Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 27(3): 1025 – 1051 (2023)
www.ejabf.journals.ekb.eg

Helminthic Fish Parasites as Bioindicators of Metals Pollution in the Aquatic Environments: Review

Osama Mostafa*, Tasneem Hanfi, Doaa Abd-eltwab, Ahmed Nigm
Zoology Department, Faculty of Science, Ain Shams University, Cairo, Egypt
***Corresponding Author:** osamamostafa@hotmail.com, osamamostafa@asu.sci.edu.eg

ARTICLE INFO

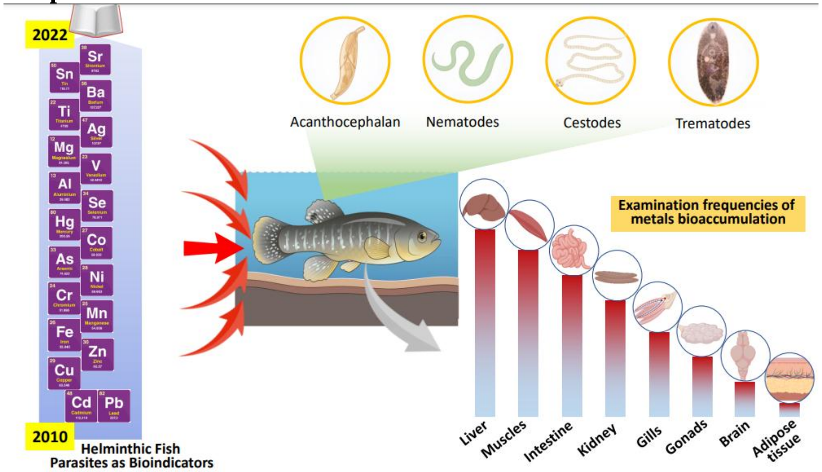
Article History:
Received: May 10, 2023
Accepted: June 25, 2023
Online: June 30, 2023

Keywords:
Fish parasites,
Biological indicators,
Metals pollution,
Aquatic environments

ABSTRACT

This review focused on comparing the capability of different helminthic taxa infecting fish to accumulate heavy metals in their bodies, as well as the conditions that influenced such accumulation. Fish-parasite models, fish habitat, elements accumulated, and host tissues analyzed were considered in the present article. The papers published between 2010 and 2022, concerned with helminthic fish parasites, which were used as biological indicators of metal contamination in aquatic environments were retrieved using specific inclusion and exclusion criteria. Four taxa of helminthic parasites were assessed to be bioindicators: acanthocephalan, nematodes, cestodes and trematodes. Fish parasites can accumulate heavy metals at levels of magnitude orders higher levels than their fish hosts' tissues, and can give helpful information on the chemical status of their environment. Compared to helminths that have a gastrointestinal tract; gutless helminths are better sentinels for metal pollution. Factors that impacted the metal accumulation in both fish and their parasites were investigated in a number of retrieved studies. There are various benefits for using fish parasites as bioindicators of heavy metal contamination, but three stand out: protecting fish health as an important element of the ecosystem, monitoring pollution levels in the environment, and safeguarding human health by determining the suitability of fish for human consumption in terms of the accumulation of heavy elements in it. In addition, researchers in the field of ecotoxicology who use fish as bioindicators must keep in mind that parasites reduce heavy metal bioaccumulation in the tissues of their hosts.

Graphical abstract



INTRODUCTION

Chemical pollution of the aquatic ecosystem represents a major hazard to aquatic organisms, especially fish **(Saeed & Shaker, 2008)**. Metals enter the aquatic environment through a number of sources, viz., natural biogeochemical cycles and anthropogenic sources such as industrial and residential effluents, urban pollution, rainwater runoff, landfill leachate and mining in addition to atmospheric sources **(Förstner & Wittmann, 2012)**.

The direct analysis of trace metals in sediments and water is an easier way to detect contaminants in the aquatic ecosystem, but metal concentrations are frequently near detection limits in sediment or water and therefore difficult to analyze in spite of the recent technologies presently available. Bioindicators accumulate the number of contaminants, which are biologically available in a particular habitat, thereby showing bioconcentration trends in biota **(Golestaninasab *et al*., 2014)**.

Fish that occupy the top of the aquatic food web and have a relatively long life span concentrate a lot of contaminants and, therefore, are commonly used as biological indicators **(Rashed, 2001)**. Since the first studies on parasites' effects on their fish hosts' tolerance to environmental toxins **(Boyce & Yamada, 1977; Pascoe & Cram, 1977)**, several studies were published on parasitism and pollutant accumulation. Fish parasites can accumulate heavy metals at levels magnitude orders higher than the tissues of their fish hosts, as reported in several studies conducted on aquatic habitats. This finding suggests that fish parasites could potentially provide useful information on the chemical state of their environment **(Nachev *et al*., 2010; Shahat *et al*., 2011; Brázová *et al*., 2012; Marijić *et al*., 2013; Paller *et al*., 2016; Mijošek *et al*., 2022)**.

Different accumulation patterns of hydrophilic and lipophilic chemicals have been documented; lipophilic substances mainly accumulate in fat and therefore become biomagnified along food webs, whereas hydrophilic substances are distributed more evenly among tissues. Due to their low fat content, parasites are unable to bioconcentrate lipophilic chemicals above the levels of the host tissues **(Heinonen *et al*., 1999)**. They can; however, contribute to the uptake of other substances such as metals within their hosts **(Evans *et al*., 2001)**. Hence, research has typically focused on the use of parasites as accumulation markers of heavy metals; organic pollutants have received less attention.

The two terms "Sink" and "Sentinel" were used to describe the fish parasites used in biomonitoring studies; **Beeby (2001)** identified sentinel species as biological monitors that accumulate a contaminant in their tissues without suffering any serious consequences. They are primarily employed to quantify the amount of a pollutant that is biologically accessible; they may also increase the sensitivity of an analytical method or summarize a complicated pollution signal. While, the sink was defined by the European Environmental Agency (2022) as a vehicle for removing a chemical or gas from the atmosphere, ecosystems and oceans that either absorbs the substance into a permanent or semi-permanent depository or transforms it to another substance. The term "Sink" was early used by **Sures and Siddall (1999)** to describe the acanthocephalan worm *Pomphorhynchus laevis* that experimentally infected chub *Leuciscus cephalus*, which was exposed to aqueous lead. They revealed that the acanthocephalan worm absorbs bile-bound lead from the host intestine, and as a result, minimizes its reabsorption by the intestinal wall of the chub, or in other words, disrupting the metal's hepatic-intestinal cycle. The term "Sentinels" was used widely to describe the accumulation bioindicators commonly applied in environmental impact studies **(Nachev & Sures, 2016)**. This review will mainly deal with fish helminthic parasites reported as aquatic biological indicators of heavy metal contaminants between 2010 and 2022.

METHODS

The search terms are metals pollution (OR heavy metals contamination OR environmental pollution OR environmental impact), AND helminthic fish parasites (OR marine parasites OR freshwater parasites OR parasitological indices) AND biological indicator (OR bioindicators OR biomonitoring OR pollution indicators OR accumulation indicators OR pollution monitoring OR effect indicators) were used in Google Scholar, Web of Science and Scopus to retrieve literature related to helminthic parasites of fish as biological indicators of metals pollution. The literature search inclusion criteria were as follows: (1) published between 2010 and 2022; (2) written in English; (3) available as full text; (4) concerned with field studies or semi-field studies; (5) concerned with helminthic parasites and (6) classified as original articles. The literature exclusion criteria were as follows: (1) classified as a thesis, letter to the editor, or review article, and (2) concerned with the experimental investigation. The retrieved articles from database were preliminary screened; duplicate articles were excluded, and the remaining articles were scanned to evaluate the relevance of the content and the inclusion-exclusion criteria. Thus, the most appropriate 47 articles were selected for analysis.

RESULTS AND DISCUSSION

In the present review, the articles retrieved were summarized in Table (1) which includes the following items: parasite species, taxa of the parasites, fish host, fish habitat (fresh/brackish/marine), region/country, host tissues examined, heavy metals measured and other environmental elements studied (water/sediments/aquatic plants/free-living organisms). A small number of studies have focused on the use of fish parasites as effect indicators, in which changes in the community structure of parasites and biology of infection in relation to variations in the physical, chemical constituents, and other types of pollution of aquatic environments have been assayed **(Igeh *et al*., 2021; Mashaly *et al*., 2020)**; the majority of studies; however, have focused on the use of fish parasites as accumulative indicators.

Fish-parasite models

Along with the majority of retrieved articles, the fish-parasite models were greatly varied, since the species of fish and parasite changed from one article to another. This vast variation in fish-parasite models could be due to the great biodiversity within fish and parasite populations. The most diverse group of vertebrate animals are fish **(Magurran *et al*., 2011)**. **Nelson (2006)** estimated a number of 32 500 different species of fish worldwide. About 28 400 are considered valid species; a valid species is made up of interbreeding populations that are presumed to be reproductively separated from other taxa **(Nelson, 1999)**. On the other hand, it was determined that over 30,000 helminthic species are fish parasites **(Williams & Jones, 1994)**.

