Fish Parasites as Biological Indicators of Metals Pollution in the Aquatic Environments

Osama Mostafa (osamamostafa@hotmail.com)
Ain Shams University https://orcid.org/0000-0002-9095-1875
Tasneem Hanfi
Ain Shams University Faculty of Science
Doaa Abd-eltwab
Ain Shams University Faculty of Science
Mohammed Al-Shehri
King Khalid University College of Science
Mahmoud Moustafa
King Khalid University College of Science
Ahmed Al-Emam
King Khalid University College of Medicine
Heba Alhamdi
King Khalid University College of Science
Ahmed Nigm
Ain Shams University Faculty of Science

Research Article

Keywords: Fish Parasites, Biological Indicators, Metals Pollution, Aquatic Environments

Posted Date: May 6th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1534992/v1

Abstract

In this review the papers concerned with fish parasites that utilized as biological indicators of metals pollution in the aquatic environments and published between 2010 and 2021 were retrieved according to certain inclusion and exclusion criteria. The fish-parasite models in the retrieved publications differed widely, and only five helminthic species were considered as bioindicators with their recurrence evaluated as follows: acanthocephalan and nematodes > cestodes > trematodes > crustacea. The majority of the investigations were focused on freshwater fish. The frequency of examinations into metals bioaccumulation within the host tissues was evaluated as follows: liver and muscles > gut > kidney > gills and gonads > brain and adipose tissue. Cd was the most commonly studied metal, followed by Pb, and the remaining elements being classified as Cu > Zn > Mn > Cr& Fe > Ni > As > Al & Co > Hg, Se, Sn, Ti& V > Mg& Ba. The elements Mo, Pt, Sb, Th, U, and Sr were all tested once. In conclusion, fish parasites can be used as a biological indicator of metal pollution while also reducing metal bioaccumulation in fish tissues, as they can accumulate heavy metals in their tissues at a higher rate than fish tissues. Therefore, the parasites might act as metal biosinks or sentinels in aquatic habitats. In addition, reduced chemical absorption in animals employed in ecotoxicological studies due to parasitic infections, may confuse researchers into believing that pollution levels are minimal.

Introduction

Chemical pollution of the aquatic habitat represents a major hazard to aquatic organisms, especially fish (Saeed& Shaker, 2008) Metals enter the aquatic environment through a number of sources, including natural biogeochemical cycles and anthropogenic sources such as industrial and residential effluents, urban pollution, rainwater runoff, landfill leachate, mining, and atmospheric sources (Wittman, 1981).

In aquatic environment most contaminants tend to accumulate in organisms, in which they can reach levels hundreds or thousands times higher than the relevant water levels (Bervoets and Blust, 2003). Fish that occupied the top of the aquatic food web and have a relatively long life span, concentrate a lot of contaminants (including metals) and, therefore, they are commonly used as biological indicators (Rashed, 2001).

Since the first studies on parasites' effects on their hosts' tolerance to environmental toxins (Boyce and Yamada, 1977& Pascoe, and Cram, 1977), several studies were published on the parasitism and pollutant accumulation. Several previous investigations in freshwater habitats found that fish intestinal parasites, mainly acanthocephalans, can accumulate heavy metals at concentrations orders of magnitude higher than the tissues of their fish hosts, and so potentially provide useful information about the chemical condition of the environment. When compared to fish tissues, the bioconcentration factors obtained for almost all metals revealed that most parasites had a significant accumulation potential.

Bioindicators can be employed as accumulation or effect indicators. By observing changes in their physiology, effect indicators can provide useful information about the chemical condition of their habitats and/or behavior (and the changes in prevalence, mean intensity, or mean abundance of the parasite in the case of fish parasites that used as bioindicators).

Accumulation indicators (sentinels) should efficiently take up chemicals and reach equilibrium where their intake is balanced by their excretion. This uptake and bioconcentration of chemicals should not be accompanied by toxic consequences on the organism (Sures, 2004). The present work aims to review the published articles in the period from 2010 to 2021 that concerned with parasites of fish as biological indicators of metals pollution in the aquatic environments.

Methods

The search terms are metals pollution (OR heavy metals contamination OR environmental pollution OR environmental impact), AND fish parasites (OR marine parasites OR freshwater parasites OR parasitological indices) AND biological indicator (OR bioindicator OR biomonitoring OR pollution indicators OR accumulation indicators OR pollution monitoring OR effect indicators) were used in Google Scholar; to retrieve literature related to parasites of fish as biological indicators of metals pollution. The literature search inclusion criteria were as follows: (1) published between 2010 and 2021, (2) written in English, (3) available as full text, (5) concerned with field studies or semi-field studies and (4) classified as original articles. The literature exclusion criteria were as follows: (1) classified as thesis, letter to the editor or review article and (2) concerned with experimental investigation. The retrieved articles from database were preliminary screened, duplicate articles were excluded, the remaining articles were scanned to evaluate the relevance of the content and inclusion-exclusion criteria; and as a result, the most appropriate 25 articles were selected for analysis.

