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Biomarkers as a tool to monitor environmental impact on Aquatic Ecosystems

Biomarcadores como ferramenta para monitorar o impacto ambiental nos Ecossistemas Aquáticos

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ABSTRACT
The assessment of aquatic contaminants through biomarkers is an efficient approach in studies of environmental risk and impact since it detects the effects of living beings exposed to the polluted environment early. In this sense, this study aims to demonstrate the use of metallothionein, acetylcholinesterase, micronuclei, comet assay, and cytochrome P450 biomarkers, correlating them

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to the xenobiotic process in the aquatic environment and how they signal changes in this environment. This is a bibliographic review, which was carried out searches in the VHL databases: Lilacs, Medline, and Google Scholar, from 2006 to 2020. Metallothioneins is a biomarker that assesses the process of detoxification and homeostasis of metal ions. Acetylcholinesterase is used to assess the neurotoxic effects caused by xenobiotics. Exposure to genotoxic compounds is verified by the micronucleus tests and comet assay, being this an evaluation at the cellular level, where the first analyzes nuclear abnormalities or deformation in the morphology of the nucleus, and the other verifies breaks in the DNA structure. Cytochrome P450 plays a central role in oxidative metabolism and detoxification of natural and xenobiotic substances present in pesticides and fertilizers. It is known that aquatic contamination is a threat to the conservation and management of these ecosystems, making it necessary to use specific and sensitive biomarkers that are capable of detecting the damage early. Therefore, biomarkers correspond to an effective tool for this purpose, as it enables the production of reliable data, favoring the implementation of adequate measures for the prevention, either-or recovery of aquatic ecosystems.

Keywords: monitoring, polluted environment, contaminants.

RESUMO

A avaliação de contaminantes aquáticos através de biomarcadores é uma abordagem eficiente nos estudos de risco e impacto ambiental, uma vez que detecta os efeitos dos seres vivos expostos ao ambiente poluído precocemente. Neste sentido, este estudo visa demonstrar o uso de metalotionina, acetilcolinesterase, micronúcleos, ensaio de cometa e biomarcadores de citocromo P450, correlacionando-os com o processo xenobiótico no ambiente aquático e como eles sinalizam mudanças neste ambiente. Esta é uma revisão bibliográfica, que foi realizada através de buscas nas bases de dados da BVS: Lilacs, Medline, e Google Scholar, de 2006 a 2020. Metallothioneins é um biomarcador que avalia o processo de desintoxicação e homeostase de íons metálicos. A acetilcolinesterase é utilizada para avaliar os efeitos neurotóxicos causados pelos xenobióticos. A exposição a compostos genotóxicos é verificada pelos testes de micronúcleo e ensaio de cometa, sendo esta uma avaliação a nível celular, onde o primeiro analisa anormalidades nucleares ou deformações na morfologia do núcleo, e o outro verifica quebras na estrutura do DNA. O citocromo P450 desempenha um papel central no metabolismo oxidativo e na desintoxicação de substâncias naturais e xenobióticos presentes em pesticidas e fertilizantes. Sabe-se que a contaminação aquática é uma ameaça à conservação e ao manejo destes ecossistemas, tornando necessário o uso de biomarcadores específicos e sensíveis, capazes de detectar os danos precocemente. Portanto, os biomarcadores correspondem a uma ferramenta eficaz para este fim, pois permitem a produção de dados confiáveis, favorecendo a implementação de medidas adequadas para a prevenção, ou a recuperação dos ecossistemas aquáticos.

Palavras-chave: monitoramento, meio ambiente poluído, contaminantes.

1 INTRODUCTION

The world population growth caused the expansion of urban and rural activities, triggering an increase in industrial activities and in the production of chemical residues that are produced on a large scale, constituting, in most cases, the main polluting source of the aquatic environment. As a consequence, these environments have been undergoing serious changes resulting from large amounts of effluents without previous treatment, which generates physical, chemical, and biological

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deterioration, putting at risk the organisms that live there and the population health (AGUILLAR et al., 2020; SAVASSI, 2019; PURIFICAÇÃO JÚNIOR et al., 2017).

