**A Study on Cadmium Accumulation in the Fingerlings of Asian Seabass *Lates calcarifer* (Bloch)**

Abstract

Heavy metals remain in the environment for extended periods, taint food chains, and lead to various health issues because of their toxic nature. Organisms face significant dangers from prolonged exposure to these environmental heavy metals. Daily, an increasing number of individuals are coming into contact with heavy metals. Excessive exposure to heavy metals in marine ecosystems can adversely affect marine life and pose risks to humans who consume seafood. Cadmium a non-essential metal that are toxic, even in trace amounts. One of the key groups for transferring metals to humans is thought to be fish, which are typically found in the lower rungs of the food chain. In this study, we conducted a 60-day experiment to investigate the accumulation of cadmium in various tissues of seabass *Lates calcarifer*, a commercially important fish species. The findings indicate that cadmium accumulates in various tissues of *L. calcarifer*. The effects of *L. calcarifer* are influenced by the dosage and duration of administration, with liver, gill, and muscle are being the primary sites of action.

**Keywords:** Bioaccumulation, Contamination, Fish, Heavy metals, Liver, Toxicity

**1. INTRODUCTION**

The pollution of aquatic ecosystems with metals has long been recognized as a major global environmental concern. Water bodies can become severely contaminated with toxic metals released from a variety of human activities, including domestic, industrial, and other anthropogenic processes (Vutukuru 2005, Gupta et al., 2009). The buildup of heavy metals in aquatic environments can severely impact aquatic organisms, leading to genetic damage, while elevated levels of these metals can negatively affect fish species, causing issues such as cytotoxicity, mutagenicity, and genotoxicity (Matos et al., 2017).

Consuming fish that contains high levels of heavy metal contaminants can significantly jeopardize one’s health. Fish absorb considerable amounts of heavy metals from their diet, surroundings, and the sediments where they live (El-Moselhy, et al., 2014). The presence of these toxic heavy metals can diminish the nutritional value of fish. Different fish species display varying capacities for bioaccumulation, and heavy metals can accumulate in various tissues, including the head, liver, bones, kidneys, stomach, heart, muscles, gills, vertebrae, and flesh (Murtalaet al., 2012, Zhao et al., 2012). Fish are recognized as a vital component of a healthy diet, providing energy, high-quality proteins, vitamins, and a variety of other essential nutrients. Furthermore, fish serve as a primary source of omega-3 polyunsaturated fatty acids, which have been well-documented for their ability to lower the risk of coronary heart disease and support normal neurodevelopment in children (Olmedo et al., 2013).

Cadmium (Cd) is a harmful and transition metal that significantly endangers various organisms in aquatic ecosystems and is recognized worldwide as a major water pollutant. Cd also traverses the food chain, ultimately endangering human health, thereby posing risks to both humans and animals (Sataruget al., 2010, Jaiswal et al., 2018, Okereafor et al., 2020) particularly fish (Olsson1998, Mohan et al., 2013, Mathumitha et al., 2021a). Chronic exposure to cadmium in humans can lead to bone disorders, fractures, and impaired kidney function, with disruptions in the regulation of proteins, phosphorus, and calcium. This condition is sometimes referred to as Itai-Itai disease (Friberg & Elinder 1985, Kagamimori et al., 1986, Satarug 2018). Cd is known for its high environmental toxicity, tendency to accumulate, and resistance to degradation. Environmental Cd pollution is often a result of the use and development of non-organic fertilizers used in agriculture, industrial activities involving metals and minerals, and the discharge of wastewater containing Cd from various industrial products (Mathumitha et al., 2021b).

Although cadmium (Cd) may be present in low concentrations in the environment, it has the ability to accumulate in algae and sediments. This metal can be taken up by the animals like fish, shellfish, shrimp, and crabs, and can become more concentrated through the food chain, ultimately leading to its entry into the human body (Schaeferet al., 2020, Wang et al., 2021, Mathumitha et al., 2021a). This bioaccumulation is particularly associated with certain fish species that are positioned in the top of the food chain (Chahidet al., 2014). Consequently, assessing the concentration of chemicals of aquatic organisms, to safeguard human health.