Results And Discussion

In the present review, the articles published in the last decade were retrieved and summarized in Table (1) including the following items: parasites, 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). Few studies have been conducted on the use of fish parasites as effect indicators, in which alterations in the biology of infection and community structure of parasites in relation to variations in the chemical, physical constituents and other types of pollution of aquatic environments have been investigated (Noor El Deen et al., 2011; Zagar et al., 2012 and Pretorius& Avenant-Oldewage, 2021), whereas most studies (the rest 22 articles) have been focused on the use of fish parasites as accumulative indicators.

Fish-parasite models

Along the retrieved articles, the fish-parasite models were varied greatly, since the species of fish and parasite changed from one article to another. However, there were some exceptions: the model *Pomphorhynchus laevis*× *Barbus barbus* was used twice by Nachev et al. (2010) and Nachev et al.

(2013). Each of the acanthocephalan *Acanthocephalus lucii* and the nematode *Eustrongylides* sp. were used twice as the parasite partner in the model by (Brázová et al., 2012& Jankovská et al 2012) and (Nachev et al., 2013& Keke et al., 2020), respectively. Concerned with the fish partner in the model, Nile tilapia *Oreochromis niloticus* was investigated in three articles (Shahat et al., 2011; Ugokwe and Awobode, 2015; Paller et al., 2016); *Clarias gariepinus* was assayed in four articles (Shahat et al. 2011; Keke et al.,2020; Erasmus et al., 2020& Pretorius& Avenant-Oldewage, 2021). The marine fish *Siganus rivulatus* was assayed in three papers (El-Lamie& Adel-Mawla, 2018; Al-Hasawi, 2019& Hassanine& Al-Hasawi, 2021). Both *Barbus barbus* and *Perca fluviatilis* were cited twice by (Nachev et al., 2010& Nachev et al., 2013) and (Brázová et al., 2012& Jankovská et al 2012), respectively. Also *Tilapia zillii* was investigated twice by (Noor El Deen et al., 2011& Keke et al., 2020).

This vast variation in fish-parasite models could be due to the great biodiversity within fish and parasite populations. Fish are the most varied group of vertebrate animals (Magurran et al., 2011). Nelson (2006) estimated the overall number of fish species to be 32 500. About 28 400 are considered as 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, about 30,000 helminthic species were defined as parasites of fish (Williams & Jones, 1994).

Host's Sex and Parasite infrapopulation

The infrapopulation size of the parasite and the host's sex play no role in the rate of metal accumulation; and there is no need to take these two aspects into account in "fish-parasite" metal monitoring purposes (Nachev et al. 2010). Also, Zagar et al. (2012) reported that the host's sex was not a significant factor determining the prevalence of parasites.

This was partially opposite to the results of Hassanine& Al-Hasawi (2021) which revealed that acanthocephalans' infection with *Sclerocollum rubrimaris* reduced the harmful effects of toxic metals on their fish hosts *Siganus rivulatus* and this reduction was dependent on acanthocephalans infrapopulation size in fish intestine; since the concentrations of both Cd and Pb in fish liver decrease as the size of the worm infrapopulation increases in the fish intestine. This decrease strongly supports intraspecific competition for the accessible quantities of these metals from the fish intestine among *S. rubrimaris* individuals. The authors presented three ways of minimizing harmful metals' negative impacts, the first was decreasing the raised concentrations of both Cd and Pb in fish liver; the second was lowering the elevated liver enzymes' levels (ALT, AST, ALP, and GGT), triglycerides, urea, and glucose in fish blood serum; and the third was increasing the levels of total protein and albumin in fish blood serum. A dilution effect could explain the decreased metal contents with large infrapopulation sizes, since there are more parasites available to detoxify their host tissues (Nachev and Sures 2016; Sures et al. 2017; Al-Hasawi 2019).

Fish habitat

The majority of investigations (64%) were conducted on freshwater fishes, whereas 32% were conducted on marine fishes. Freshwater farmed fishes were the subject of one article (Noor El Deen et al., 2011).

Zargar et al. (2012) made their investigations on both fresh water and saline wetland fishes. Therefore, about the third of the researches was conducted on freshwater fish and the remaining third was performed on marine fish.

The increased interest in fresh water biomonitoring research might be ascribed to the fact that pollution concentrations in inland waters are likely to be substantially greater than that in marine ecosystem (Poulin, 1992). The relationships among metals pollution, fish parasitic infection, seasonal variations and trophic level of the aquatic environment were evaluated by several authors. Noor El Deen et al. (2011) investigated the relationship among Cd pollution in water, crustacean gill parasites *Ergasilus* sp. and *Lamproglena* sp. in freshwater cultured *Tilapia zilli* fish and seasonal variations. The results declared that, during the spring, summer, and fall seasons, there was an inversely proportional association between Cd concentration pollution in aquaculture and the prevalence of gill crustacean infection, while infestation was absent during the winter season. Zagar et al. (2012) investigated the monogenean gill parasite *Diplozoon kashmirensis* of the carp fish *Carassius carassius* to assess infection levels as well as factors influencing infection such as contaminants and trophic status. The highest prevalence (34.22%) of *D. kashmirensis* was found in a lake with a high trophic level, while the lowest prevalence (10.90%) was found in a lake with a low trophic status. Infection levels were significantly higher at sites with poor water quality compared to those with good water quality. The combined effect of pollutants and eutrophication resulted in a decrease in *D. kashmirensis* intensity in one of the polluted/hypertrophic sites in the hypertrophic lake, while a synergistic effect (i.e. an increase) in intensity and prevalence was observed in one of the polluted/hypertrophied sites in the eutrophic lake. Because of their simple life cycle, ecologists are interested in monogeneans, which are regarded one of the most significant and sensitive parasites to changes in water quality (Zagar, 2012).

