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Depuration of Heavy Metals in Bivalves: A Review

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ABSTRACT

Bivalves are known to be contaminated with pollutants, particularly heavy metals, making them less suitable for human consumption. They are frequently used as bioindicators to assess trace metal pollution. To ensure the safety of bivalves intended for human consumption, a depuration period is necessary. This study aimed to conduct a literature review on depuration process, mechanism, techniques and factors that influence depuration efficiency in bivalves. The efficiency of depuration is influenced by various factors, including the size of the bivalves, their siphoning activity, physiological conditions, the type and amount of contamination, water quality parameters such as temperature and salinity, the ratio of shellfish to water, flow rate, oxygenation, species, and the duration of the depuration process. Further research in this field is essential to develop effective strategies for heavy metal contamination control and management.

INTRODUCTION

Mollusca are the second largest phylum of the animal kingdom and are divided into 9 classes. Among these, the class of Bivalvia (e.g. clams, mussels, and oysters) has about 200,000 extant species **(Runnegar, 1996)**. Bivalves have an internal and external symmetry; they are flattened shaped laterally and their soft components are even protected by external shell consisting of two hinged valves (i.e. a bivalve shell). Furthermore, they are characterized by particular gills that are highly developed and suited to both respiratory and feeding activities **(Saba, 2011; Sami *et al.*, 2016)**.

Shellfish such as clams, mussels, cockles and oysters are good sources of relatively cheap and high quality protein **(Sami *et al*., 2024)**. Their shells are used to produce ornaments, handicrafts, cosmetic and medicinal products. Recent researches have indicated the possibility of using the shells to produce higher value products such as bone spare-parts, anti-cancer peptide **(Leng *et al*., 2005)**, cements for bone structures and surgical glue (from the byssal thread). Shellfish (biofiltering) improves water quality by removing particulates (silts, organic matter, nutrients, virus, bacteria, etc.) in the water column thus making it an effective way to remove pollution and nitrification **(Shunway *et al*., 2003)**.

As a result of urban development, rapid industrialization and tourism activities, the coastal ecosystems have been subjected to human (or anthropogenic) stressors and complex mixtures of contaminants that affect the water quality and finally the marine organisms causing severe damage on the natural resources **(Cajaraville *et al.* 2000; Monserrat *et al*., 2007; Cravo *et al*., 2009; 2012; Tlili *et al*., 2010; 2013)**. Metals toxic pollutants constitute significant pollutants to the marine ecosystems **(Krause-Nehring *et al.,* 2012)**. Contamination in marine ecosystems is related to industrial activities, sewage waste, fossil fuel or the remains of leaded gasoline and soil erosion **(Kalman *et al*., 2008; Krause-Nehring *et al.,* 2012)**.

Heavy metals can harm aquatic organisms and reduce species diversity due to their uptake into the food chain, biomagnification, and accumulation **(Yu *et al.,* 2011; Ibrahim & Abu El-Regal, 2014)**. Ultimately, these metals can be incorporated into seafood consumed by humans, posing health risks **(Baeyens *et al.,* 2005)**. Toxicity of heavy metals can cause neutralization of the central nervous functions, as well as weakness in lungs, liver, kidney and other vital organs, resulting in neurological degenerative disorder like Parkinson’s disease, Alzheimer’s disease, multiple sclerosis and muscular dystrophy. It is worthnoting that long time contact with some metals causes cancer **(Hogstrand & Haux, 2001)**.

Depuration is a process of holding filter-feeding shellfish in clean seawater, typically for periods of 24 to 48h, to enable release of pathogens and other contaminants **(Blogowaski & Stewart, 1983; Drake *et al.,* 2007)**. Depuration is a standard procedure for reducing the risk of food poisoning due to *Escherichia coli* **(Lee *et al*., 2008)**. Most studies concerning depuration exposed bivalves to pollutants in the laboratory, and then transferred them to clean waters under laboratory or field conditions **(Seymour & Nelson, 1971; Mason *et al*., 1976; Zaroogian, 1979; Wahi *et al*., 2009)**. A few studies used clams containing naturally high concentrations of heavy metals and followed their depuration at a relatively clean field **(Okazaki & Panietz, 1981; El-Shenawy, 2004)**. This study aimed to conduct a literature review on depuration process, depuration mechanism, depuration techniques and factors influencing depuration efficiency in bivalves.

