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Review / Revisión

HEAVY METALS CONTAMINATION IN THE GULF OF GUAYAQUIL: EVEN LIMITED DATA REFLECTS ENVIRONMENTAL IMPACTS FROM ANTHROPOGENIC ACTIVITY

Contaminación por metales pesados en el Golfo de Guayaquil: incluso datos limitados reflejan impactos ambientales de las actividades antrópicas

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Key words: cadmium, mercury, lead, mangrove, tropical eastern Pacific

ABSTRACT

The Gulf of Guayaquil, the largest estuary on the Pacific coast of South America, provides livelihoods for fishing communities that supply seafood to national markets. Activities like mining and agriculture are major sources of contamination in the estuary, yet their effects on the ecosystem have not been determined. Publicly-available data were compiled to provide an overview of the level of contamination in water, sediment and seafood in this system. Measured concentrations (C_m) were compared with their corresponding permitted levels (C_{sl}) defined in international regulations. Comparison outcomes were classified using a traffic-light color scale: green for ideal conditions ($C_m < C_{sl} \times 10^{-1}$), yellow for alert situations that require precautionary measures ($C_{sl} \times 10^{-1} \leq C_m \leq C_{sl} \times 10$), or red for dangerous situations that must be remediated ($C_m > C_{sl} \times 10$). A total of 24 studies were found. Cadmium, mercury and lead were the most commonly analyzed elements. Water samples showed the highest percentage of dangerous levels (> 70 % for Cd, > 80 % for Hg). Extreme concentrations of Hg (1000 times > C_{sl}) were reported for clams (*Anadara* spp.) and crabs (*Ucides occidentalis*) collected in the southern zone impacted by gold mining. Studies evidenced the limited use of quality assurance and control procedures on the data-gathering process, resulting in uncertainty. By using orders of magnitude to assess contamination levels, the effects of low precision in the pattern of contamination were reduced. This contribution intends to inform stakeholders about the implications for public health.

Palabras clave: cadmio, mercurio, plomo, manglar, Pacífico tropical oriental

RESUMEN

El golfo de Guayaquil, el mayor estuario de la costa Pacífica sudamericana, provee sustento para comunidades pesqueras artesanales que surten el mercado nacional. Actividades como la minería y la agricultura son fuentes de contaminación del estuario, pero sus efectos en el ecosistema no han sido monitoreados. Se recopilaron datos públicos para mostrar el nivel de contaminación del agua, sedimentos y mariscos del sistema. Las concentraciones medidas (C_m) se compararon con sus correspondientes niveles permisibles (C_{sl}) definidos en regulaciones internacionales. Los resultados fueron clasificados usando una escala de color de tipo semáforo: verde para condiciones ideales ($C_m < C_{sl} \times 10^{-1}$), amarillo para situaciones de alerta ($C_{sl} \times 10^{-1} \leq C_m \leq C_{sl} \times 10$), o rojo para situaciones peligrosas que deben ser remediadas ($C_m > C_{sl} \times 10$). Se encontraron 24 estudios, principalmente sobre cadmio, mercurio y plomo. Los estudios de agua mostraron el mayor porcentaje de muestras en niveles peligrosos (Cd > 70 % y Hg > 80 %). Concentraciones extremas de mercurio (1000 veces > C_{sl}) se reportaron en almejas (*Anadara* spp.) y cangrejos (*Ucides occidentalis*) recolectados en un sector impactado por la minería de oro. Los estudios ponen en evidencia un limitado uso de procedimientos para asegurar y controlar la calidad durante la recolección de datos, lo cual resulta en incertidumbre. Usando órdenes de magnitud para evaluar los niveles de contaminación, se redujeron los efectos de la imprecisión en el patrón de contaminación. Esta contribución busca informar a los encargados de la toma de decisiones sobre las implicaciones en salud pública.

INTRODUCTION

Heavy metals are broadly defined, high-density chemical elements that occur naturally in the environment in low concentration levels (Calamari and Naeve 1994). They are relevant for coastal management and public health because of their increased levels in the environment due to human activities, and represent highly harmful pollutants (Han et al. 2000).