Fish habitat

Freshwater fishes were the subject of the majority of the studies in the current review, followed by marine fishes. Whereas, fewer studies were done on brackish water fishes **(Akinsanya & Kuton, 2016; Akinsanya *et al*., 2020; Chine *et al*., 2021; Radwan *et al*., 2022)**. This finding is correlated with **Mendes *et al*. (2013)** who stated that the studies on the metal accumulation in parasite-fish host systems from the marine environment are still limited in comparison to freshwater ecosystems. The fact that pollution concentrations in inland waters are probably far higher than those in marine ecosystems may be the cause of the growing interest in fresh water biomonitoring research **(Poulin, 1992)**.

It is noteworthy that, metal ions are more easily accessible to organisms in limnetic ecosystems since the concentration of hydrated ions decreases with the increase of salinity **(Merian, 2004)**. In the marine environment, fish mostly uptake metals through the water and food that they ingest. Per contra, due to the osmotic differences between fish body fluids and ambient water, which cause water and solutes to pass through the gill membrane and subsequently enter the fish's circulatory system, the uptake in limnetic habitat primarily occurs through the gills **(Nachev *et al*., 2022)**.

Parasite taxa

The vast majority of articles on metal accumulation in parasites dealing with metal concentrations in endohelminths for protozoan parasites appear to be far too tiny to allow for a reliable chemical study. Additionally, since leeches, crustaceans and monogeneans are ectoparasites mostly affected by the ambient water, their accumulation patterns are probably similar to those of related free-living species such as annelids, non-parasitic crustaceans and turbellaria **(Bergey *et al*., 2002)**.

Metals were mostly detected at significantly higher levels in fish parasites; compared to their host tissues. This high concentration of metals in parasites could be attributed to their inability to synthesize certain organic compounds including organo-metallics, especially those with heavy metals. This has been the case for acanthocephalans as well as other parasites **(Sures, 2001)**.

Metal accumulation in fish parasites was found to be highly dependent on parasite taxa and developmental stage. It was discovered that acanthocephalan parasites absorb organometallic or bile substances more effectively through their tegument than the intestinal wall of the fish host **(Sures & Siddal, 1999)**. **Paller *et al.* (2016)** determined the Pb concentration in acanthocephalans *Acanthogyrus* sp., their host *Oreochromis niloticus* and the ambient waters; the levels of Pb were significantly higher in the acanthocephalan parasites, compared to the fish host tissues, and they were hundreds of 988 times greater than the ambient waters. The parasites' bioaccumulation capability against fish tissues was 102, 119 and 147 times greater than the gut, liver and the muscles of the fish, respectively, indicating that the acanthocephalan parasites might act as metal biosinks in aquatic habitats **(Paller *et al*. 2016)**. **Marijić *et al*. (2013)** suggested that acanthocephalans are sensitive indicators of the quality of the environment, even under low metal contaminations.

Compared to other helminthic parasites, acanthocephalans accumulate metals in higher concentrations. **Brázová *et al.* (2012)** investigated the concentrations of heavy metal in parasites, *Acanthocephalus lucii* (acanthocephalan) and *Proteocephalus percae* (cestode) in comparison with the tissues of their host European perch *Perca fluviatilis*. Among the elements investigated, the acanthocephalan accumulated Cd, Pb, Hg, Cr, and Cu in significantly higher concentrations, compared to cestodes. **Al-Hasawi (2019)** reported that, the accumulation of Pb and Cd in the tissues of *Siganus rivulatus* fishes infected with *Gyliauchen volubilis* (Trematoda: Digenea) and *Procamallanus elatensis* (Nematoda) were slightly lower than those in non-infected ones, while in the tissues of fishes infected with *Sclerocollum rubrimaris* (Acanthocephala), they were much lower. The concentration of Pb and Cd accumulated in the parasite taxa was in the following order: acanthocephala > nematoda> trematode. In addition, acanthocephalans appeared more effective in metal accumulation compared to gammarids (Crustacea) **(Mijošek *et al*., 2022)**.

Intestinal acanthocephalans mostly bioconcentrate the toxic elements of As, Cd and Pb, whereas the intraperitoneal nematodes accumulate the essential elements of Co, Cu, Fe, Se and Zn. **Nachev *et al.* (2013)** analyzed eleven elements (As, Cd, Co, Cu, Fe, Mn, Pb, Se, Sn, V and Zn) in the muscle, intestine and liver of barbell fish *Barbus barbus*, as well as its parasites *Pomphorhynchus laevis*, acanthocephalan parasitized in the intestine and Eustrongylides sp., L4 nematode larva parasitized in the body cavity. They reported that, the fourth-stage larval nematodes have higher levels of essential elements than adults, which could be due to their biological and morphological properties. It is important to note that the larva enters the body cavity through the intestinal wall, where it begins feeding on blood and tissues before becoming encapsulated. The fourth larval stage has a well-developed digestive system **(Moravec, 1994)**, which suggests that they can accumulate metals through the consumption of food. Moreover, nutrients and metals can also be absorbed by larval worms via their body surface because their cuticles are not as complicated as adults **(Bird & Bird, 1991;**

Szefer *et al*., 1998). Therefore, the fourth-stage larval nematodes exhibit an even better accumulation capacity than adult worms because of the two different uptake routes. In contrast, the larval acanthocephalans' accumulation ability was discovered to be quite low, and metal uptake begins in the intestinal lumen of their definitive host **(Brown & Pascoe, 1989; Sures *et al*., 1994; Sures *et al*., 1995)**.

Furthermore, **Nachev *et al.* (2013)** offered a satisfactory explanation of why nematode larvae accumulate essential elements, while adult acanthocephalans and adult nematodes accumulate toxic elements. These differences could be attributed to competition between *P. laevis*, an acanthocephalan parasitizing in the intestine, and *Eustrongylides* sp., a L4 nematode larva parasitized in the body cavity in the double-infected fish, or the relative importance of various element absorption routes during various stages of parasitized worm growth. Nematode larvae actively consume food in order to develop quickly; therefore, they rely on two methods for absorbing important elements, then the larvae become encapsulated and unable to feed, whereas adult worms actively feed on host tissues, and thus taking up and concentrating toxic metals such as Cd and Pb. Due to the competence of acanthocephalans in the gut with the host tissues for food and metals, the acanthocephalan *P. laevis* has a high concentration of toxic elements. Acanthocephalans actively take up metals bound in bile complexes that are discharged in the small intestine, making them unavailable for reabsorption by the host gut .

Within the same parasitic taxa, an interspecific variation is found in metals' accumulation, which may be linked to cuticle morphology, microhabitats specificity as well as interspecific competition. **Mazhar *et al.* (2014)** noticed this variation in their study on the Cd, Cu, Cr, Hg, Sr, Mn, Se, Pb, Ni, Al, As, Fe and Zn concentrations in notched threadfin bream, *Nemipterus peronii*, addressing two nematode parasites *Hysterothalycium reliquens* and *Paraphilometroides nemipteri*. The results showed that *H. reliquens* accumulated high concentrations of Cu, Cr, Fe, Mn, Se, Ni and Zn; whereas, *P. nemipteri* accumulated high accumulations of As, Hg, Cd, Al, Pb and Sr.

Leite *et al.* (2017) evaluated thirteen element concentrations: Mg, Al, Ti, Cr, Mn, Fe, Ni, Cu, Zn, As, Cd, Ba and Pb in L3 nematode larvae of *Contracaecum* sp. and in their host *Acestrorhynchus lacustris*. Twelve out of the thirteen examined elements were found in L3 nematode larvae in at least 2-fold greater quantities (e.g. Ni) and up to 50-fold higher concentrations (e.g. Pb), where only Mg was found in higher concentration in the tissues of the host than in the parasite. **Morsy *et al.* (2012)** defined and determined the anisakid larvae nematode for the first time in the European seabass, *Dicentrarchus labrax* collected from the Egyptian coasts of the Mediterranean Sea. The concentrations of the heavy metals (Pb, Zn, Fe, Cd, Cu, Mn & Ni) were measured in anisakid larvae as well as in the gill, liver, and muscles of fish. Only the concentrations of Fe, Cd, Mn and Ni in the anisakid larvae appeared greater than those recorded in the host tissues .

In contrast to the high concentrations found in the nematode *Hysterothylacium* sp., the digenean *Phyllodistomum* sp. in the study of **Leite *et al.* (2021)** had lower trace metal concentrations than nematodes for all elements examined, but yet, in comparison, they had higher concentrations than the tissues of their fish host, particularly for the elements of Al, Cr, Ni, As and Pb. The same observation was recorded in the study of Al-**Hasawi (2019)** who reported that, the concentrations of Cd and Pb were higher in the digenean *Gyliauchen lubilis* compared to the tissues host of its fish host *Siganus rivulatus,* but lower, compared to nematodes *Procamallanus elatensis* parasitizing the same host. On the other hand, **Hassan *et al.* (2018)** evaluated the accumulation capacity of helminthic parasites belonging to three taxa: Digenea, Cestoda and Nematoda parasitizing the emperor fish *Lethrinus mahsena*; they found that of the six elements examined, digeneans had higher concentrations regarding four of them (As, Cu, Fe and Zn), compared to nematodes, which only had higher concentrations of Cd and Pb in comparison with the digeneans. However, because only a few studies targeted the digeneans, the accumulation patterns are not yet fully understood **(Sures *et al.*, 2017)**.