The Asian seabass, *Lates calcarifer* (Bloch), is recognized as the appropriate fish for aquaculture in brackish and freshwater environments, particularly in earthen ponds and floating net cages. This fast-growing and economically valuable species is widely cultivated in Southeast Asian nations and the Indo-Pacific region (Thirunavukkarasuet al., 2004) and it ranks among the most commonly farmed fish in India for brackish water aquaculture (Thirunavukkarasuet al., 2001, Kailasam et al., 2006). The objective of this research was to investigate the concentration of heavy metal cadmium in various organs, specifically the muscle, gills, and liver, of this commercially important edible fish, *L. calcarifer*.

**2. MATERIALS AND METHODS**

An investigation was conducted at the Central Institute of Brackishwater Aquaculture (CIBA) Fish Hatchery located in Muttukkadu, near Chennai, India. Healthy fingerlings of *L. calcarifer*, measuring 8.06±0.05 cm in length and weighing 6.38±0.14 g, were kept in a 10-ton RCC (Reinforced Concrete Cement) tank to adapt to the experimental conditions over the course of a week. Throughout this acclimatization phase, they received minced Tilapia and Sardine meat, equivalent to 3% of their body weight. Cadmium chloride monohydrate (CdCl2.H2O) (99% purity, Merck) was prepared using deionized water. Test solutions were created by diluting a stock solution in exposure tanks with filtered seawater at 27 ppt to achieve the required cadmium concentrations for each treatment. Seawater without the addition of cadmium served as the control. The 96-hour LC50 value for cadmium, calculated using the probit analysis method (Finney 1971), was determined to be 6.00 ppm for *L. calcarifer*. Fishes were exposed to sublethal concentrations of cadmium at 5% (0.3 ppm), 10% (0.6 ppm), and 15% (1.2 ppm) of the 96-hour LC50 for a duration of 60 days. The experiments were conducted in 100-liter fibre-reinforced plastic (FRP) tanks, with ten fish per concentration group, in triplicate. Fish were fed twice daily with minced Tilapia and Sardine flesh at 3% of their body weight. The control tank showed cadmium concentrations below the detectable level (BDL). Water in both the control and cadmium-treated tanks was refreshed daily to minimize any reduction in metal concentrations.

Water quality parameters such as dissolved oxygen, temperature, and pH were monitored on a daily basis, while ammonia, nitrogen, and nitrite levels were checked weekly. Two fish from each tank were sampled at 15, 30, 45, and 60 days of exposure to assess cadmium levels in selected organs. The fish were dissected, and various organs such as muscle, gills, and liver were collected from both experimental and control groups separately. The tissues were dried in an oven at 60ºC until a consistent weight was achieved. Dried samples of each tissue were weighed and subjected to dry digestion using a 20 ml mixture of nitric and perchloric acid (1:1) until a clear solution was obtained.

The digested samples were subsequently diluted to 100 ml with double-distilled water and analyzed for cadmium concentration using a Varian Spectra 2000 Atomic Absorption Spectrophotometer following the method described by (Perkins 1970). The data were subjected to statistical analysis through Duncan’s multiple range test (DMRT), comparing the test concentrations and exposure durations with SPSS software.