In their studies on digenean parasites *Haplorchoides cahirinus*, *Acanthostomum spiniceps* and *Acanthostomum absconditum* parasitized silver catfish, *Bagrus bajad*, the results of Mashaly et al. (2021), indicated that 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 in the autumn and winter in the water, gills, and intestine, and in the winter and spring in the intestinal digenean parasites.

At six sites along the Vaal River in South Africa, Pretorius& Avenant-Oldewage (2021) investigated changes in the infection parameters of the crustacean gill parasite *Lamproglena clariae* in relation to variable water quality impacted by metal pollution Cu, Cr, Zn, and Cd concentrations in water. They were found negative associations between the intensity and prevalence of *L. clariae* and Cu, Cr, Zn, Cd concentrations in water. Sites with high metal concentrations in sediment and water, as well as high levels of organic pollutants, had a negative impact on parasite infections. More polluted sites had lower mean intensity and mean abundance of *L. clariae*, showing that pollution has an impact on this ectoparasite's survival.

Parasite taxa

Only five helminthic taxa were included as bioindicators in this review, and their recurrence was graded as: acanthocephalan& nematodes > cestodes > trematodes > crustacea. Parasitic protozoa have never been employed as effect or accumulative indicators in the present retrieved articles. Only metazoic parasites have been studied in terms of metal accumulating capability among other fish parasites. Protozoan parasites appear to be far too tiny to allow for a reliable chemical study. Monogeneans, crustaceans, and leeches are ectoparasites that are mostly impacted by the surrounding water, and their accumulation patterns are most likely comparable to those of related free-living species such as turbellaria, non-parasitic crustaceans, and annelids. The vast majority of articles on metal accumulation in parasites deal with metal concentrations in endohelminths due to these restrictions (Bergey et al. 2002).

Elements were mostly detected in significantly higher levels in the parasites compared to host tissues. The elements accumulation among parasites was found to be highly dependent on parasite taxa, developmental stage and site of parasitism within the host. The higher concentration of heavy metals in parasites than their hosts could be due to their inability to synthesize certain organic compounds, including organo-metallic compounds that have heavy metals in their structure. This has been shown for acanthocephalans (Sures, 2001) and several investigations have suggested that this is also true for other parasites.

It was found that acanthocephalan parasites impede re-absorption and absorb organometallic or bile compounds more efficiently through their tegument than the fish host's intestinal wall (Sures and Siddal, 1999& Sures, 2002). Paller et al. (2016) determined the Pb concentration in of acanthocephalans *Acanthogyrus* sp., their host *Oreochromis niloticus* and the ambient waters. The levels of Pb were significantly higher in the acanthocephalan parasites relative to the fish host tissues and 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 muscles of the fish, respectively; indicating that the acanthocephalan parasites might act as metal biosinks in aquatic habitats.

El-lamie& Abel-Mawla (2018) isolated the acanthocephalan *Neohydinorhynchus macrospinosus* from *Siganus revulatus* fishes and the two acanthocephalans *Echinorhynchus* sp. and *Serrasentis sagittifer* from *M. flavolineatus* fishes for determination the heavy metal concentration in both fishes and parasites. Their results showed that the heavy metal concentration in infected fish organs was lower than in non-infested fish organs. The acanthocephalan could be considered as a bioindicators for heavy metals pollution besides being a competitor to fish organs for heavy metals accumulation.

Acanthocephalan accumulated metals in higher concentrations compared to other helminthic parasites; 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 another investigation, it was reported that intestinal acanthocephalans bioconcentrated mainly toxic elements As, Cd and Pb whereas the intraperitoneal nematodes accumulated essential elements Co, Cu, Fe, Se and Zn; since 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 could be due to their biological and morphological properties. The larva migrates through the intestinal wall into the body cavity, where it begins feeding on blood and tissues before becoming encapsulated. The fourth larval stage have a well-developed digestive system (Moravec, 1994), which suggests that they can accumulate metals through 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 and Szefer et al., 1998). Therefore, the fourth stage larval nematodes exhibit an even better accumulation capacity than adult worms because of 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 and Sures et al., 1995). Furthermore, Nachev et al. (2013) offered a satisfactory explanation of why larval nematodes accumulate essential elements and adult acanthocephalans and adult nematodes accumulate toxic elements. These differences could be due to competition between *P. laevis*, an acanthocephalan parasitized 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 different element uptake routes between developmental stages of parasitized worms. Because nematode larvae feed actively to grow quickly during development, they depend on essential elements absorption via two routes of uptake processes, then the larvae encapsulated and become unable to feed, whereas adult worms actively feed on host tissues and thus take up and concentrate toxic metals like Cd and Pb. Because acanthocephalans living in the intestine compete for nutrients and metals with the host tissues, the acanthocephalan *P. laevis* has a high concentration of toxic elements (Sures, 2002). Acanthocephalans actively take up metals bound in bile complexes that discharged in the small intestine, making them unavailable for reabsorption by the host gut.