Heavy metals are released from land-based anthropogenic and natural sources; discharged through river runoffs, drainage and atmospheric deposition; and finally collected into receiving systems, such as estuaries and mangroves (Amirah et al. 2013). Coastal mangroves provide regulating ecosystem services, like waste decomposition, detoxification and retention because their sediments act as a chelating matrix for metals (Amaro-Pinheiro et al. 2012).

Thus, mangroves reduce the mobilization of metals to plant tissues and dependent trophic webs. However, mangrove deforestation is reducing this capacity, potentially allowing previously trapped metals to disperse and enter adjacent ecosystems (Sandilyan and Kathiresan 2014). For this reason, the accumulation of heavy metals in mangroves has become a worldwide threat (NOAA 1990, Macfarlane et al. 2007, Lewis et al. 2011).

Some aquatic organisms living in mangrove ecosystems tend to accumulate heavy metals that may relate to several public health effects. Animals that live in close association with sediments, in which they bury and feed, seem to be more exposed to these contaminants than other organisms (Storelli 2008).

Crabs have been extensively used for the study of heavy metals bioaccumulation because they feed mainly on litter, promote organic matter incorporation to sediments, display slow growth rates and long life cycles, and are abundant and easy to collect (Amaro-Pinheiro et al. 2012). These popular seafood items represent a pathway for heavy metal transfer to human populations (Chien et al. 2002, Martí-Cid et al. 2007, Chen et al. 2008, Dórea 2008).

Documented toxicity mechanisms of heavy metals in humans are related to enzymes of cellular respiration and central nervous system control of respiratory movements, among others (Marques et al. 2010). Effects include reduced central nervous system functioning, lower energy levels, damage to blood composition, lungs, kidneys, liver, and other organs (Amirah et al. 2013).

Long-term exposure to heavy metals may result in Alzheimer's and Parkinson's diseases, muscular dystrophy, multiple sclerosis, and several types of cancer (Han et al. 2000, Amirah et al. 2013). Heavy metals are considered among the most concerning causes of major foodborne diseases (WHO 2015).

Fish consumption has increased worldwide in the last five decades, as it represents an excellent source of nutrients (FAO 2016). In Ecuador, annual fish consumption is 5-10 kg/person, the average for developing countries, and seafood is mainly provided by the artisanal sector (FAO 2003, 2016).

The Ecuadorian government has recognized the negative impact of contamination on fisheries, and among its national policies is the prevention, control and mitigation of contamination in maritime areas and coastal zones (STM 2015). However, Ecuador does not conduct continuous monitoring of water quality (CPPS 2012, MAE 2014, Nolivos et al. 2015). In this review, the available information of heavy metal contamination in the main estuary of the country is synthesized, focusing on artisanal fisheries products.

Study area

The Gulf of Guayaquil (GG) is the largest estuarine ecosystem on the Pacific coast of South America. Its surface area is estimated to cover 13 711 km^2 (**Fig. 1**) and its depth varies between 20 and 180 m. It receives water from 24 out of the 79 drainage basins in the country, resulting in an annual average flow of 1654.5 m^3/s. The catchment covers 53 299 km^2 and includes 12 of the 24 provinces in the country (Montaño-Armijos and Sanfeliu-Montolío 2008).

Economic activities across the GG's watershed include agriculture, cattle raising, artisanal fishing, aquaculture, tourism, mining, manufacturing, navigation and urban development. Crops like rice, sugar cane, corn, banana, oil palm, cacao and coffee represent the main agricultural products of the region (Montaño-Armijos and Sanfeliu-Montolío 2008).

The GG's influence area includes the city of Guayaquil, the largest in Ecuador, with more than 2.3 million inhabitants (INEC 2010). It is the main port city and a hub for economic, commercial and industrial activities.

Guayaquil is located on the banks of the Guayas river (**Fig. 1**), which is formed by the union of Daule, Vinces and Babahoyo rivers (Montaño-Armijos and Sanfeliu-Montolío 2008). The landscape around the Guayas river system is dominated by banana, rice, sugar cane, cacao, corn, passion fruit and soy fields, while shrimp ponds are abundant near the river mouth.

The GG accounts for 42 % of the Ecuadorian continental platform area and holds the largest fisheries production in the country (Montaño-Armijos and Sanfeliu-Montolío 2008, CPPS 2012). Official landings data, however, is only available for the red mangrove crab (*Ucides occidentalis*) and ark (*Anadara* spp., a bivalve), which are highly demanded seafood products. In 2011, more than 14 million crabs and 12 million black arks were landed in the GG (INP 2013).