**3. RESULTS AND DISCUSSION**

The findings on the bioaccumulation of heavy metals in different tissue samples of *Lates* *calcarifer* observed during different days are presented in (Table1, 2 and 3). After 15 days of experimental period cadmium accumulation in muscle tissue shows significant difference. In the muscle of control fish, concentration of cadmium was below detectable limit (BDL). In 0.3ppm of cadmium the concentration recorded was 0.43μg/g for 15 days of exposure, while in 0.6ppm and 1.2ppm it was 0.67μg/g and 1.13μg/g respectively, indicating the gradual increase of the cd in muscle tissue and the accumulation was proportionate to dose and duration dependants. Likewise, the bioaccumulation of cadmium in the muscle was recorded high after 60 days of exposure period 1.60μg/g in 0.3ppm, 1.95μg/g and 2.80μg/g in 0.3ppm and 1.2ppm (Table 1). In the gill highest concentration of cadmium was recorded after 60 days of exposure period in all the three concentrations 2.03μg/g, in 0.3 ppm, 2.63μg/g and 3.976μg/g in 0.6ppm and 1.2ppm (Table 2). Whereas in the liver tissue of control (normal) fish, cadmium content was below detectable level throughout the experimental period, while on exposure to sublethal concentrations of cd 15 days of experimental period, the accumulation level of cadmium in the liver tissue raises to 1.03μg/g, 1.47μg/g and 2.13μg/g in 0.3, 0.6 and 1.2 ppm respectively (Table 3). After 60 days of experimental period the cadmium level increased to 3.80μg/g, 4.39μg/g and 5.53μg/g in 0.3, 0.6 and 1.2ppm respectively.

Table 1: Bio accumulation of cadmium on the muscle tissue of seabass *Lates calcarifer*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Conc. ppm** | **Days of exposure** | | | |
| **15** | **30** | **45** | **60** |
| Control | BDL | BDL | BDL | BDL |
| 0.3 | 0.43l±0.06 | 0.97i±0.12 | 1.27f±0.06 | 1.60c±0.10 |
| 0.6 | 0.67k±0.06 | 1.10h±0.10 | 1.57e±0.06 | 1.95b±0.10 |
| 1.2 | 1.13j±0.12 | 1.80g±0.10 | 2.27d±0.06 | 2.80a±0.10 |

The values with different superscript alphabets (DMR Test) are significant (P≤ 0.05)

Table 2: Bio accumulation of cadmium on the gill tissue of seabass *Lates calcarifer*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Conc. ppm** | **Days of exposure** | | | |
| **15** | **30** | **45** | **60** |
| Control | BDL | BDL | BDL | BDL |
| 0.3 | 0.77l±0.15 | 1.23i±0.15 | 1.60f±0.10 | 2.03c±0.12 |
| 0.6 | 1.10k±0.10 | 1.87h±0.15 | 2.13e±0.15 | 2.63b±0.15 |
| 1.2 | 1.90j±0.10 | 2.80g±0.10 | 3.23.40d±0.10 | 3.97a±0.06 |

The values with different superscript alphabets (DMR Test) are significant (P≤ 0.05)

Table 3: Bio accumulation of cadmium on the liver tissue of seabass *Lates calcarifer*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Conc. ppm** | **Days of exposure** | | | |
| **15** | **30** | **45** | **60** |
| Control | BDL | BDL | BDL | BDL |
| 0.3 | 1.03k±0.15 | 1.57i±0.06 | 3.13f±0.16 | 3.80c±0.1 |
| 0.6 | 1.47±j0.15 | 2.07g±0.06 | 3.60e±0.1 | 4.39c±0.1 |
| 1.2 | 2.13±h0.15 | 3.10±d0.01 | 4.73b±0.16 | 5.53a±0.25 |

The values with different superscript alphabets (DMR Test) are significant (P≤ 0.05)

The effects of heavy metals, particularly cadmium, are of significant concern due to their well-documented toxicity to humans and their potential health risks, which include lethal, sublethal, acute, and chronic toxicity Levenson & Barnard 1988). Cadmium is a harmful, non-essential element that can accumulate in humans through the food chain due to biomagnification (Kumar 2011 et al., 2011). In this study, cadmium accumulation in various tissues of *Lates calcarifer* showed a consistent increase over a 60-day period, correlating directly with the exposure concentration (Fig. 1, 2 & 3). The liver exhibited the highest concentrations of cadmium, with the gills and muscles showing lower levels. Notably, cadmium accumulation in the muscles was significantly greater than in the control treatments throughout the exposure duration.

