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RESEARCH ON CADMIUM ACCUMULATION OF UNDULATE VENUS CLAM (*PAPHIA UNDULATA* BORN, 1778) IN THE COASTAL WATERS OF BINH THUAN PROVINCE

SUMMARY OF DISSERTATION ON
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INTRODUCTION

1. The urgency of the thesis

Short-necked clam *Paphia undulata* (Born 1778) is one of the exported bivalve molluscs species with high economic value. Environmental pollution is increasing day by day due to industrial development can be create pressure for aquaculture in particular, leading to affecting export ability.

Some major heavy metals such as Pb, Hg, Cd can be toxicity even low concentrations, which are found in sediments and aquatic environments.

In trace form, they are assessed as toxic elements and can cause immediate poisoning or long-term effects on biological life and human health. In the world, many countries have had cases of poisoning due to the use of seafood products that accumulate pollutants, or farmed products that do not ensure food safety and hygiene, affecting public health and causing serious harm to the community. heavy economic losses for farmers, such as the event of methyl mercury poisoning in Minamata Bay - Japan (1932 - 1971); Cd pollution causes Itai-Itai disease in Toyoma - Japan; etc .

From the specific structures and biological characteristics (passive filter feeding, bottom living,...) of marine mammals, researchers have assessed that some of these objects have a high ability to accumulate pollutants. environment, and is used as an indicator organism to monitor and evaluate the level of environmental pollution in coastal estuaries. Through many studies, it has been shown that the ability of bivalves to accumulate heavy metals is much higher than that of other aquatic species. The accumulation of heavy metals in the body of marine mammals is hundreds or even thousands of times higher than that of metals in the aquatic environment. The ability to accumulate Cd in tissues is 100,000 times higher than in water; This accumulation will persist through the food chain for a long time, posing a threat to ecosystems, the environment and human health.

Cd is considered to be highly toxic, capable of accumulating and accumulating long-term in the organism, especially high accumulation in bivalves.

Short-necked clam are one of the aquatic species with economic and export value. The fact that short-necked clam have accumulated Cd does not guarantee food safety in Binh Thuan and Kien Giang provinces. Therefore, there is a need for research on Cd accumulation in this species.

2. The objectives of the thesis

- *Overall objectives*: Determine the accumulation of Cd in the body of the short-necked clam serve for environmental monitoring and food safety problem.

- *Specific target*:

+ Assessment of the fluctuation and relationship between Cd content in water environment, sediments, and food sources (suspended matter and plankton);

+ Assessment of the Cd fractions in the sediment and relationship between Cd-bounding and their accumulation in short-necked clam.

+ Assessment of the level of Cd accumulation in the body of short-necked clam according to their body parts (gills, mantle, legs, digestive system, total tissues, etc.) and the relationship between environmental factors and food sources.

3. Major research contents in the thesis

- Review of domestic and foreign literature relate to the research contents of the thesis

- Studies on the relationship between cadmium contents in the seawater, food sources (suspended sediment and plankton), and sedimentary environment.

- Study of cadmium accumulation according to size and other parts of the short-necked clam and relate to them with environmental factors and food sources.

- Experiment studys of the cadmium accumulation from water environment and food source under laboratory conditions.

4. Scientific and practical significance of the topic

- Contribute to clarifying the source of Cd accumulation in silk clams in the coastal area of Binh Thuan province; Cd accumulation level in parts and sizes of clams; interactions between the environment and organisms.

- Meaningful results in the practice of raising/exploiting and harvesting marine mammals to ensure food safety, as well as the practice of environmental monitoring and warning

CHAPTER 1. OVERVIEW

1.1. Introduction research subjects

Short-necked clam *Paphia undulata* (Born, 1778) is a commercially important bivalve species of the phylum Mollusca, class Bivalvia, order Venerida, family Veneridae, genus Paphia Roding, 1798. *P. undulata* has a moderately inflated and transversely elongate shell. Its outer surface is smooth and glossy, with fine, slightly oblique undulating grooves. Their shell has light yellow outside while white inside. Main harvesting season lasts from December to June after year.

The weight growth rate of the short-necked clam Paphia undulata is faster than height development. Speciality biological characteristics of this species is passive filter eating. Plankton (zooplankton, phytolankton), suspended matter, organic humus are the foods type were found in their stomach (Quayle & Newkirk, 1989).

Therefore, these species are assessed to have a great ecological role in cleaning the aquatic environment (Carter, 1980). They have a high ability to accumulate pollutants in the body, hundreds or even thousands of times higher than metals in water.

1.2. Ovallview cadmium in the marine environment

In the water environment, the metals can be speciation-free ion or complex-bound metals with organic and inorganic appearances in aquatic.

Cd is generally less mobile than other heavy metals. Cd can be complexed with Humic content in the aquatic. The chemical properties of Cd depend on the pH conditional.

In marine water, ion Cd^{2+} will be bound ion Cl^- to chloride and when the salinity decrease, $CdCl_2$ can be divided to create ion Cd^{2+} and form toxicity in the aquatic species. In the reduction conditional, Cd can be speciation Cd^{2+}, Cd^0, CdS; CdS content is slightly soluble in water and forms adsorbed precipitates on the sediment surface.

Cd parameter is one of the three important metal parameters (including Cd, Hg, Pb) relative to food safety quality monitoring program of bivalvia in the world and Vietnam.

1.3. Studies in the world on heavy metal accumulation

1.3.1. Heavy metal accumulation levels in bivalves

- Assessment heavy metals and cadmium in the survey
- Assessment heavy metals and cadmium in laboratory conditional
- Cadmium accumulation in the parts of the bivalve body
- Cadmium accumulation in the short-necked clam according to their body size.

1.3.2. Relationship between heavy metal accumulation in bivalve and environment factors

1.3.3. Study on heavy metal fraction in sediment

1.3.4. The path way and mechanism accumulate heavy metal

Up to now, there are many studies relate to metal accumulation in bivalve species in the world, both of them in the survey and expriment laboratory model. Studies focus on assessment of accumulation levels of species, in organs, elimination ability, relationship with aquatic environment, sediment and food, sources and causes of accumulation, mechanism of accumulation; management and mitigation solutions. The research results are important scientific database to serve monitoring the environment by indicator organism, food safety and hygiene issues, and serve the practice of producing bivalve more efficiently.