According to the World Health Organization (WHO), water scarcity will affect two-thirds of the world population in 2050 as a result of the excessive use of water resources for food production and agriculture (FAO, 2015). Brazil holds almost 15% of the world's water reserves, which is a scarce natural resource, indispensable for life and most economic activities. Contamination of this water can occur in several ways, with emphasis on pollution by sewage, heavy metals, pesticides, and fertilizers (MIGUEL, 2019).

The consequences resulting from impacts on the aquatic environment lead to the degradation of this environment, through changes in the characteristics of the local biota, resulting from human activities that directly or indirectly affect the health of this ecosystem (GARCIA et al., 2018). Therefore, it is necessary to assess the impact that pollutants cause on environmental quality, thus identifying their effects on the living beings of these ecosystems. The use of biological parameters to assess water quality is based on the response of organisms to the environment in which it is inserted. In this context, the use of biomarkers arises, which are important tools for assessing ecological risks, also used to assist in understanding the effects at the population or community level, besides to determine the degree of impact on the biota, as well as identifying the stressors or pollutants responsible for this effect. These biomarkers also assist in the diagnosis of risk of exposure to the human population (GOMES et al., 2019).

Thus, the assessment of aquatic contaminants through biomarkers is an efficient approach in studies of risk and environmental impact due to they detect early the effects that are occurring in living beings exposed to the polluted environment. Also, The use of biomarkers is essential so that protective measures can be taken for this environment. This review demonstrates the use of metallothionein, acetylcholinesterase, micronuclei, comet assay, and cytochrome P450 biomarkers. These correlated to the xenobiotic process in the aquatic environment and how they can signal the processes of alteration in this medium.

2 METHODOLOGIES

This is a bibliographic review with a qualitative approach to the exploratory narrative type. For this, there used as a strategy for the identification and selection of articles, the survey of studies indexed in the databases available in the Virtual Health Library - VHL such as Lilacs, Medline, and Google Scholar. In the bibliographic survey, there used descriptors based on the Health Sciences Descriptors (HSD): Biomarkers and Aquatic Environment, also used in isolation and combination.

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There used uncontrolled descriptors to meet the objective of this study, which are aquatic environment and pollution biomarkers. Controlled descriptors represent the terms registered in the HSD, while the uncontrolled ones refer to words or synonyms that represent the subject to be searched. There used studies from 2006 to 2019, Portuguese and English were considered eligible, besides theses and dissertations.

3 ENVIRONMENTAL IMPACTS CAUSED TO THE AQUATIC ECOSYSTEM

Water is an indispensable resource for the survival of various forms of living beings. Also, it is essential for the maintenance of the physiological conditions of organisms. Due to the increased demand for consumption, the availability of potable water is becoming increasingly limited, as well as the increase in population and the consequent degradation of its quality (YAMAMOTO, 2016).

According to CONAMA Resolution No. 01 of 01/23/86, the designation of environmental impact corresponds to any changes in the physical, chemical, and biological properties of the environment, as a result of human activities that, directly or indirectly, affect the health, safety, either-or well-being of the population. Besides, social and economic activities, biota, sanitary and aesthetic conditions of the environment, and quality of environmental resources.

Industrial growth and urbanization have been increasing exponentially in recent decades, causing the expansion of urban and rural activities and significantly altering the aquatic ecosystem, due to the multiple impacts arising from human activities. The increase in these activities generates important damages to these environments, since the improper destination of aquatic contaminants such as solid, liquid, and volatile residues. Without the proper treatment, it can subsequently lead to bioaccumulation and biomagnification processes in the different trophic levels of the food chain, thus reaching places far from the starting point of the discharge (MENEZES et al., 2019; SILVA, 2016).

