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RESEARCH ARTICLE

Accumulation of Heavy Metal in *Faunus ater* and its Population Structure in Bale River Lhoknga Aceh Besar Indonesia

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ABSTRACT

This study aims to analyze the accumulation of Lead (Pb) and Zinc (Zn) in *Faunus* (*F.*) *ater* and population structure of *F. ater* in Bale River Lhoknga Aceh Besar Indonesia. Samples of sediment and *F. ater* were taken from November 2016 to April 2017, the first 3 months represent the rainy season and the second 3 months represent the dry season. The population structures analyzed include density, dispersion patterns and growth patterns. The content of heavy metals in *F. ater* and sediments was analyzed by using Atomic Absorption Spectrophotometer, Shimadzu AA 630 after it was devised using Toxicity Characteristic Leaching Procedure (TCLP) method. The population structure was analyzed by calculating the dispersion pattern of *F. ater* using the Morisita Index, while the growth pattern was analyzed through the shell length and body weight data. The population density of *F. ater* was calculated using the formula D = ni/a. The results showed that The Accumulation of heavy metals Pb and Zn in *F. ater* and sediments varies at each station and each month, respectively 0-54.190 mg-Pb/kg and 18.935-113.04 mg-Zn/kg in rainy season, while 0-32.87 mg-Pb/kg and 0-84.53 mg-Zn/kg in dry season; The accumulation of heavy metals does not affect the existence of *F. ater* in the Bale river, but excessive levels for a long time will certainly have a negative effect on the health of the people who consume them. The highest density of *F. ater* are found in the dry season in April at Station 2 which is a rocks area and is favored as a habitat of its life, amounting to 442 species. The *F. ater* populations on the Bale River have a grouped distribution pattern commonly; uniform pattern only found in January for rainy season, and in February and April for dry season. The growth pattern of *F. ater* in Bale River was negative allometric characterized which long increment faster than weight gain, this happens both in the rainy and dry seasons.

INTRODUCTION

Lhoknga is located on the west coast of Aceh Besar. The rivers have important role in several activities such as industry, agribusiness, tourism, and in residential areas. Therefore, waters areas are vulnerable to contamination. Some important sources of pollutants are from housing, industry, climate change. These pollutants either directly or indirectly influence the quality of water (Abdel-Satar et al., 2017). Lead (Pb) and Zinc (Zn) metals that enter biodegradable water come from the activities of human life. It might also be through the stage of crystallization in the air by rain, so that Pb in the waters would be dissolved and suspended or it also settle on sediment (Palar, 2008). Molluscs are the best biota for use as heavy metal pollution bioindicators because they live in the bottom of the water and cannot move quickly. Molluscs has wide tolerance to brackish water and can indicate the relationship between the contaminant content in the water and inside (Cognetti and Maltagliati, 2000).

Faunus (*F.*) *ater* is one of the potentially bioaccumulative molluscs and it is found in many rivers in Aceh Besar district, such as Leupung river, Reuleng river, and Bale River. Afkar et al. (2014) showed that *F. ater* was dominant in the rivers on the west coast of Aceh Besar. The natural living place of *F. ater* is in the tropics with moderately warm temperatures (28-30 ˚C), in shallow waters. It lives on the base of muddy substrates and estuary environments. The *F. ater* is a group of herbivores that feed on detritus and organic materials on which snail lives in a favorable habitat because of a muddy substrate there are very abundant food particles (Lok et al., 2011). The *F. ater* spends its whole life in the aquatic environment. The existence of *F. ater* has a role in a food chain at the river ecosystem of Bale. The *F. ater* density can be used as an indicator of the environmental quality of water. The physico-chemical characteristics determine living conditions comprising composition, species density and aquatic biology which will further determine the density of the organism population associated with habitat conditions including the *F. ater* population (Choubisa, 2008).

The tsunami that occurred in 2004 had a profound effect for descruction of the population and changes in sediment composition in the river. The Bale River empties into the Lhoknga sea which is one of the worst points of the tsunami disaster. Its location is very close to the cement factory and it also gives its own tinge to the quality of this river. The cement plant does not produce liquid waste, but the remaining water from washing of heavy equipment was poured directly into the river. Contamination of heavy metals in water and sediment is largely due to industrial presence and at the low level due to agricultural activities (Michalik-Kucharz, 2008). As a consequence of industrial influence, water in most of habitats has chloride, phosphate, nitrate, sulfate, and high electrolytic conductivity. Sediments are sometimes polluted by heavy metals (Czaja, 1999; Jankowski, 2000). This study aims to analyze the accumulation of heavy metals in the *F. ater* and the population structure in the Bale River Lhoknga District, Aceh Besar Regency. The population structures analyzed include density, growth patterns and dispersal patterns of the *F. ater* Population.

Fig. 1: ***Faunus ater***

MATERIALS AND METHODS

Study area

Field sites were selected in Bale rivers Lhoknga Aceh Besar, Indonesia. This river passes through residential and industrial area. The location was divided into 3 stations: station 1 was upstream, station 2 at the river side, and station 3 close to the estuary of the river. Each station was assigned 3 sampling plots of 1 m × 1m each specified systematically. Sampling was done once a month for 6 months, November 2016, up to April 2017. The first 3 months constitute rainy season. The collection of sediment and snail samples of *F. ater* was done by diving and took directly from the bottom of the waters by hand set, then put in a sample bottle that has been labeled according to the observation station and transported to the laboratory for the analysis process.

Analysis

The accumulation of heavy metals in the *F. ater* and sediment was analyzed by using Atomic Absorption Spectrophotometer, Shimadzu AA 630 (Eaton and Epps, 1995) after destruction with Toxicity Characteristic Leaching Procedure (US-EPA, 1989). The observed population structure includes the density, dispersion patterns, and growth patterns of the *F. ater*. The analysis of the propagation pattern of *F. ater* was obtained through the calculation of the Morisita Indek (Krebs, 1989), with the formulation $I\delta = n\,[(\Sigma x^2 - \Sigma x)/((\Sigma x)^2 - \Sigma x)]$. The data of shell length and body weight were used to analyze growth patterns.

The relationship between length and tryness was calculated using the formula proposed by Hile (1936) in Effendi (2003): W = aLb where: W = dry weight; L = shell length; a and b = constants. The Sampling is done on each location for 3 months, with 1 taking each month. The population density of *F. ater* is calculated using the formula: Di = Ni/A, where: Di = Number of individuals per unit area (individual/m^2). Ni = Number of individuals in a quadratic transect. A = Area of quadratic transect (m2).

RESULTS

Content of pollutants in the Bale River Based on the preliminary analysis, Pb and Zn are the dominant heavy metals found on Bale river. The accumulation of Pb and Zn metal in *F. ater* and sediment in the Bale River for each station for 6 months of observation is tabulated in Tables 1 and 2.

Density level

Population density is the number of individuals per unit area or volume (Campbell et al., 2004). the density of *F. ater* in the bale river can be seen in Figures 2 and 3.

Dispersion pattern

The results of Index Morisita's data analysis indicate that the pattern of *F. ater* population spread in the period of November 2016 to January 2017, occurs in

Table 1: Concentrations of Pb and Zn in sediments and *Faunus ater* in Bale River representing the rainy season

Observation Station	sample	Concentrations of Pb and Zn(mg/kg)					
		November		December		January	
		Pb	Zn	Pb	Zn	Pb	Zn
Station 1	sediments	ND	46.62	ND	113.04	43.605	56.157
	F. ater	ND	93.81	ND	36.20	9.566	18.935
Station 2	sediments	ND	49.02	ND	50.30	54.190	50.012
	F. ater	ND	58.80	ND	20.31	6.977	23.778
Station 3	sediments	ND	48.81	ND	71.11	42.896	61.252
	F. ater	ND	78.75	ND	48.36	8.341	21.255

ND: Not detected.

Table 2: Concentrations of Pb and Zn in sediments and *Faunus ater* in Bale River representing the dry season

Observation Station	sample	Concentrations of Pb and Zn(mg/kg)					
		February		March		April	
		Pb	Zn	Pb	Zn	Pb	Zn
Station 1	sediments	14.31	71.36	17.21	84.53	ND	46.50
	F. ater	ND	12.06	4.53	15.05	ND	16.48
Station 2	sediments	ND	ND	32.87	44.06	ND	32.37
	F. ater	ND	8.63	1.11	15.86	ND	16.83
Station 3	sediments	16.59	15.86	22.08	39.72	ND	21.05
	F. ater	ND	12.02	1.15	16.83	ND	22.41

ND: not detected.

Table 3: Distribution pattern of *Faunus ater* representing the rainy season

Time of sampling	Station	Plot			Σx	Σx^2	$(\Sigma x)^2$	n	Iδ	Distribution pattern
		1	2	3						
November 2016	1	106	42	54	202	15916	40804	3	1.16	grouped
	2	19	22	38	79	2289	6241	3	1.08	grouped
	3	2	0	3	5	13	25	3	1.2	grouped
December 2016	1	89	63	76	228	17666	51984	3	1.01	grouped
	2	44	59	62	165	9261	27225	3	1.01	grouped
	3	9	3	0	12	90	144	3	1.77	grouped
January 2017	1	111	80	60	251	22321	63001	3	1.05	grouped
	2	75	42	49	166	9790	27556	3	1.05	grouped
	3	11	6	7	23	195	529	3	0.98	uniform

Table 4: Distribution pattern of *Faunus ater* representing the dry season

Time of sampling	Station	Plot			Σx	Σx^2	$(\Sigma x)^2$	n	Iδ	Distribution pattern
		1	2	3						
February	1	119	118	80	317	34485	100489	3	1.02	grouped
	2	73	95	95	263	23379	69169	3	1.01	grouped
	3	5	3	1	9	35	1225	3	0.06	uniform
March	1	112	91	118	321	34749	103041	3	1.01	grouped
	2	119	98	126	343	39641	117649	3	1.01	grouped
	3	17	13	23	53	987	2809	3	1.02	grouped
April	1	86	139	113	338	39486	114244	3	1.03	grouped
	2	141	197	104	442	69506	195364	3	1.06	grouped
	3	5	4	5	14	66	4356	3	0.04	uniform

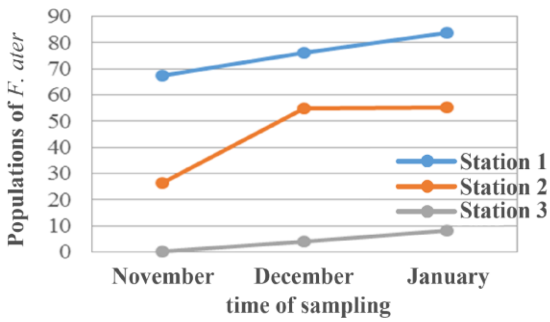

Fig. 2: Density of *Faunus ater* representing the rainy season

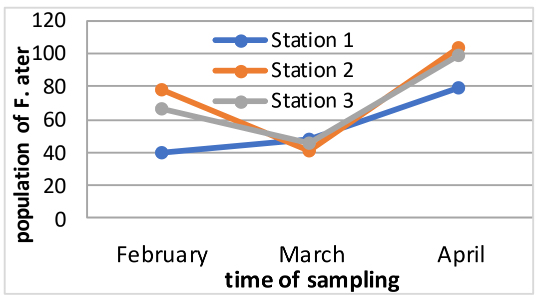

Fig. 3: Density of *Faunus ater* representing the dry seasons

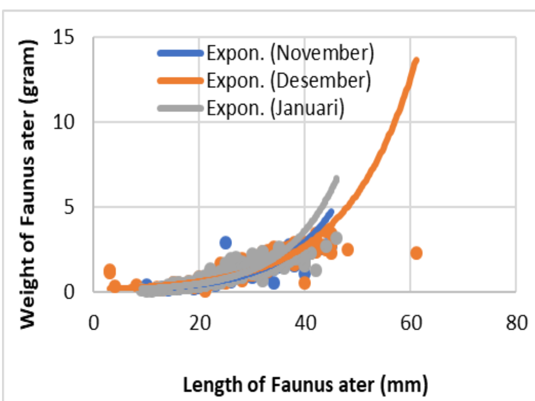

Fig. 4: Growth pattern of *Faunus ater* representing the rainy seasons

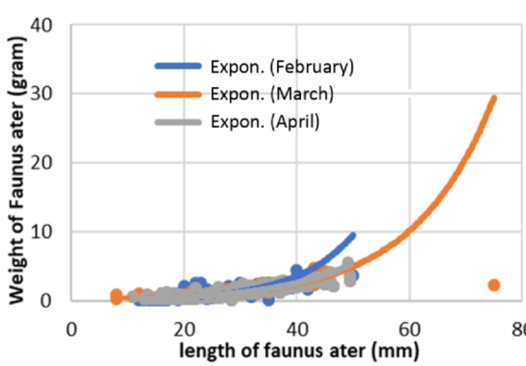

Fig. 5: Growth pattern of *Faunus ater* representing the rainy seasons

groups and uniforms. The results of the Morisita Index measurements are shown in Table 3.

The results of Index Morisita's data analysis indicate that the pattern of *F. ater* population spread over the period February to April 2017, also occurs in clusters and uniforms. The results of the Morisita Index measurement are shown in Table 4.

Growth patterns

Measurements of the *F. ater* growth pattern on the Bale River is shown in Figure 4. The growth rates of the *F. ater* in the Bale River show that the minimum and maximum shell lengths in November 2016 observations are 14-54 mm with a weight of 0.15-5.25 gram.

DISCUSSION

Table 1 presents data of heavy metal content in the first 3 months, representing rainy season (November - January 2017), the analysis results show that Pb and Zn metal content in the sediments ranged from 0-54.19mg-Pb/kg and 46.62-113,04mg-Zn/kg and the accumulation of Pb and Zn metal at *F. ater* ranges from 0-9.57 mg-Pb/kg and 18.93-93.81mg-Zn/kg, respectively. The content of Pb in the sediments and *F. ater* in November and December indicates that the metal content of both the sediments and the *F. ater* was too small. The results of the analysis in January show that it gave significantly increased values, where in Pb content in sediments was found to be 43.60mg-Pb/kg (Station 1); 54.19mg-Pb/kg (Station 2); and 42.89mg-Pb/kg (Station 3). This difference may occur due to differences in ecological conditions in the area where in November and December that the study areas tend to extremes with marked occurrence of several storms resulting in unstable water currents. Current conditions can affect the accumulation of heavy metals in sediments and *F. ater*. This situation differs from the results of the analysis on the Zn metal, where the metal is found both in sediments and accumulated in the *F. ater* at each observation station. The easily decomposed nature of Pb was an indication of this difference (Reed et al., 1988).

The results showed that Zn content in the highest-grade sediment found at Station 1 in December 2016 reached 113.04 mg-Zn/kg. Station 1 was located in the upstream of the Bale River adjacent to the hills, where in the rainy season some of the rocks and soil from the hills will be eroded by rainwater into the river. Lack of community activity and low river velocity also causes Zn to tend to settle into sediment. Similarly, what happened to *F. ater* where the highest Zn content at *F. ater* was found at Station Observation 1 in November 2016 which reached 93.81 mg-Zn/kg. Table 2 presents data on heavy metal content in the second 3 months, representing dry season (February-April 2018) of Pb and Zn metal content in the sediments ranging from 0-

32.87mg-Pb/kg and 0-84.53mg-Zn/kg respectively and metal accumulation Pb and Zn at *F. ater* ranged from 0-4.53mg-Pb/kg and 8.63-22.41mg-Zn/kg, respectively.

The density of the *F. ater* in the Bale River is variable with each station. The population density of *F. ater* at Bale River is shown in Figure 1 which shows that the density level at each station fluctuates every month. Based on the calculation of *F. ater* density during three months of the rainy season, it is known that the average *F. ater* density range on the three stations shows that is very significant differences. The highest density of *F. ater* is found in Station 3 and the lowest density is at Station 2. The highest density is at Station 3, this is related because Station 3 is a rocks area which is favored by *F. ater* as the habitat of its life. This snail is attached to the union because many bentos are attached which is one of the food sources so that the density of slugs at Station 3 is higher than Station 1 and 2. The difference in the presence of Pb (table 1 and 2) is more commonly in the dry season, (almost in every stasion), it's not happen in the rainy season, the metal content will be smaller because of solution process, while in the dry season the metal content will be higher because the metal becomes concentrated. In addition to the corresponding substrate conditions.

The *F. ater* density is also influenced by the amount of food contained in substrates containing high organic matter. The *F. ater* density is associated with organic ingredients, as most gastropods, including *F. ater* are deposits of feeders that utilize the deposition of organic matter on the bottom substrate of the water as food. Siregar (2013) explains that food availability factors are also influential in supporting the survival and growth of *F. ater*. The availability of organic matter will provide variations in density to existing organisms (Gilles et al., 2015). The Factors that limit the distribution and density of snail species in nature are categorized into two factors, namely natural factors in the form of genetic traits and the behavior or tendency of a biota to select the preferred habitat type. Therefore, the distribution and density of snails in nature can be an indication of habitat suitability to a particular biota (Stensgaard et al, 2006). In addition, the food availability factor also contributes in supporting the survival and growth of snails (Tanaka et al, 1999). The population of *F. ater* differs in the rainy and dry seasons (fig 1 and 2), the population of *F. ater* increases in the dry season, the highest was found in April amounting to 442 individuals. *F. ater* prepares for its development in the rainy season, the abundant food makes the fertile *F. ater* and spawns a lot egg. After about 3 months the egg has turned into an adult snail. Snail live more actively in a warm and dry environment; high mobility also causes many of these snails found in the dry season.

The pattern of dispersion of *F. ater* was similar in both dry and rainy seasons (table 3 and 4) the observations in November showed that all stations showed a clustered pattern of distribution. In observation of December and January, the pattern of spreading in groups only occurs in Station 3, which is near the river estuary. Based on the criteria of the Morisita Index, the snail dispersal pattern, *F. ater* is clustered because of the Morisita Index score is greater than one. Worthington et al (2008) states that most of the basic animals of distribution are clustered, because they choose to live in the habitat that suitable for them Hubendick (1958) asserted that the main cause of distributed distribution pattern for aquatic biota is environmental condition, mode of production, and eating habits. The splitting patterns of distribution will make it easier for individuals to connect with each other for various needs, such as reproducing and feeding.

The pattern of uniform deployment mostly occur in December and January (for Stations 1 and 2) are unusual, as uniform distribution patterns are rare in natural populations. Conditions that close to this situation is in the event of thinning due to competition between individuals who are relatively tight (Michael, 1994). Interventions of pollutants entered the waters can also trigger this unusual, Station 1 and Station 2 are areas that pass through residential areas. The presence of household wastes and other small industries causes an unfavorable environmental condition for *F. ater*. The availability of organic substances is low and competition for food is getting tougher. The data revealed that the pattern of snail growth varies every month but did not show any significant difference. This growth pattern increases with increasing the shell size. Calow (1973) states that after reaching the maximum average length, the snail will experience a decrease in the acceleration of growth (growth will stop). The linkage of the substrate to the availability of food in the form of detritus and plankton becomes a factor in the growth that occurs on snails.

The growth pattern in both seasons shows the same pattern, ie negative allometric (fig 3 and 4), in which the shell increase is faster than the addition of *F. ater* weight. Allometrik negative is a characteristic of *F. ater*, because the mollusks protect themselves from the environment with their shells, so that the growth of the shell takes precedence over the growth of the rest of the body. Goodfriend (1986) mentions that the shell is the most prominent part of the mollusk so that the growth of this mollusc is the increase in the length of the shell followed by the increase of its body. The presence of heavy metals Pb and Zn did not significantly affect the life of *F. ater* in the Bale river, the density of *F. ater* is still high (Fig 1 and 2), the pattern of spreading and growth pattern, patterned as normal, only in 2 stations showing an unusual distribution pattern (tables 3 and 4). but high levels of Pb and Zn in the body of *F. ater* (Table 1 and 2) certainly gives a bad effect for people who routinely consume this snail. Lead is a non-essential metal that can cause acute and chronic poisoning because of the nature of heavy metals that can accumulate in the body. In addition to suspected carcinogenic, lead metal (Pb) can cause disturbances in digestion, especially in the kidneys and liver, as well as bone damage (Pandey and Madhuri, 2014). According to Indonesian National Standard (SNI) in 2009 the maximum limit of Zn and Pb contamination in mollusca is 1.5 mg/kg, while according to UNESCO/WHO/ UNEP (1992) normal limits of Pb levels for aquatic organisms are 0.001-0.007 mg/litre, and 0.03 for Zn.

In conclusion, the Accumulation of heavy metals Pb and Zn in *F. ater* and sediments varies at each station and each month, respectively i.e. 0-54.19 mg-Pb/kg and 18.94-113.04 mg-Zn/kg in rainy season: while 0-32.87 mg-Pb/kg and 0-84.53 mg-Zn/kg in dry season. The accumulation of heavy metals does not affect the existence of *F. ater* in the Bale river, but excessive levels for a long time will certainly have a negative effect on the health of the people who consume them. The highest density of *F. ater* are found in the dry season in April at Station 2 which is a rocks area and is favored as a habitat of its life, amounting to 442 species. The *F. ater* populations on the Bale River have a grouped distribution pattern commonly; uniform pattern only found in January for rainy season, and in February and April for dry season. The growth pattern of *F. ater* in Bale River was negative allometric characterized which long increment faster than weight gain, this happens both in the rainy and dry seasons.

Authors' contributions

RA designed and revised manuscript. The sample acquisition and preparation was done by Rahmadi. While MAS, FY, Suhendrayatna and Lelifajri participated in data analysis, interpretation and revision.

REFERENCES

Abdel-Satar, Amaal M Ali, and H Mohamed, 2017. Indices of water quality and metal pollution of Nile River, Egypt. Egyptian Journal of Aquatic Research, 43: 21-29.

Afkar A, D Djufri, MA Sarong, 2014. Asosiasi Makrozoobenthos Dengan Ekosistem Mangrove Di Sungai Reuleng Leupung, Kabupaten Aceh Besar. Jurnal EduBio Tropika, 2: 210-215.

Calow P, 1973. On the regulatory nature of individual growth: some observations from freshwater snails. Journal of Zoology, 170: 415-428.

Campbell NAR, B Jane and MG Lawrence, 2004. Biologi Edisi Kelima Jilid 3, Erlangga, Jakarta, Indonesia.

Choubisa SL, 2008. Focus on pathogenic trematode cercariae infecting fresh water snails (Mollusca: Gastropoda) of tribal region of southern Rajasthan (India). Journal of Parasitic Diseases, 32: 47-55.

Cognetti G and F Maltagliati, 2000. Biodiversity and adaptive mechanisms in brackish water fauna. Marine Pollution Bulletin, 40: 7-14.

Czaja S, 1999. Changes in water relations under the conditions of strong anthropopression (A case study of Katowice conurbation). Katowice: Wydawnictwo Uniwersytetu S´ laskiego, Indonesia.

Eaton AD and AA Epps, 1995. Standart Methods for the Examination of Water and Wastewater. 19th Edition, APHA, AWWA and WEF, Baltimore, MD, USA.

Effendi H, 2003. Telaah Kualitas Air Bagi Pengelolaan Sumber Daya dan Lingkungan Perairan. Penerbit Kanisius, Yogyakarta, Indonesia.

Gilles A, S Viquerat, EA Becker, KA Forney, SCV Geelhoed, J Haelters and FM Van Beest, 2016. Seasonal habitat-based density models for a marine top predator, the harbor porpoise, in a dynamic environment. Ecosphere, 7: e01367.

Goodfriend G, 1986. Variation in land-snail shell form and size and its causes: a review. Systematic Biology, 35: 204-223.

Hile R, 1936. Age and growth of the cisco, Leucichthys artedi (Le Sueur), in the lakes of the northeastern highlands, Wisconsin, USA.

Hubendick B, 1958. Factors conditioning the habitat of freshwater snails. Bulletin of the World Health Organization, 18: 1072.

Jankowski A, 2000. Silesian Upland and its borders – condition and anthropogenic changes of the surface water quality. State and Anthropogenic Changes of Water Quality in Poland, pp: 143-154.

Kabat P, 2004. Climate changes the water rules: how water managers can cope with today's climate variability and tomorrow's climate change. Water and Climate (Available online at: https://portals.iucn.org/library/sites/library/files/documents/2003-107.pdf).

Krebs CJ, 1989. Ecology: The Experimental Analysis of Distribution and Abundance. 3rd Edition. Harper and Row Publishers, New York, USA.

Lok AFSL, W Ang, PX Ng, BY Ng and SK Tan, 2011. Status and distribution of *Faunus ater* (Linnaeus, 1758) (Mollusca: Cerithioidea) in Singapore. Nature in Singapore, 4: 115-121.

Michael PE, 1994. Metode Ekologi untuk Penyelidikan Ladang dan Laboratorium. Universitas Indonesia, Jakarta, Indonesia.

Michalik-Kucharz A, 2008. The occurrence and distribution of freshwater snails in a heavily industrialised region of Poland (Upper Silesia). Limnologica 38: 43–55.

Pandey G and S Madhuri, 2014. Heavy metals causing toxicity in animals and fishes. Research Journal of Animal, Veterinary and Fishery Sciences, 2: 17-23.

Reed AE, LA Curtiss and F Weinhold, 1988. Intermolecular interactions from a natural bond orbital, donor-acceptor viewpoint. Chemical Reviews, 88: 899-926.

Standar Nasional Indonesia (SNI) 7387, 2009. Batas Maksimum Cemaran Logam Berat dalam Pangan. Badan Standaridasi Nasional, Indonesia.

Siregar S, 2013. *Metode Penelitian Kuantitatif*. Jakarta: PT Fajar Interpratama Mandiri, Indonesia.

Stensgaard AS, A Jørgensen, NB Kabatereine, C Rahbek and TK Kristensen, 2006. Modeling freshwater snail habitat suitability and areas of potential snail-borne disease transmission in Uganda. Geospatial Health, 1: 93-104.

Tanaka K, T Watanabe, H Higuchi, K Miyamoto, Y Yusa, T Kiyonaga and T Wada, 1999. Density-dependent growth and reproduction of the apple snail, *Pomacea canaliculata*: a density manipulation experiment in a paddy field. Researches on Population Ecology, 41: 253-262.

UNESCO W, 1992. UNEP. Water Quality Assessment-A Guide to Use Biota, Sediment and Water in Environmental Monitoring. (Available online: https://www.earthprint.com/universityoflondon/)

US-EPA, 1989. EPA Superfund Record of Decision: Picatinny Arsenal (US Army). Rockaway Township, NJ, U.S. Environmental Protection Agency Superfund. (Available online at: http://www.epa.gov/superfund/sites/rods/fulltext/r0289093.pdf).

Worthington WJ, C Elkin, C Wilcox, L Murray, D Niejalke and H Possingham, 2008. The influence of multiple dispersal mechanisms and landscape structure on population clustering and connectivity in fragmented artesian spring snail populations. Molecular Ecology, 17: 3733-3751.