The gills serve as the primary site for gas exchange in fish, acting as conduits for the exchange of metal ions from the surrounding water due to their extensive surface area, which facilitates rapid diffusion (Dhaneeshet al., 2012). Consequently, it is believed that metals that bioaccumulate in the gills are primarily sourced from the water. The cadmium absorbed through the gills is subsequently transported directly into the circulatory system and eventually stored in the liver and kidneys (Bebiannoet al., 2007). In this investigation, there was no accumulation of cadmium in the control fish, while all three tested concentrations demonstrated a consistent increase in cadmium levels throughout the experimental period (Fig. 1, 2 & 3). Correspondingly, (Xue et al., 2023) studied on the accumulation of cadmium in the gills of Tilapia (*Oreochromis mossambicus*) reported levels ranging from 31.57 to 41.08 mg/kg for fish exposed to 0.5 mg/L and from 57.52 to 87.72 mg/kg for those exposed to 1.5 mg/L cadmium, findings that align with the results of the current study.

The liver functions as the main detoxification organ in fish, mainly protecting the body by transforming heavy metals into less harmful forms that can be eliminated (Francoet al., 2021). The accumulation and distribution of metals in fish are often inconsistent across various body tissues, influenced by factors such as the specific bioavailability of tissues and the concentration and duration of exposure (Kim et al., 2021). In this study, seabass displayed significant dose- and time-dependent accumulation of cadmium (Cd) across all assessed tissues, with the liver identified as the most critical organ for Cd sequestration. The observed pattern of Cd accumulation was as follows: liver > gill > muscle. In a similar vein, research by Sumet & Blust 2001 indicated that cadmium accumulation in carp (*Cyprinus carpio*) occurs in this order: kidney > liver > gills. Kumar et al., (2005) also noted a comparable concentration pattern in *Clarias batrachus* during exposure to cadmium. Additionally, Cao et al., (2012) reported that the distribution of cadmium in flounder juveniles showed a significant decline in accumulation from liver > kidney > gill > muscle when exposed to concentrations of 2, 4, and 8 mg/L. His findings indicated that Cd accumulation in the liver at a concentration of 2 mg/L was 19 times greater than that of the control group, which aligns with the current study's finding of 1.2 mg of cadmium in the liver, measured at 5.53 μg/g. Recent studies further support the notion that cadmium accumulates in fish livers at elevated levels (Rangsayatorn et al., 2004). The European Commission has established a threshold concentration of 0.1 mg/g wet weight for cadmium in fish muscle intended for human consumption, while FAO (1983) has set a guideline limit of 0.05 mg/kg for fish. However, in this study, the cadmium levels recorded at all three concentrations exceeded the permissible limits.

Typically, the kidney, liver, and gills of fish are discarded when preparing them for human consumption. As a result, there are no immediate concerns regarding the accumulation of cadmium (Cd) in these organs. However, it is advisable to implement measures to prevent Cd contamination in the environments where fish are cultivated. Similar to other heavy metals, cadmium can persist in the body for extended periods and can bioaccumulate over many years, even with prolonged exposure to low levels (Groundwork 2002). Consequently, if fish contaminated with these metals enter the human food chain, biomagnification could occur, potentially leading to adverse health effects.

**4. CONCLUSION**

Cadmium is introduced into aquatic ecosystems primarily through human activities and can subsequently become biomagnified within the food chain. Research has shown significant variations in cadmium levels among the muscle, gills, and liver of the Asian seabass, *Lates calcarifer*. Significantly, elevated levels of cadmium have been identified in the liver of *L. calcarifer*, despite the fact that fish liver and gills are rarely consumed. These findings suggest that fish are a significant source of cadmium accumulation in their hematopoietic organ, the liver. The study underscores that the regular consumption of fish with elevated levels of accumulated cadmium poses a considerable health risk to human consumers.