Mazhar et al. (2014) investigated the concentration of Cd, Cu, Cr, Hg, Sr, Mn, Se, Pb, Ni, Al, As, Fe, and Zn in notched threadfin bream, *Nemipterus peronii*, and in its two nematode parasites *Hysterothalycium reliquens* and *Paraphilometroides nemipteri*. The results declared that *H. reliquens* showed highest accumulation potential for Cu, Cr, Fe, Mn, Se, Ni, and Zn while the *P. nemipteri* had high accumulation capacity of As, Hg, Cd, Al, Pb, and Sr. Therefore, within the same parasitic taxa, there was interspecific variation in metals accumulation which could be due to cuticle morphology, microhabitats specificity and interspecific competition (Mazhar et al., 2014). 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 of the thirteen examined elements were found in L3 nematode larvae at least 2-fold greater quantities (e.g. Ni) and up to 50-fold higher concentrations (e.g. Pb), only Mg found in in higher concentration in the tissues of the host than in the parasite. Morsy et al. (2012) assessed the anisakid larvae nematode for the first time in European seabass, *Dicentrarchus labrax* collected from 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 gill, liver and muscles of fish. Only the concentrations of Fe, Cd, Mn, and Ni in the anisakid larvae appeared greater than those in the host tissues. However, some studies have been shown that the nematodes were ineffective concentrators of heavy metals; according to Morris et al. (2016), the gonad of a shark *Rhinobatos annulatus* infected with the nematode parasite *Proleptus obtusus* had the greatest concentration of metals of all the tissues investigated. The intestine, muscle, liver, kidney, and lastly the host's parasite, *P. obtuse*, follow the gonad. The largest concentration of metals was found in the intestine of a shark *R. blochii* infected with the same nematode parasite, followed by the gonad, kidney, parasite, muscle, and lastly the liver.

Cestodes were used as indicator of heavy metal pollution by Nhi et al. (2013) since they assessed the concentrations of Mn, Zn, Cu, Cd and Pb in muscle, liver, intestine and kidney of *Channa micropeltes* (snakehead fish) parasitized by the cestode *Senga parva*. In addation, the same metals were measured in the lake water and sediments. As expected, the results indicated that the parasite concentrated some heavy metals to a greater extent than the water and some fish tissues, but less than the sediment.Only Cu and Cd appeared higher in the host liver than the cestode parasite.

Cestode parasites have a significantly higher accumulating capability than trematodes, nematodes, and fish organs; Hassan et al. (2018) determined the role of intestinal helminthes in bioremediating the accumulation of some heavy metals in the muscle tissues of *Lethrinu smahsena* (emperor fish). Concerned with parasite taxa, all measured metals were accumulated in cestodes in higher concentration than nematodes and trematodes. Leite et al. (2019) reported that the cestode parasites *Proteocephalus macrophallus* presented a reasonable capacity of metal accumulation comparing 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. According to Erasmus et al. (2020), *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*.

When using cestodes for biomonitoring research, an important factor must be taken into account. The body of adult tapeworms differentiated into the anterior region of the body (scolex, neck, immature and mature proglottids without eggs) and the posterior region (gravid or pregnant proglottids). The posterior part is older than anterior one and, consequently, the exposure time to metals would be higher and as results the concentration of heavy metals would be higher than the anterior part (Sures et al. 1997).

By comparing metal accumulations in different helminthic taxa utilized in retrieved articles in the present review, a higher metal accumulation capacity is described for gutless helminthes acanthocephalans and cestodes which absorbs the nourishment through their tegument and nematode larvae which take up their nutrients through two routes, their digestive system and tegument. Gutless helminthes are more appropriate sentinels for trace metal pollution or act as biosinks than other helminthes, trematodes and adult nematodes which have a gastro-intestinal tract. This conclusion is completely consistent with earlier studies (Sures, 2004, Nachev et al., 2013 and Sures et al., 2017). In addition, intestinal parasites such as acanthocephalans and cestodes, according to Sures et al. (1999) are unable to produce their own cholesterol and fatty acids, they have obligated to take them from the intestine. Metallothioneins (organometallic complexes) in the host bile passed down the biliary duct into the small intestine, and then they are taken up by acanthocephalans and cestodes. This does explain why the gutless parasites are excellent biosinks.