Objectives

The GG is under strong pressure from human activities that have polluted its aquatic environment (CPPS 2012). Yet, this situation is not well represented in international scientific literature.

Therefore, this systematic literature review intends to provide an overview of the current situation and identify major information gaps. It focuses on local studies about heavy metals concentrations in

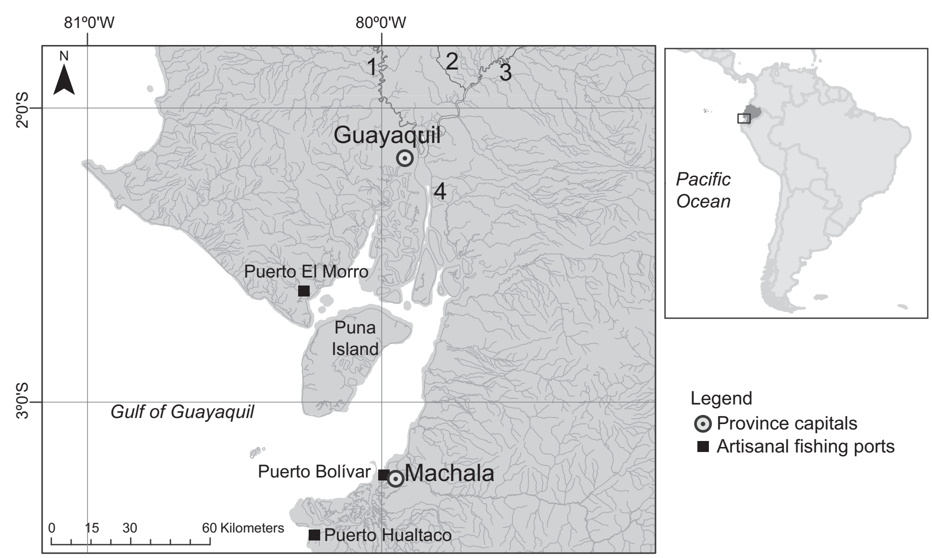

Fig. 1. Study area. Location of the Gulf of Guayaquil in South America, and main sites mentioned in the text. Rivers: (1) Daule, (2) Vinces, (3) Babahoyo, (4) Guayas

water, sediments and major artisanal seafood products of the region.

The specific objectives of this contribution are to: (*a*) evaluate data quality to describe the robustness of available evidence, (*b*) assess the level of potential risk of heavy metal contamination, and (*c*) explore spatial patterns of heavy metal contamination across the region.

MATERIALS AND METHODS

Data collection

A search for empirical studies of heavy metal concentrations in mangrove ecosystems of the GG was done. Public online catalogues, such as universities' online repositories, research centers' websites, and scientific (Scopus) and academic (Google Scholar) databases were consulted. Search keywords were: "contamination", "heavy metals", and "Gulf of Guayaquil", in English and Spanish.

Search results were not filtered by year. Information about heavy metal accumulation in plants was not included, as it was out of the scope of this study. In cases where only an abstract was available online, libraries were visited in person to access full-text documents. If a study was available as a thesis and peer-reviewed article, both documents were considered in the analysis.

Information retrieved from these documents includes: sampling location coordinates, sampling design description, lists of test materials and metals, analytical techniques, supplies and reagents used for preservation of samples and extraction of metals, analytical quality assurance procedures (AQA) (Taverniers et al. 2004), reported indicators of data quality and heavy-metal concentration values.

Analytical quality assurance assessment

Information regarding AQA procedures and data quality indicators were used to assess the robustness of the available evidence for water, sediments and seafood metal contamination in the GG. Reported AQA practices were classified as being at the intra-, inter- or external-laboratory levels of quality control.

Use of certified reference material was interpreted as an accuracy indicator. Coefficient of variation (CV) was calculated for all studies as a common indicator of precision (Taverniers et al. 2004).