1.4. Studies in the domestic on heavy metal accumulation

In Vietnam, research on heavy metal accumulation in bivalve has been carried out in recent years. The studies mainly assessed the level of accumulation and some evaluation of the metal elimination ability in bivalve species (Meretrix lyrata, scallops, mussels, etc… these species have living in esturary or recess)

So far, there have been no reports on Cd accumulation in short-necked clam, according to their body size and distribution areas. Some studies mentioned the relationship between heavy metal accumulation in bivalve molluscs and aquatic environment, sedimentary environment, but mainly *meretrix lyrata* species living in intertidal zone, not yet available. There are no reports on the relationship with Cd concentration in short-necked clam and in the environment. The studies on how Cd metals in the food source, their form of existence, and the ability to cause accumulation from the food source into short-necked clam is rarely and asynchronous. Some studies mention the existence of heavy metals, but they are in rivers and intertidal areas, with different environmental and geological characteristics from the study area of the thesis. Up to now, there has been no synchronous study to show the source of Cd metal accumulation, distribution and existence of Cd in the body parts of short-necked clam.

1.5. Overview of natural and environmental conditions in coastal Binh Thuan province

The coastal area of Binh Thuan is considered as one of the distribution and high yielding areas of bivalve species (focus harvesting area). The economic development activity can be also have the potential to emit heavy metals, along with the river system will bring pollutants to the coastal area. The coastal area of Binh Thuan also has natural, hydrographic and environmental conditions with its own characteristics, such as the influence of upwelling water, high biodiversity, and high plankton density. In fact, some bivalve species in Binh Thuan coastal areas contamined cadmium with high levels and not safe.

CHAPTER 2. MATERIAL AND METHODOLOGY

2.1. Object and scope of the study

2.1.1. Object study

Cd accumulation in short-necked clam *Paphia undulata* collected in the survey and laboratory experiment. In addtion, molluscs species also collected to research cadmium accumulation due to simillar aquatic ecosystem and serve assessment differrent other species.

Fluctuations and relationship between Cd content in water environment, sediments, food sources (suspended sediment and plankton) and Cd accumulation according to parts and sizes of short-necked clam.

2.1.2. Study area descreption

- Estuary system: 06 main estuaries distribute in study area (such as Dinh river, Phan river, Ca Ty river, Cai river, Luy river and Long Song river) with 22 sampling sites. Representative sampling points are located in the river, in the estuary and outside the river mouth.

- The coastal area: Survey and sample collection at 08 stations (BT1 to BT8) in the bivalve harvesting areas: Phan Thiet (02 stations), TX. La Gi (03 station) and Tuy Phong district (03 statons).

Along with the samples and data in Binh Thuan, the thesis also collects some samples and inheritance Cd data in the seawater and bivalve of Quang Ninh (2 points) and Kien Giang (2 points).

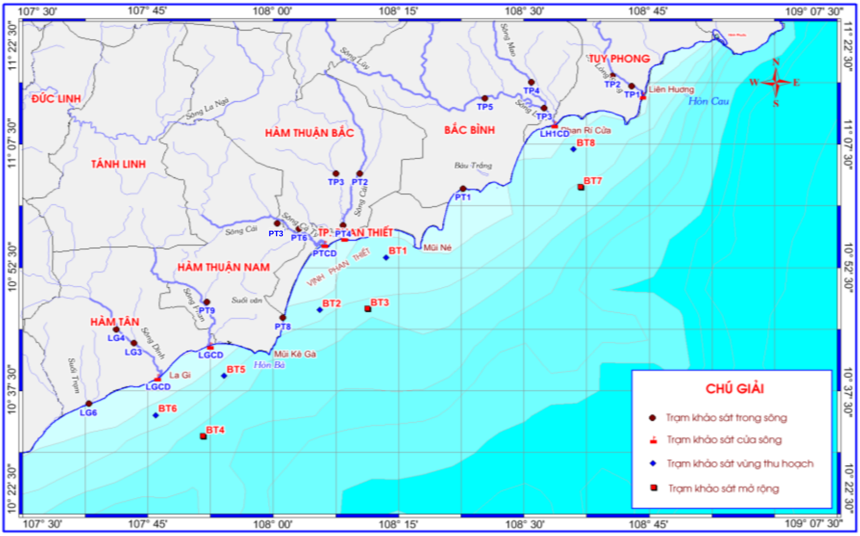

Figure 2.2. Study area in Binh Thuan province

- Base on the system of sampling points in the harvesting area of Binh Thuan province, 10 sampling times in 2015 were investigated from March to December; In 2016, sampling three times were collected: February; April and June.

- Inheriting samples and data from 04 evaluations at stations in the river, estuary and harvesting areas (outside the estuary and offshore, expansion stations in the harvesting area) synchronized with four times survey in harvesting area: October - November 2013 (rainy season); April and May 2014 (dry season) and November 2014.

2.2. METHODOLOGY

2.2.1. Collecting, synthesizing, and inheriting information method

Inheriting to synthesize data and information of programs, topics and research projects in the harvesting areas of the three research provinces (Quang Ninh, Binh Thuan and and Kien Giang).

2.2.2. Investigating and Sampling Method In Survey

Collecting and preserving samples are carried out are carried out by Circular No. 24/201 7 /TT-BTNMT dated 1st September, 2017 on regulations on technical procedures for environmental monitoring and Circular No. 31/2011/TT-BTNMT dated 1st August, 2011 on regulations on technical procedures for environmental monitoring of seawater (including bottom sediments and sediments).

2.2.3. Analytical Methods in the Laboratory

Sample analysis according to Circular No. 24/2017/TT-BTNMT dated on 1st September, 2017 of the Ministry of Natural Resources and Environment on the Regulation on the technical process of environmental monitoring and the Circular No. 31/2011/TT-BTNMT dated August 1, 2011 of the MONRE; as prescribed in QCVN 08-MT:2015/BTNMT for river water, QCVN 10-MT:2015/BTNMT for seawater; QCVN 43-MT:2017/BTNMT for quality sediments and according to Standard method (SMEWW).

Modified Tessier sequential extraction procedure to determine the bound franctions (F1, F2, F3, F4, F5) of Cd in the sedimentary environment according to Tessier *et al*. (1979), improved by Davidson & Thomas (1995).

Analysis of total Cd content in suspended sediments & plankton and sedimentary environment: after inactivation of samples with acid mixture in sealed Teflon digestion flasks under high pressure and temperature according to the documentation of US.EPA, Method 3052.

Determination of Cd content in microorganisms: after homogenization sample, about of 0.5 g sample were immered with a mixture of HNO_3 acid and H_2O_2 solution dedicated digestion flask Teflon according to the FDA Elemental Analysis Manual for Food and Related Products of the FDA according to Patrick et al (2015).

2.2.4. Experimental research in the laboratory

The technical parameters, and environmental criteria designed in the experimental batches are based on: (1) Measurement and analysis results in the field of the parameters of temperature, salinity, pH, DO, TSS, and Cd in Water Environment; Cd content in plankton and suspended sediment; size short-necked clam and Cd concentration in bivalves; (2) refer to the threshold of effect, causing death (LC 50, LD 50) for CAD; (3) results of research works.