Depuration mechanism in bivalves

Bivalves possess specialized cells called epithelial cells that line their gills, digestive tract, and other tissues. These cells actively transport heavy metals from the bivalve's tissues back into the surrounding water. The transport process involves the use of ion channels and transporters that facilitate the movement of heavy metal ions across the cell membranes. This active transport mechanism enables bivalves to regulate their internal metal concentrations and maintain a balance with their environment **(Saha *et al*., 2006)**.

Studies on the depuration mechanism of heavy metals in bivalves have been conducted using various species such as *Perna viridis, Anomalocardia brasiliana, Ruditapes decussatus, Modiolus modiolus, Mytilus edulis, Pinna nobilis,* and *Corbicula fluminea* **(Lakshmanan *et al*., 1989; Wallner-Kersanach *et al*., 1994; El-Shenawy, 2004; Dovzhenko *et al*., 2005; Serafim *et al*., 2007; Turner *et al*., 2009; Chalkiadaki *et al*., 2014; Jebali *et al*., 2014; Nan *et al*., 2016; Denil *et al*., 2017)**. These studies have focused on the bioaccumulation and depuration of metals such as Hg, Cu, Zn, Pb, Cd, Mn, Fe, Ni, and As in different tissues of bivalves.

The depuration effects on trace metals in *Anomalocardia brasiliana* have been examined to understand the impact of depuration on tissue concentrations of metals. Additionally, the behavior and physiology of bivalves like *Ruditapes decussatus* have been studied in relation to heavy metal and microbial depuration, with differences observed between contaminated and less contaminated sites **(El-Shenawy, 2004)**. Furthermore, the response of metallothionein (MT) during Cd accumulation and elimination in *Ruditapes decussatus* has been investigated, showing the tissue-dependent accumulation of Cd and the role of MT in metal detoxification **(Serafim *et al*., 2007)**. Moreover, the mechanisms of Cd accumulation in freshwater bivalves like *Corbicula fluminea* have been studied under different hydrodynamic conditions, emphasizing the need to remove extracellular Cd adsorbed on tissues to accurately assess Cd pollution **(Nan *et al*., 2016)**.

Depuration techniques

The depuration techniques of heavy metals in bivalves have been a topic of interest in various studies. Several methods and techniques have been used to reduce or remove heavy metals from bivalves and make them safe for consumption (Table 1, 2). **Lingard *et al*. (1992)** developed a method to estimate organic-bound and crystal-bound metal concentrations in bivalve shells, providing insights into the distribution of trace metals in shell nacre components. **Cheney *et al.* (1996)** investigated the heavy metal effects on the metabolic activity of *Elliptio complanata* using a calorimetric method. **Maenpaa *et al.* (2002)** evaluated the remediation of heavy metal-contaminated soils using phosphorus and its effect on bioavailability using an earthworm bioassay. **Hédouin *et al.* (2007)** focused on nickel bioaccumulation in bivalves from the New Caledonia Lagoon through seawater and food exposure.

Table 1. The different methods of depuration used for heavy metals removal

Method	Description	Reference
Natural depuration	Bivalves can naturally eliminate accumulated heavy metals over time when placed in clean water. This process involves transferring the contaminated bivalves to an area with clean water and allowing them to filter-feed for a certain period. The duration of natural depuration varies depending on the species, the initial metal concentration, and the water quality.	**Gabr and Gaba-Alla (2008); Ulinuha and Perwira (2022)**
Controlled depuration	Controlled depuration involves placing bivalves in tanks or depuration systems specifically designed for heavy metal removal. The water parameters, such as temperature, salinity, and pH, are carefully controlled to optimize depuration efficiency. The bivalves are fed with clean, uncontaminated food to encourage the elimination of heavy metals.	**Ibrahim *et al*. (2022)**
Purification systems	Purification systems are commonly used in commercial bivalve aquaculture operations. These systems involve circulating water through tanks or raceways where bivalves are held. The water is typically filtered and treated to remove contaminants including heavy metals. The bivalves are kept in these systems for a specific duration to allow depuration.	**Guimaraes Filho *et al*. (2022)**
Bioremediation	Bioremediation techniques involve the use of microorganisms or plants to remove heavy metals from the environment. In the case of bivalves, certain species of microorganisms can be introduced to the depuration system or the bivalve culture environment. These microorganisms have the ability to bind or transform heavy metals, aiding in their removal from the bivalve tissues.	**Rosa *et al*. (2014)**
Chemical treatments	Chemical treatments can be employed to facilitate heavy metal removal from bivalves. Chelating agents, such as ethylenediaminetetraacetic acid (EDTA) or citric acid, can be added to the depuration system to promote the release of heavy metals from bivalve tissues. However, cautions must be exercised to ensure that the chemical treatments do not cause adverse effects on bivalve health or compromise their edibility.	**Budiawan *et al*. (2018)**