In addition, cestodes were used as indicators of heavy metal pollution. **Nhi *et al.* (2013)** assessed Mn, Zn, Cu, Cd, and Pb concentrations in the muscle, liver, intestine and kidney of *Channa micropeltes* (snakehead fish), parasitized by the cestode *Senga parva*. The same metals were measured in the ambient lake water as well as the sediments. The findings confirmed what was predicted, showing that the parasite concentrated some heavy metals more than the water and certain fish tissues though less than the sediment. Only Cu and Cd were detected in the host liver tissues at levels greater than those detected in the cestode parasite's tissues.

In the study of **Hassan *et al.* (2018)**, cestode parasites have a significantly higher accumulating capability than trematodes, nematodes and tissues of the emperor fish *Lethrinu smahsena.* **Leite *et al.* (2019)** reported that, the cestode parasites *Proteocephalus macrophallus* presented a reasonable capacity for metal accumulation compared to its hosts (Butterfly Peacock Bass, *Cichla ocellaris*). In comparison to its host, *P. macrophallus* had higher concentrations of the metals Al, As, Ba, Cd, Cr, Fe, Hg, Mg, Mn, Ni, Pb, Ti and Zn. In this context, **Erasmus *et al.* (2020)** elucidated that, *Atractolytocestus huronensis* (cestode) accumulated significantly higher concentrations of Cr, Ni and Pt than its host *Cyprinus carpio*, while *Contracaecum* sp. (nematode) accumulated significantly higher concentrations of Pt and Zn than its host *Clarias gariepinus*.

Upon considering cestodes for biomonitoring, it is worth noting that the accumulated metal concentrations found in the posterior part of the parasite's body would usually be higher than those found in the anterior part. This is because the adult tapeworms' body differentiates into an anterior region (scolex, neck, immature and mature proglottids without eggs) and a posterior region (gravid or pregnant proglottids). The latter is relatively older than the former, providing it with a higher exposure time to accumulate metals **(Sures *et al.*, 1997)**.

In their study on the migratory fish *Alosa immaculata* at its spawning region (Danube River), **Nachev *et al.* (2022)** analyzed the elements of As, Cd, Co, Cu, Fe, Mn, Pb, Se and Zn in the tissues of the monogenean parasite *Mazocraes alosae* (from the host gills) as well as the nematode *Hysterothylacium aduncum* (from the host intestine) in cases of double infection. They found that *M. alosae* does not exhibit a high metal accumulation, compared to *H. aduncum*.

For gutless helminths like cestodes and acanthocephalans, which absorb nutrients through their tegument, as well as the nematode larvae, where nutrient uptake occurr in both their digestive tract and tegument, a higher metal accumulation capability was documented in the retrieved articles selected for the present review. Compared to other helminthes, trematodes and adult nematodes that have a gastro-intestinal tract, gutless helminthes are better suitable sentinels for trace metal contamination. In this respect, **Sures *et al.* (1999)** explained that, intestinal parasites such acanthocephalans and cestodes are compelled to absorb cholesterol and fatty acids from the intestine since they are unable to synthesize these substances on their own. Metallothioneins in the host bile is passed down the biliary duct into the small intestine, and then they are taken up by cestodes and acanthocephalans. However, this does explain why gutless helminths are excellent biosinks.

Elements investigated

The total number of metallic elements investigated in the retrieved articles was 29. Concerned with the number of the element measured per each retrieved article, the maximum number of elements investigated was 17 **(Morris *et al*., 2016)**. Whereas, the minimum number was one element Cd or Pb **(Jankovská *et al.*, 2011; Paller *et al*., 2016; Duarte *et al*., 2020)**; accidentally, both elements (Cd and Pb) were measured in four articles **(Khaleghzadeh-Ahangar *et al*., 2011; Golestaninasab *et al*., 2014; Al-Hasawi, 2019; Hassanine and Al-Hasawi, 2021)**. The most common metals investigated in the retrieved articles were both the Cd and Pb, followed by Cu and Zn. For the rest of the elements, they have been investigated in a smaller number of articles. **Liu *et al*. (2013)** classified the 29 metallic elements investigated in the reviewed articles into four categories: major toxic metals (As, Cd, Cr, Hg, Ni& Pb), essential metals with potential for toxicity (Co, Cu, Fe, Mg, Mn, Zn, Mo& Se), minor toxic metals (Ba, Sb, Sn, Ti, U, Ag, Rb, Sr, Th, Pd, Rh, Cs & V) and metals related to medical therapy (Al& Pt).

Host tissues examined

In the present review, the frequency of host tissues investigated for metal bioaccumulation followed the following order, where muscles> liver> intestine> kidney> gills > gonads> skin> brain, for adipose tissue and swim bladder. The two most investigated tissues were the those of the muscles and liver since the liver serves as a heavy metals storage site, and it plays a part in the detoxication and elimination of numerous dangerous compounds from the body **(Coyle *et al*., 2002; Langston *et al*., 2002)** and muscles (fish meat), which serve as a great source of proteins for humans;

therefore, the monitoring of fish muscle and liver is of great importance.

One of the least metal-containing tissues is the fish muscle **(Nachev *et al*., 2010; Khaleghzadeh-Ahangar *et al*., 2011; Brázová *et al*., 2012; Jankovská *et al*., 2012; Morsy *et al*., 2012; Nhi *et al*., 2013; Mazhar *et al*., 2014; Paller *et al*., 2016; Al-Hasawi, 2019; Leite *et al*., 2019; Keke *et al*., 2020)**. Nevertheless, few metals were shown to have a particular affinity for muscular tissues, including Sn **(Nachev *et al*., 2010)**; Hg **(Brázová *et al*., 2012)**; Al **(Mazhar *et al*., 2014)**; Mg **(Leite *et al*., 2017)**, and Cu **(Hassan *et al*., 2018)**. Liver accumulates Pb, Cd, Cu, Mn, Zn, As, Hg, Mg and Fe in higher concentrations than other fish tissues **(Khaleghzadeh-Ahangar *et al*., 2011; Jankovská *et al*., 2012; Morsy *et al*., 2012; Nhi *et al*., 2013; Mazhar *et al*., 2014; Paller *et al*., 2016; Leite *et al*., 2017)**. In their investigation on the butterfly peacock bass *Cichla ocellaris*, parasitized with tapeworm *Proteocephalus macrophallus*, **Leite *et al*. (2019)** found that, all elements examined (Al, As, Ba, Cd, Cr, Fe, Hg, Mg, Mn, Ni, Pb, Ti, Zn) were detected in higher concentrations in the liver compared to those recorded for the gut and muscles.

The highest concentration of metals was found in the intestine of a shark *R. blochii* infected with the nematode parasite *Proleptus obtusus*, followed by the gonad, kidney, parasite, muscle and the liver **(Morris *et al*., 2016)**. They explain why the intestine accumulates a higher level of metals than other organs in some investigations and referred to organometallic complexes or metallothioneins, which were passed down the biliary duct into the intestine of the host .

The kidney was shown to be the important organ in fish receiving the greatest amount of heavy metals. It is a metabolically active and eliminative organ that conducts a variety of critical activities including heavy metal elimination from the body **(Barbier, 2005)**. However, **Brázová *et al.* (2012)** reported that, in comparison with muscle, liver, brain, gonads and adipose tissue, the kidney perches *Perca fluviatilis* parasitized by acanthocephalan *Acanthocephalus lucii* and the cestode *Proteocephalus percae* was a key target organ receiving the highest mean concentrations of all metals analyzed (As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn). Furthermore, **Mazhar *et al.* (2014)** found that kidney accumulated Pb and Se in higher concentration values than liver and muscles.

Khaleghzadeh-Ahangar *et al.* (2011) and **Brázová *et al.* (2012)** assayed the concentration of the metals in the gonads and reported that the organ has the capability of accumulating metals in high concentration. **Jankovská *et al* (2012)** postulated that the gonads showed the maximum level of Zn. The gonad of shark *Rhinobatos annulatus* infected with the nematode parasites *Proleptus obtusus* contained the highest concentration of Al, As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sb, Se, Sn, Th, Ti, U, V and Zn metals compared to the intestine, kidney, liver and muscular tissues **(Morris *et al*., 2016)**. This may be explained by metals' affinity for proteins, as the gonads, like the liver and kidney, were protein-rich storage organs, but they are unable to regulate concentrations of metal in the same way **(Dallinger *et al*., 1987)**.

In addition, gills bioaccumulate a larger concentration of Ni and Mn than other tissues measured; moreover, the Pb and Zn were found in the liver and gills in higher concentrations than the parasite **(Morsy *et al*., 2012)**. Heavy metals were higher in the gills than intestines, except for Fe, which showed the same mean in the fish's tissues **(Mashaly *et al*., 2021)**.