Interactions between parasites at the same infection site appear to have a significant impact on these organisms' accumulation capacity. In mixed infections, for example, the competition between species for resources is stronger, which increases the potential of these parasites to take metals (Leite et al., 2019). Brázová et al. (2015) investigated parasite-host associations in the determination of metals in parasitized perch by *P. percae* and *Acanthocephalus lucii*, and found that hosts parasitized by both species had statistically greater bioconcentration factors than hosts parasitized by only one of them.

Host tissues examined and Elements investigated

For metals bioaccumulation within the host tissues, the liver and muscles were the most frequently investigated tissues (72%). Liver and muscles were followed by intestine which was assayed in 12 retrieved articles (48%). Kidney, gills and gonads were examined in 20, 16 and 16% of the retrieved articles, respectively. Adipose tissue and brain were analyzed once by Brázová et al. (2012). In the articles of Oyoo-Okoth et al. (2010), Noor El Deen et al. (2011) and Pretorius& Avenant-Oldewage (2021) no elements were measured in host's tissues.

The overall number of elements investigated in the retrieved articles was 24. Concerned with the number of element measured per each article, the maximum number of elements investigated was 17 (Morris et al., 2016) and the minimum number was one element Cd or Pb (Noor El Deen et al., 2011& Paller et al.,2016); accidentally the both elements were measured in three articles (Khaleghzadeh-Ahangar et al., 2011, Al-Hasawi, 2019& Hassanine& Al-Hasawi, 2021). The most common metal investigated in the retrieved articles was Cd (22 articles), followed by Pb which was assayed in 21 articles. The elements Cu, Zn, Mn, Cr, Fe, Ni, As, Al and Co were investigated in 18, 17, 12, 10, 10, 9, 8, 4, and 4 papers, respectively. Hg, Se, Sn, Ti and V were measured in 3 articles. Mg& Ba were investigated in only 2 papers. The following elements were assayed once: Mo (Nachev et al., 2010), Pt (Erasmus et al., 2020), Sb, Th, U (Morris et al., 2016) and Sr (Mazhar et al., 2014).

The 24 metallic elements investigated in the retrieved articles of the current review were classified into four categories, according to Liu et al. (2013): 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& V), and metals related to medical therapy (Al& Pt). For metals bioaccumulation within the host tissues, frequency of investigation in the present review was graded as liver and muscles > intestine > kidney > gills and gonads > brain and adipose tissue.

The liver and muscles were the most frequently investigated tissues, since the liver serves as heavy metals storage site for heavy metals, and it also plays a part in detoxication and elimination of numerous dangerous compounds from the body (Coyle et al., 2002 and Langston et al., 2002), and muscles (fish meat) serves 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 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 at al .,2020) but few metals were shown to have a particular affinity for muscular tissues like 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 accumulated Pb, Cd, Cu, Mn, Zn, As, Hg, Mg and Fe in higher concentration than other fish tissues (Khaleghzadeh-Ahangar et al., 2011, Jankovská et al 20122012, Morsy et al., 2012, Nhi et al., 2013, Mazhar et al., 2014, Paller et al .,2016 and Leite et al., 2017).

Largest 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 lastly the liver (Morris et al., 2016). All elements examined (Al, As, Ba, Cd, Cr, Fe, Hg, Mg, Mn, Ni, Pb, Ti, Zn) were detected in higher concentrations in the liver than in the gut and muscles (Leite et al., 2019). Morris et al. (2016) explain why the intestine accumulates a higher level of metals than other organs in some investigations and referred that to organometallic complexes or metallothioneins which were passed down the biliary duct into the intestine of the host.

In comparable with Muscle, Liver, brain, gonads and adipose tissue, the kidney was a key target organ receiving the highest mean concentrations of all metals analyzed As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn (Brázová et al., 2012). Kidney accumulated Pb and Se higher than liver and muscles (Mazhar et al., 2014). The kidney was shown to be the important organ in the fish that received 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).

Khaleghzadeh-Ahangar et al. (2011) and Brázová et al. (2012) assayed the metals concentration in the gonads and reported that organ has the capability to accumulate metals in high concentration. Jankovská et al (2012) reported that the gonads showed the lowest Mn concentrations and 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 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 were unable to regulate concentrations of metal in the same way (Dallinger et al., 1987).

Gills were found to bioaccumulate larger concentration of Ni and Mn than other tissues measured, moreover the Pb and Zn were found in liver and gills in higher concentration than the parasite (Morsy et al., 2012). Heavy metals were higher in the gills than intestine except for Fe that 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 to confirm the accumulating power of helminthic endoparasites, implying 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 metals concentration 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. According to Sures and Sidall (1999), this remarkable phenomenon could potentially create issues in defining the terms parasite and parasitism.

Other environmental elements studied

Metal concentrations in water and sediments were assessed in six of the twenty-five publications reviewed (Oyoo-Okoth et al., 2010, Brázová et al., 2012, Nhi et al., 2013, Ugokwe and Awobode, 2015, Al-Hasawi, 2019, Pretorius& Avenant-Oldewage, 2021). The concentrations of metal in the water alone were examined also in eight articles (Khaleghzadeh-Ahangar et al., 2011, Noor El Deen et al., 2011, Shahat et al., 2011, Paller et al.,2016, El-Lamie and Adel-Mawla, 2018, Keke et al., 2020, Hassanine & Al-Hasawi, 2021 and Mashaly et al., 2021). Sediment alone was not investigated in any of the retrieved articles. Zargar et al. (2012) analyzed the physico-chemical characteristics of water, no metal concentration were assayed.