**6. REFERENCES**

Bebianno, M.J., Santos, C., Canário, J., Gouveia, N., Sena Carvalho, D., Vale C, et al. (2007). Hg and metallothionein-like proteins in the black scabbard fish *Aphanopus carbo*. *Food and Chem. Toxicol.* 45, 8, 1443-1452. doi: [10.1016/j.fct.2007.02.003](https://doi.org/10.1016/j.fct.2007.02.003)

Cao, L., Huang, W., Shan, X., Ye, Z. & Dou, S. (2012). Tissue-specific accumulation of cadmium and its effects on antioxidative responses in Japanese flounder juveniles. *Environ. Toxicol. Pharmacol.,* 33, 1, 16-25. doi: 10.1016/j.etap.2011.10.003.

Chahid, A., Hilali, M., Benlhachimi, A. & Bouzid, T. (2014). Contents of cadmium, mercury and lead in fish from the Atlantic Sea (Morocco) determined by atomic absorp­tion spectrometry. *Food Chem.,* 147, 357-360. doi: [10.1016/j.foodchem.2013.10.008](https://doi.org/10.1016/j.foodchem.2013.10.008)

Dhaneesh, K.V., Gopi, M., Ganeshamurthy, R., Kumar, T.T. & Balasubramanian, T. (2012). Bio-accumulation of metals on reef associated organisms of Lakshadweep Archipelago. *Food Chem.* 131, 3, 985-991. doi: [10.1016/j.foodchem.2011.09.097](http://dx.doi.org/10.1016/j.foodchem.2011.09.097)

El-Moselhy, K.M., Othman, A.I., Abd El-Azem, H. & El-Metwally, M.E.A. (2014). Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt. Egypt *J. Basic Appl. Sci.,* 4,1(2), 97-105. [doi.org/10.1016/j.ejbas.2014.06.001](https://doi.org/10.1016/j.ejbas.2014.06.001)

FAO, WHO. (1983). Compilation of legal limits for hazardous substances in fish and fishery products. Fish Circular. 464, 5-100.

Finney, D.J. (1971). Probit analysis, 3rd (ed) Cambridge University Press, New York.

Franco-Fuentes E, Moity, N., Ramírez-González, J., Andrade-Vera, S., González-Weller, D., Hardisson, A., Paz, S., Rubio, C. & Gutierrez, A.J. (2021). Metal and metalloids concentration in Galapagos fish liver and gonad tissues. *Mar. Pollut. Bull.,* 173, 112-120. [doi.org/10.1016/j.marpolbul.2021.112953](https://doi.org/10.1016/j.marpolbul.2021.112953)

Friberg, L. & Elinder, C.G. (1986). Cadmium and compounds In: Encyclopedia of occupational health and safety third Edn. (Second impression).

Groundwork. (2002) Retrieved from: http://www. Groundwork.org.za/chemical-profiles.htm.

Gupta A, Rai, D.K., Pandey, R.S. & Sharma, B. (2009). Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. *Environ. Monit Assess*., 57, 449-458. doi: [10.1007/s10661-008-0547-4](https://doi.org/10.1007/s10661-008-0547-4)

Jaiswal, A., Verma, A. & Jaiswal, P. (2018). Detrimental Effects of Heavy Metals in Soil, Plants, and Aquatic Ecosystems and in Humans. *J. Environ. Pathol. Toxicol.,* 37, 83-197. doi: [10.1615/Jept.2018025348](https://doi.org/10.1615/jenvironpatholtoxicoloncol.2018025348)

Kagamimori, S., Williams, W.R. & Watanable, M. (1986). GMP levels in chronic cadmium disease and osteoarthritis. *British journal of Exp. Path.,* 67, 517-528.