The previous different patterns of metal concentration distribution in host tissues help confirming the accumulating power of helminthic endoparasites, indicating that they play a major role in lowering concentrations at infection sites **(Sures, 2001, 2003)**. Parasites appear to be playing a beneficial role in reducing the concentration of the metals that could be harmful to the host organism and resisting the metals that could affect the animal's health by competing with the host for food availability and preventing direct metal uptake at the infection site. **Sures and Sidall (1999)** clarified that, this remarkable phenomenon could potentially create issues in defining the terms of parasite and parasitism.

Other environmental elements studied

Metal concentrations in water and sediments were assayed in nine of the forty-seven publications reviewed **(Oyoo-Okoth *et al*., 2010; Brázová *et al*., 2012; Nhi *et al*., 2013; Ugokwe & Awobode, 2015; Akinsanya & Kuton, 2016; Al-Hasawi, 2019; Akinsanya *et al*., 2020; Igeh *et al*., 2021)**. While, the concentrations of metal in the water alone were examined in nine articles **(Khaleghzadeh-Ahangar *et al*., 2011; Shahat *et al*., 2011; Paller *et al*., 2016; El-Lamie & Adel-Mawla, 2018; Keke *et al*., 2020; Mashaly *et al*., 2020; Hassanine & Al-Hasawi, 2021; Mashaly *et al*., 2021; Radwan *et al*., 2022)**. On the other hand, sediment alone was not investigated in any of the retrieved articles .

When heavy metal accumulation in sediments and water were compared, it was observed that heavy metals accumulated more in sediments than water. This is mostly due to the fact that in aquatic habitats, metals are usually attached to suspended particles or adsorbed to particulate organic matter, which settles and accumulates at the bottom of the waterbodies **(Nhi *et al*., 2013; Ugokwe & Awobade, 2015; Al-Hasawi, 2019)**. Pollutants are stored in large quantities in sediments; only about 1% of pollutants are dissolved in water during any stage of the hydrological cycle, while the rest is deposited in sediments **(Salomons & Stigliani, 1995)**.

Other environmental elements were studied in fish-parasite monitoring investigations. **Baruš *et al.* (2012)** assayed the heavy metals accumulation in the river water crowfoot *Batrachium fluitans* during their investigation on the cestode Ligula intestinalis that parasitized three host fishes: *Abramis brama, Blicca bjoerkna* and *Rutilus rutilus*. They reported that, the concentrations of Cd, Ni and Cr in the aquatic plant *B. fluitans* were higher in the river water crowfoot, compared to the tapeworms and both parasitized and non-parasitized fishes. Notably, it is recommended to use multiple indicators to reflect the conditions of an environment as accurate as possible

(Golestaninasab *et al.*, 2014). The previous authors addressed Cd and Pb accumulation in two rays' species *Glaucostegus granulatus* and *Himantura cf. gerrardi* parasitized with the four cestode species *Rhinebothrium* sp1, *Rhinebothrium* sp2, *Tetragonocephalum* sp. and *Polypocephalus* sp., as well as three species of free-living animals: two bivalve species *Barbatia obliquata* and *Saccostrea cucullatam* and *Amphibalanus amphitrite* barnacle from the Oman Gulf. Although parasites themselves are sedentary, they are considered to be mobile indicators as their hosts are mobile; thus, the authors combined two indicators mobile parasites and immobile barnacles in their investigation. They concluded that, rays and their cestodes, especially *Polypocephalus* sp., are applicable mobile bioindicators for larger area monitoring, while the barnacle *A. amphitrite* is the most appropriate non-mobile bioindicator for confined local habitats.

Factors influencing metal bioaccumulation in the fish-parasite model

Along with the articles retrieved, a number of studies have investigated some factors impacting the metal accumulation in both fish and their parasites.

Host's sex and parasite infrapopulation

In their study on the acanthocephalan *Pomphorhynchus laevis* parasitizing fish host *Barbus barbus*, **Nachev *et al.* (2010)** noted that, the infrapopulation size of the parasite and the host's sex play no role in the rate of metal accumulation, and they recommended that, there is no need to take these two aspects into account in "fish-parasite" metal monitoring purposes. This was opposite to the results of **Duarte *et al.* (2020)** who studied the Cd content in the organs of detritivorous fish *Prochilodus lineatus* and carnivorous fish *Serrasalmus marginatus*, as well as their acanthocephalan parasites: *Neoechinorhynchus curemai* and *Echinorhynchus salobrensis*. They observed that, the size of the acanthocephalan parasites' infrapopulation and the levels of Cd in the fish organs were strongly inversely correlated. This is consistent with the findings of **Hassanine and Al-Hasawi (2021)** who found that, the infection of acanthocephalans reduced the negative effects of toxic metals on their fish hosts. This reduction was based on the size of the acanthocephalans infrapopulation in the fish intestine, as Cd and Pb concentrations in fish liver decrease as the size of the worm infrapopulation in the fish intestine increases. **Soler-Jiménez *et al*. (2020)** consider that such a negative relationship is not related to intraspecific competition but to the bio-dilution of the element inside the host's body. Thus, in larger infrapopulation, cadmium could be diluted among all parasite individuals, promoting lower Cd values in parasites and hosts' tissues since Cd is not essential to organisms and is considered a toxic element without any known biological function **(Torres *et al.*, 2015)**. This correlates with the finding of **Sures *et al.* (1999)** who considered that the concentrations of several elements inside the parasites decrease as the infrapopulation of *Acanthocephalus luccii* get enhanced. A dilution effect could explain the decreased metal contents with large infrapopulation sizes given that there are more parasites available to detoxify their host tissues **(Nachev & Sures 2016; Sures *et al*. 2017; Al-Hasawi 2019)**.

Leite *et al*. (2021) explained that, the metal concentrations in the host tissues are affected by the infrapopulations sizes as a whole, regardless of the infection occurring by a single species of parasite or more than one species. In their study on co-infected fish parasitized by *Hysterothylacium* sp. (Nematoda) and *Phyllodistomum* sp. (Digenea), the afore- mentioned authors stated that, the infection with larger infrapopulations of both parasites did not differ from mono-infection by larger infrapopulations of nematodes or digeneans.

Seasonal changes

Dural *et al.* (2010) noted seasonal fluctuations in the concentrations of metals in fish and parasites, and they hypothesized that such variations could be due to innate factors like the development and reproduction cycles, variations in water temperature, and the severity of local pollution. In this context, **Igeh *et al*. (2021)** investigated how water quality and trace elements affected the seasonal occurrence of the monogenean *Cichlidogyrus philander* parasitizing *Pseudocrenilabrus philander* fish, and they reported that, trace elements had no effect on the occurrence of the parasite, concluding that the variations were related to seasonal fluctuation in the infection biology rather than changes in water quality as a result of pollution. The largest concentrations of heavy metals were found in the summer in the water, gills, gut, and intestinal digenean worms, while the lowest concentrations were found during autumn and winter in the water, gills and intestine, while they were detected during winter and spring in the intestinal digenean parasites. These observations were recorded in the study of **Mashaly *et al.* (2021)** on digenean parasites, *Haplorchoides cahirinus*, *Acanthostomum spiniceps* and *Acanthostomum absconditum*, parasitizing silver catfish *Bagrus bajad* in the River Nile .

Physiological status of the host

There are scanty investigations concerned with the relation between the physiological conditions of fish on the accumulation of heavy metals in their parasites. For the first time, Marijic´ *et al.* (2014) examined whether metal variability related to fish physiology might be reflected in the metal concentrations and bioconcentration factors of acanthocephalan parasites, *Pomphorhynchus laevis*& *Acanthocephalus anguillae*, parasitized in European chub, *Squalius cephalus*, from the Sava River, Croatia. Twice as high average bioconcentration factors during the post-spawning than the spawning phase were found for Pb, Ag, Mn, and Fe in *P. laevis* and for Ag and Fe in *A. anguillae*, due to lower fish metabolic needs during the post-spawning phase and as a result, lower gastrointestinal metal levels in the fish. On other hand, acanthocephalans affected Cu, Cd, and Pb levels in the fish intestine, which were lower in infected than uninfected fish, probably reflecting the high metal accumulation capacity of acanthocephalans. Nachev *et al* (2022) concluded that the osmotic adaptations made during the spawning migration of *Alosa immaculata* fish infected with monogenean *Mazocraes alosae* and the nematode *Hysterothylacium aduncum* play a vital role in the metal accumulation process, which is primarily regulated by the host's physiology.