In Brazil, there produced, approximately 214 thousand tons of solid waste daily, almost all of them are disposed of on the ground, either in the form of landfills, controlled landfills, or open-air dumps. The main arising damages from these residues that can be considered the eutrophication of water bodies, leaching, mainly nitrate, and the emission of greenhouse gases. The inadequate disposal of organic waste produced through agricultural activities, mainly ranching, leads to the production of a large number of contaminants in the environment. The main damages resulting from these residues are the eutrophication of water bodies, which causes partial and even total death of aquatic life, and leaching, mainly of nitrate, which can reach groundwater, generating damage mainly for the man who uses this water for consumption. If not treated efficiently before being

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released into the environment, Leachates are potentially adverse to the environment and can contaminate soil and ground, and surface water (MORAES et al., 2020; TROMBETTA et al., 2020). This changing process in the aquatic environment over time can compromise the species' permanence in the ecosystem, which causes higher ecological damage if the community is affected as a whole (SANTOS, 2013).

The environmental impact assessment (EIA) is a measure to predict changes that will occur in the environment and aims to assess environmental impacts and their consequences. According to the United Nations (UN), the United Nations Environment Program (UNEP) corresponds as the main global authority on the environment, responsible for promoting conservation and sustainable development to improve the quality of population´s life without compromising environmental resources and services of future generations (ALMEIDA; GARRIDO; ALMEIDA, 2017).

4 BIOMARKERS AS A TOOL FOR ASSESSING EXPOSURE TO CONTAMINANTS

The homeostasis of a natural ecosystem depends on the process of monitoring and adopting adequate prevention and precautionary measures, based on the analysis of the harmful effects caused by contaminants to the aquatic environment. Therefore, environmental contamination biomonitoring is a tool that provides information about the effects caused in this environment. One of these biological tools is biomarkers, which can define as a measurable response that reflects the interaction between a biological system and a potential stressor, whether physical, chemical, or biological (SILVA, 2016; YAMAMOTO, 2016).

Biomarkers can be identified at the biochemical, cellular, individual, population, community, or ecosystem levels. However, the initial effects have the highest impact on the most basic organizational levels of biochemical and molecular responses. These responses can be used as biomarkers of early contamination since, at a low level, it is sufficient to cause physiological effects. Thus, determining the nature and degree of contamination, making it possible, in some situations, to reverse the impact or prevent the environment from a more severe impairment (LOUREIRO, 2017).

The use of biomarkers is largely advantageous since it is considered an indicator of biological response to contaminants or environmental stressors. Its inclusion in environmental research, especially in contaminated areas, is increasingly frequent. It is due to its potential to evaluate the general health of organisms that live in contaminated ecosystems, in addition to having the ability to detect contaminants early, reflecting a reversible toxic effect and subclinical. These

enable efficiently and relatively quickly environmental changes, as they are low cost and robust in their information (GOMES et al., 2019; VASCO et al., 2016).

The need to detect and evaluate arising impacts from polluting substances in low concentrations and sublethal leads to the assessment of a range of biological responses in several species, often using biomarkers at the cellular/molecular level. They assess changes in high levels of biological organization, which is before death or disease onset. These can analyze damage caused by exposure to metals, organic xenobiotics, and organometallic compounds. The choice of the species that indicates the quality of the environment under study, it must be done correctly, since it will assist in the process of identifying the impacts caused to the environment.

Among the countless animals present in these ecosystems, fish, mollusks, and benthic macroinvertebrates have been widely used in the biomonitoring of aquatic environments, due to their easy geographical distribution and position in the trophic chain (CAMARGO; SOUZA; BURANELLO, 2019; RIBEIRO; NUNES 2017).

5 GENERAL CLASSIFICATION OF BIOMARKERS

Several types of biomarkers respond differently to the toxic effect of contaminants, presenting different functions, where some allow defining the presence of substances that cause changes in the genetic material of the organism. It can cause mutagenic either-or potentially carcinogenic effects (VASCO et al., 2016). These can be divided into three different classes the exposure, effect, and susceptibility biomarkers.