Kailasam, M., Thirunavukkarasu, A.R., Sundaray, J.K., Mathew Abraham, Subburaj, R., Thiagarajan, G. & Karaiyan, K. (2006). Evaluation of different feeds for nursery rearing of Asian sea bass *Lates calcarifer* (Bloch). *Indian J. Fish.,* 53, 2, 185-190.

Kim, T.H., Kim, J.H., Le Kim, M.D., Suh, W.D., Kim, J.E., Yeon, H.J. et al. (2020). Exposure assessment and safe intake guidelines for heavy metals in consumed fishery products in the Republic of Korea. *Environ. Sci. Pollut. Res. Int.,* 27, 33042–33051. doi:10.1007/s11356-020-09624-0

Kumar, B., Mukherjee, D.P., Kumar, S. et al. (2011). Bioaccumulation of heavy metals in muscle tissue of fishes from selected aquaculture ponds in east Kolkata wetlands. *Ann. Biol. Res.,* 2, 5, 125-134.

Kumar, P., Prasad, Y., Swarup, D., Patra, R.C. & Nandi, D. (2005). Bioaccumulation of cadmium in fresh water Indian catfish *Clarias batrachus*. Proceedings of an international conference held in Lucknow (India). 45.

Levensen, H. & Barnard, W.D. (1988). Wastes in Marine Environment. Hemisphere Publishing Corporation. Cambridge New York London. Chapter. 6, 123-136.

Mathumitha, C., Mohan Raj, V., Sangeetha, R., Susan George. & Ragumaran, M. (2021a). Study on Accumulation of Heavy Metal Concentrations in the Tissues of Aquatic Species from Ennore Estuary. *Res. Jr. of Agri. Sci.,* 12, 5, 1871-1875.

Mathumitha, C., Mohan Raj, V., Sangeetha, R., Susan George. & Ragumaran, M. (2021b). A Review on the Effect of Heavy Metal Contamination and its Impact on the Environment. *Inter. J. of Zoo. Invest.,* 7, 2, 762-771. doi.org/10.33745/ijzi.2021.v07i02.061

Matos L.A., Cunha, A.C., Souza, A.A., Maranhao, J.P., Santoa, N.R. & Goncalves, M.M.C., (2017). The influence of heavy metals on toxicogenetic damage in a Brazilian tropical river. *Chemosphere*., 185, 852-859. doi: [10.1016/j.chemosphere.2017.07.103](https://doi.org/10.1016/j.chemosphere.2017.07.103)

Mohan Raj, V., Thirunavukkarasu, A.R., Kailasam, M., Muralidhar, M., Subburaj, R. & Stalin. (2013). Acute Toxicity Bioassays of Cadmium and Mercury on the Juveniles of Asian seabass *Lates calcarifer* (Bloch). *Indian Journal of Sci. and Tech.,* 6, 4, 4329-4335. doi: [10.17485/ijst/2013/v6i4.23](http://dx.doi.org/10.17485/ijst/2013/v6i4.23)

Murtala, B.A., Abdul, W.O. & Akinyemi, A.A. (2012). Bioaccumulation of Heavy Metals in Fish (*Hydrocynus forskahlii, Hyperopisus bebe Occidentalis and Clarias gariepinus*) Organs in Downstream Ogun Coastal Water, Nigeria. *Trans. J. Agri. Sci.,* 4, 51-59**.** doi:[10.5539/jas.v4n11p51](https://doi.org/10.5539/jas.v4n11p51)

Okereafor, U., Makhatha, M., Mekuto, L., Uche-Okereafor, N., Sebola, T. & Mavumengwana, V. (2020). Toxic Metal Implications on Agricultural Soils, Plants, Animals, Aquatic life and Human Health. *Int. J. Environ. Res. Public Health.,*17, E2204. doi: [10.3390/ijerph17072204](https://doi.org/10.3390%2Fijerph17072204)

Olmedo, P., Pla, A., Hernandez, A.F., Barbier, F., Ayouni, L. & Gil, F. (2013). Determination of toxic elements (mer­cury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. *Environ. Int.,* 59, 63-72. [doi.org/10.1016/j.envint.2013.05.005](https://doi.org/10.1016/j.envint.2013.05.005)

Olsson, P.E. (1998). Disorders associated with heavy metal pollution, Fish Diseases and Disorders (Non-infectious Disorders), Edn. Leatherland JE and Woo PTK, CABI International, UK. 2, 105-131.

Perkins, H.F. (1970). Soil science and Plant analysis. 1, 35.

Rangsayatorn, N., Kruatrachue, M., Pokethitiyook, P., Upatham, E.S., Lanza, G.R. & Singhakaew, S. (2004). Ultrastructural changes in various organs of the fish *Puntius gonionotus* fed cadmium-enriched cyanobacteria. *Environ. Toxicol.,* 19, 6, 585-93. doi: [10.1002/tox.20066](https://doi.org/10.1002/tox.20066).

Satarug, S. (2018). Dietary Cadmium Intake and Its Effects on Kidneys. *Toxics*.,6, E15.

Satarug, S., Garrett, S.H., Sens, M.A. & Sens, D.A. (2010). Cadmium, environmental exposure, and health outcomes. *Environ. Health Perspect.,* 118, 182-190. doi: [10.1289/ehp.0901234](https://doi.org/10.1289%2Fehp.0901234)

Schaefer, H.R., Dennis, S. & Fitzpatrick, S. (2020). Cadmium: Mitigation strategies to reduce dietary exposure. *J. Food Sci.,* 85, 260-267. doi: [10.1111/1750-3841.14997](https://doi.org/10.1111%2F1750-3841.14997)

Smet, H.D. & Blust, R. (2001). Stress responses and changes in protein metabolism in carp *Cyprinus carpio* during cadmium exposure. *Ecotoxicol. Environm. Saf.,* 48, 30, 255-262. doi: [10.1006/eesa.2000.2011](https://doi.org/10.1006/eesa.2000.2011)

Thirunavukkarasu, A.R., Kailasam, M., Kishore Chandra, P., Shiranee, P., Mathew Abraham, Charles, A.V.K. & Subburaj, R. (2001). Captive broodstock development and breeding of sea bass *Lates calcarifer* (Bloch) in India. In: Menon NG, Pillai PP. (Eds.), Perspectives in Mariculture. 111-124.

Thirunavukkarasu, A.R., Mathew Abraham. & Kailasam, K. (2004). Handbook of seed production and culture of Asian seabass, *Lates calcarifer* (Bloch). CIBA, Bulletin. 18, 1–58.

Vutukuru S.S., (2005). Acute effects of hexavalent chromium on survival, oxygen consumption, hematological parameters and some biochemical profiles of the Indian major carp *Labeo rohita*. *Int. J. Environ. Res. Public Health*., 2, (3), 456-462.

Wang, M., Chen, Z., Song, W., Hong, D., Huang, L. & Li, Y. (2021). A review on Cadmium Exposure in the Population and Intervention Strategies Against Cadmium Toxicity. *Bull. Environ. Cont. Toxicol.,* 106, 65-74. doi: [10.1007/s00128-020-03088-1](https://doi.org/10.1007/s00128-020-03088-1)

Xue, Y., Huang, J., Wang, J. & Li, F.Y. (2023). Tissue-specific accumulation and depuration of cadmium in tilapia: role of salinity and cadmium concentration. *Applied Ecol. and Environ. Res.,* 21, 5, 4177-4194.

Zhao, S., Feng, C., Quan, W., Chen, X., Niu, J. & Shen, Z. (2012). Role of living environments in the accumulation characteristics of heavy metals in fishes and crabs in the Yangtze River Estuary, China. *Mar. Pollut. Bull.,* 64, 6, 1163-1171**.**

doi: [10.1016/j.marpolbul.2012.03.023](https://doi.org/10.1016/j.marpolbul.2012.03.023)