The infection site: Infection sites may have been a key element in the variation in the capacity for metal accumulation among parasites; Leite *et al.* (2021) in their study on *Hoplias malabaricus* fish parasitized by nematode larvae of *Hysterothylacium* sp. and digenean *Phyllodistomum* sp. The main infection sites of nematode larvae of *Hysterothylacium* sp. were the stomach and intestine of the host and had direct contact with the metals both taken through the feeding activities of its host and those taken up through gills. In the case of digenean *Phyllodistomum* sp. the main infection site was the urinary bladder, which contains a small amount of metals, since metals have the characteristic of adhering to blood plasma macromolecules, which are too large to pass through the glomerular filtration sieve, they only reach the urine bladder in a small amount (Wood, 2011); this can partially explain why nematode larvae of *Hysterothylacium* sp. have a better accumulation capacity compared to digenean *Phyllodistomum* sp. Moreover, interactions between parasites at the same infection site appear to have a significant impact on these organisms' accumulation capacity; Brázová *et al.* (2012) in their investigation on *Perca fluviatilis* (European perch) parasitized by two intestinal parasites, *Acanthocephalus lucii* (acanthocephala), and *Proteocephalus percae* (cestode) revealed that bioconcentration factors of As, Ni, Pb, and Zn were higher in mixed infections than in mono-infections.

The fish trophic level: The concentrations of metals in fish tissues and consequently their parasites can be impacted by the trophic level of the fish. Since top-chain, predatory fish that feed on smaller fish may contain higher metal concentrations than fish at lower trophic levels (Subotić *et al*., 2013).

Age of the host and parasite: The age of the host and the parasite both contribute to the variation in metal concentrations and the older the parasite, the higher the metal concentration because of the longer exposure time. (Leite *et al*., 2019).

CONCLUSION

As they are able to accumulate heavy metals in their tissues at a higher rate than fish tissues, fish parasites could be employed as a biological indicator of heavy metal pollution while at the same time lowering heavy metal bioaccumulation in fish tissues; the fish parasites may therefore serve as metal sentinels in aquatic ecosystems. Researchers may become misled into thinking that pollution levels are at their lowest due to decreased chemical absorption in animals used in ecotoxicological investigations, therefore, biomonitoring programmers should include the influence of parasite infections on levels of pollution. By comparing metal accumulations in various helminthic taxa used in the articles retrieved for this review, it is shown that nematode larvae, which take up their nutrients through both their digestive system and tegument and gutless helminths like cestodes and acanthocephalans, have a higher metal accumulation capacity than other taxa. Moreover, the developmental stage of the parasite was found to have a significant impact on the accumulation of the elements. In metal exposure assessment by using fish parasites as bioindicators, the following factors should be considered: parasite infrapopulation, seasonal changes, fish physiology, infection site, the trophic level of the fish, and the status of local pollution. In the estimation of the average pollution level in wider geographical zones, combining "mobile" parasites (gained from the mobility of their hosts) with immobile non-parasitic species may be the most effective technique to determine local pollution levels.

Table (1) Fish Parasites as Biological Indicators of Metals Pollution in the Aquatic Environments in the Period 2010 to 2022

Parasites	**Systematic group**	**Fish host**	**Habitat (Fresh/Brackish/Marine)**	**Region/ Country**	**Host Tissues examined**	**Metals Measured**	**Other environmental elements studied**	**References**
Pomphorhynchus laevis	Acanthocephala	*Barbus barbus*	Fresh water	The Danube River, Bulgaria	Muscles, Intestine, Liver	As, Cd, Co, Cu, Fe, Mn, Mo, Ni, Pb, Sn, V, Zn	-	Nachev *et al*., 2010
Ligula intestinalis	Cestoda	*Rastreneobola argentea*	Fresh water	Lake Victoria, Kenya	it is not mentioned in the article	Pb, Cd, Cr,Cu	Water, Sediments	Oyoo-Okoth *et al*., 2010
Hysterotylacium aduncum	Nematoda	*Pagellus erythrinus*	Marine	Gulf of Iskenderun, Turkey	Muscles, liver, intestine, swim bladder and skin	Cd, Cr, Cu, Fe, Hg, Mn, Mg, Pb, Zn	-	Dural *et al*., 2010
Hysterothylacium sp.	Nematoda	Cutlassfish, *Trichiurus lepturus*	Marine	Iranian coast of the Gulf of Oman	Liver, Muscles, Gonad ,Intestine	Pb, Cd	Water	Khaleghzadeh-Ahangar *et al*., 2011
Acanthosentis tilapiae, Paracamallanus cyathopharynx, Orientocreadium lazeri	Acanthocephala Nematoda Trematoda	*Oreochromis niloticus niloticus* and *Clarias gariepinus*	Fresh water	EL-Ibrahimia and EL-Malah canals, Assuit, Egypt	Intestine	Cu, Cd, Pb	Water	Shahat *et al*., 2011
Hysterothylacium aduncum	Nematoda	*Sparus aurata*	Marine	Gulf of Iskenderun, Turkey	Muscles, liver, gills intestine, skin	Cd, Cr, Cu, Fe, Hg, Mn, Mg, Pb, Zn	-	Dural *et al*., 2011
Acanthocephalus lucii	Acanthocephala	European perch: *Perca fluviatilis*	Fresh water	Jevansky´ potok stream, Prague, Czech Republic	liver, gonads, Muscles with skin and bone	Pb	-	Jankovská *et al* 2011
Ligula intestinalis	Cestoda	*Abramis brama, Blicca bjoerkna* and *Rutilus rutilus*	Fresh water	Jihlava River, Czech Republic	Muscles	Pb, Cd, Ni, Cr	Aquatic plant river water crowfoot *Batrachium fluitans*	Baruš *et al*., 2012
Bathybothrium rectangulum		*Barbus barbus*						

Acanthocephalus lucii & *Proteocephalus percae*	Acanthocephala & Cestoda	European perch: *Perca fluviatilis*	Fresh water	The Ružín water reservoir, Slovakia	Muscles, Liver, Kidney, Brain, Gonads, Adipose tissue	As, Cd, Cr, Cu, Hg, Mn, Ni, Pb ,Zn	Water, Sediments	Brázová *et al*., 2012
Acanthocephalus lucii	Acanthocephala	European perch: *Perca fluviatilis*	Fresh water	Jevansky´ potok stream, Prague, Czech Republic	Muscles, Gonads, Liver	Cd, Cu, Mn, Zn	-	Jankovská *et al*., 2012
Anisakid juveniles	Nematoda	*Dicentrarchus labrax*	Marine	coasts of Mediterranean Sea, Egypt	Gills, Liver, Muscles	Pb, Zn, Fe, Cd, Cu, Mn, Ni	-	Morsy *et al*., 2012
Pomphorhynchus laevis & *Acanthocephalus anguillae*	Acanthocephala	European chub: *Squalius cephalus*	Fresh water	Sava River, Croatia	Gastrointestinal tissue	Cu, Mn, Ag, Cd, Pb, Zn, Fe	-	Marijić *et al*., 2013
Pomphorhynchus laevis& *Eustrongylides sp.,*	Acanthocephala , Nematoda	barbell fish: *Barbus barbus*	Fresh water	Danube River, Bulgaria	Intestine, Liver, Muscles	As, Cd, Co, Cu, Fe, Mn, Pb, Se, Sn, V, Zn	-	Nachev *et al*., 2013
Senga parva	Cestoda	snakehead fish: *Channa micropeltes*	Fresh water	Lake Kenyir, Malaysia	Intestine, Kidney, Liver, Muscles	Mn, Zn, Cu, Cd, Pb	Water , Sediments	Nhi *et al*., 2013
Pomphorhynchus laevis & *Acanthocephalus anguillae*	Acanthocephala	*European chub*∶ *Squalius cephalus*	Fresh water	Sava River, Croatia	Gastrointestinal tissue	Cu, Mn, Ag, Cd, Pb, Zn, Fe	-	Marijić *et al*., 2014
Tetragonocephalum sp., *Polypocephalus sp.*, *Rhinebothrium* sp1., *Rhinebothrium* sp2.	Cestoda	*Himantura* cf. *gerrardi* & *Glaucostegus granulatus*	Marine	Gulf of Oman	Intestine, Muscles	Cd, Pb	barnacle *Amphibalanus amphitrite*, two bivalve species *Saccostrea cucullata and Barbatia obliquata* & Sedimnts	Golestaninasab *et al*., 2014

Robphildollfusium fractum & Neoapocreadium chabaudi	Digenea	*Sarpa salpa& Balistes capriscus*	Marine	The coast of Mahdia and Sfax, Tunisia	Kidney, Liver, Muscles	Se, Hg	-	Torres *et al*., 2014
Hysterothalycium reliquens, Paraphilometroides nemipteri	Nematoda	*Nemipterus peronii*	Marine	South China Sea	Kidney, Liver, Muscles	Cd, Cr, Cu, Hg, Sr, Mn, Se, Pb, Ni, Al, As, Fe, Zn	-	Mazhar *et al*., 2014
Hysterothylacium aduncum	Nematoda	Common Sole: *Solea solea*	Marine	Coasts of Alexandria City, Mediterranean Sea, Egypt	Liver, Gills, kidney, Muscles	Fe, Cu, Zn, Ni, Pb, Cd,	-	Abdel-Ghaffar *et al*., 2015
Clestobothrium crassiceps	Cestoda	European Hake *Merluccius merluccius*	Marine	The Gulf of Lion (Northwestern Mediterranean Sea), Spain	Kidney, Liver, Muscles	As, Cd, Pb, Hg, Se	-	Torres *et al*., 2015
Allocreadiumghanensis, Phagicola longa, Clinostomum tilapiae, Dipylidium caninum and Acanthogyrus tilapiae	Trematoda, Acanthocephala	Nile Tilapia: *Oreochromis niloticus*	Fresh water	River Ogun, Abeokuta, Nigeria	Intestine, Liver, Muscles	Cd, Cu, Pb, Zn	Water, Sediments	Ugokwe and Awobode , 2015
Polyonchobothrium clarias	Cestoda	African sharptooth catfish: *Clarias gariepinus*	Brackish water	Lake Manzala, north-east quadrant of the Nile Delta, Egypt	Liver, Kidney, Muscles	Zn, Cu, Mn, Cd, Pb, Ni	-	Abdel-Gaber *et al*., 2016
Lacistorhynchus dollfusi	Cestoda	*Citharichthys sordidus*	Marine	Santa Monica Bay, Southern California, USA	Intestine, Liver, Muscles	Ag, As, Cd, Cr, Cu, Fe, Hg, Pb, Rb, Se, Sr, Ti, Zn	-	Courtney-Hogue, 2016

Contracaecum sp.	Nematoda	*Acestrorhynchus lacustris*	Fresh water	Batalha River, southeast Brazil	Liver, Muscles	Mg, Al, Ti, Cr, Mn, Fe, Ni, Cu, Zn, As, Cd, Ba, Pb	-	Leite *et al*., 2016
Procamallanus spp.	Nematoda, Trematoda	*Synodontis clarias*	Brackish water	Lekki Lagoon, Lagos, Nigeria	Intestine	Fe, Mn, Zn, Pb, Cd	Water, Sediments	Akinsanya& Kuton, 2016
Siphodera ghanensis		*Chrysichthys nigrodigitatus*						
Gyrocotyle plana, Proleptus obtusus	Cestoda, Nematoda	*Callorhinchus capensis, Rhinobatos annulatus, Rhinobatos blochii*	Marine	False bay, Saldanha bay, South Afrcia	Gonads, Intestine, Kidney, Liver, Muscles	Al, As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sb, Se, Sn, Th, Ti, U, V, Zn	-	Morris *et al*., 2016
Acanthogyrus sp.	Acanthocephala	*Oreochromis niloticus*	Fresh water	Sampaloc lake, Philippine	Intestine, Liver, Muscles	Pb	Water	Paller *et al*., 2016
Larva of *Contracaecum* sp.	Nematoda	*Acestrorhynchus lacutris*	Fresh water	Batalha River water catchment lagoon, Brazil	Liver, Muscles	Mg, Al, Ti, Cr, Mn, Fe, Ni, Cu, Zn, As, Cd, Ba, Pb	-	Leite *et al*., 2017
Electrotaenia malapteruri *Dujardinnascaris malapteruri*	Cestoda Nematoda	Electric catfish: *Malapterurus electricus*	Brackish water	Lake Manzala, north-east quadrant of the Nile Delta, Egypt	Liver, Kidney, Spleen, Gills, Muscles, Brain	Zn, Cu, Mn, Cd, Pb, Ni, Fe	Water, Sediment	Abdel-Gaber *et al*., 2017

Neohydinorhynchus macrospiosus Echinorhynchus	Acanthocephala	*Siganus revulatus*, *Mulloides flavolineatus*	Marine	Suez canal, Egypt	Gills, Liver, Muscles	Pb, Zn, Cu, Cd, Fe	Water	El-Lamie and Adel-Mawla, 2018
Harmacreadium khalili, *Hamacreadium mutabile*, *Hamacreadium cribbi*, *Pseudoplagioporus lethrini*, *Floriceps* sp., *Terranova* sp., *Cucullanus maldivensis*, *Ascarophisnema tridentatum*	Trematoda, Cestoda, Nematoda	*Lethrinu smahsena*	Marine	Raas Mehsen, Red Sea, Jeddah, Saudi Arabia	Intestine, Kidney, Liver, Muscles	As, Fe, Zn, Pb, Cu, Cd	-	Hassan *et al*., 2018
Gylianuchen volubilis, *Procamlanus elatensis*, *Sclerocollum rubrimaris*	Digenea Nematoda Acanthocephala	*Siganus rivulatus*	Marine	Red sea, Egypt	Intestine, Liver, Muscles	Cd, Pb	Water, Sediment	Al-Hasawi, 2019
Proteocephalus macrophallus	Cestoda	*Chicla ocellaris*	Fresh water	Jacaré-Pepira River, São Paulo, Brazil	Intestine, Liver, Muscles	Al, As, Ba, Cd, Cr, Fe, Hg, Mg, Mn, Ni, Pb, Ti, Zn	-	Leite *et al*., 2019
Camallanus sp., *Capillaria* sp., *Eustrongylides* sp., *Cucullanus* sp. and *Alvinocaris markensis. Dactylogyrus* sp., *Polyonchobothrium clarias*, and *Acanthocephalus* sp.	Nematoda Monogenea Cestoda Acanthocephala	*Clarias gariepinus* *Tilapia zillii* *Raiamas nigeriensis*	Fresh water	Chanchaga River, Nigeria	Muscles	Fe, Zn, Cr, Mn, Pb, Cu	Water	Keke *et al*., 2020
Atractolytocestus huronensis, *Contracaecum* sp.	Cestoda Nematoda	*Cyprinus carpio*, *Clarias gariepinus*	Fresh water	Hex River, South Africa	Liver, Muscles	Cd, Cr, Cu, Ni, Pb, Pt, Zn	-	Erasmus *et al*., 2020
Quadriacanthus Spp.	Monogenea	*Clarias gariepinus*	Brackish water	Manzala Lake	-	Cd, Pb, Cu, Fe, Zn	Water	Mashaly *et al*., 2020

			Agricultural drainage water	Nawasa El-Gheit Drain				
			Fresh water	Demietta branch of the River Nile				
Neoechinorhynchus curemai	Acanthocephala	*Prochilodus lineatus*	Fresh water	Baía and Paraná rivers, Brazil	Intestine, Liver, Muscles	Cd	-	Duarte *et al*., 2020
Echinorhynchus salobrensis		*Serrasalmus marginatus*						
Tenuisentis niloticus	Acanthocephala	*Heterotis niloticus*	Brackish water	Lekki Lagoon, Lagos, Nigeria	Intestine, Liver	Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, Zn	Water, Sediment	Akinsanya *et al*., 2020
Cichlidogyrus philander	Monogenea	*Pseudocrenilabrus philander*	Fresh water	Padda Dam, South Africa	-	V, Cr, Mn, Fe, Ni, Cu, Zn, As, Rh, Pd, Ag,Cd , Pt, Pb	Water, Sediment	Igeh *et al*., 2021
Hysterothylacium sp. *Phyllodistomum sp.*	Nematoda, Digenea	*Hoplias malabaricus*	Fresh water	Jacaré-Pepira and Jacaré-Guaçú rivers, in southeastern Brazil	Muscles, Intestine, Liver	Al, Cr, Mn, Fe, Ni, Cu, As, Cd, Pb		Leite *et al*., 2021
Neoechinorhynchus agilis	Acanthocephala	*Mugil cephalus, Chelon ramada*	Brackish waters	Ichkeul Lagoon in northern Tunisia	Muscles, Intestine, Liver	Ag, As, Cd, Co, Cu, Fe, Mn, Ni, Pb, Se, V, Zn	-	Chine *et al*., 2021
Acnthostomum spiniceps *Acnthostomum absconditum* *Halporchoides chairrinus*	Digenea	*Bagrus bajad*	Fresh water	Damietta Branch of the River Nile, Egypt	Gills, Intestine	Fe, Zn, Cu, Ni, Cd, Cr, Mn, Co, Pb	Water	Mashaly *et al*., 2021

Sclerocollum rubrimaris	Acanthocephala	*Siganus rivulatus*	Marine	Red Sea, Sharm El-Sheikh, South Sinai, Egypt	Liver	Cd, Pb	Water	Hassanine& Al-Hasawi, 2021
Cichlidogyrus tilapiae *Enterogyrus cichlidarum* *Centrocestus formosanus* *Heterphyes* sp. *Pygidiopsis genata* *Diplostomum tilapiae* *Cyanodiplostomum* sp. *Opisthorchis* sp. *Prohemistomum* sp. *Polyonchobothrium clarias* *Procamallanus* sp. *Paracamallanus* sp. *Acanthosentis tilapiae*	Trematoda Cestoda Nematoda Acanthocephala	*Oreochromis niloticus*	Brackish waters	Burullus Lake (a wild fish source), a private fish farm in Kafr El-Sheikh Governorate, Egypt	Muscles, Intestine, Liver, Gills	Fe, Zn, Cu, As, Cd, Pb	Water	Radwan *et al*., 2022
Mazocraes alosae *Hysterothylacium aduncum*	Monogenea Nematoda	*Alosa immaculata*	Fresh water	Danube River, Bulgaria	Muscles, Intestine, Liver, Gills	As, Cd, Co, Cu, Fe, Mn, Pb, Se, Zn	-	Nachev *et al*., 2022
Hysterothylacium spp.	Nematoda	*Psettodes erumei*	Marine	Bushehr, Iran	Muscles	Fe, Cu, Zn, Co, Ni, Cr, As, Cd, Hg, Pb	-	Sedaghat *et al*., 2022
Dentitruncus truttae	Acanthocephala	*Salmo trutta*	Fresh water	Krka River, Croatia	Intestine	Cd, Co, Cs, Pb, Cu, Fe, Mn, Rb, Se, Sr, Zn, Ca, K, Mg, Na	-	Mijošek *et al*.,2022
		Gammarus balcanicus						

REFERENCES

Abdel-Ghaffar, F.; Abdel-Gaber, R.; Bashtar, A. R.; Morsy, K.; Mehlhorn, H.; Al Quraishy, S. and Saleh, R. (2015). *Hysterothylacium aduncum* (Nematoda, Anisakidae) with a new host record from the common sole *Solea solea* (Soleidae) and its role as a biological indicator of pollution. Parasitology research, 114: 513-522.