Qualitative diagnosis of contamination risk

A qualitative diagnosis of heavy metal contamination levels in the GG was elaborated in three steps using quantitative indicators according to the following steps:

1. The design of a classification system for contamination levels consisted in adapting the "traffic-light" method (Baigún 2013), developed for artisanal fisheries management in the Paraná river basin in Argentina (**Table I**). Measured concentrations (C_m) were compared with their correspondent permitted levels (C_{sl}) defined in international regulations, following EC (2016) for seafood, CCME (2014) for water and sediments, and USEPA (1980) for Pb in water. Qualitative indicators resembled the colors of a traffic-light, green for ideal conditions ($C_m < C_{sl} \times 10^{-1}$), yellow for alert situations that require precautionary measures ($C_{sl} \times 10^{-1} \leq C_m \leq C_{sl} \times 10$), or red for dangerous situations that must be reverted ($C_m > C_{sl} \times 10$).
2. The classification system (**Table I**) was applied to available data (i.e., reported average concentration per sampling site, per study) for the most frequently analyzed elements, and obtained a matrix of samples versus test elements, containing traffic-light colors in each cell.
3. The geographic coordinates of sampling sites were added to the database to map results using the QGIS 2.8 application (QGIS Development Team 2015). Each element was represented in a separate point vector layer, with symbol color defined by cells' values.

Spatial analysis

Boxplots were elaborated to show the variability of heavy metal concentrations in three sectors of the GG for available water, sediments and seafood data. Sectors were delimited around clusters of sampling sites.

All data available for each sector were included in the graph. (Geo-) statistical analyses were not conducted with data because of the large variation in sampling designs (spatio-temporal scales, focus species), which resulted in several confounding factors without the sufficient sample size to account for them. Therefore, results were interpreted qualitatively.

RESULTS

Twenty-four published studies performed between 2010 and 2017 were found, of which only one (Fernández-Cadena et al. 2014) was indexed in the scientific database Scopus (**Table II**). No studies conducted prior to 2010 were found.

TABLE I. LEVELS OF POTENTIAL RISK BY HEAVY METAL CONTAMINATION

Level	Level description	Quantitative definition	Reference color
Ideal conditions	Ideal/desired conditions associated to practices that promote ecological integrity conservation and long-term fisheries sustainability	Heavy-metal concentration below safety level's order of magnitude. $C_m < (C_{sl\ e} \times 10^{-1})$	Green
Alert	Situations or practices that might threaten ecosystem functioning and fisheries status, and require precautionary measures	Heavy-metal concentration in the same order of magnitude as safety level. $C_m \leq (C_{sl} \times 10)$ and $C_m \geq (C_{sl} \times 10^{-1})$	Yellow
Danger	Dangerous or inviable situations or scenarios that must be reverted for they seriously compromise riverine ecosystem functioning, resources and fishing communities	Heavy-metal concentration above safety level's order of magnitude. $C_m > (C_{sl} \times 10)$	Red

The framework is an adaptation of the "traffic-light" system described in Baigún (2013). C_m: measured concentration, C_{sl}; safety level concentration

Three types of materials were tested for contaminants: water, sediments and seafood. The most common test elements were Pb (n = 117), Cd (n = 114) and Hg (n = 58), so our analyses focused on them. Seafood species represented in these studies comprised eight mollusks, two crustaceans and two fish species (**Tables II** and **V**).

Other test elements analyzed less frequently in studies included chromium (Cr), zinc (Zn), arsenic (As), copper (Cu), nickel (Ni), cobalt (Co) and manganese (Mn), among others (Appendix II).

Summary of analytical methods

All studies found in this review used spectrometry methods to measure the concentrations of heavy metals in samples (**Tables II-IV**). However, there were some differences among the methods used prior to the analysis. For instance, most studies focusing in organisms analyzed what authors generally called "soft tissues", and only one study (Feys-Espinoza 2013) was carried out using hard parts (crab exoskeleton).

The extraction of metals from organisms was done using HNO_3 in all cases, but some authors added other acids in this process: Ortega-Pereira (2015) also used $HClO_4$, while Ayala-Armijos et al. (2015) added H_2SO_4 for Hg measurements, and HCl for Cr, As and Pb.

Water samples were reportedly fixed with HNO_3 in the field and transported in low temperature conditions to the lab in all cases (**Table III**). Water was filtered using papers of varied pore sizes, ranging from 0.2 to 8 µm, while this information was missing in half the studies.

The most common method to extract the metals from the sediments used pyrrolidine dithiocarbonate ammonium, ammonium acetate and chloroform (PDAAAC), but this information was often not explicit. The authors simply cited the "standard methods" guidelines (APHA 2005) in the methods' section, leaving uncertainty about the exact procedures conducted in each case.

Finally, sediment samples were sieved to collect particles below 71 or 63 µm (**Table IV**). The extraction was done using HNO_3 in all but two cases: Fernández-Cadena et al. (2014) used HNO_3 and H_2O_2, and Rivera-Pizarro (2016) used HCl.

Summary of analytical quality assurance procedures

Implicit references to AQA procedures in the methods section were found in most (88 %) studies (Appendix I). References to methods used by other authors, and at least one intra-laboratory procedure were reported in 71 % of the studies found. Certified reference materials (mainly sediment) were reportedly used in 38 %.

Inter-laboratory AQA procedures or participatory proficiency testing schemes were not mentioned in any of the studies. The laboratories from Universidad de Guayaquil and Universidad Técnica de Machala together hosted 88 % of published studies, and both hold the certification ISO/IEC 17025 – general requirements for the competence of testing and calibration laboratories.

Of the six (25 %) studies mentioning the ISO certification to support their data reliability, only two reported the use of reference materials, and none reported the resulting percentage of recovery.

TABLE II. DETAILS OF THE METHODS USED TO MEASURE HEAVY METAL CONCENTRATIONS IN ORGANISMS ACROSS THE GULF OF GUAYAQUIL

Species	Test elements	Analytical method*	Body part analyzed (textual translations)	Preservation prior to extraction	Extraction reagents	References
			Crustacea			
Callinectes arcuatus	Cr, Ni, Cd, Hg, Pb	FAAS, GH-AAS	Soft tissues and hepatopancreas	In cool box (4°C)	HNO_3	Franco-Solórzano (2015)
Ucides occidentalis	Cd, Pb	AAS	Exoskeleton	Room temperature	HNO_3	Feys-Espinoza (2013)
Ucides occidentalis	Cd, Hg, Pb,	FAAS, GH-AAS	Hepatopancreas tissue and claw muscle	In cool box	HNO_3	Chuquimarca-Montesdeoca (2015)
Ucides occidentalis	Cd, Pb	AAS	Soft tissues and digestive gland	Live to the lab	HNO_3	Siavichay-Lalangui (2013)
Ucides occidentalis	Cr, As, Hg, Pb	AAS	Soft tissues	Not specified	Hg: HNO_3, H_2SO_4; Cr, As, Pb: HCl, HNO_3	Ayala-Armijos et al. (2015)
			Mollusca			
Anadara tuberculosa	Cd, Hg, Pb	AAS	Soft tissues	In cool box	HNO_3	Ordóñez-Lucin (2015)
Anadara tuberculosa, Anadara similis	Cr, Mn, Co, Ni, Cu, Zn As, Cd, Hg, Pb	FAAS, CVAA	Soft tissues	In cool box	HNO_3, $HClO_4$	Tobar-Ordóñez (2013)
Anadara tuberculosa, Mytella guyanensis, Leukoma asperrima	Cr, Cu, As, Cd, Hg, Pb	AAS, Polaro-graphy	Soft tissues	Freezer (-20°C)	HNO_3	Carrasco-Peña and Webster-Coello (2016)
Crassostrea columbiensis	Cr, Ni, Cd, Pb	AAS	Soft tissues	In cool box (4°C)	HNO_3	Jiménez-Verdesoto (2012)
Crassostrea columbiensis	Cd, Hg, Pb,	FAAS, GH-AAS	Soft tissues	In cool box	HNO_3	Castro-Infante (2015)
Mytella guyanensis	Ni, Cd, Pb	FAAS	Soft tissues	In cool box	HNO_3	Banguera-Rodríguez (2013)
Mytella strigata	Cr, Cd, Pb	FAAS	Soft tissues	In cool box	HNO_3	Kuffó-García (2013)
Mytella strigata, Ostrea columbiensis	Cd, Pb	FAAS	Soft tissues	In cool box	HNO_3	Mero-Valarezo (2010)
Pomacea canaliculata	Cd	AAS	Soft tissues	In cool box	HNO_3	Ramírez-Prado et al. (2016), Ramírez-Prado (2016)
			Teleostei			
Diapterus peruvians, Sardinops sagax	Mn, Ni, Cu, Zn Cd, Hg, Pb	FAAS, CVAA	Soft tissues	Freezer	HNO_3, $HClO_4$	Ortega-Pereira (2015)

