentration in the environment. Specifically, at a Zn concentration of 0.5 ppm, the BCF value was 48.89 mL.g^{-1} , and it increased to 85.43 mL.g^{-1} at a Zn concentration of 2.0 ppm. Additionally, the uptake constant (k_u) and elimination constant (k_e) increased with the increased of Zn concentration. For example, the uptake constant (k_u) increased from 1.81 $\text{mL.g}^{-1}.\text{d}^{-1}$ at a concentration of 0,5 ppm to 5.64 $\text{mL.g}^{-1}.\text{d}^{-1}$ at a concentration of 2.0 ppm. Similarly, the elimination constant (k_e) increased from 0.037 day^{-1} at a Zn concentration of 0.5 ppm to 0,066 day^{-1} at a concentration of 2.0 ppm.

The biological half-life of Zn ($t_{b1/2}$) was longer at lower concentrations, decreasing from 18.73 day at a concentration of 0.5 ppm to 10.50 day at a Zn concentration of 2.0 ppm, as shown in Table 1. The absorption kinetics demonstrate that Zn accumulates rapidly and efficiently due to its high affinity for sulfhydryl groups. Zn binds to cellular proteins and transports them across cell membranes. The depuration process shows strong Zn retention, indicating efficient detoxification and large deposits of Zn metal[17].

The effect of salinity on the kinetics of Zn bioaccumulation in *H. raphidea* can be seen in Figures 4 - 6. In the experiment salinity variations were from 25 to 31 ppt. At all salinities tested, bioaccumulation and depuration of Zn occurred in *H.raphidea* as seen in Figures 4.a and 4 b. The effect of salinity on Zn bioaccumulation in *H. raphidea* was observed as follows: with an increase in seawater salinity from 25 ppt to 31 ppt, the absorption constant (k_u) decreased from 1.98 mL.g^{-1} to 1.26 mL.g^{-1} . The elimination constant (k_e) decreased from 0.066 day^{-1} to 0.048 day^{-1} . Increasing salinity has been shown to decrease zinc absorption and release. The bioconcentration factor (BCF) value decreased from 30.00 mL.g^{-1} to 26.25 mL.g^{-1} as seawater salinity increased, and biological half-life ($t_{b1/2}$) increased from 10.50 days to 14.44 days with increasing salinity. These findings are summarized in Table 1.

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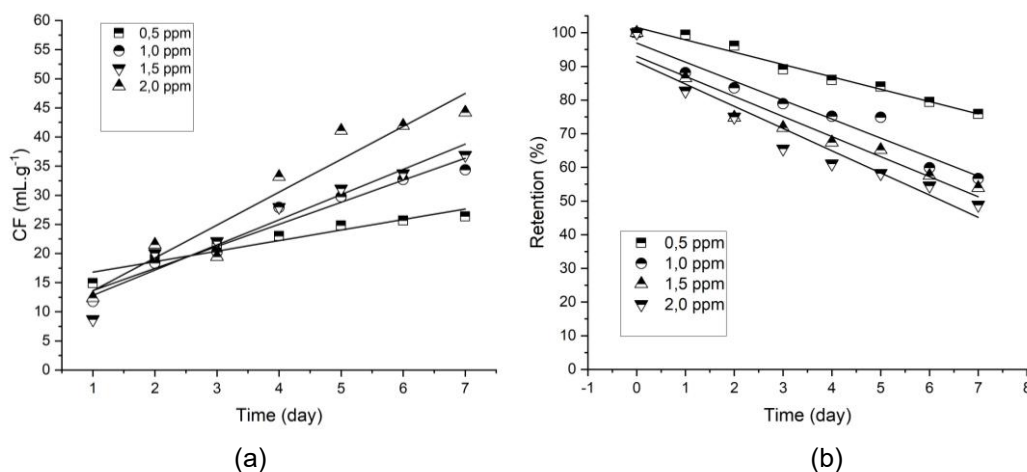


Figure 1. The effect of Zn concentration on the bioaccumulation (a) and the effect of Zn concentration on the depuration process (b).