When heavy metal accumulation in sediments and water were compared, it was observed that heavy metals accumulated more in sediments than in 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 settle and accumulate in the bottom (Ugokwe and Awobade, 2015, Nhi et al., 2013& 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; the rest is deposited in sediments (Salomons and Stigliani, 1995).

Region/Country

In the Middle East, Egypt had the most researchers investigating the issue, with 7 papers out of 25 analyzed (Noor El Deen et al., 2011, Shahat et al., 2011, Morsy et al., 2012, El-Lamie and Adel-Mawla, 2018& Al-Hasawi, 2019); one study was recorded from both Iran and Saudi Arabia (Khaleghzadeh-Ahangar et al., 2011& Hassan et al., 2018). For the rest of African countries three studies were conducted in South Africa (Morris et al., 2016, Erasmus et al., 2020& Pretorius& Avenant-Oldewage, 2021), two were done in Nigeria (Ugokwe and Awobode, 2015& Keke et al .,2020) and one was achieved in Kenya (Oyoo-

Okoth et al., 2010). Concerned with Far East countries, only one study was recorded in each of the following countries: Malaysia (Nhi et al., 2013), China (Mazhar et al., 2014) & Philippine (Paller et al., 2016). In regard of European nations, two studies were performed in Bulgaria (Nachev et al., 2010& Nachev et al., 2013), one was conducted in each of Slovakia (Brázová et al., 2012) and Czech (Jankovská et al., 2012). In South America, two studies were achieved in Brazil (Leite et al., 2017& 2019). Only one article was realized in India (Zargar et al., 2012). It has been noted that no study on the use of fish parasites as bioindicators has been reported in a number of countries in the last decade, which might be owing to their reliance on alternative methods or models to assess pollution in their environment.

Conclusions

Fish parasites could be used as a biological indicator of heavy metal pollution while simultaneously reducing heavy metal bioaccumulation in fish tissues, as they are able to attain heavy metals in their tissues at a higher rate than fish tissues. Therefore, the parasites might act as metal biosinks or sentinels in aquatic habitats. In addition, parasite-induced changes in metal absorption and accumulation in organisms are a relatively new and important area of ecotoxicological investigation. Following the discovery of reduced metal absorption in infected fish compared to uninfected fish, an increasing number of publications have been published revealing changes in chemical uptake in final and intermediate hosts related to parasitism. Reduced chemical absorption in animals employed in ecotoxicological studies, such as accumulation indicators, may confuse researchers into believing that pollution levels are minimal. As a result, biomonitoring programmers should include the impact of parasite infections on pollutant levels in sentinels. As a result, helminthic infections in fish could be used as a biological indicator of heavy metal pollution while also reducing heavy metal concentration in the tissues of fish.

Declarations

Acknowledgements

Authors thank the Deanship of Scientific Research, King Khalid University, Saudi Arabia for funding this work.

Author’s contribution

All authors contributed to the study conception and design. Methodology, validation, formal analysis, investigation, resources, writing original draft, writing review and editing were performed by **Osama Mostafa, Tasneem Hanfi, Doaa Abd-eltwab and Ahmed Nigm**. Project administration, methodology, validation, investigation, resources, writing review and editing were performed by **Mohammed Al-Shehri, Mahmoud Moustafa, Ahmed Al-Emam, Heba Alhamdi.** All authors read and approved the final manuscript.

Funding

The current research was funded by the Deanship of Scientific Research, King Khalid University, Saudi Arabia under grant no. (R.G.P. 1/145/42).

Data availability

Not applicable.

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Competing interests: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Al-Hasawi ZM (2019) Environmental Parasitology: intestinal helminth parasitesof the siganid fish *Siganus rivulatus* as bioindicators for trace metal pollution in the Red Sea. Parasite 26:12
2. Barbier O, Jacquillet G, Tauc M, Cougnon M, Poujeol P (2005) Effect of heavy metals on, and handling by, the kidney. Nephron Physiol 99:105–110
3. Bergey L, Weis JS, Weis P (2002) Mercury uptake by the estuarine species *Palaemonetes pugio* and *Fundulus heteroclitus* compared with their parasites, *Probopyrus pandalicola* and *Eustrongylides* sp. Mar Pollut Bull 44:1046–1050
4. Bervoets L, Blust R (2003) Metal concentrations in water, sediment and gudgeon (*Gobio gobio*) from a pollution gradient: relationship with fish condition factor. Environ Pollut 126:9–19
5. Bird AF, Bird J (1991) The Structure of Nematodes. 2nd edition. New York: Academic
6. Boyce NP, Yamada SB (1977) Effects of a parasite, *Eubothrium salvelini* (Cestoda: Pseudophyllidea), on the resistance of juvenile sockeye salmon *Oncorhynchus nerka* to zinc. J Fish Res Board Can 34:706–709
7. Brázová T, Torres J, Eira C, Hanzelová V, Miklisová D, Šalamún P (2012) Perch and its parasites as heavy metal biomonitors in a freshwater environment: the case study of the Ružín water reservoir. Slovakia Sens 12:3068–3081
8. Brown AP, Pascoe D (1989) Parasitism and host sensitivity to cadmium: an acanthocephalan infection of the freshwater amphipod *Gammarus pulex*. J Appl Ecol 26:473–487
9. Coyle P, Philcox JC, Carey LC, Rofe AM (2002) Metallothionein: the multipurpose protein. Cell Mol Life Sci 59:627–647
10. Dallinger R, Prosi F, Segner H, Back H (1987) Contaminated food and uptake of heavy metals by fish: a review and a proposal for further research. Oecologia 73:91–98
11. El-lamie MM, Abdel-Mawla HI (2018) Investigation of Acanthocephalan parasites in some marine fishes as a bio-indicator for heavy metals pollution. Egyt J Aquac 8:13–30