Exposure biomarkers are capable of detecting and quantifying exogenous substances or a metabolite, or even a product of the interaction between the xenobiotic or metabolite and an endogenous component, establishing a relationship between external exposure and internal concentrations (OLIVEIRA, 2014). Exposure to a xenobiotic is a necessary condition, although not sufficient to bring about changes in the body. Bearing in mind that these can be used for the most varied purposes, such as leading to the early detection of exposure, although significant changes in the health of the exposed organism have not yet occurred. Thus, they can contribute to the primary prevention and adoption of measures useful for reducing exposure (SILVA, 2016).

The effect biomarkers do not provide information about their nature, but they are characteristic of the occurrence of stress that can be reversible. These include biochemical, physiological, or other changes in the tissues of an organism, which begins with an adaptive response at the molecular/biochemical level. However, if this recognition mechanism fails or if its response capacity is exceeded, it can lead to physiological or histopathological irreversible damage,

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depending on the capacity of the organ or system to respond to the stressor (CANTANHÊDE, 2016; NOGUEIRA, 2013).

Susceptibility biomarkers are indicators of processes that cause variations in responses over time between exposure and the effect of a xenobiotic, which are predominantly genetic, although pathologies, physiological changes, drugs, and exposure to other environmental agents can also change individual susceptibility (CANTANHÊDE, 2016).

Thus, biomarkers are sensitive and specific to chemical exposure and reflect the interaction between a substance and a biological system, being able to identify an early effect before it becomes irreversible at a more complex level of biological organization (YAMAMOTO, 2016). Below are described some of the biomarkers used in programs for monitoring impacted aquatic environments.

5.1 METALLOTHIONEINS

Metallothioneins (MT) correspond to a class of cytosolic proteins, rich in cysteines that have low molecular weight and affinity for divalent cations. TM has the function of detoxification and homeostasis of metal ions. It is through the presence of thiol groups (-SH) that they bind to excess metals, polluting or not, protecting the organism from the toxicity of these compounds. It acts on the intracellular metabolism of copper (Cu), zinc (Zn), and cadmium (Cd), helping to protect against oxidative damage and toxicity resulting from excessive exposure to third metals. Thus, they act as fundamental chelating agents for the mechanism detox (LAVRADAS et al., 2016; GÓMEZ et al., 2018; KROON; STRETENN; HARRIES, 2017).

In aquatic organisms, there is induced production of MT by an increase in the entry of metals into cells. The gills, kidney, and digestive glands are directly involved in this process of entry, storage, and excretion. These also act against cellular oxidative stress, being directly connected to the cellular antioxidant defense system (SEVCIKOVA et al., 2013; SAVASSI, 2019).

The study by Rajeshkumar; Mini; Munuswamy (2013), found that the metals most often related to inducing MT synthesis are Cd and Hg. Although the higher synthesis of this protein is associated with the organs involved in the uptake, metabolism, and excretion of metals, this author detected a higher concentration of metals in the liver of the evaluated organism, the milk-fish (*Chanos chanos*).

According to Buzzi; Marcovecchio (2016), MTs are early warning signs of exposure to metals. In this study, they evaluated the levels of heavy metals in sediments and the synthesis of MT in the crab Neohelice granulata from the estuary of Bahía Blanca, Argentina. The authors

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demonstrated that there was a slow decrease in the level of metals in the analyzed area, and the female crabs showed a higher MT when compared to the males.

5.2 ACETYLCHOLINESTERASE (ACHE)

Acetylcholinesterase (AChE) is a biomarker widely used in the diagnosis of neurotoxic effects resulting from xenobiotics. It is an enzyme in the group of serine esterases that catalyzes the hydrolysis of the neurotransmitter acetylcholine (ACh) in excess in the synaptic cleft, releasing choline and acetate and preventing an exacerbated stimulation of neurons in order to guarantee the normal functioning of the motor and sensory system (ARAUJO et al., 2016).

Inhibition of AChE activity leads to a block in the transmission of nerve impulses, paralyzing vital functions, resulting from the overlap of nerve impulses caused by the permanence of open Na^+ channels. This consequence results in death in the exposed organisms, as an effect of hyperstimulation of the parasympathetic autonomic nervous system (ARAÚJO et al., 2018; FU et al., 2018).

Besides, AChE is inhibited by pesticides of the carbamate and organophosphate classes, as well as by metals. The toxicity mechanism results in the accumulation of acetylcholine in the synaptic cleft, leading to cholinergic hyperstimulation and alterations in the functionality of the Central Nervous System (CNS), causing changes in behavior and even the death of the organism. Thus, this enzyme has been frequently used in the biomonitoring of the aquatic environment, being considered as one of the best indicators of effect on acute or chronic exposure of fish species (ARAÚJO et al., 2016; MORENO et al., 2019).

The organophosphate compounds phosphorylate AChE irreversibly, which prevents the hydrolysis of acetylcholine, causing its accumulation in the muscarinic and nicotinic synapses, resulting in a continuous propagation of nerve impulses. Carbamates cause an action similar to organophosphates, differing only in the intensity and duration of the carbamylation bond, which is lower, causing a reversible inhibition of acetylcholinesterase (SILVA, 2016).

Although these pesticides are rapidly hydrolyzed in the environment, the increase in their use and discharge causes high toxic effects to the organisms exposed in the aquatic ecosystem. Determination of the activity inhibition of this enzyme is a useful tool in the evaluation of the effects of contamination, which makes it possible to monitor the presence of these compounds and their possible risk for both the environment and human health (COIMBRA et al., 2018; ARAÚJO et al., 2016).

In their research, Alavinia et al., (2019) report that the exposure of rainbow trout (*Oncorhynchus mykiss*) to malathion leads to inhibition of AChE activities due to the binding of this pesticide to the active enzyme site and consequent over-stimulation in synaptic transmission between nerve cells. The maximum reduction in AChE activity in brain tissue during the time of exposure to malathion can be seen by the increase in neurotransmission at synapses and subsequent hyperactivity of cholinergic pathways. Recently, some researchers have reported significant inhibition of AChE brain activity in Nile tilapia (*Oreochromis niloticus*) (HAMED, 2015, as well as juvenile coho salmon (*Oncorhynchus kisutch*) (WANG et al., 2016).

According to Araújo et al., (2016), the activity of cholinesterases (ChEs) of several fish has been widely used as biomarkers in programs for monitoring water resources. In their work, the authors investigated the activity of ChEs in the Jaguar cichlid (*Parachromis managuenis*), observing the behavior of the enzyme in the presence of different substrates and selective inhibitors, metal ions, as well as organophosphate and carbamate pesticides. The use of these substrates and selective inhibitors evidenced the presence of AChE and butyrylcholinesterase (BChE) in the brain of *P. managuensis*. In another work by Araújo et al., (2018), they observed the in vitro exposure of Tamoatá (*Hoplosternum littorale*) to pesticides and metal ion, and it led to AChE inhibition in the brain of this species, as well as in the presence of specific AChE (BW284c51) and BChE (Iso-OMPA) inhibitors (ARAÚJO et al., 2018).

5.3 MICRONUCLEUS

Another biomarker recently used for monitoring aquatic environments corresponds to micronuclei. These are biomarkers at the cellular level for exposure to genotoxic compounds, formed from the condensation of the acentric chromosomes either-or whole chromosomes that do not migrate to the poles of the mitotic spindles in cell mitosis, as they present a delay in cell division due to lack of centromere, damage or defect in cytokinesis. These nuclear abnormalities or deformations in the nucleus' morphology are considered indicators of genotoxic effects (SANTOS et al., 2016).

Xenobiotics can act in two ways on the nucleus, directly on the chromosome or on the mitotic spindle, leading to the loss of part or all of the chromosome (D'COSTA; SHYAMA; HUMAR, 2017). As previously mentioned, this process occurs during cytokinesis in the formation of the nuclear envelope and, if not incorporated into the main nucleus, they form their own envelope, generating the micronuclei. These changes tend to be irreversible and continue to manifest

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themselves in future generations through heredity, which may lead to a reduction in species diversity in the impacted aquatic ecosystems (BUENO et al., 2017; COIMBRA et al., 2018).

The frequency of micronucleus has been used as a quick and sensitive indication of changes as it shows breaks in the genetic material that lead to chromosomal abnormalities. This test aims to assess the mutagenic potential that substances have to cause structural or numerical chromosomal damage to cells in the division stage. Damage is often associated with the appearance either-or progression of tumors and with adverse reproductive effects, which makes early detection importante (CANTANHÊDE, 2016; COBANOGLU et al., 2019).

According to Costa; Shyama; Kumar (2017), the increased incidence of micronucleus in the blood cells of *Arius arius* fish occurred due to high concentrations of trace metals, after long-term exposure even with low concentrations of these, leading to an increase in the effects genotoxic in cells of this species and potentially other aquatic organisms.

The work of Khalek; Morsy; Shati (2020) demonstrated that the *O. niloticus* (Nile tilápia) species, when exposed to zinc, showed an increase in nuclear deformities. However, when exposed to nanoparticles of this metal, a significant increase in MN induction was observed, thus exerting a clastogenic effect causing direct, irreversible chromosomal damage to DNA and loss of genetic information. A similar result was demonstrated in the study by Gaete et al., (2019), showing that when *Perumytilus purpuratus* was exposed to copper, the frequency of micronuclei was significantly higher in all concentrations tested (1, 30 and 45 μg L^{-1} by 24, 48 and 96 h).

It is worth mentioning that this test constitutes a relatively simple, inexpensive, and fast results methodology on mutagenicity effects through simple laboratory tests of cell staining and observation under an optical microscope. The erythrocyte's observation under the microscope allows this identification. However, to be considered a micronucleus, it must be separated from the main nucleus of the cell, which presents distinguishable edges and with the same refringence as the main nucleus. It is possible to observe changes in the morphology and the nuclear envelope since they are caused by the effects of chemical substances present in the water (ALVES, 2017).

5.4 COMET TEST

The comet assay (SCGE, Single-Cell Gel Electrophoresis) is an alternative widely used to determine genotoxicity in aquatic environments. This method checks for breaks in the DNA structure after exposure that can be performed in vivo or in vitro. It has as a principle the investigation of DNA damage of cells, which are identified in the shape of a comet structure, whose tail size is proportional to the damage suffered in the genetic material (LAPUENTE et al., 2015).

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It is a test widely used to assess the genotoxic effects of industrial, domestic, and agricultural effluents that cause damage induction and DNA repair. It has the advantage of high sensitivity to various types of damage, being considered in some cases more sensitive to the action of toxic agents than the micronucleus test, in addition to requiring a small number of cells and the mitotically active cells do not need to be analyzed, enabling the analysis of any cell nucleus. This assay allows the detection of breaks in single and double DNA bands, cross-links, alkali labile sites, and incomplete excision repair sites (BIANCHI et al., 2017).

The basic principle of the test is the lysis of cell membranes, followed by the induction of electrophoretic migration of DNA released in an agarose matrix. Thie test, in turn, promotes the migration of DNA fragments through the flow of electrons. The smaller fragments after migration along with the larger ones (encapsulated in the agarose mesh), when viewed under a microscope, assume the apparent shape of a comet, with its head, nuclear region, and tail. Cells with a round nucleus are considered normal and without detectable damage. In contrast, the injured are visually identified by a species of the tail, which corresponds to the DNA fragments that were dragged by the electrophoresis electric current, and the damage observed is proportional to the length of the comet's tail (KNAPPIK; RAMSDORF, 2020).

According to Singh et al., (2019), exposure to metals in freshwater triggered the process of genotoxicity in fish of the species Channa punctatus. This study evaluated exposure to metals in different periods and concentrations and revealed that they cause selective DNA damage, with Arsenic (As), Nickel (Ni), and Chromium (Cr) being the main ones. Cadmium (Cd) did less damage. However, at the time of the tail extension, the damage was observed in all evaluated organisms.

According to Gallão et al., (2019), the leaching process increases the damage to the DNA of fish exposed to sublethal concentrations, given that this is considered a polluting process of aquatic ecosystems that provides the transport of several toxic substances, such as metals. When present in water bodies, these agents can interact with aquatic organisms and present risks to local biota due to their deleterious effects on organisms at various trophic levels. The use of the comet assay technique in this condition allows detection even in small concentrations of these substances when it causes DNA damage.

5.5 CITOCHROME P450

Cytochrome P450 (CYP 450) belongs to the family of enzymes of the Mixed Function Monooxygenase (MFO) system and plays a central role in the oxidative metabolism and detoxification of natural and xenobiotic substances present in pesticides and fertilizers, for example.

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The isoenzymes of CYP 450 are an enzyme complex that contains the heme group involved in the metabolism of many drugs, steroids, and carcinogenic agents, and these enzymes are responsible for catalyzing the oxygenation of numerous endogenous and xenobiotic substrates (RAINONE et al., 2015).

CYP 450 has different isoforms, some of which are used as biomarkers. These are present mainly in the liver, although they occur in a lower concentration in extrahepatic tissues. In fish, different cytochrome subfamilies are responsible for the metabolism of xenobiotics, such as CYP1, CYP3, and, to a lesser extent, CYP4, while CYP 450 is related with the metabolism of endogenous substrates (BHUTIA; RAI; PAL, 2015; CARDOSO; OLIVEIRA; ROCHA, 2019).

The subfamily CYP1A, especially the enzyme etoxiresorufina-O-deethylase (EROD), plays an important role in the biotransformation of organic compounds, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dioxins. They are among the most dangerous compounds released into aquatic habitats. The induction of this enzyme represents one of the most studied biomarkers for contamination, as its levels and activities are related to exposure to aromatic hydrocarbons in a dose-dependent manner, both in fish and in mammals (VIEIRA et al., 2018; YAMAMOTO, 2016).

This enzyme has the function of metabolizing lipophilic xenobiotics into more hydrophilic compounds to favor its excretion, but many of these metabolites formed in the detoxification process are potentially reactive and can be genotoxic, which can cause DNA damage or lead to carcinogenesis. After exposure to xenobiotics, EROD levels increase, and this is the basis for using this enzyme as a biomarker of the effects of water contamination by organic pollutants resulting from anthropic activities (BURKINA et al., 2018; SANTANA et al., 2018).

According to Araújo et al., (2018), there reported increasing EROD activity in fish exposed to a wide range of pollutants, such as PAHs. These findings demonstrate that the lowest EROD activity is concentrated in an area where most pollutants are incorporated into the sediment by decantation due to the decrease in water flow. In contrast, Leggieri et al., (2019) showed that oil contamination induces the enzyme CYP1A in rainbow trout (*Oncorhynchus mykis*). Similar results have been reported in *O. niloticus* under oil pollution, as demonstrated in the study of Ahmed et al., (2019), which showed that oil spills into natural water resources expose fish to serious problems. The authors also observed a significant increase in CYP1 A1 mRNA expression levels in the liver tissue of this fish.

6 CONCLUSION

Aquatic contamination represents a direct threat to the conservation and management of these ecosystems and drastically reduces the availability of quality water for the population. Besides, it causes damage to the organisms that live there, influenced directly by human activities.

The growing use of toxic substances, such as pesticides, metals, and other organic compounds, brings to the fore the need for their effects being evaluated in the environments in which they are disseminated, to analyze the damage caused, and avoid consequences to the aquatic environment. In this context, the use of biomarkers is a very useful tool for this purpose.

Biomarkers serve different purposes in the aquatic environment, as shown throughout this study, and can be used for assessments of genotoxicity, neurotoxicity, cytoplasmic organelle integrity, which are indicators often used to assess damage to aquatic organisms caused by xenobiotics.

For effective monitoring with these tools, it is important to pre-determine which biomarkers and species will be used as a possible damage indicator. Besides, taking into consideration the internal particularities of each biomarker, considering extrinsic and intrinsic factors process that may cause changes in the assessment.

Therefore, there strongly recommended the use of biomarkers in assessing impacts on the aquatic environment, so that reliable data can be produced, enabling the implementation of appropriate measures for the prevention, either-or recovery of aquatic ecosystems.

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