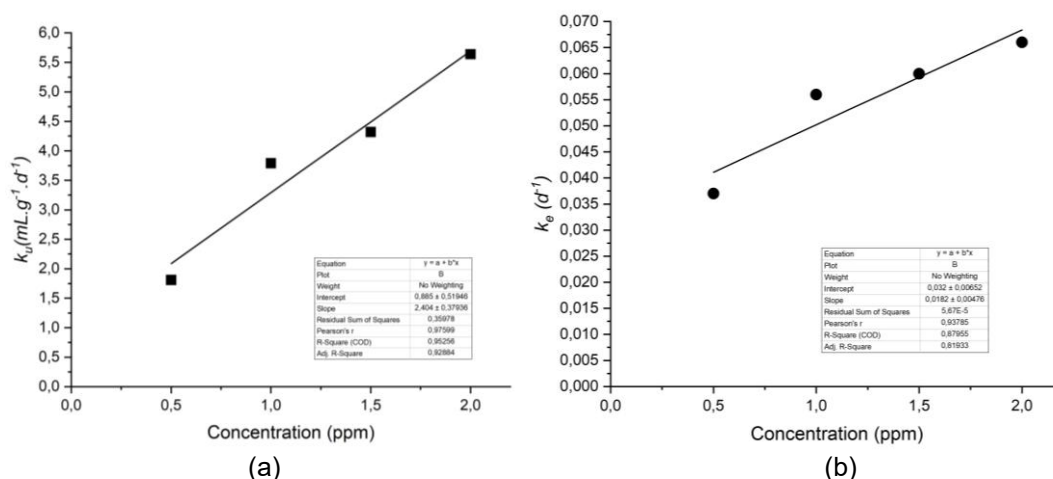


Figure 2. The effect of Zn concentration on the uptake constant (k_u) (a) and the effect of Zn concentration on the elimination constant (k_e) of Zn (b).

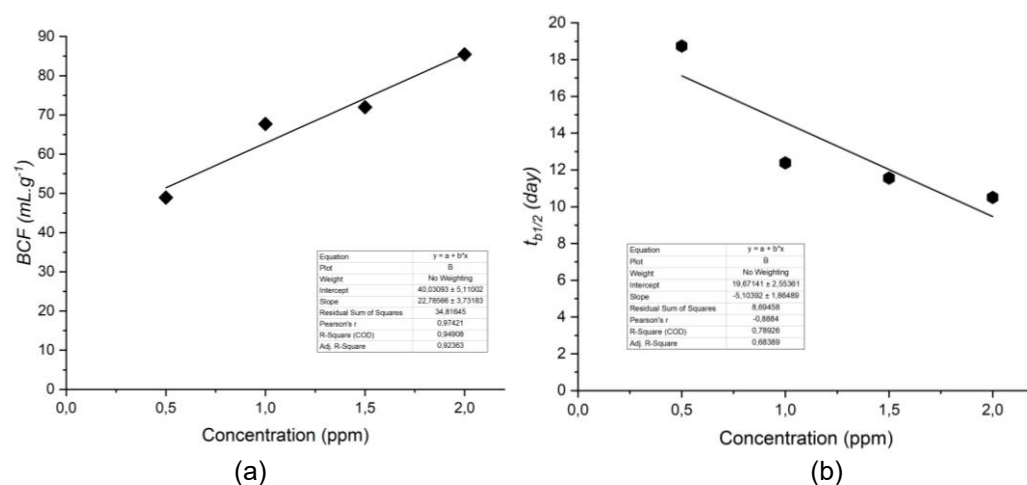


Figure 3. The effect of Zn concentration on the Zn bioconcentration factor (BCF) (a) and Zn biological half-life ($t_{1/2}$) (b).

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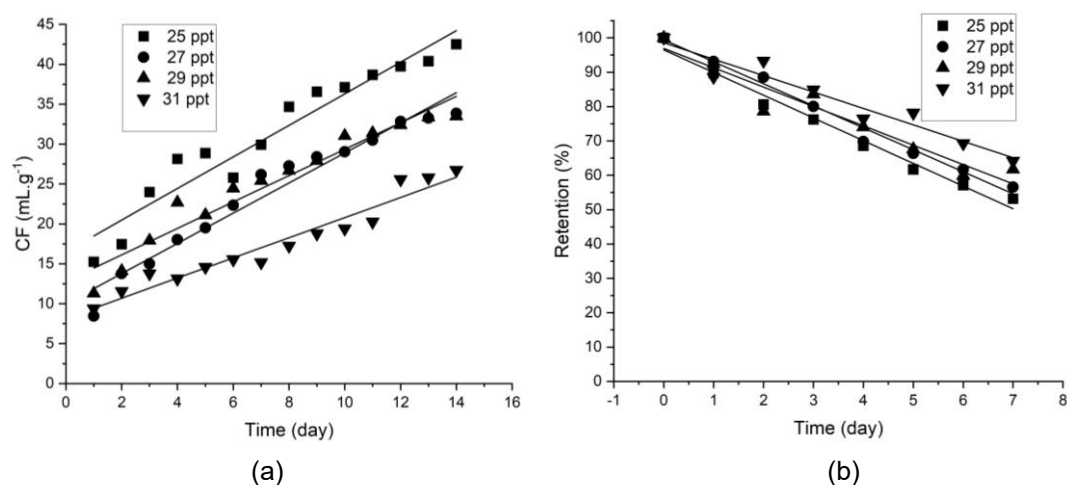


Figure 4. The effect of salinity on the Zn bioaccumulation (a) and Zn depuration (b).