12. Erasmus JH, Wepener V, Nachev M, Zimmermann S, Malherbe W, Sures B, Smit NJ (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. Parasitol Res 119:2783–2798
13. Hassan A, Moharram S, El-Helaly H (2018) Role of Parasitic helminths in bioremediating some heavy metal accumulation in the tissues of *Lethrinus mahsena*. Turk J Fish Aquat Sci 18:435–443
14. Hassanine R, Al-Hasawi Z (2021) Acanthocephalan worms mitigate the harmful impacts of heavy metal pollution on their fish hosts. Fishes 6:49
15. Hellawell JM (1986) Biological Indicators of Freshwater Pollution and Environmental Control. Elsevier Applied Science Publishers Ltd., London
16. Jankovská I, Miholová D, Lukešová D, Kalous L, Válek P, Romočuský Å, Vadlejch J, Petrtýl M, Langrová I, 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). Environ Res 112:83–85
17. Keke UN, Mgbemena AS, Arimoro FO, Omalu IC (2020) Biomonitoring of effects and accumulations of heavy metals insults using some helminth parasites of fish as bio-indicators in an Afrotropical stream. Frontb Environb Sci 8:155
18. Khaleghzadeh-Ahangar H, Malek M, 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 138:1400–1405
19. Langston WJ, Chesman BS, Burt GR, Pope ND, McEvoy J (2002) Metallothionein in liver of eels *Anguilla anguilla* from the Thames Estuary: an indicator of environmental quality? Mar Environ Res 53:263–293
20. Leite LA, Januário FF, Padilha PM, do Livramento ET, de Azevedo RK, Abdallah VD (2019) Heavy Metal Accumulation in the Intestinal Tapeworm *Proteocephalus macrophallus* Infecting the Butterfly Peacock Bass (*Cichla ocellaris*), from Southeastern Brazil. Bull Environ Contam Toxicol 103:670–675
21. Leite LAR, Pedro NHO, de Azevedo, Kinoshita RK, Gennari ARF, Watanabe S, Abdallah VD (2017) *Contracaecum* sp. parasitizing *Acestrorhynchus lacustris* as a bioindicator for metal pollution in the Batalha River, southeast Brazil. Sci Total Environ 575:836–840
22. Liu J, Goyer RA, Waalkes MP (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
23. Magurran AE, Khachonpisitsak S, Ahmad AB (2011) Biological diversity of fish communities: pattern and process. J Fish Biol 79:1393–1412
24. Mashaly MI, El-Naggar AM, El-Tantawy SA, Al-Gaafari SA (2021) Accumulation of nine heavy metals in water and gills, intestine and digenean parasites of the silver catfish, *Bagrus bajad* Forska°l 1775. J Parasit Dis 45:490–501
25. Mazhar R, Shazili NA, Harrison FS (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). Parasitol Res 113:3737–3743