Abdel-Gaber, R.; Abdel-Ghaffar, F.; Bashtar, A. R.; Morsy, K. and Saleh, R. (2016). Interactions between the intestinal cestode *Polyonchobothrium clarias* (Pseudophyllidea: Ptychobothriidae) from the African sharptooth catfish *Clarias gariepinus* and heavy metal pollutants in an aquatic environment in Egypt. Journal of helminthology, 90(6)**:** 752.

Abdel-Gaber, R.; Abdel-Ghaffar, F.; Shazly, M. A.; Morsy, K.; Al Quraishy, S.; Mohamed, S. and Mehlhorn, H. (2017). Morphological re-description of *Electrotaenia malapteruri* (Cestoda: Proteocephalidae) and *Dujardinnascaris malapteruri* (Nematoda: Heterocheilidae) infecting the Electric catfish *Malapterurus electricus* and heavy metal accumulation in host and parasites in relation to water and sediment analysis in Lake Manzala, North Delta, Egypt. Acta Parasitologica, 62: 319-335.

Al-Hasawi, Z.M. (2019). Environmental Parasitology: intestinal helminth parasitesof the siganid fish *Siganus rivulatus* as bioindicators for trace metal pollution in the Red Sea. Parasite, 26: 12

Barbier, O.; Jacquillet, G.; Tauc, M.; Cougnon, M. and Poujeol, P. (2005). Effect of heavy metals on, and handling by, the kidney. Nephron Physiology, 99(4): 105-110.

Bergey, L.; Weis, J. S. and Weis, P. (2002). Mercury uptake by the estuarine species *Palaemonetes pugio* and *Fundulus heteroclitus* compared with their parasites, *Probopyrus pandalicola* and *Eustrongylides* sp. Marine Pollution Bulletin, 44(10): 1046-1050.

Bird, A. F. and Bird, J. (2012). The structure of nematodes. Academic Press.

Boyce, N. P. and Yamada, S. B. (1977). Effects of a parasite, *Eubothrium salvelini* (Cestoda: Pseudophyllidea), on the resistance of juvenile sockeye salmon, *Oncorhynchus nerka*, to zinc. Journal of the Fisheries Board of Canada, 34(5): 706-709.

Brázová, T.; Torres, J. ; Eira, C. ; Hanzelová, V. ; Miklisová, D. and Šalamún, P. (2012). Perch and its parasites as heavy metal biomonitors in a freshwater environment: the case study of the Ružín water reservoir, Slovakia. Sensors, 12(3): 3068-3081.

Brown, A. F. and Pascoe, D. (1989). Parasitism and host sensitivity to cadmium: an acanthocephalan infection of the freshwater amphipod *Gammarus pulex*. Journal of Applied Ecology, 473-487.

Coyle, P.; Philcox, J. C.; Carey, L. C. and Rofe, A. M. (2002). Metallothionein: the multipurpose protein. Cellular and Molecular Life Sciences CMLS, 59: 627-647.

Dallinger, R.; Prosi, F.; Segner, H. and Back, H. (1987). Contaminated food and uptake of heavy metals by fish: a review and a proposal for further research. Oecologia, 73: 91-98.

El-lamie, M. and Abdel-Mawla, H. I. (2018). Investigation of Acanthocephalan parasites in some marine fishes as a bio-indicator for heavy metals pollution. Egyptian Journal for Aquaculture, 8(1): 13-30.

Erasmus, J. H.; Wepener, V.; Nachev, M.; Zimmermann, S.; Malherbe, W.; Sures, B. and Smit, N. J. (2020). The role of fish helminth parasites in monitoring metal pollution in aquatic ecosystems: a case study in the world's most productive platinum mining region. Parasitology Research, 119(9): 2783-2798.

Hassan, A.; Moharram, S. and El Helaly, H. (2018). Role of parasitic helminths in bioremediating some heavy metal accumulation in the tissues of *Lethrinus mahsena*. Turkish Journal of Fisheries and Aquatic Sciences, 18(3): 435-443.

Hassanine, R. and Al-Hasawi, Z. (2021). Acanthocephalan worms mitigate the harmful impacts of heavy metal pollution on their fish hosts. Fishes, 6(4): 49.

Jankovská, I.; Miholová, D.; Lukešová, D.; Kalous, L.; Válek, P.; Romočuský, Š. ... and Čadková, Z. (2012). Concentrations of Zn, Mn, Cu and Cd in different tissues of perch (*Perca fluviatilis*) and in perch intestinal parasite (*Acanthocephalus lucii*) from the stream near Prague (Czech Republic). Environmental research, 112: 83-85.

Keke, U. N.; Mgbemena, A. S.; Arimoro, F. O. and Omalu, I. C. (2020). Biomonitoring of effects and accumulations of heavy metals insults using some helminth parasites of fish as bio-indicators in an Afrotropical stream. Frontiers in environmental science, 8: 576080.

Khaleghzadeh-Ahangar, H.; Malek, M. A. and McKenzie, K. (2011). The parasitic nematodes *Hysterothylacium* sp. type MB larvae as bioindicators of lead and cadmium: a comparative study of parasite and host tissues. Parasitology, 138(11): 1400-1405.

Langston, W. J.; Chesman, B. S.; Burt, G. R.; Pope, N. D. and McEvoy, J. (2002). Metallothionein in liver of eels *Anguilla anguilla* from the Thames Estuary: an indicator of environmental quality?. Marine Environmental Research, 53(3): 263-293.

Leite, L. A.; Januário, F. F.; Padilha, P. M.; do Livramento, E. T.; de Azevedo, R. K. and Abdallah, V. D. (2019). Heavy metal accumulation in the intestinal tapeworm *Proteocephalus macrophallus* infecting the butterfly peacock bass (*Cichla ocellaris*), from southeastern Brazil. Bulletin of Environmental Contamination and Toxicology, 103: 670-675.

Leite, L. A.; Pedro, N. H.; de Azevedo, R. K.; Kinoshita, A.; Gennari, R. F.; Watanabe, S. and Abdallah, V. D. (2017). Contracaecum sp. parasitizing *Acestrorhynchus lacustris* as a bioindicator for metal pollution in the Batalha River, southeast Brazil. Science of the Total Environment, 575: 836-840.

Liu, J.; Goyer, R.A. and Waalkes, M.P. (2013). Toxic effects of metals. In: Klaassen CD (ed) Casarett and Doull's toxicology: the basic science of poisons, 7th edn. McGraw-Hill, New York, pp 931- 979.

Magurran, A. E., Khachonpisitsak, S., and Ahmad, A. B. (2011). Biological diversity of fish communities: pattern and process. Journal of Fish Biology, 79(6): 1393-1412.

Mashaly, M. I.; El-Naggar, A. M.; El-Tantawy, S. A. and Al-Gaafari, S. A. (2021). Accumulation of nine heavy metals in water and gills, intestine and digenean parasites of the silver catfish, *Bagrus bajad* Forskål, 1775. Journal of Parasitic Diseases, 45:490-501

Mazhar, R.; Shazili, N. A. and Harrison, F. S. (2014). Comparative study of the metal accumulation in *Hysterothalycium reliquens* (nematode) and *Paraphilometroides nemipteri* (nematode) as compared with their doubly infected host, *Nemipterus peronii* (Notched threadfin bream). Parasitology Research, 113: 3737-3743.

Moravec, F. (1994). Parasitic nematodes of freshwater Fishes of Europe. Dordrecht: Kluwer Academic Publishers.

Morris, T.; Avenant-Oldewage, A.; Lamberth, S. and Reed, C. (2016). Shark parasites as bio-indicators of metals in two South African embayments. Marine pollution bulletin, 104(1-2): 221-228.

Morsy, K.; Bashtar, A. R.; Abdel-Ghaffar, F.; Mehlhorn, H.; Al Quraishy, S.; El-Mahdi, M.... and Mostafa, N. (2012). First record of anisakid juveniles (Nematoda) in the European seabass *Dicentrarchus labrax* (family: Moronidae), and their role as bio-indicators of heavy metal pollution. Parasitology research, 110: 1131-1138.

Nachev, M.; Schertzinger, G. and Sures, B. (2013). Comparison of the metal accumulation capacity between the acanthocephalan *Pomphorhynchus laevis* and larval nematodes of the genus *Eustrongylides* sp. infecting barbel (*Barbus barbus*). Parasites & Vectors, 6(1): 1-8.

Nachev, M.; Zimmermann, S.; Rigaud, T. and Sures, B. (2010). Is metal accumulation in Pomphorhynchus laevis dependent on parasite sex or infrapopulation size?. Parasitology, 137(8): 1239-1248.

Nelson, J. S. (1999). Editorial and introduction: the species concept in fish biology. Reviews in Fish Biology and Fisheries, 9(4): 277-280.

Nelson, J. S. (2006) Fishes of the World, 4th ed. New York, NY: Wiley.

Nhi, T. T. Y.; Shazili, N. A. M. and Shaharom-Harrison, F. (2013). Use of cestodes as indicator of heavy-metal pollution. Experimental Parasitology, 133(1): 75-79.

Oyoo-Okoth, E.; Wim, A.; Osano, O.; Kraak, M. H.; Ngure, V.; Makwali, J. and Orina, P. S. (2010). Use of the fish endoparasite Ligula intestinalis (L., 1758) in an intermediate cyprinid host (*Rastreneobola argentea*) for biomonitoring heavy metal contamination in Lake Victoria, Kenya. Lakes & Reservoirs: Research & Management, 15(1): 63-73.

Paller, V. G. V.; Resurreccion, D. J. B.; de la Cruz; C. P. P. and Bandal, M. Z. (2016). Acanthocephalan parasites (*Acanthogyrus* sp.) of Nile tilapia (*Oreochromis niloticus*) as biosink of lead (Pb) contamination in a Philippine freshwater lake. Bulletin of environmental contamination and toxicology, 96: 810-815.

Pascoe, D. and Cram, P. (1977). The effect of parasitism on the toxicity of cadmium to the three-spined stickleback, *Gasterosteus aculeatus* L. Journal of Fish Biology, 10(5): 467-472.

Poulin, R. (1992). Toxic pollution and parasitism in freshwater fish. Parasitology Today, 8(2): 58-61.

Rashed, M. N. (2001). Cadmium and lead levels in fish (*Tilapia nilotica*) tissues as biological indicator for lake water pollution. Environmental monitoring and assessment, 68: 75-89.

Saeed, S. M. and Shaker, I. M. (2008, October). Assessment of heavy metals pollution in water and sediments and their effect on *Oreochromis niloticus* in the northern delta lakes, Egypt. In 8th international symposium on Tilapia in Aquaculture (Vol. 2008, pp. 475-490). Central Laboratory for Aquaculture Research, Agricultural Research Center.

Salomons, W. and Stigliani, W. (1995). Biogeodynamics of Pollutants in Soils and Sediments. Springer-Verlag, Heidelberg, p. 352

Shahat, M.A.; Amer, O.S.O.; AbdAllah, A.T.; Abdelsater, N. and Moustafa, M.A. (2011). The distribution of certain heavy metals between intestinal parasites and their fish hosts in the River Nile at Assuit Province, Egypt. The Egyptian Journal of Hospital Medicine, 43(1): 241-257.

Sures, B.; Nachev, M.; Selbach, C. and Marcogliese, D. J. (2017). Parasite responses to pollution: what we know and where we go in 'Environmental Parasitology'. Parasites & Vectors, 10: 1-19.

Sures, B.; Taraschewski, H. and Jackwerth, E. (1994). Lead accumulation in *Pomphorhynchus laevis* and its host. The Journal of parasitology, 355-357.

Sures, B. and Taraschewski, H. (1995). Cadmium concentrations in two adult acanthocephalans, *Pomphorhynchus laevis* and *Acanthocephalus lucii*, as compared with their fish hosts and cadmium and lead levels in larvae of *A. lucii* as compared with their crustacean host. Parasitology Research, 81: 494-497.

Sures, B. (2004). Environmental parasitology: relevancy of parasites in monitoring environmental pollution. Trends in parasitology, 20(4), 170-177.

Sures, B. (2001). The use of fish parasites as bioindicators of heavy metals in aquatic ecosystems: a review. Aquatic Ecology, 35: 245-255.

Sures, B. (2003). Accumulation of heavy metals by intestinal helminths in fish: an overview and perspective. Parasitology, 126(7): S53-S60.

Sures, B. and Siddall, R. (1999). Pomphorhynchus laevis: the intestinal acanthocephalan as a lead sink for its fish host, chub (*Leuciscus cephalus*). Experimental Parasitology, 93(2): 66-72.

Sures, B.; Siddall, R. and Taraschewski, H. (1999). Parasites as accumulation indicators of heavy metal pollution. Parasitology Today, 15(1): 16-21.

Sures, B.; Taraschewski, H. and Siddall, R. (1997). Heavy metal concentrations in adult acanthocephalans and cestodes compared to their fish hosts and to established free-living bioindicators. Parassitologia, 39(3): 213-218.

Szefer, P.; Rokicki, J.; Frelek, K.; Skóra, K. and Malinga, M. (1998). Bioaccumulation of selected trace elements in lung nematodes, *Pseudalius inflexus*, of harbor porpoise (*Phocoena phocoena*) in a Polish zone of the Baltic Sea. Science of the total environment, 220(1): 19-24.

Ugokwe, C. U. and Awobode, H. O. (2015). Heavy metals in organs and endoparasites of *Oreochromis niloticus*, sediment and water from River Ogun, Ogun State, Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology, 9(11): 101-109.

Williams, H. and Jones, A. (1994). Fish worms and man. Parasitic worms of fish, 1st ed. Taylor and Francis, London, United Kingdom, pp.371-443

Wood, C.M. (2011). An introduction to metals in fish physiology and toxicology: basic principles. In: Wood CM, Farrell AP, Brauner CJ (Eds), Fish Physiology (pp. 1-5). Elsevier Inc.

ARABIC SUMMERY

ديدان الأسماك الطفيلية كمؤشرات حيوية على التلوث بالمعادن في البيئات المائية: دراسة مرجعية

أسامة مصطفى، تسنيم حنفي، دعاء عبد التواب، أحمد نجم

قسم علم الحيوان، كلية العلوم، جامعة عين شمس، القاهرة، مصر

ركزت هذه المراجعة على مقارنة قدرة الأنواع المختلفة من الديدان الطفيلية التي تصيب الأسماك على تراكم المعادن الثقيلة داخل أجسامها، وكذلك الظروف التي تؤثرعلى هذا التراكم حيث تم استرجاع الأوراق البحثية المنشورة في الفترة بين عامي ٢٠١٠ و ٢٠٢٢ والتي تهتم بطفيليات الأسماك المستخدمة كمؤشرات بيولوجية لتلوث المعادن في البيئات المائية وذلك باستخدام معايير إدراج واستبعاد محددة. تم أعتبار المؤشرات الاتية في فحص الابحات موضع الدراسة: ثنائية الطفيلي/العائل ، بيئة الأسماك ، العناصر المعدنية المتراكمة ، أنوع أنسجة العائل التي تم تحليلها. تم ملاحظة أربعة مجموعات من الديدان الطفيلية أُستخدمت كمؤشرات بيولوجية في هذه الابحاث المسترجعة: الاكنثوسيفيلا (شوكيات الرأس) ، النيماتودا (الديدان الاسطوانية) ، السيستودا (الديدان الشريطية) ، و التريماتودا (المثقبيات) . وقد ثَبُت أن ديدان الأسماك الطفيلية تراكم العناصر المعدنية بمستويات أعلى بكثير من أنسجة عوائلها، كما يمكنها أن تقدم معلومات مفيدة حول الحالة الكيميائية لبيئتها. وقد أظهرت البحوث ان الديدان المعوية هي أفضل في قدرتها على تراكم العناصر المعدنية مقارنة بالديدان الطفيلية في مواقع تطفل اخرى. أيضا تم فحص العوامل التي تؤثر في تراكم المعادن في كل من الأسماك والطفيليات في الدراسات المسترجعة مثل جنس العائل وحجم مستعمرة الطفيلي داخل العائل، التغيرات الموسمية، مكان التطفل، المستوي الذى يوجد به العائل في الهرم الغذائي، عمر العائل وعمر الطفيلي . تظهر عدة فوائد لاستخدام طفيليات الأسماك كمؤشرات حيوية للتلوث بالمعادن الثقيلة ، ولكن تبرز ثلاثة فوائد: حماية صحة الأسماك كعنصر مهم في النظام البيئي ، ومراقبة مستويات التلوث في البيئة ، وحماية صحة الإنسان من خلال تحديد مدى ملاءمة الأسماك للاستهلاك البشري من حيث تراكم العناصر الثقيلة فيه. بالإضافة إلى ذلك ، يجب على الباحثين في مجال السموم البيئية الذين يستخدمون الأسماك كمؤشرات حيوية أن يضعوا في اعتبارهم أن الطفيليات تقلل من التراكم الحيوي للمعادن الثقيلة في أنسجة عوائلها.