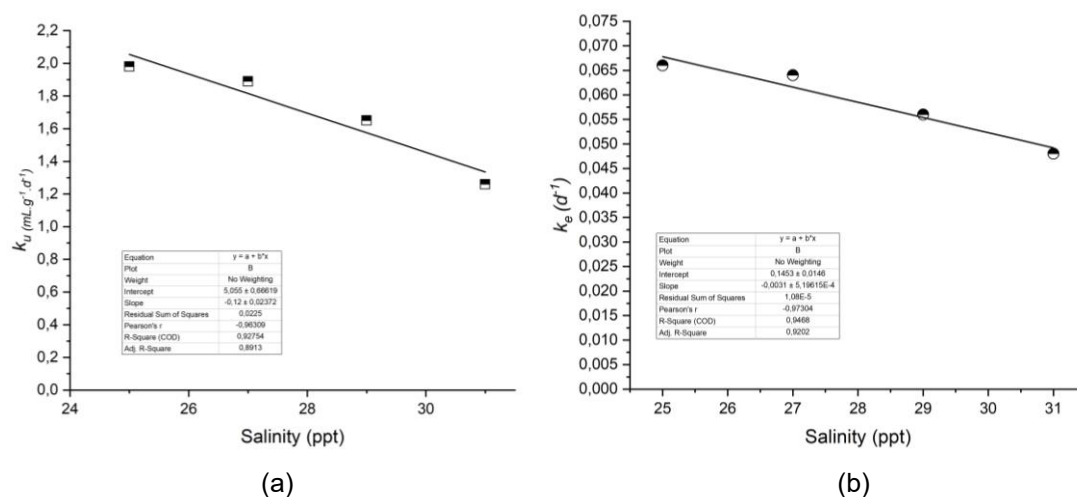


Figure 5. The effect of salinity on the uptake constant (k_u) of Zn (a) and elimination constants (k_e) of Zn.

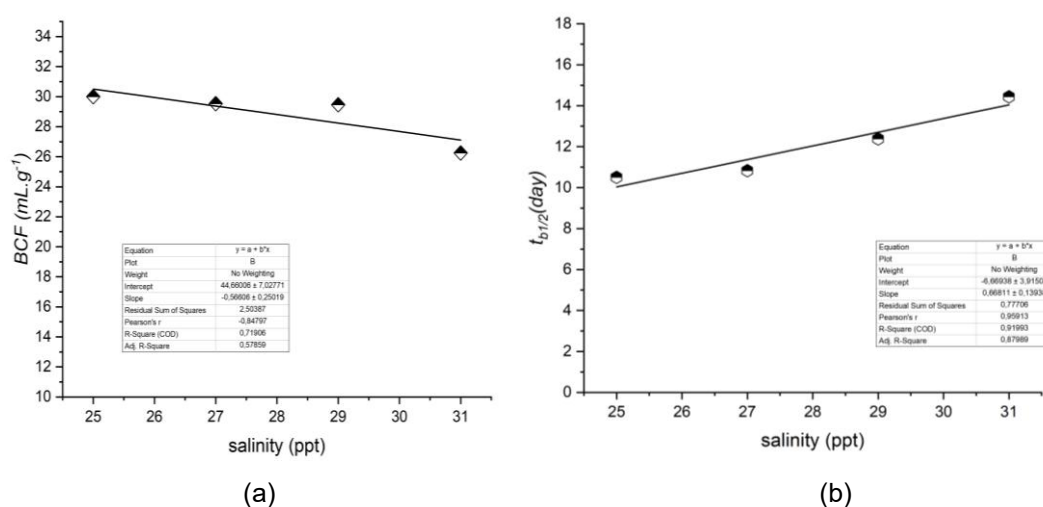


Figure 6. The effect of salinity on Zn bioconcentration factor (BCF) (a) and Zn biological half-life ($t_{1/2}$) (b).

The chemical makeup of natural waters and a variety of marine biological activity are significantly impacted by salinity [23]. The physicochemical characteristics and conditions of the medium have a direct impact on the bioavailability of metals. Salinity influences affect animal physiology, particularly osmoregulatory processes, and alter the chemical speciation of metals [24]. The gills of crustaceans become the main site of metal uptake and accumulation when they are exposed to high concentrations of heavy metals through water. The principal location of metal toxicity in crustaceans is probably the gills, which carry out a number of vital physiological processes, such as gas and ion exchange with the environment. Because crustacean gills are crucial for maintaining internal homeostasis, changes in external conditions affect the characteristics of their gills [13]. Zn toxicity was found to diminish with increased salinity in an experiment by Loro et al. (2014) on killer fish larvae (*Fundulus heteroclitus*). This is because the increased complexation by anions in saltwater causes a decrease in the availability of free Zn^{2+} . As salinity rises, acute Zn^{2+} toxicity sharply declines, primarily due to an increase in Ca^{2+} concentrations in the exposure medium [25].

Zinc (Zn) is an essential element that plays a crucial role in the physiological and metabolic processes of many organisms. However, high concentrations of zinc can be toxic. Salinity and temperature are important factors in determining the rate of many physiological functions. Experiments conducted by Rao et.al. on *T. Jarbua* demonstrated that salinity plays a significant

role in metal toxicity to estuarine and marine organisms. The LC_{50} value of zinc is 1,1-1,7 times smaller at lower salinities compared to higher salinities [26].

The behavior of zinc in seawater is not well understood, but the main dissolved species is probably Zn^{2+} forms. The amount of zinc in seawater depends on the concentration and type of particles and dissolved materials. A high percentage of zinc accumulates in hepatopancreatic tissue, such as protein- and metal-rich granules, where it is detoxified and stored in metallothionein [27]. Figure 7-9 shows the effect of body weight on the kinetics of Zn bioaccumulation in *H. raphidea*.

It was observed in this experiment that body weight had an impact on *H. Raphidea* zinc accumulation. Zn bioaccumulation and depuration increased, but as *H. raphidea* body weight increased, the rate of bioaccumulation and depuration reduced. The absorption constant value (k_u) of *H. raphidea* decreases with increasing body weight, from $2.63 \text{ mL.g}^{-1}.\text{d}^{-1}$ at a weight of 15 grams to $1.66 \text{ mL.g}^{-1}.\text{d}^{-1}$ at a weight of 40 grams. Similarly, the elimination constant value (k_e) decreases with increasing body weight, with k_e values of 0.071; 0.061; 0.042, and 0.038 day⁻¹ for weights of 15, 20, 30, and 40 grams, respectively. Meanwhile, as the weight of *H. raphidea* increases, so do the BCF and $t_{b1/2}$ values. At weights of 15, 20, 30, and 40 grams, the BCF value rises to 37.04; 38.85; 42.38, and 43.68 mL.g^{-1} , respectively. In contrast, the biological half-life for *H. raphidea* rises from 9.76; 11.37; 16.50 and 18.24 days for weight 15 ; 20; 30 and 40 grams.

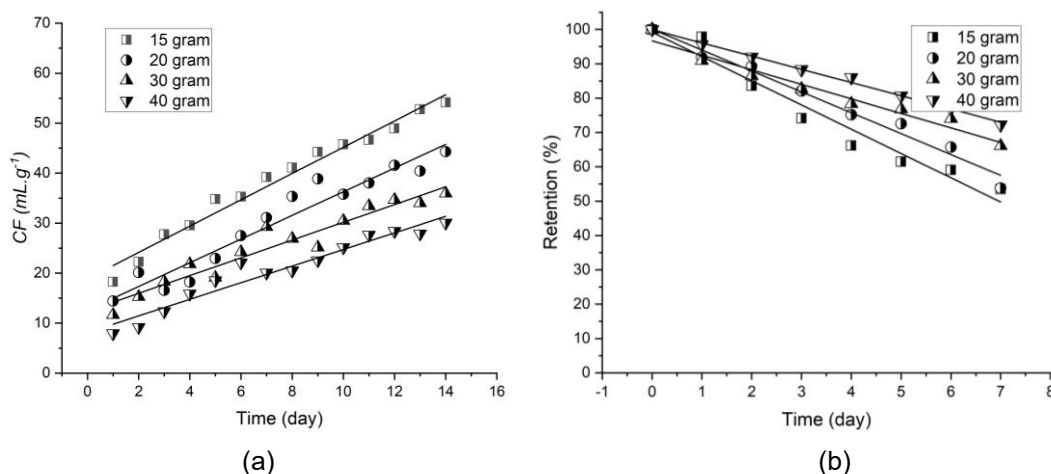


Figure 7. The effect of the body weight of an organism on the Zn bioaccumulation (a) and Zn depuration (b).

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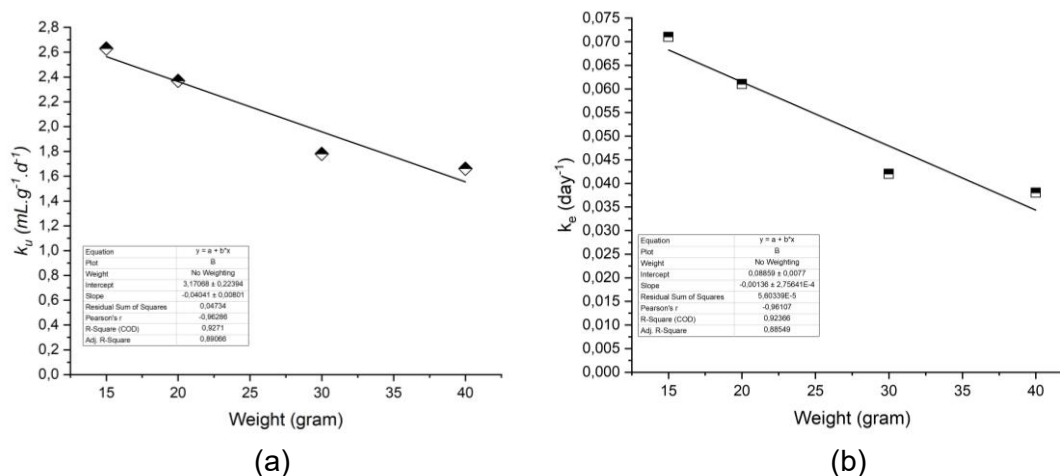


Figure 8. The effect of the body weight of an organism on the Zn uptake constant (k_u) (a) and Zn elimination constant (k_e) (b).

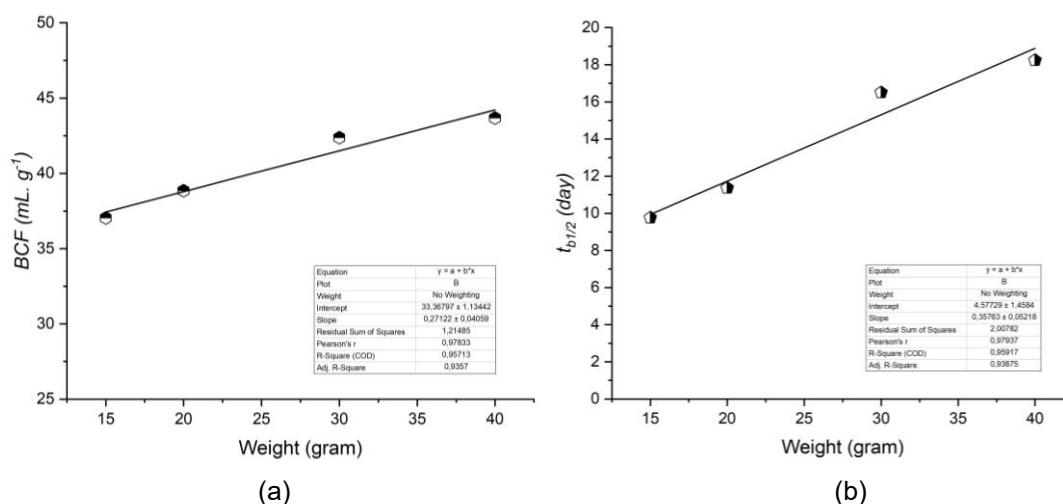


Figure 9. The effect of the body weight of an organism on Zn bioconcentration factor (BCF) (a) and Zn biological half-life ($t_{b1/2}$) (b).

One factor that influences metal bioaccumulation is body size, which is the most important biological attribute of an animal. A function of body size, known as allometry, is the most useful predictor of physiological rate. The concentration of metals suggests that the uptake of metals from water was facilitated passively rather than actively regulated. This means that the effect of size on the uptake of water-borne metals can be explained by the general observation that the ratio of gill surface area to volume-specific weight and pumping rate decreases as the dry body weight [28].

The effect of organism body weight on Zn bioaccumulation in *H. raphidea* can be seen in Table 1. The kinetics of Zn

bioaccumulation in other biota can be seen in Table 2.

Body size and body weight are known factors that influence the bioconcentration of trace elements in organisms, showing a decrease in the efficiency of trace element uptake with increasing individual weight. In contrast, no allometric relationship was found in blood cockles during the cleaning period, either after dissolved or trophic exposure. The decrease in the bioaccumulation capacity of dissolved trace elements in larger/older individuals could be related to the size-dependent ratio of gill surface area to volume, as well as physiological differences in organisms such as higher metabolic requirements in smaller organisms with

consequent higher fluid filtration [33]. In an experiment with *Crassostrea virginica* oysters, Mo & Nelson (1993) discovered that at the same Zn concentration, little oysters absorbed more zinc than giant oysters. [34]. Baptista et al. (2019) experiments on juvenile *Mola-mola* fish revealed that as the fish's body weight

increased, the concentration of zinc decreased throughout the body. On the other hand, zinc levels rose as fish grew in size in both the gills and the red muscle, which may have resulted from a higher physiological demand on those tissues [35].

Table 1. Zn biokinetics.

Parameters		CF (mL.g ⁻¹)	k _u (mL.g ⁻¹ .d ⁻¹)	k _e (days ⁻¹)	BCF (mL.g ⁻¹)	T _{b1/2} (days)
Concentration (ppm)	0.5	14.92 – 26.37	1.81	0.037	48.89	18.73
	1	11.76 – 34.38	3.79	0.056	67.68	12.38
	1.5	8.69 – 36.91	4.32	0.060	72.00	11.55
	2	12.38 – 44.20	5.64	0.066	85.43	10.50
Salinity (ppt)	25	15.25 – 42.50	1.98	0.066	30.00	10.50
	27	8.44 – 33.84	1.89	0.064	29.53	10.83
	29	9.39 – 26.74	1.65	0.056	29.46	12.38
	31	15.25 – 42.50	1.26	0.048	26.25	14.44
Body weight (g)	15	18.23 – 54.14	2.63	0.071	37.04	9.76
	20	14.43 – 44.30	2.37	0.061	38.85	11.37
	30	11.64 – 35.94	1.78	0.042	42.38	16.50
	40	7.93 – 30.05	1.66	0.038	43.68	18.24

Table 2. Zn biokinetics in another biota.

Biota	CF (mL.g ⁻¹)	k _u (mL.g ⁻¹ .d ⁻¹)	k _e (days ⁻¹)	BCF (mL.g ⁻¹)	T _{b1/2} (days)	Ref.
<i>Portunus pelagicus</i>	19.43 – 37.99	0.47	0.08	-	-	[29]
<i>M. micropterus</i>	31.94 – 45.54	0.52	0.03	-	-	[17]
<i>Sepia officinalis</i>	3.8 ± 1.4	-	-	-	-	[30]
<i>Mytilus edulis</i>	341.2 – 488.2	62.4	0.16	-	-	[31]
<i>S.glomerata</i>	-	0.160 – 0.503	0.13 – 0.53	-	-	[32]

CONCLUSIONS

Based on the experiments conducted, it can be inferred that the concentration of Zn, salinity, and the weight of the organism all affect the biokinetics of Zn in mantis shrimp (*H.raphidea*). Higher Zn concentration led to increased absorption (k_u) and elimination (k_e) rates in *H. raphidea*, while the biological half-life (t_{b1/2}) decreased with higher Zn concentration. Increasing salinity results in a decrease in the absorption constant (k_u) and elimination constant (k_e). Increasing salinity decreases the BCF value, on the other hand increasing salinity increases the biological half-life (t_{b1/2}). As the organism's body weight increased, the absorption rate (k_u) and the elimination rate (k_e) decreased. Additionally, the bioconcentration factor (BCF) and biological half-life (t_{b1/2}) increased with the organism's body weight.

The findings indicate that environmental variables influence the bioaccumulation pattern of Zn metal in *H. raphidea*. Each organism has a unique bioaccumulation pattern that reflects environmental changes. The influence of environmental changes on the Zn bioaccumulation pattern in biota needs to be understood to obtain an overview of the safety of biota against these environmental changes, especially for consumption biota to maintain food security. The use of radiotracer techniques is very advantageous because it can provide accurate, real-time analysis results and the use of fewer experimental animals.

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AUTHOR CONTRIBUTIONS

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