Table 2. Comparison between depuration methods used for heavy metals removal

Method	**Cost**	**Time**	**Effectiveness**	**Side effects**
Natural depuration	Relatively low cost as it relies on natural filtration in clean water.	Natural depuration can be a slow process, taking weeks to months, depending on the initial metal concentrations and the species being depurated.	The effectiveness of natural depuration can vary and may not completely eliminate heavy metals, especially at higher concentrations.	Generally considered safe, although the accumulation of new contaminants from the clean water source is a potential concern.
Controlled depuration	Moderate to high cost due to the need for specialized depuration systems and monitoring equipment.	Controlled depuration can be more efficient than natural depuration, typically taking weeks to a few months.	This method can be highly effective in reducing heavy metal concentrations, especially when combined with optimized water parameters and clean food sources.	Requires careful monitoring of water quality parameters, as any deviations can affect the bivalves' health and depuration efficiency.
Purification systems	High initial investment cost for setting up purification systems, including tanks, filters, and treatment equipment.	Similar to controlled depuration, typically taking weeks to a few months.	Purification systems can be highly effective in removing heavy metals when properly designed and maintained.	Regular maintenance and monitoring are required to ensure proper functioning of the system and prevent potential issues.
Bioremediation	The cost can vary depending on the specific bioremediation approach used, such as introducing specific microorganisms or plants. It can range from low to moderate.	Bioremediation processes can take a considerable amount of time, ranging from weeks to months or even longer.	The effectiveness of bioremediation methods can vary depending on the specific organisms used, their interaction with bivalves, and the environmental conditions. Further research is needed to optimize this approach.	Potential ecological impacts and interactions between introduced organisms and the natural ecosystem need to be considered.
Chemical treatments	Chemical treatments can be relatively inexpensive, depending on the type and quantity of chemicals used.	The depuration process can be accelerated with chemical treatments, usually taking a few weeks to a couple of months.	Chemical treatments can effectively facilitate the release of heavy metals from bivalve tissues. However, the efficiency may vary depending on the specific chemical used and its interaction with the target metals.	Potential negative effects on bivalve health, as well as the need for careful control of chemical concentrations to prevent unintended consequences.

Factors influencing depuration efficiency

The efficiency of depuration on bivalves is influenced by various factors (Table 3). **Laughlin *et al*. (1986)** studied the accumulation of Bis (tributyltin) oxide in the marine mussel *Mytilus edulis*, highlighting the importance of understanding the accumulation pathways of contaminants in bivalves. **Luoma *et al*. (1992)** determined the bioavailability of selenium to a benthic bivalve, emphasizing the significance of both particulate and solute pathways in influencing depuration efficiency. **Thomann *et al*. (1995)** developed a model to assess the biota sediment accumulation factor for metals in marine bivalves, indicating that the food route of metal accumulation is significant, especially for certain metals.

Wang *et al*. (1995) investigated the assimilation of trace elements ingested by *Mytilus edulis*, showing the effects of algal food abundance on the process. **Reinfelder *et al*. (1997)** compared assimilation efficiencies and turnover rates of trace elements in different marine bivalves, highlighting the differences between oysters, clams, and mussels. **Simon *et al*. (2004)** conducted a kinetic analysis of uranium accumulation in the bivalve *Corbicula fluminea*, demonstrating the effects of pH and direct exposure levels on the process. **Croteau *et al*. (2005)** delineated copper accumulation pathways in the freshwater bivalve *Corbicula* using stable copper isotopes, showcasing the importance of understanding the relative contribution of water and food as copper sources.

Arnot *et al*. (2015) developed a database of dietary bioaccumulation test data for organic chemicals in fish, emphasizing the importance of depuration rate constants, absorption efficiency, and biomagnification factors in assessing bioaccumulation. **Silvestre *et al*. (2021)** focused on meeting the salinity requirements of the bivalve mollusc *Crassostrea gigas* in the depuration process, suggesting that salinities between 25 and 30‰ are preferable for efficient depuration and subsequent quality during shelf-life. Furthermore, **Sami *et al.* (2020)** and **Ibrahim *et al*. (2022)** studied the impact of bivalve size, temperature and feeding and starvation on the elimination of heavy metals like Cu, Fe, Pb, Co, Ni, and Zn in commercial bivalves (*Ruditapes decussatus*, *Paphia undulat*a and *Venerupis pullastra*).

Table 3. The different factors that affect depuration efficiency

Factor	Effect	Reference
Initial metal concentration	The initial concentration of heavy metals in bivalves affects the efficiency of the process. Higher initial metal concentrations may require longer depuration periods or more aggressive depuration methods to achieve desired reduction levels.	**Benaltabet *et al*. (2021)**
Species and physiology	Different bivalve species exhibit variations in their physiology, including filtration rates, metabolic rates, and tissue composition. These variations can influence the accumulation and elimination of heavy metals, making certain species more efficient in depuration than others.	**El-Shenawy (2004); EL-Khodary *et al.* (2018); Machado *et al.* 2020; Sami *et al.* (2020)**
Water quality	The quality of the depuration water is a critical factor. Clean, uncontaminated water is essential for efficient depuration. Factors such as temperature, salinity, pH, dissolved oxygen, and nutrient availability can influence bivalve health and their ability to eliminate heavy metals. Optimal water quality parameters should be maintained to support the depuration process.	**Machado *et al.* (2020)**
Food source	Bivalves rely on filter-feeding to obtain nutrients, and their diet can affect depuration efficiency. Providing clean, uncontaminated food sources during depuration enhances the elimination of heavy metals. The nutritional composition and quality of the food can indirectly influence the bivalve's ability to eliminate contaminants.	**Ibrahim *et al.* (2022)**
Depuration time	The duration of depuration plays a crucial role in achieving desired reduction levels of heavy metals. Longer depuration periods generally result in more efficient elimination of contaminants. However, excessively long depuration periods may negatively impact bivalve health and marketable quality.	**Budiawan *et al.* (2018)**
Water exchange rate	The rate at which water is exchanged in depuration systems can impact depuration efficiency. Proper water circulation promotes the removal of heavy metals from bivalve tissues by providing a continuous supply of clean water. Insufficient water exchange rates may prolong the depuration process or lead to incomplete metal removal.	**Budiawan *et al.* (2018)**
Environmental factors	Environmental factors, such as ambient temperature, salinity, and nutrient availability in the natural habitat of bivalves, can influence their ability to eliminate heavy metals. Changes in these factors can affect the metabolic activity and physiology of bivalves, which, in turn, may impact depuration efficiency.	**Budiawan *et al.* (2018); Ibrahim *et al.* (2022)**
Health and condition of bivalves	The overall health and condition of bivalves play a significant role in depuration efficiency. Stressors, such as disease, parasites, or poor nutrition, can compromise the bivalves' ability to eliminate heavy metals. Maintaining optimal health through appropriate husbandry practices is crucial for efficient depuration.	**Ibrahim *et al.* (2022)**
Heavy metal speciation	Different heavy metals exhibit variations in their chemical properties, bioavailability, and affinity to bind with bivalve tissues. Factors such as metal speciation, particle size, and complexation with organic matter can influence depuration efficiency. Metals may be more readily eliminated than others.	**Belabed and Soltani (2018)**
Depuration method	The choice of depuration method can influence efficiency. Controlled depuration systems with optimized water parameters, purification systems, and chemical treatments can enhance depuration efficiency compared to natural depuration alone. The specific depuration method should be selected based on the target heavy metals, bivalve species, regulatory requirements, and available resources.	**Budiawan *et al.* (2018); Liu *et al*. (2018); Martinez-Albores *et al.* (2020)**

CONCLUSION

Depuration offers a partial solution for heavy metal bioaccumulation in bivalves. While, its effectiveness varies depending on the specific heavy metal, its concentration, the duration of depuration, depuration method, the physiology of the bivalve species and environmental factors. A comprehensive risk assessment and cost-benefit analysis should be conducted to determine the most suitable depuration method for a particular scenario. Further research in this area is essential to develop effective strategies for heavy metal contamination control and management. It is important to consider and optimize these factors to maximize depuration efficiency and to ensure the safety of bivalve products for human consumption.

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