Control experiment: Keep the cultured subjects in the filtered seawater tank.

Experimental plots: The experimental plots include: (1) the ability to accumulate Cd through exchange with the seawater environment; (2) the ability to accumulate Cd through exchange with the marine environment supplemented with algae; (3) the ability to accumulate Cd through the food route by supplementing with Cd-contaminated in suspended and plankton.

- Experimental batch to investigate the accumulation of Cd on mammals through dissolution, exchange, and without food supplementation: In this experiment, Cd was designed at concentrations of 5 µg/l, 10 µg/l, and 20 µg/l for short-necked clam, and scallops.

- Experimental batch to investigate Cd accumulation on marine mammals through dissolution, exchange, and supplementation with algae: Short-necked clam and scallops were raised in experimental tanks with Cd concentrations of 2µg/l, 5µg/l and 10µg/l. Supplementing with chaetoceros algae during the rearing process every 2 days.

- Experimental batch to investigate the accumulation of Cd on bivalve through the absorption of Cd-contaminated food: Suspended sediment & plankton after collection from the harvest area are soaked in Cd solution with concentrations of 0 ,2 mg/ l and 0.5 mg/l, stirring continuously (aeration). In this experiment, the amount of contaminated suspended sediment was added to seawater to achieve TSS with a concentration range of 50 - 60mg/l.

2.2.5. Data processing methods, assessment and technical

- Using the license according to QCVN 10-MT:2015/BTNMT, QCVN 08- MT:2015/BTNMT serve to assess water quality; QCVN 43:2017/BTNMT for sediments; TCVN 8681:2011 evaluates Cd in bivalve.

- Using ICF and CF indexes to assess the level of Cd pollution in sediments (Hakanson, 1980, Zhao et al., 2012).

- Using the Risk Assessment Code - RAC (Jain, 2004; Baran and Tarnawski, 2015) to assess the risk of Cd infection based on the composition of the total forms of F1, F2 (exchange, dissolve). - F1, carbonate bonds - F2) in the study areas.

+ RAC < 1% at no risk;

+ RAC from 1 ÷ 10% at low risk;

+ RAC from 11 ÷ 30% at medium risk;

+ RAC from 31 ÷ 50% at high risk;

+ RAC > 50% at very high risk.

- Determination of bioaccumulation factor (BCF: Bioconcentration Factor) according to USEPA (1997), Landis *et al.* (2011):

$$BCF = Ct/Cw$$

- Use the BSAF coefficient according to Szefer *et al.* (1999) and Ziyaadini *et al.* (2017) to assess the degree of Cd accumulation from sediments.

- Research data was processed by statistical method and graphed using Excel, SPSS software. Compare the mean values by analysis of variance (Anova), checking for the least significant difference. Using correlation coefficient (r), linear regression to evaluate the relationship. Use the t-test to evaluate the difference.

The main equipment to carry out the project is the Australian Spectr AA 220 Varian atomic absorption spectrometer system (including the VGA 77 vaporization system and the GTA 110 graphite furnace); spectrometer VA 797; device ICP/MS NexION 2000B; specialized inorganic Teflon equipment under high pressure and temperature, standard samples MESS 3, DOLT-5,...

CHAPTER 3. RESULTS AND DISCUSSION

3.1. Study on the variation and relationship of Cd content in environmental components in coastal areas of Binh Thuan province

3.1.1. Cd concentration in the water

3.1.1.1. Cd content in river water

The average Cd concentration in the rainy season is 0.65 µg/l and 0.70 µg/l in the dry season. Compared with the permissible limit (5µg/l) according to QCVN 08-MT:2015/BTNMT, the Cd concentration observed in the areas is still lower than the permitted level (Fig 3.1).

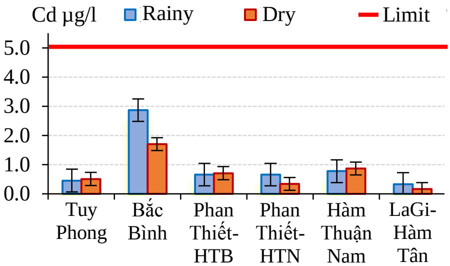

Figure 3.1. Cd content in river water in the harvesting area of Binh Thuan province

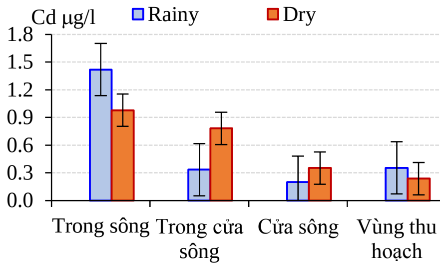

Figure 3.3. Cd content in river water and sea water in coastal areas of Binh Thuan

The observed Cd in seawater is lower than the permissible limit (5µg/l) according to QCVN 10-MT:2015/BTNMT, the highest concentration is only 2.86 µg/l. Cd content in seawater in the harvest area is much lower than in river water; The surface layer (0.308 µg/l) is higher than the bottom layer (0.283 µg/l **)** , the rainy season (0.354 µg/l) is higher than the dry season (0.238 µg/l).

The Cd content in water tends to decrease gradually from the river to the harvest area, showing this trend in both rainy and dry seasons (Figure 3.3); inversely distributed with salinity and water pH.

3.1.2. Cd content in suspended sediments and plankton

- ***Cd content in suspended sediment and planton in estuary areas***

The content of Cd contained in SS&PLANK is quite high, the recorded values range from 1.08 to 26.97 mg/kg. During the dry season, the accumulation of Cd metal in SS&PLANK is not much different from that in the rainy season.

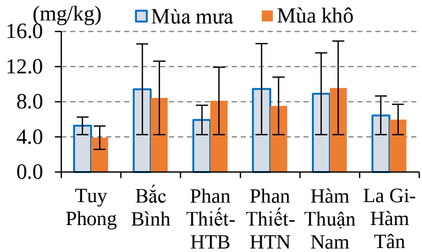

Figure 3.4. Concentration of Cd in SS&PLANK in rivers by coastal districts of Binh Thuan

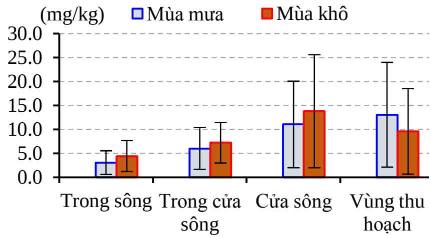

Figure 3.5. Concentration of Cd in SS&PLANK from river to harvest area

- ***Cd content in suspended sediment and plankton in harvesting area***

The results of analysis of Cd in suspended matter and plankton in the study area are very high, 10 thousand times higher than in water environment and about 6 times higher than in sediment. The observed values of Cd in the common ranged from 0.15 to 88.66 mg/kg, with an average of 11.32 mg/kg; rainy season is higher than dry season.

Cd content in plankton tends to be inversely distributed with Cd in water. According to the cross-sections from the river to the estuary and to the harvesting area, the Cd content in the plankton shows an increasing trend (Fig 3.7), with the tendency of Cd to be covariate with the pH and sea salinity.

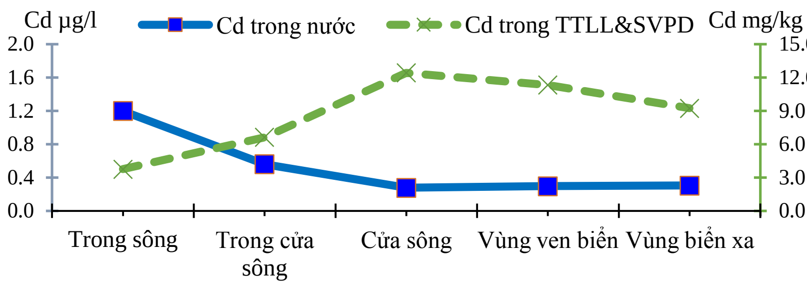

Fig 3.7. Distribution of Cd content in water and in CLL & SVPD according to cross section from river to coastal area of Binh Thuan province

3.1.3. Cd content in sediments

- ***Total Cd content in river sediments:***

The Cd content in the sediments varied greatly among the surveyed rivers. The observed values ranged from 0.80 to 2.22 mg/kg, averaging 1.24

mg/kg in the rainy season; from 0.22 to 1.38 mg/kg, averaging 0.96 mg/kg in the dry season. Compared with QCVN 43:2017/BTNMT, the Cd content in river sediments is still within the permissible limit.

In general, the Cd concentration in sediments in the rainy season tends to be higher than that in the dry season, except for some areas in Bac Binh and Phan Thiet-Ham Thuan Bac.

- ***Cd content in the sediment of the harvest area***

The concentration of Cd in the sediments observed in the mangrove harvesting area of Binh Thuan is also lower than the permitted level (4.2mg/kg) according to QCVN 43:2017/BTNMT. The mean value was 1.79 ± 1.37mg/kg. According to the season, in general, the Cd concentration in the rainy season (average 1.96 ± 1.25 mg/kg) is higher than in the dry season (average 1.62 ± 0.82 mg/kg), which is shown in different regions. research research. Among areas in Binh Thuan, the Cd concentration in Tuy Phong area was highest (average 2.06 mg/kg), followed by La Gi (1.89 mg/kg) and lowest in Phan Thiet, with an average concentration of 1.43 mg/kg (Fig 3.9).

According to the cross-section from the river to the harvest area, Cd in the sediment shows an increasing distribution, similar to Cd in suspended matter (Fig 3.10).

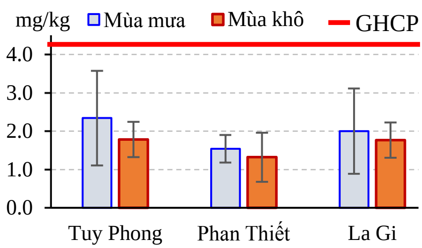

Figure 3.9. Cd content (mg/kg) in sediments according to harvesting areas in Binh Thuan

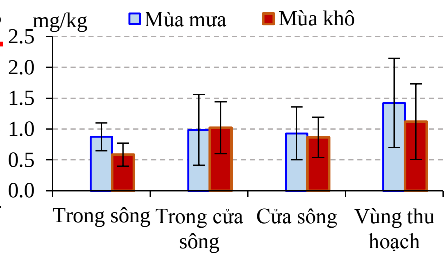

Figure 3.10. Variation of Cd content (mg/kg) in sediments in the coastal area of Binh Thuan

The level of Cd pollution in sediments in Binh Thuan (CF index is 3.58 - at a fairly high level of pollution) is higher than in Kien Giang (CF is 2.58) and Quang Ninh (CF is 1.96) - at average pollution.

3.2. Study of the binding form of Cd in sediments

3.2.1. Cd binding patterns in river and estuarine sediments

The binding form of Cd in sediments has seasonal variation, in the rainy season the proportions of forms are in the order F2 > F3 > F5 > F1 > F4 and in the dry season F5 > F2 > F3 > F1 > F4. The total forms (F1 + F2 + F3) ranged from 52.3 to 84.1% in the wet season, from 33 to 74.8% in the dry season.

The results of analysis of Cd bond form in Binh Thuan during the rainy season showed that the exchange rate (F1) fluctuates between 6.5 and 49.3%, the carbonate form (F2) fluctuates between 18.3 and 53.9%, the form of iron-manganese bond (F3) ranges from 10.3 to 31.7%, the bound form of organic compounds (F4) ranges from 2.7 to 31.5%, the residual form (F5) fluctuates in the range of 9.1 -31.1 % (Figure 3.12).

In the dry season, the rate of F1 form ranges from 1.7 to 32.4%, F2 form ranges from 10.5 to 54.5%, F3 form ranges from 9.3 to 34.6%, the F4 form ranges from 1.9 to 10.5%, the F5 form ranges from 17.4 to 65.1% (Figure 3.13).

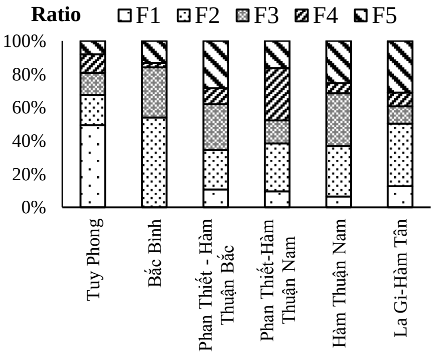

Figure 3.12. Cd bond form (%) in river sediments during the rainy season in coastal areas of Binh Thuan province

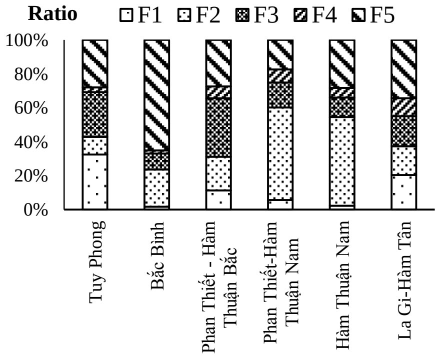

Figure 3.13. Cd bond form (%) in river sediments during dry season in coastal areas of Binh Thuan province

3.2.2. Conjugated form of Cd in coastal sediments

- *Tuy Phong - Binh Thuan area:* Cd in F1 form ranges from 3 to 19%, F2 form from 15 to 28%; F5 form ranges from 32 to 50%; F4 form accounts for the lowest rate ranging from 4.6 to 9.7%; F3 form accounts for 5-24%. The F2 form varies strongly between the rainy and dry seasons. The total form F1, F2 accounts for a high proportion, ranging from 27.1 to 44.6%.

The linkage distribution of Cd in the sediments of Tuy Phong area follows the trend of F5 > F2 > F3 > F1 > F4 (Figure 3.15).

• *La Gi - Binh Thuan:* The percentage of Cd existing in sediments in the F1 form ranges from 6 to 20%, the F2 form ranges from 10 to 34%, the F3 form ranges from 5 to 39 %, the F4 form ranges from 4 to 21%, the F5 form ranges from 23 to 46% (Figure 3.16). The total form F1 and F2 have a high rate, ranging from 20.5 to 39.7%, but the total value of the two forms F1 + F2 is still lower than that in Tuy Phong area.

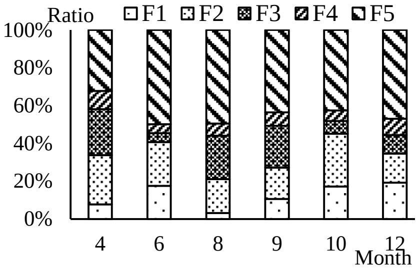

Figure 3.15. Distribution of Cd binding forms in the sediments of the harvest zone in Tuy Phong-Binh Thuan region

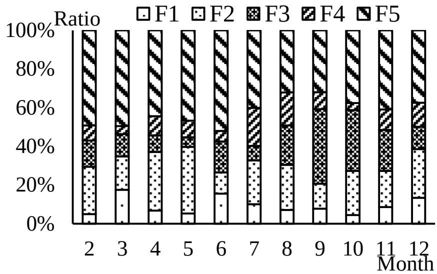

Figure 3.16. Distribution of the bound form of Cd in the sediments of the harvest zone in the La Gi-Binh Thuan region

In general, the residual form F5 is the highest and most stable. Forms F2, F3 have strong fluctuations in space and time. The distribution of linkage forms of Cd in the sediments of this area follows the trend of F5 > F2 > F3 > F4 > F1, which is different from the order of F1 and F4 compared to Tuy Phong area.

•*Phan Thiet - Binh Thuan area:* The percentage of Cd in the form of F1 is low, ranging from 4 to 24%; F2 form accounts for a high percentage, ranging from 22 to 50%; F3 form ranges from 7 to 27%; F4 form accounts for the lowest percentage, ranging from 2 to 19%, F5 form ranges from 16 to 52% (Fig 3.17).

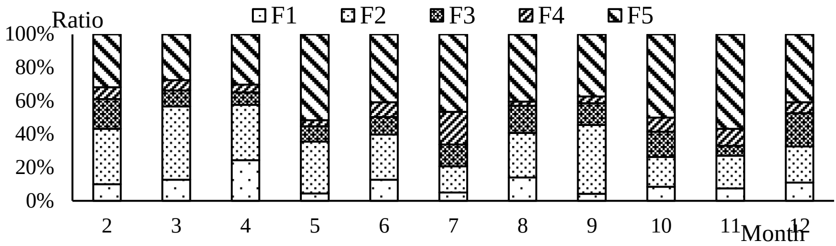

Figure 3.17. Distribution of the bound form of Cd in the sediments of the harvest area in Phan Thiet - Binh Thuan region

The trend of concentration distribution of Cd binding forms in Phan Thiet - Binh Thuan also follows the trend of F5 > F2 > F3 > F1 > F4 similar to Tuy Phong area, but different order F4 and F1 compared to La Gi region.

- *Kien Luong - Kien Giang* area: The rate of F1 form ranges from 4 to 24%, F2 form ranges from 21 to 34%, F3 form ranges from 9 to 21%, F4 form ranges from 2 to 28%, and the F4 form ranges from 2 to 28%. F5 ranges from 28 to 61%. Cd patterns follow the trend F5 > F2 > F3 > F4 > F1.

- *Van Don - Quang Ninh area*: F1 and F2 forms account for the smallest proportion, ranging from 4 to 19% and from 8 to 35%, respectively, F3 form ranges from 10 to 26%, F4 form ranges from 4 to 31% and the F5 form ranging from 27 to 65% accounted for the highest percentage. The ratio distribution of the binding forms of Cd in the order: F5 > F2 > F3 > F4 > F1.

In generally, the ordinal distribution of Cd binding forms in the coastal areas of Binh Thuan, Kien Giang and Quang Ninh has the highest concentration of F5, followed by F2 and F3, and the lowest is F1, F4. Distribution of Cd bond forms in marine sediments of Tuy Phong and Phan Thiet in the order F5 > F2 > F3 > F1 > F4, with the order F1 and F4 different from La Gi, Van Don and Kien Luong (F5 > F2 > F3 > F4 > F1). However, the total mobility of F1 + F2 in Binh Thuan areas is much higher, with this trend representing the risk of Cd release from sediments into the aquatic environment, a risk to organisms.

3.2.3 Correlation between Cd-bond forms in sediments

The correlation between Cd forms and total Cd content shows a positive correlation. Correlation coefficients of the forms F1, F2, F3, F4, F5 with the corresponding total Cd content in the order r = 0.31; r = 0.64; r = 0.41; r = 0.05; r = 0.58, where F1, F2, F3 and F5 are statistically significant.

The results of multivariable regression analysis (y is the total Cd content and x_i is the forms F1, F2, F3, F4, F5) recorded the coefficient $R^2 = 0.58$, adjusted $R^2 = 0.54$ and has statistical significance (Sig. < 0.05). The Cd content of the F2 and F5 franction clearly shows a close correlation and has a great influence on the dependent variable, which is the total Cd content ($p < 0.05$).

3.2.4. Risk assessment of Cd binding forms in sediments

The results of the calculation of the ICF index in the studied seas are all at the average pollution level (ICF = 1 - 3). Pollution levels in Phan Thiet (1.54), Tuy Phong (1.48) and La Gi (1.44) of Binh Thuan are higher than those in Kien Luong - Kien Giang (1.24) and other areas. Van Don - Quang Ninh (1.16).

The RAC index in the waters of Tuy Phong, Phan Thiet and Lagi are mostly at high risk to organisms, the average value is at high risk. In particular, in the Phan Thiet - Binh Thuan area, there were episodes with a very high risk RAC index (RAC > 50%). Van Don - Quang Ninh region is at low risk (mean RAC < 30%) (Tab 3.10). This RAC index is the basis for assessing the level of risk and clarifying the fact that marine mammals have accumulated Cd at levels exceeding the permissible limit in this region, but not recorded in other sea areas.

Table 3.1. RAC index (%) of Cd in sediments in coastal areas of Binh Thuan, Kien Giang and Quang Ninh

Harvest area		**RAC % (form F1 + F2) of Cd**		
		The shortest	Tallest	Medium
Binh Thuan	Tuy Phong	27.1	44.6	**33.7** ± 8.7
	Phan Thiet	32.6	58.5	**38.7** ± 11.9
	La Gi	20.5	39.7	**31.3** ± 5.9
Van Don - Quang Ninh		13.4	36.2	**22.6** ± 8.6
Kien Luong - Kien Giang		22.6	38.6	**30.8** ± 5.7

3.3. Study evaluating Cd accumulation in short-necked clam

3.3.1. Accumulation of Cd in the soft tissue of short-necked clam

The results of Cd accumulation in short-necked clam in harvesting areas in Binh Thuan province ranged from 0.64 to 2.58mg/kg, with an average of 0.90 ± 0.40 mg/kg wet. Although the average Cd value was lower than the permissible limit (2.0mg/kg) according to TCVN 8681:2011 and QCVN 8-2:2011/BYT (Figure 3.27), some samples were encountered (with a rate of 16.7%). The concentration of Cd accumulated in short-necked clam in the rainy season (1.024 ± 0.429 mg/kg wet) was higher than that in the dry season (0.728 ± 0.272 mg/kg wet), which was statistically significant ($p < 0.05$).

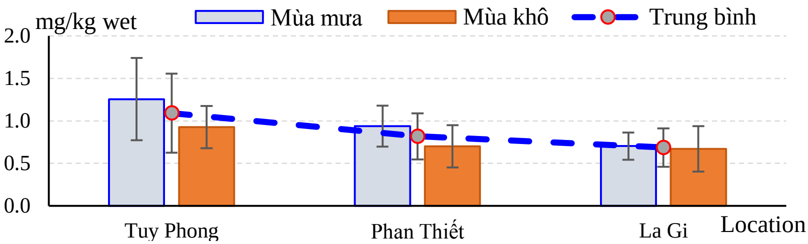

Figure 3.27. Cd content (mg/kg wet) in total tissue of short-necked clam in coastal areas of Binh Thuan province

By region, the Cd concentraion in short-necked clam recorded was highest in Tuy Phong (average 1.09mg/kg), followed by Phan Thiet (0.82mg/kg) and lowest in La Gi (0.69mg/kg), followed by Kien Luong and the lowest is Van Don (Fig 3.28). The level of Cd accumulation in short-necked clam was similar to the RAC risk index value.

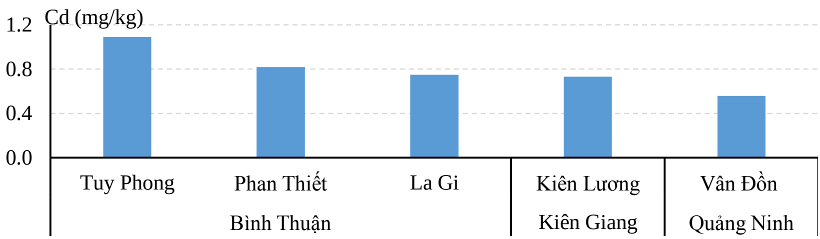

Figure 3.28. Cd concentration in soft tissue of short-necked clam in the study areas

Compared with other species, Cd accumulation in short-necked clam in Binh Thuan is also quite high. Compared with the simillar species of short-neck clam, Cd accumulate in soft tissue in Quang Ninh, Kien Giang are also lower than in Binh Thuan regions. However, compared with Cd accumulated in scallops and scallops at the same study site as Binh Thuan, Cd in short-necked clam was lower.

Accumulated Cd concentration in clam has a strong correlation with shell height and weight, the correlation coefficient is r = 0.56, respectively; r = 0.72, with statistical significance p < 0.01.

BCF index accumulation coefficient in Binh Thuan is quite high, averaging 3,446. Tuy Phong area has the highest BCF accumulation coefficient (average 3,896), followed by La Gi were areagae 3,410 while Phan Thiet area is lower (3,031). Compared with Kien Giang (2,137) and Quang Ninh (1,367) regions, the BCF coefficient in the regions of Binh Thuan province is much higher.

Calculation results of BSAF accumulation coefficient show that BSAF accumulation coefficient in most areas is low (BCF < 1), only Tuy Phong - Binh Thuan has an average accumulation level. jar.

3.3.2. Accumulation by different size in short-necked clam

The evaluation results according to the size groups < 20, 20 - 30mm and over 30mm of clam showed that Cd accumulation followed the increasing size of shell height; same for scallops. In the same size group, Cd accumulation in clam and scallops was higher in Binh Thuan than in Kien Giang and Quang Ninh (Tab 3.14). During the same sampling period, the level of Cd accumulation in clam also increased with size.

Table 3.14. Cd metal accumulation (mg/kg) with shell height dimensions

Species	**Case Height (mm)**	**Cd content (mg/kg wet)**		
		Quang Ninh	Binh Thuan	Kien Giang
Short-necked Clam	< 20	0.459	0.818	0.677
	from 20 - 30	0.665	1.072	0.718
	> 30	0.631	1.252	0.926
Scallops	< 30	0.879	1.057	0.861
	from 30 - 40	1.329	1.263	1,360
	> 40	1.353	1,915	1.456

3.3.3. Cd accumulation by different parts of short-necked clam

The results of analysis of Cd according to body parts of short-necked clam showed that Cd accumulated in the digestive system was highest, followed by the mantle, gills and the lowest leg. Accumulation of clam parts was highest in Tuy Phong, followed by Phan Thiet, and lowest in La Gi (Fig 3.33). Accumulation of Cd in gills and digestive system in the rainy season is higher than in the dry season, similar to Cd in suspended matter.

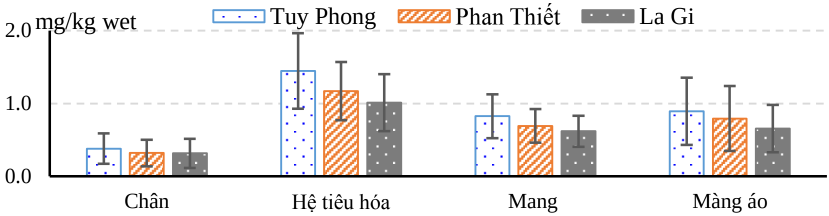

Figure 3.33. Cd content (mg/kg wet) in some parts of short-necked clam in Binh Thuan

Total cadmium soft tissue and Cd content in other parts in short-necked clam showed a positive correlation and had statistical significance ($p < 0.01$ for digestive system, gills and mantle membrane, $p < 0.05$ for digestive system, gills and mantle membrane). foot). This show that Cd-infected clam accumulated in many parts, however, the level of accumulation between parts is different.

The results of linear regression analysis showed that the Cd content in all 4 parts had an effect on total tissue Cd accumulation (F = 8,513, Sig. F < 0.05). However, Cd accumulation in gills had the greatest effect on Cd accumulation in total short-necked clam tissues (coefficient is 0.447, Sig. < 0.05).

3.3.4. The relationship between Cd in clam and in the environment

To synchronize and reduce fluctuations in the dependent variable, Cd accumulation in clams, researchers filtered the data:

- Clams have a shell height size of 20 - 30 mm (commercial size) as the dependent variable;

- Cd content in water and sediment environments (total and bound forms, food sources (TTLL&SVPD), ICF index, RAC are independent variables.

The results of calculation and evaluation of the correlation of Cd concentration accumulated in short-necked clam with Cd in the environment show that: **(1)** there is a statistically significant correlation (r = 0.601, Sig. < 0.05) with Cd content in suspended matter (food source); **(2)** shows a weak correlation with total Cd content in the sediment (r = 0.341, Sig. > 0.05); **(3)** does not show a clear correlation with the Cd content in seawater.

Accumulated Cd content in clam is correlated with Cd form F1 and F2, weakly correlated with form F3, not clearly showing correlation with form F4 and F5 in sediment.

The results of building a regression model have selected the model (with adjusted $R^2 = 0.56$, Sig. F of the model < 0.05, VIF < 2) which has 56.1% influence on the content. Cd in total tissue of short-necked clam, including: (1) Cd content in suspended matter; (2) RAC index (F1 + F2 binding); (3) Cd is in the form of F3 bonds in sediments.

3.4. Study on Cd accumulation in clam at experimental conditional

The experiment was conducted with 02 sources that can cause accumulation:

(1) Assess the possibility of Cd accumulation from water environment (dissolved ions):

a) Experiment without adding food (algae) with Cd concentrations: 5, 10 and 20 µg/l

b) Experiment with added food (algae) with Cd concentrations: 2, 5 and 10µg/l

(2) Assess the possibility of accumulation from food sources (suspended sediment and SVPD):

a) Experiment on feed combined with Cd at a concentration of 0.2mg/l (TN21).

b) Experiment on feed combined with Cd at a concentration of 0.5mg/l (TN22).

The goal of these experimental batches is to evaluate whether or not Cd contamination from the water environment, sediment, and food sources causes Cd accumulation in short-necked clam.

3.4.1. Testing the possibility of accumulation from Cd ions in water

During the accumulation period of 7 days, the amount of Cd^{2+} dissolved in seawater with a concentration of 5 µg/l when no feed was added did not occur Cd contamination on the tissues of clam. Cd accumulation began to accumulate in short-necked clam tissues at two concentrations of 10 µg/l and 20 µg/l, and Cd accumulation was most evident at the Cd concentration of 20 µg/l (Table 3.24).

Table 3.24. Total Cd content (mg/kg) on short-necked clam was investigated for Cd accumulation through metal ion exchange in contaminated water environment.

Time (days)	Short-necked Clam TN5	Short-necked Clam TN10	Short-necked Clam TN20	Control sample
first	kph	kph	0.226	kph
2	kph	kph	0.322	kph
3	kph	kph	0.335	kph
4	kph	0.096	0.443	kph
5	kph	0.101	0.508	Kph
6	kph	0.105	0.494	Kph

3.4.2. Testing the ability to accumulate Cd in water and supplement algae

Cd^{2+} concentration on tissues of clam and scallops found that there was an accumulation of Cd in the body of these two species at the concentrations of Cd^{2+} 5 µg/l and 10 µg/l (Tab 3.26). In particular, the level of Cd accumulation on the body of clam was higher than that of feathered clam. According to the results of Cd analysis on the fleshy tissue of short-necked clam, Cd increased with the survey time.

Table 3. 26. The results of Cd analysis (mg/kg) on test cockles and short-necked clam accumulate Cd through water exchange, supplementing with chaetoceros algae

Time (days)	**Scallops**				**Short-necked clam**			
	scall ops	Scallops TN11 (2µ/l)	Scallops TN12 (5µ/l)	Scallops TN13 (10µ/l)	Clam –	Clam TN11 (2µ/l)	Clam TN12 (5µ/l)	Clam TN13 (10µ/l)
first	1.977	1.908	1.97	2.194	0.012	0.481	0.387	0.401
2	2.073	2.021	2,079	2.209	0.018	0.762	0.859	1.133
3	2.050	2.164	2.393	2.477	0.013	0.554	0.714	1.169
4	1.966	2.192	2.466	2.675	0.010	0.601	0.865	1.482
5	1.972	2.104	2.453	2,621	0.015	0.656	1.187	1.534
6	1.955	2.203	2.495	2.704	0.019	0.892	1.089	1.814

3.4.3. Testing the possibility of accumulation of Cd from food sources contaminated with Cd

The analysis results showed that there was accumulation of Cd on short-necked clam when supplemented with Cd contaminated feed (Figure 3.44). Comparing anova (α=0.05) in experimental batches TN21 and TN22 found no difference in all tissues of short-necked clam, scallops. This contributes to the evidence that the source of Cd accumulation in short-necked clam, mollucsc and fan scallops is mainly through the food route - which is a passive filter feeder species.

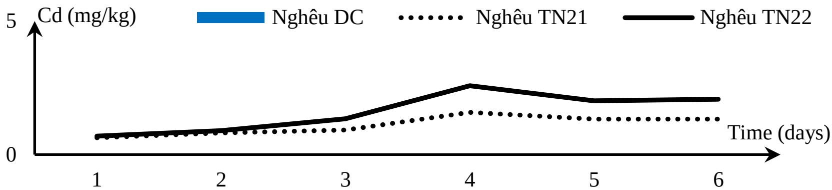

Figure 3.44. The content of Cd in the body of short-necked clam in the experimental group accumulates Cd through food absorption

3.4.4. The source of Cd accumulation in short-necked clam

From the analysis and evaluation of field data sources and the experimental scale, it was found that according to two path way following:

(1) Cause of contamination from Cd in water: This cause is excluded;

(2) Cause of contamination from food sources: This was identified as the main source and cause of Cd infection in short-necked clam

3.4.5. Proposing some solutions to minimize Cd accumulation

- There is a need for post-harvest solutions such as rearing;
- Additional monitoring of food sources is SS&PLANK in the harvest area;
- Strengthen control of waste sources in coastal districts;
- Regarding harvest size and food safety usage quantity.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

From the overview research and experimental research results, the thesis has come up with some main results as follows:

1. Fluctuations in Cd content in river and sea water environments in the mangrove harvesting area of Binh Thuan are lower than the permissible limit. Distribution of Cd content in water decreases gradually from river to harvest area. Seasonally, the Cd concentration in the rainy season months is higher than the dry season months, showing the characteristics of the coastal waters;
2. In SS&Plank, the Cd content fluctuated greatly, from 0.15 mg/kg to 88.66 mg/kg, an average of 11.32mg/kg, much higher in the rainy season than in the dry season. In both seasons, the distribution of Cd content

clearly shows the trend of increasing gradually from the river to the coastal area and decreasing in the offshore area. In the harvesting area, the Cd content in SS&Plank is very high, about 10 thousand times higher than the concentration in the aquatic environment and more than 6 times higher than the Cd in the sediment;

3. Cd content in sediments in coastal areas of Binh Thuan reached 1.79 mg/kg, higher than many other sea areas. According to the cross section from the river to the harvest area, Cd in the sediment shows an increasing trend of distribution. Fluctuations of Cd content in SS&Plank and Cd in sediment from river to harvest area tend to be inverse with Cd content in water, along with increasing trend of distribution of salinity and pH of water. The increase in Cd content in the SS&Plank from the river to the estuary and the harvest area is greater than the increase of Cd in the sediment;
4. The distribution of Cd in the sediments in the coastal area of Binh Thuan follows the trend of F5 > F2 > F3 > F1 > F4, which is different from Kien Giang and Quang Ninh in the order of F1, F4. Cd in the form of F2, F3, F5 is correlated with the total Cd content in the sediment. The form of F2 binding is always high in the studied areas and has a higher positive correlation than other forms, the change in total Cd content will lead to a large change of the F2 form. The ICF index of Cd in the coastal sediments of Binh Thuan is at an average level of pollution, however, the distribution of Cd in the mobile form F1 + F2 accounts for a large proportion, representing the risk of Cd accumulation for organisms. Cd's RAC risk is high to very high; RAC in Phan Thiet reached 38.7%, Tuy Phong reached 33.7%, 31.3% in La Gi, higher than Quang Ninh and Kien Giang;
5. The concentration of Cd accumulated in short-necked clam in the coastal areas of Binh Thuan province varied from 0.64 to 2.58 mg/kg wet, with an average of 0.90 ± 0.40 mg/kg wet. According to the short-necked clam division, the level of Cd accumulation is in the following order: Digestive system > mantle > gill > legs. Cd in the mantle and digestive system is different between the rainy season and the dry season. Cd accumulation in organs was positively correlated with Cd in total soft

tissue of short-necked clam. According to size, the degree of Cd accumulation increased with the increase of shell height and weight of short-necked clam. In the same size range, the level of Cd accumulation in the rainy season is higher than in the dry season;

6. The degree of Cd accumulation in short-necked clam in coastal Binh Thuan has a strong correlation with the Cd content in suspended matter and the RAC index - corresponding to the total Cd content in the form of mobile F1 + F2 in the sediment. From the results of survey studies and laboratory scale, it was initially determined that the source of Cd accumulation in short-necked clam in Binh Thuan is mainly from the food source of Cd in suspended sediments and plankton.

Recommendation

- Research on postharvest postharvest culture of short-necked clam, combined with feed supplements to reduce Cd;
- More in-depth research on the existence of Cd in suspended sediments and plankton, affecting aquatic organisms;
- Adding the environmental component that needs to be monitored in the marine mammal harvest area is Cd, Pb, Hg metals in suspended sediment and plankton, which is the food source in marine ecosystems.

NEW FINDINGS OF THE THESIS

1. This study determined the level and fluctuation of cadmium (Cd) content in suspended sediment and plankton in the coastal area of Binh Thuan. This study, published for the first time on the binding form of Cd in marine sediments in bivalve mollusc farming and harvesting areas,
2. This study determined the level and coefficient of Cd accumulation in total tissue according to shell height, size, and parts (digestive system, mantle, gills, and legs) of the undulate venus clams (*Paphia undulata*), and determined its the relationship with Cd in environmental components. In this study, the level of Cd accumulation in clams was within the allowable limit for food safety.
3. This study initially identified the accumulation of Cd in undulate venus clams (*Paphia undulata*) in the coastal area of Binh Thuan, mainly from their food sources.

LIST OF THE PUBLICATIONS RELATED TO THE D THESIS

During the research and implementation of the thesis, the author has published 5 articles. In there:

01 article published in an international journal;

04 articles in domestic magazines, with 02 articles published in English.

1. Luu Ngoc Thien, **Nguyen Cong Thanh**, 2017, A preliminary study of cadmium accumulation on noble scallop (mimachlamys nobilis) and undulating venus (paphia undulata) under experimental conditions, *Journal of Fisheries Science and Technology,* No 1/2017, p 60 - 67.
2. Luu Ngoc Thien, **Nguyen Cong Thanh**, 2018, Distribution of Cadmium in Seawater, Sediment and Soft Tissue of Bivalve in Van Don Coastal on Quang Ninh, Vietnam, *Asian Journal of Chemistry*, 30(7), pp. 1487-1490. https://doi.org/10.14233/aichem.2018.21189.
3. **Nguyen Cong Thanh**, Luu Ngoc Thien, Nguyen Thi Hue, 2018, Fuctuation cadimium (Cd) in havest bivalve mollusk area in Binh Thuan province, *Science and Technology Journal of Agriculture & Rural Development*, Ministry of Agriculture & Rural Development, Marine Fisheries Research, 12/2018.
4. **Nguyen Cong Thanh,** Nguyen Thi Hue, 2022, Initial assessment of Cadimi accumulation in soft tisue of *Mimachlamys nobils* clams collected from coastal areas of Binh Thuan, *Vietnam Journal of Science and Technology*, 60(5B), pp. 31-38.
5. **Nguyen Cong Thanh**, Luu Ngoc Thien, Nguyen Thi Hue, Nguyen Quang Hung, 2023, Fraction distribution of Cadimi in surface sediment collected from bivalve species harvesting areas in Binh Thuan province (Tuy Phong, Phan Thiet, La Gi). *Vietnam Journal of Marine Science and Technology*, 23(1), pp. 93-102.