*Methods used to quantify the concentration of test elements present in test materials: AAS: atomic absorption spectrometry, CVAA: cold vapor, AAS, FAAS: flame AAS, GH-AAS; hydride generation AAS

TABLE III. DETAILS OF THE METHODS USED TO MEASURE HEAVY METAL CONCENTRATIONS IN WATER SAMPLES ACROSS THE GULF OF GUAYAQUIL

Test elements	Analytical method*	Pore-size of water filtration paper	Preservation prior to extraction	Extraction	References
As, Cd, Hg, Pb	AAS	Not specified	In cool box (< 10 °C); HNO_3	HCl	Alcívar-Tenorio and Mosquera-Armijo (2011)
Cr, Ni, Cu, Zn, Cd, Hg, Pb	AAS	0.45µm	In cool box; HNO_3	Not specified	Banguera-Rodríguez (2013)
Cd	AAS	8 µm (Whatman No. 40)	4°C; HNO_3	Not specified	Carpio-Rivera (2016)
Cd, Hg, Pb,	AAS	Not specified	In cool box (< 10 °C); HNO_3	Not specified	Del Pezo-Quijije and Ruíz-Chiriguaya (2016)
Cd, Pb	FAAS	Not specified	In cool box (< 10 °C)	PDAAAC**	Huayamave (2013)
Cd, Pb	AAS	Not specified	HNO_3	Not specified	Jiménez-Verdesoto (2012)
Cr, Cd, Pb	AAS	0.2 µm	In cool box (< 10 °C); HNO_3	PDAAAC**	Kuffó-García (2013)
Cr, Ni, Cd, Pb	AAS	0.47 µm	In cool box; HNO_3	PDAAAC**	Mero-Valarezo (2010)
Ni, Cd, Pb	FAAS	Not specified	In cool box; HNO_3	PDAAAC**	Proaño-Alvarado (2016)
Cd, Cr, Pb	FAAS	8 µm (Whatman No. 40)	HNO_3	PDAAAC**	Ramírez-Prado et al. (2016); Ramírez-Prado (2016)
Cr, Cd, Pb	FAAS	Not specified	HNO_3	Not specified	Rivera-Pizarro (2016)

*Methods used to quantify the concentration of test elements present in test materials: AAS: atomic absorption spectrometry, FAAS: flame atomic absorption spectrometry
**Pyrrolidine dithiocarbonate ammonium, ammonium acetate, and chloroform

TABLE IV. DETAILS OF THE METHODS USED TO MEASURE HEAVY METAL CONCENTRATIONS IN SEDIMENT SAMPLES ACROSS THE GULF OF GUAYAQUIL

Test elements	Analytical method	Grain fraction analyzed	Preservation prior to extraction	Extraction	References
Cr, Cd, Pb	AAS	< 71 µm	In cool box (<10°C)	HNO_3	Alcívar-Tenorio and Mosquera-Armijo (2011)
Ni, Cd, Pb	FAAS	< 71 µm	In cool box	“ “	Banguera-Rodríguez (2013)
Cd, Pb	AAS	< 71 µm	In cool box	“ “	Carpio-Rivera (2016)
Li, Be, Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Sn, Pb	ICP-MS	Not specified	Not specified	HNO_3, H_2O_2	Fernández-Cadena et al. (2014)
Cr, Ni, Cd, Hg, Pb	FAAS, GH-AAS	Not specified	In cool box	HNO_3	Franco-Solórzano (2015)
Cr, Ni, Cd, Pb	AAS	< 71 µm	In cool box	“ “	Jiménez-Verdesoto (2012)
Cd, Pb	AAS	< 71 µm	In cool box	“ “	Jiménez-Verdesoto (2017)**
Cd, Pb	FAAS	< 63 µm	Not specified	“ “	Mero-Valarezo (2010)
Cd, Cr, Pb	FAAS	< 63 µm	Not specified	“ “	Proaño-Alvarado (2016)
Cd	AAS	< 71 µm	In cool box	“ “	Ramírez-Prado et al. (2016), Ramírez-Prado (2016)
As, Cd, Hg, Pb	AAS	Not specified	Not specified	HCl	Rivera-Pizarro (2016)
Cd, Pb	AAS	< 71 µm	In cool box	HNO_3	Siavichay-Lalangui (2013)

*Methods used to quantify the concentration of test elements present in test materials: AAS: atomic absorption spectrometry, FAAS: flame AAS, GH-AAS: hydride generation AAS, ICP-MS: inductively coupled plasma mass spectropmetry

**This study also analized organisms (fish) but those data were not included in the present review because, according to the author, the specimens were bought on a nearby fish market, and thus lacked evidence of the geographic location where they were collected. Also, the species was not determined

TABLE V. HEAVY METAL CONCENTRATION RANGES IN SEAFOOD ORGANISMS COLLECTED IN THE GULF OF GUAYAQUIL

Species (Spanish/English common names)	Concentration* (ppm)			References
	Cd	Hg	Pb	
Crustacea	0.5	0.5	0.5	EC (2016)
Callinectes arcuatus (jaiba azul/ arched swimming crab)	0.01-0.03	BDL	0.05-**0.57**	Franco-Solórzano (2015)
Ucides occidentalis (cangrejo rojo/mangrove crab)	**2.97-3.67**		**37.26-43.10**	Feys-Espinoza (2013)
Ucides occidentalis (cangrejo rojo/mangrove crab)	0.08-0.10	**1.47**	**0.96-1.59**	Chuquimarca-Montesdeoca (2015)
Ucides occidentalis (cangrejo rojo/mangrove crab)	0.03-0.04		0.01-0.32	Siavichay-Lalangui (2013)
Ucides occidentalis (cangrejo rojo/mangrove crab)		**137.83-142.54**	**10.26-13.50**	Ayala-Armijos et al. (2015)
Mollusca	1	0.5	1.5	EC (2016)
Anadara tuberculosa (concha prieta, pustulose ark)	**1.40-3.97**	0.242-**1.743**	BDL	Ordóñez-Lucin (2015)
Anadara tuberculosa (concha prieta, pustulose ark)	**1.68**	**364.38**	**7.52**	Tobar-Ordóñez (2013)
Anadara tuberculosa (concha prieta, pustulose ark)	**2.14**	0.21	0.11	Carrasco-Peña and Webster-Coello (2016)
Anadara similis (concha, brown ark)	**1.21**	**618.70**	**8.51**	Tobar-Ordóñez (2013)
Crassostrea columbiensis (ostión de mangle, columbia black oyster)	0.07-0.30		0.14-1.5	Jiménez-Verdesoto (2012)
Crassostrea columbiensis (ostión de mangle, columbia black oyster)	**5.8-17.4**	0.32-**0.96**	BDL	Castro-Infante (2015)
Mollusca	1	0.5	1.5	EC (2016)
Mytella guyanensis (mejillón/guyana swamp mussel)	0.09-0.28		0.61-**2.89**	Banguera-Rodríguez (2013)
Mytella guyanensis (mejillón/guyana swamp mussel)	0.08	BDL	BDL	Carrasco-Peña and Webster-Coello (2016)
Mytella strigata	**1.7-1.95**		1.04-**1.98**	Mero-Valarezo (2010)
Ostrea columbiensis	**6.25-8.24**		1.02-**1.96**	Mero-Valarezo (2010)
Pomacea canaliculata (caracol manzana/applesnail)	0.738-**1.221**			Ramírez-Prado et al. (2016); Ramírez-Prado (2016)
Leukoma asperrima	0.08-**2.14**	BDL-0.21	BDL-0.4	Carrasco-Peña and Webster-Coello (2016)
Teleostei (fishes)	0.5	0.5	0.3	EC 2016
Diapterus peruvians (chaparra/Peruvian mojarra)	**1.55**	**0.80**	**12.30**	Ortega-Pereira 2015
Sardinops sagax (sardina/sardine)	**1.51**	0.36	**12.03**	" "

*Heavy metal concentration ranges in seafood organisms collected in the Gulf of Guayaquil, regulated by the European Commission (2016). BDL: below detection level, EU: European Commission. Figures in bold: samples exceeding the EC limits. Empty cells indicate that the metal was not tested. Scientific names follow WoRMS Editorial Board (2016)