26. Moravec F (1994) Parasitic nematodes of freshwater Fishes of Europe. Kluwer Academic Publishers, Dordrecht
27. Morris T, Avenant-Oldewage A, Lamberth S, Reed C (2016) Shark parasites as bio-indicators of metals in two South African embayments. Mar Pollut Bull 104:221–228
28. Morsy K, Bashtar A-R, Abdel-Ghaffar F, Mehlhorn H, Al Quraishy S, El-Mahdi M, Al-Ghamdi A, 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. Parasitol Res 110:1131–1138
29. Nachev M, Schertzinger G, 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*). Parasit Vectors 6:1–18
30. Nachev M, Zimmermann S, Rigaud T, Sures B (2010) Is metal accumulation in *Pomphorhynchus laevis* dependent on parasite sex or infrapopulation size? Parasitology 137:1239–1248
31. Nelson JS (1999) Editorial and introduction: the species concept in fish biology. Rev Fish Biol Fish 9:277–280
32. Nelson JS (2006) Fishes of the World, 4th edn. Wiley, New York, NY
33. Nhi TTY, Shazili NAM, Shaharom-Harrison F (2013) Use of cestodes as indicator of heavy-metal pollution. Exp Parasitol 133:75–79
34. Deen NE, Shalaby AIE, Zaki SIA MS (2011) Field study on cadmium pollution in water and crustacean gill parasites in freshwater cultured *Tilapia zilli* fish. Life Sci J 8:599–605
35. Oyoo-Okoth E, Wim A, Osano O, Kraak MHS, Ngure V, Makwali J, Orina PS (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 Reserv 15:3–73
36. Paller VGV, Resurreccion DJB, de la Cruz CPP, Bandal MZ Jr (2016) Acanthocephalan Parasites (*Acanthogyrus* sp.) of Nile Tilapia (*Oreochromis niloticus*) as Biosink of Lead (Pb) Contamination in a Philippine Freshwater Lake. Bull Environ Contam Toxicol 96:810–815
37. Pascoe D, Cram P (1977) The effect of parasitism on the toxicity of cadmium to the three-spined stickleback, *Gasterosteus aculeatus* L. J Fish Biol 10:467–472
38. Poulin R (1992) Toxic pollution and parasitism in freshwater fish. Parasitol Today 8:58–61
39. Pretorius M, Avenant–Oldewage A (2021) Parasites as biological indicators: the impact of environmental quality on the infections of *Lamproglena clariae* (Crustacea) on *Clarias gariepinus* along the Vaal River, South Africa. Biol Trace Elem Res 1:11
40. Rashed MN (2001) Cadmium and lead levels in fish (*Tilapia nilotica*) tissues as biological indicator for lake water pollution. Environ Monit Assess 68:75–89

41. Saeed SM, Shaker IM (2008) 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. Limnology Department
42. Salomons W, Stigliani W (1995) Biogeodynamics of Pollutants in Soils and Sediments. Springer-Verlag, Heidelberg, p 352
43. Shahat MA, Amer OSO, AbdAllah AT, Abdelsater N, Moustafa MA (2011) The distribution of certain heavy metals between intestinal parasites and their fish hosts in the River Nile at Assuit Province, Egypt. Egypt J Hosp Med 43:241–257
44. Sures B, Nachev M, Selbach C, David J, Marcogliese DJ (2017) Parasite responses to pollution: What we know and where we go in 'Environmental Parasitology'. Parasit Vectors 10:1–19
45. Sures B, Taraschewski H, Jackwerth E (1994) Lead accumulation in *Pomphorhynchus laevis* and its host. J Parasitol 80:355–357
46. Sures B, Taraschewski H (1995) Cadmium concentrations of two adult acanthocephalans (*Pomphorhinchus leavis*, *Acanthocephalus lucii*) compared to their fish host and cadmium and lead levels in the larvae of *A. lucii* compared to their crustacean host. Parasitol Res 81:494–497
47. Sures B (2004) Environmental parasitology: Relevancy of parasites in monitoring environmental pollution. Trends Parasitol 20:170–177
48. Sures B (2001) The use of fish parasites as bioindicators of heavy metals in aquatic ecosystems: a review. Aquat Ecol 35:245–255
49. Sures B (2003) Accumulation of heavy metals by intestinal helminths in fish: an overview and perspective. Parasitology 126:S53–S60
50. Sures B (2004) Environmental parasitology: relevancy of parasites in monitoring environmental pollution. Trends Parasitol 20:170–177
51. Sures B, Siddall R (1999) *Pomphorhynchus laevis*: the intestinal acanthocephalan as a lead sink for its fish host, chub (*Leuciscus cephalus*). Exp Parasitol 93:66–72
52. Sures B, Siddall R, Taraschewski H (1999) Parasites as accumulation indicators of heavy metal pollution. Parasitol Today 15:16–21
53. Sures B, Taraschewski H, Siddall R (1997) Heavy metal concentrations in adult acanthocephalans and cestodes compared to their fish hosts and to established free-living bioindicators. Parasitologia 39:213–218
54. Szefer P, Rokicki J, Frelek K, Skora K, Malinga M (1998) Bioaccumulation of selected trace elements in lung nematodes, *Pseudalius inflexus*, of harbor porpoise (*Phocoena phocoena*) in a Polish zone of Baltic Sea. Sci Total Environ 220:19–24
55. Ugokwe CU, Awobode HO (2015) Heavy Metals in organs and endoparasites of *Oreochromis niloticus*, Sediment and Water from River Ogun, Ogun State, Nigeria. IOSR J Environ Sci Toxicol Food Technol 9:101–109

56. Williams H, Jones A (1994) Fish worms and man. Parasitic worms of fish, 1st edn. Taylor and Francis, London, United Kingdom, pp 371–443
57. Zagar UR, Chishtia MZ, Yousufa AR, Fayazb A (2012) Infection level of monogenean gill parasite, *Diplozoon kashmirensis* (Monogenea, Polyopisthocotylea) in the Crucian Carp, *Carassius carassius* from lake ecosystems of an altered water quality: What factors do have an impact on the Diplozoon infection? Vet Parasitol 189:218– 226

Tables

Table 1 is available in the Supplementary Files section.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx