Review Article

Role of Parasites as indicators of Environmental Pollution: A Review

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Abstract

Parasites interact with environmental pollution in different ways. Therefore, they can provide valuable information not only about the chemical conditions of their host, but also provide insights into the biological availability of allochthonous substances in the environment. Thus, they can be used as effective monitoring tools in environmental impact studies. Parasites can be used as effect indicators as accumulation indicators because of the variety of ways in which they respond to anthropogenic pollution. Among endoparasites, acanthocephalans and cestodes have been studied for their pollutant bioaccumulation property. But, the recent data has shown other parasites like nematodes, crustaceans, leeches, etc. exhibit an excellent metal accumulation capacity. Apart from measuring and indicating anthropogenic ecosystem disturbances, such as pollution and degradation, parasites can help to monitor and assess the redevelopment and restoration of ecological habitats. Thus, the review highlights the importance of parasites as indicators from the organism level to the ecosystem level.

Keywords: Parasites, Environment, Pollution, Indicators

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Introduction

The role of parasites in ecosystems being multiple are often neglected by scientists [1-3]. The sporadic attempts at understanding the synergistic or antagonistic interactions between parasites and pollutants have in general been ignored by the scientific community for decades [4, 5]. Pollution has typically been viewed as an added stress to hosts leading to an increased vulnerability to parasitic diseases [6, 7] or affecting parasites' biodiversity [8] but the parasites have been ignored in evaluating the effects of environmental pollutants on organisms. With the passing of time, the complexity of the relationship between parasitism and pollution has begun to unravel, showing the importance of parasites in evaluating the environmental stressors [9-11]. Parasites may also affect the host’s response to pollutants by influencing their hosts physiology and tolerance of stressed conditions [12-16]. Recently, parasites have been utilized in evaluating environmental pollution i.e. their ability to concentrate inorganic elements (heavy metals in particular) at much higher levels than free-living organisms [17, 18].

Parasites interact with environmental pollution in different ways. They can interfere with established bio indication procedures which could lead to both false-negative and false positive indications of pollution. Also, parasites can be used as effect indicators as well as accumulation indicators because of the different ways by which they respond to anthropogenic pollution. If host defence mechanisms are negatively affected, then pollution can increase parasitism simply by increasing the population densities of suitable intermediate or final hosts [9]. Besides this, pollution can also decrease parasitism either when the infected hosts suffer more from environmental exposure as parasites are more susceptible to the particular pollutant than their host or pollution causes the intermediate and final hosts to become extinct. Effects of the pollution have been found to vary between parasite species and between developmental stages. However, if parasites are to be considered as indicators for environmental quality, then they have fall in the categories that are commonly accepted by ecologists and ecotoxicologists [19].

Helminths as Bioaccumulators of heavy metals

Pioneering studies on the presence of heavy metals in parasites occurred as early as the late 19th century as well as in the mid-late 20th century [20, 21]. E.g. Greichus and Greichus [22] worked on an ascarid, Pascoe and Mattey [23] studied heavy metal effects on a metacestode and Riggs et al [24] examined an adult cestode. The first models studied by these workers were aquatic and involved freshwater fish infected by adult acanthocephalans (*Paratenuis ambiguus*, *Acanthocephalus lucii* and *Pomphorhynchus laevis*), larval *A. lucii*, and adult nematodes, *Anguillicolla (Anguillicoloides) crassus*. Among these parasites, adult acanthocephalans were found to accumulate high levels of lead (Pb) and cadmium (Cd) compared to their hosts' tissues.

The capability to bioaccumulate various metals has been tested in acanthocephalans [25, 26]; nematodes [27, 28], cestodes [29a, 30-32]. Host's tissues and organs typically tested are usually muscle, liver, intestine and may also include the gills and gonads of fish and the kidneys in mammals. Among the parasites, cestodes and acanthocephalans are much more efficient accumulators than digeneans and nematodes, but monogeneans have not been tested. Helminths of terrestrial mammals are not as effective heavy metal accumulators as those recorded from fishes and birds [30]. Various factors affect the ability of the parasites to accumulate metals like the nature of the metal, the host's age and motility [32], the parasite's age, developmental stage [33, 34], sex [32], organs of the parasites examined [35, 18] and the location of the parasites in the host [36, 37]. Significant interspecific [38, 39] and intraspecific [27] variations have also been found to occur. In nutshell *in vivo* adult acanthocephalans (but not cystacanths), adult digeneans, (but not metacercariae), and both adult cestodes and their plerocercoids, are known to accumulate some heavy metals. Nematodes show most variation in their ability to bioaccumulate heavy metals and adult philometrids [32, 40] larvae and adults of *Anisakis* [41] are only ones reported to be efficient accumulators whereas other species display no concentration or only little concentration of certain metals and not others [27, 30, 42]. Adult acanthocephalans have been found to accumulate Pb, Cd, chromium (Cr), silver (Ag), nickel (Ni), and copper (Cu) [43, 33] and Cd levels were found as high as 400 fold over control levels and Pb levels as high as 2,700 fold higher than hosts' tissues [43]. The capacity to retain extremely high concentrations of Cd and Pb make acanthocephalans better bio indicators than zebra mussel, *Dreissena polymorpha* which is commonly used in monitoring water contamination [44].

Acanthocephalans as Bio accumulators

Though uptake process and accumulation of metals in the worms still remains unexplained, but acanthocephalans appear to be tolerant of high concentrations of heavy metals. This could be due to the fact that acanthocephalans might have devised an entirely novel mechanism to acquire heavy metals from their surroundings. The recent works suggest that the uptake may be occurring via mechanisms similar to those described for divalent cation transport in other organisms and this uptake could be due to the lack of discrimination between Ca^{2+} ions and heavy metal ions by the parasite [18]. Activated cystacanths exposed *in vitro* to Pb have shown the potential role of bile salts in enhancing heavy metal uptake [17], but the hypothesis was challenged by the fact that cadmium-exposed rats infected by acanthocephalans had no decrease in the amount of Cd in their tissues [26]. Thus, the authors proposed that different metals may have different uptake mechanisms. The acanthocephalans' tolerance to heavy metals indicates that they may detoxify heavy metals [45, 46] and it has been suggested that metals are stored as intracellular granules [45]. But, in acanthocephalans, that metals may be stored as 'amorphous material' in the worm' tissues which supports the idea of Tarachewski [18].

Parasites as Bioindicators

Bio indicators can be used either as effect indicators or as accumulation indicators in which effect indicators can provide valuable information about the chemical state of their environment by changes in their physiology and/or behaviour. For example, if mussels change their shell-opening frequency, these alterations can indicate the presence of toxins within the water [47] and this behaviour can be monitored online using the commercially available *Dreissena polymorpha* or *Mytilus edulis* as indicator species for monitoring contamination in freshwater or marine habitats, respectively.

Accumulation indicators on the other hand should efficiently take up substances and then reach at equilibrium when the uptake of the respective substance is balanced by its excretion. Toxic effects should not accompany this uptake and bio concentration of substances on the organism. Parasites interfere with bio indication applications by modifying biomarker responses of their hosts; and parasites themselves being useful as effect or accumulation indicators.

Parasites and Biomarkers

Parasites may also affect the physiological homeostasis of their hosts. In recent exposure studies using pentachlorophenol, several physiological reactions such as the heat output or mean survival times in the freshwater clam *Pisidium amnicum* infected with larvae of *Bunodera luciopercae* was lower than in uninfected clams. The first report of parasitic effects on the resistance of their hosts to environmental chemicals were published as early as 1977 [48] in which juvenile *Oncorhynchus nerka* infected with the cestode *Eubothrium salvelini* was found to be more susceptible to waterborne Zn than uninfected species. Similarly, a shorter median period of survival was reported for sticklebacks infected with plerocercoids of the cestode, *Schistocephalus solidus* compared with uninfected fish. The reason could be that the fish under the stress of their parasite load are weakened and become more susceptible to other environmental stress including poisons. The adverse effects of parasites on the host health are often masked by acute toxic effects of pollutants, especially at higher concentrations. E.g. exposure of the amphipod *Gammarus pulex* at Cd concentrations of 0.01-1.0 mg L^{-1} resulted in median lethal concentrations that were not significantly different between uninfected crustaceans and amphipods parasitized by the acanthocephalan *Pomphorhynchus laevis*. Parasitism has thus become more important in determining toxic effects within infected populations during low-level discharges of pollutants than during high-concentration pollution.

More-recent studies have focused on parasite-induced stress in relation to environmental pollution on physiological basis. This stress, measured as an increased stress hormone concentration, is often the first step in physiological reactions such as a depressed immune response or other fundamental physiological reactions [49, 50].

Effect Indication with Parasites

Effect indication with parasites seems to focus on the individual organisms, populations and communities. With regard to individual organisms, effect indication might be possible using the direct toxic substance on free-living parasitic stages [51]. A large number of parasites have free-living larval stages, but most of the toxicological studies have been conducted on miracidia and cercariae of trematodes. During these studies, known number of larval stages was subjected to treatment with chemicals, and the subsequent longevity, viability and infectivity of these stages were analysed. Environmental pollutants such as metals in high concentrations typically reduce the survival of the test organisms owing to the binding of toxicants ultimately leading to deactivation of a variety of enzymes. When cercarial test systems were compared with conventional effect indication procedures, such as the automatic mussel monitor, it appeared to be less promising. With respect to environmental pollution, changes of parasite populations and communities have also been frequently analysed. Although large numbers of reports say that changes in parasite communities could be used as a measure of environmental change, but still only a few parasite-ollution combinations are present that show predictable changes for linking levels of environmental pollution with parasitism [52].

Parasites as Accumulation Indicators

Certain organisms are able to provide information about the chemical state of their environment through their presence or absence, while as others concentrate environmental pollutants inside their tissues even if they are less affected by toxic substances [19]. Several studies have focused on the use of parasites as accumulation indicators of heavy metals, including hydrophilic and lipophilic substances. Lipophilic chemicals tend to accumulate in fat and therefore become biomagnified along food webs, whereas hydrophilic substances get distributed evenly among tissues. Parasites having low percentage of fat do not bio concentrate lipophilic substances above the levels of the host tissues. However, if parasites are not able to accumulate organic pollutants, they then alter the uptake of chemicals of their hosts, including metals. Recent experiments performed with the freshwater clam *Pisidium amnicum* exposed to 2,4,5-trichlorophenol (TCP) or benzo (a) pyrene and simultaneously infected with larval trematodes revealed that infected mussels contained 12% less TCP and 40% less benzo (a) pyrene than their uninfected conspecifics. This phenomenon could be related to the fact that parasites affect the physiology of their hosts in manifold ways.

In addition to effects of infection on the uptake and accumulation of organic pollutants in host tissues, numerous reports are available on the uptake and accumulation of metals by parasites. Most of these studies were carried on helminths of fish, which accumulate metals above ambient environmental concentrations several thousand-fold higher levels than their hosts. In case of fish parasites, only metazoic endoparasites have been investigated with respect to their metal accumulation capacity and protozoan parasites are not reliable for chemical analysis. Among ectoparasites monogeneans, crustaceans and leeches are predominantly affected by the surrounding water and are probably similar in their accumulation pattern to turbellarians, non-parasitic crustaceans and annelids. Keeping these limitations into consideration, the majority of researchers have focused on metal accumulation in parasites particularly in endohelminths. Among the most abundant groups of fish parasites, nematodes don’t appear to be suitable as sentinels (only *Philometra ovata* was found to contain high metal levels), whereas cestodes and especially acanthocephalans were found to accumulate a higher metal accumulation. In the trematodes of fish, no information has been available on metal accumulation till now, but acanthocephalans were found to show metal levels up to 2700 times higher than in the tissues of their final hosts.

Need for New Sentinels / Ideal Sentinel Organism

It was known as early as 1900s that organisms possess the ability to concentrate pollutants from the environment into their bodies. Sentinels have the advantage over direct analysis of pollutants (e.g. in water or sediment samples) as the fractions that are biologically available are taken up and concentrated by the animals. Furthermore, accumulation indicators are able to detect substances, even if they are not permanently present in the environment as they integrate pollutants over the time. The sentinels could be used cases where, the concentrations of pollutant in the environment are relatively low and are not important enough for monitoring procedures, such as the monitoring of noble metals, or pollutants in pristine areas.

Criteria for Ideal Sentinels

- It should have high accumulation potential and should reveal the same correlation between pollutant content in the sentinel and the average pollutant concentration in the in environment at all locations and under all conditions.
- It should not get killed or rendered incapable of reproduction on long-term basis by maximum possible levels of the pollutant in the environment.
- It should have sedentary life or with a well-defined home range, so that findings relate to the area being studied.
- It should be large enough to provide sufficient tissue for analysis.
- It should be abundant species from which large numbers can be taken without altering the age structure or having some other significant effect on the population.
- Widespread, to facilitate comparisons among different areas.
- Easy to collect and identify.
- Well-studied physiology, including the effects of age, size, season and reproductive activity on the assimilation of the pollutant.

Among the different types of parasites, acanthocephalans and cestodes meet most of the criteria. The only drawback with acanthocephalans and cestodes are that they easily age and are long-lived (ix) and sedentary (iii) An estimated life of acanthocephalans appears to be about 50–140 day. Usually the final hosts are long-lived, therefore parallel analysis of metals in host tissues and the parasites represents a combination of short-time and long-time exposure, which is more valuable than the information obtained only from one organism. Even if, cestodes are known to be long-lived, their exact age determination appears to be difficult as proglottids are of different age, and gravid cestodes constantly destrobilize from t he posterior parts of their bodies. Therefore, it becomes essential to standardize the sampling procedures for cestodes used for indication purposes and should be inevitable to use worms of approximately the same length, which might stand as a measure of age. It is suggested that only those parts of the strobila should be taken that are similar in size and have gravid proglottids as cestodes easily break into several parts during sampling. Although parasites are unable to provide information on small-scale differences of pollution that can be obtained using sessile organisms such as the zebra mussel [53], but in the natural home range, they can provide information on the average exposure of amobile host.

Owing to the enormous accumulation capacity of acanthocephalan worms, very low concentrations of metals can be detected in the environment. This could be used for assessing the presence and availability of anthropogenic pollution in pristine areas such as the Antarctic [54] and has detected the presence of biologically available concentrations of lead and silver in the Antarctic, when both were hardly detectable in the fish host tissues. In order to assess the distribution of pollutants, particularly in remote areas, it is necessary to have the most efficient indicators. Besides this, parasites could also be used to pre-concentrate metals of their surrounding environment to the concentrations which is above the detection limit of an analytical method, thus supporting the chemical analysis. Nowadays, amongst the man-made metal pollution resulting from cars, the platinum group elements (PGE), palladium (Pd), platinum (Pt) and rhodium (Rh) are emitted with exhaust fumes. Though the field studies demonstrated a cumulative increase of PGE concentrations in road dust and soils along heavily frequented roads, still only a poor dataset on the biological availability of these metals is presently available.

In a recent study on European Eels which are naturally infected with the acanthocephalan *Paratenuisentis ambiguus*, were experimentally exposed to ground catalytic converter material. It was observed that the parasites accumulated Pt and Rh, whereas in the examined host tissues no metal uptake was found. These results indicate that bioaccumulation of PGE in the parasites could facilitate analytical procedures as a pre-concentration step before the metal detection. Among the variety of aquatic parasites that have been investigated so far, the acanthocephalan *Pomphorhynchus laevis* particularly meets some of the criteria commonly suggested for sentinels. This parasite shows very high metal accumulation rate and is a common and widespread parasite of chub and barbel, which are distributed on a global scale. *P. Laevis* occurs as a Freshwater strain found in trout, barbel and chub and a Euryhaline strain found in eels and flounder in the UK. Using Eels and flounder species as definitive hosts, *P. laevis* might be used as a sentinel in brackish and marine habitats in future. These strains also found in the Europe and USA. *P. bulbocolli* and *P. lucyi* occur in different fish hosts of freshwater, while as parasites of *Morones xatilis* and other marine and brackish fish species include *P. rocci* and *P. tereticollis*. Thus, *Pomphorhynchus* genus appears to be a promising sentinel in many aquatic areas of the world. Also intestinal parasite of rats like *M. moniliformis* and *H. diminuta* appear very promising. Cestodes being widespread and common parasites of mammals [55] are easily identified and provide enough tissue for metal analysis. Rats, which are the final hosts of *H. diminuta* are also widely distributed and abundant in all kinds of terrestrial habitats worldwide. Thus, rats and their cestodes could be a useful tool in environmental monitoring. For accumulation indicators, there are some other characteristics which are to be studied in future so as to decide whether cestodes meet these criteria. More field and experimental studies are needed to explore the relationship between parasite bioaccumulation and environmental metal exposure. *H. diminuta* could appear as suitable bio indicator if a linear relationship exists between cestode and environmental concentrations over a wide range of ambient pollution levels in terrestrial habitats.

Conclusion

Environmental pollution affects the parasite population and communities either directly or through effects on intermediate, paratenic and final hosts. A high degree of complexity and uncertainty has been reported in the interpretation of parasitological data in the context of pollution. Analyses of parasite population and community structures are useful as it integrates effects of environmental parameters over different trophic levels. Thus, it is necessary to intensify research in this interdisciplinary field.

Parasites could be utilized as valuable effect indicators, if changes of populations or communities are monitored. But considerable information on effects of parasites on common bioindication procedures and the use of parasites as indicators is still lacking. We need to explore more knowledge about the basic physiological effects that parasites have on their hosts at the time of infection, development as well as reproduction. Understanding of these basic processes could benefit ecotoxicological research. Thus parasitologists should try to combine their knowledge and expertise with toxicologists and ecotoxicologists for sustainable long-term changes of ecosystems. But, more information is required to establish certain host-parasite assemblages as effect indication systems.

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References

[1] H. Moller. Pollution and parasitism in the aquatic environment. International Journal of Parasitology, 1987,17: 353-361.
[2] D. J. Marcogliese, D. K. Cone. Food webs: a plea for parasites. Trends in Ecolology and Evolution, 1997,12: 389-399.
[3] K. D. Lafferty, S. Allesina, M.Arim, C. J. Briggs, G. de Leo, A. P. Dobson, J. A. Dunne, P. T. J. Johnson, A. M. Kuris, D. J. Marcogliese, N. D. Martinez, J. Memmott, P. A. Marquet, J. P. McLaughlin, E. A. Mordecai, M. Pascual, R. Poulin, D. W. Thieltges. Parasites in food webs the ultimate missing links. Ecology Letters, 2008,11: 533-546.
[4] D. Pascoe, P. Cram. The effect of parasitism on the toxicity of cadmium to the tree-spined stickleback, Gasterosteus aculeatus. Journal of Fish Biology, 1977,10: 467-472.
[5] A. F. Brown, D. Pascoe. Parasitism and host sensitivity to cadmium: an acanthocephalan infection of the freshwater amphipod Gammarus pulex. Journal of Applied Ecology, 1977, 26: 473-487.
[6] J. T. Zelikoff. Metal pollution-induced immunomodulation in fish. Annual Review of Fish Diseases, 1993, 3: 305-325.
[7] M. R. Aarkoosh, E. Casillas, E. Clemons, A. N. Kagley, R. Olson, P. Reno, J. E. Stein. Effect of pollution on fish diseases: potential impacts on salmonid populations. Journal of Aquattic Animal Health, 1998,10: 182-190.
[8] L. Dusek, M. Gelnar, S. Sebelova. Biodiversity of parasites in a freshwater environment with respect to pollution: metazoan parasites of chub (Leuciscus cephalus L.) as a model for statistical evaluation. International Journal of Parasitology, 1998, 28:1555-1571.
[9] K. D. Lafferty, A. M. Kuris. How environmental stress affects the impacts of parasites. Limnology Oceanogr, 1999, 44: 925-931.
[10] C. Schludermann, R. Konecny, S. Laimgruber, J. W. Lewis, F. Schiemer, A. Chovanec, B. Sures. Fish

macroparasites as indicators of heavy metal pollution in river sites in Austria. Parasitology, 2003, 123: S61-S69.

[11] P. J. Hudson, A. P. Dobson, K. D. Lafferty. Is a healthy ecosystem one that is rich in parasites? Trends in Ecology & Evolution, 2006, 21: 381-385.

[12] K. MacKenzie. Parasites as pollution indicators in marine ecosystems: a proposed early warning system. Marine Pollution Bulletin, 1999, 38: 955-959.

[13] D. J. Marcogliese. Food web and the transmission of parasites to marine fish. Parasitology, 2002, 124: S83-S99.

[14] L.Turcekova. V. Hanzelova, M. Spakulova. Concentration of heavy metals in perch and its endoparasites in the polluted water reservoir in Eastern Slovakia. Helminthologia, 2002. 39: 23-28.

[15] B. Sures. How parasitism and pollution affect the physiological homeostasis of aquatic hosts. Journal of Helminthology, 2006, 80:151-157.

[16] B. Sures, H. Radszuweit. Pollution-induced heat shock protein expression in the amphipod Gammarus roeseli is affected by larvae of Polymorphus minutus (Acanthocephala). Journal of Helminthology, 2007, 81: 191-197.

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

[18] H. Taraschewski. Host-parasite interactions in Acanthocephala: a morphological approach. Advances in Parasitology, 2000, 46: 1-179.

[19] D. M. Rosenberg, V. H. Resh. Freshwater Bio-monitoring and Benthic Macro-invertebrates, Chapman & Hall, New York, 1993, 488pp.

[20] A. J. Ince. The use of real time procedure in the semiautomatic analysis of Ascaris lumbricoides var suis International Journal of Applied Radiation and Isotopes, 1975, 26: 220-222.

[21] A. J. Ince. Some elements and their relationships in Ascaris sum. International Journal of Parasitology, 1976, 6: 127-128.

[22] A. Greichus, Y. A. Greichus. Identification and quantification of some elements in the hog roundworm,Ascaris lumbricoides sum and certain tissues of its host. International Journal of Parasitology, 1980, 10: 89-91.

[23] D. Pascoe, D. L. Mattey. Studies on the toxicity of cadmium to the three-spined stickleback Gasterosteus aculeatus. Journal of Fish Biology, 1977, 11: 207-215.

[24] M. R. Riggs, A. D. Lemly, G. Esch. The growth, biomass, and fecundity of Bothriocephalus acheilognathi in North Carolina cooling reservoir. Journal of Parasitology, 1987, 73: 893-900.

[25] P. Galli, G. Crosa, A. Occhipinti Ambrogi. Heavy metals concentrations in acanthocephalans parasites compared to their fish host. Chemosphere, 1998, 37: 2983-2988.

[26] G. Scheef, B. Sures, H. Taraschewski. Cadmium accumulation in Moniliformis moniliformis (Acanthocephala) from experimentally infected rats. Parasitology Research, 2000, 86: 688-691.

[27] P. Szefer, J. Rokicki, K. Frelek, K. Skora, M. Malinga. Bioaccumulation of selected trace elements in lung nematodes, Pseudalius inflexus, of harbor porpoise (Phocoena phocoena) in a Polish zone of the Baltic Sea. The Science of the Total Environment, 1998, 220: 19-24.

[28] B. Sures, G. Jurges, H. Taraschewski. Relative concentrations of heavy metals in the parasites Ascaris sum (Nematoda) and Fasciola hepatica (Digenea) and their respective porcine and bovine definitive hosts. International Journal of Parasitology, 1998, 28: 1173-1178.

[29] B. Sures, H. Taraschewski, J. Rokicki. Lead and cadmium content of two cestodes, Monobothrium wagneri and Bothriocephalus scorpii, and their fish hosts. Parasitology Research, 1997a, 83: 618-623.

[30] V. Barus, F. Tenora, R.Sumbera. Relative concentrations of four heavy metals in the parasites Protospirura muricola (Nematoda) and Inermicapsifer arvicanthidis (Cestoda) in their definitive host silvery mole-rat (Heliophobius argenteocinereus: Rodentia). Helminthologia, 2003, 40: 227-232.

[31] F. Tenora, V. Barus, Prokes M. Next remarks to the knowledge of heavy metal concentrations in gravid tapeworm species parasitizing aquatic birds. Helminthologia. 2002, 39: 143-148.

[32] F. Tenora, V. Barus, S. Kracmar, Dvoracek, J. Concentrations of some heavy metals in Ligula intestinalis plerocercoids (Cestoda) and Philometra ovata (Nematoda) compared to their hosts (Osteichtheyes). Helminthologia, 2000, 37: 15-18.

[33] B. Sures, H. Taraschewski. 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, (1995), 81: 494-497.

[34] R. Siddall, B. Sures Uptake of lead by Pomphorhynchus laevis cystacanths in Gammarus pulex and immature worms in chub (Leuciscus cephalus). Parasitology Research,1998, 84: 573-577.

[35] V. Barus, F. Tenora, S. Kracmar. Heavy metal (Pb, Cd) concentrations in adult tapeworms (Cestoda)

parasitizing birds (Aves). Helminthologia, 2000, 37: 131-136.
[36] B. Sures, R. Siddall. Comparison between lead accumulation of Pomphorhynchus laevis (Palaeacanthocephala) in the intestine of chub (Leuciscus cephalus) and in the body cavity of goldfish (Carassius auratus auratus). International Journal Parasitology, 2001, 31: 669-673.
[37] B. Sures, R. Siddall. Pomphorhynchuslaevis (Palaeacanthocephala) in the intestine of chub (Leuciscus cephalus) as an indicator of metal pollution. International Journal of Parasitology, 2003, 33: 65-70.
[38] B. Sures, T. Scheible, A. R. Bashtar, H. Taraschewski, 2003. Lead concentrations in Hymenolepis diminuta and Taenia taeniaformis larvae compared to their rat hosts (Rattus norvegicus) sampled from the city of Cairo, Egypt. Parasitology, 127: 483-487.
[39] B. Sures, R. Siddall, H. Taraschewski. Parasites as accumulation indicators of heavy metal pollution. Parasitology Today, 1999, 15: 16-21.
[40] V. Barus, J. Jarkovsky, M. Prokes. Philometraovate (Nematoda: Philometroidea): a potential sentinel species of heavy metal accumulation. Parasitology Research, 2007, 100: 929-933.
[41] S. Pascual, E. Abollo. Accumulation of heavy metals in the whale worm Anisakis simplex (Nematoda: Anisakidae). Journal of Marine Biology Association, U.K. 2003, 83: 905-906.
[42] F. Tenora, V. Barus, S. Kracmar, J. Dvoracek, J. Srnkova. Parallel analysis of some heavy metals concentrations in the Anguillicola crassus (Nematoda) and the European eel Anguilla Anguilla (Osteichthyes). Helminthologia, 1999, 36: 79-81.
[43] B. Sures, H. Taraschewski, Jackwerth. Lead accumulation in Pomphorhynchus laevis and its host. Journal of Parasitology, 1994, 80: 355-357.
[44] B. Sures, H. Taraschewski, M. Rydlo. Intestinal fish parasites as heavy metal bioindicators: a comparison between Acanthocephalus lucii (Palaeacanthocephala) and the Zebra mussel, Dreissena polymorpha. Bulletin of Environment Contamination and Toxicology, 1997, 59: 14-21.
[45] P. S. Rainbow, D. J. H. Philips. Cosmopolitan bio-monitors of trace metals. Marine Pollution Bulletin, 1993, 26: 593-601.
[46] M. G. Vijver, C. A. M. Van Gestel, R. P. Lanno, N. M. Van Straalen, W. J. G. M. Peijnenburg. Internal metal sequestration and its ecotoxicological relevance: a review. Environmental science & Technology, 2004, 18: 4705-4712.
[47] J. Borcherding, J. Wolf. The influence of suspended particles on the acute toxicity of 2-chloro-4-nitro-aniline, cadmium, and pentachlorophenol on the valve movement resoponse of the Zebra mussel (Dreissena polymorpha). Archives of Environment Contamination & Toxicology, 2001, 40: 497-504.
[48] N. P. Boyce, S. B. Yamada. Effects of a parasite Eubothrium salvelini (Cestoda: Pseudophyllidea), on the resistance of juvenile sockeye salmon, Oncorhynchus nerka to zinc. Journal of Fish Research Board Cantonment, 1977, 34: 706-709.
[49] S. E. Wendelaar Bonga. The stress response in fish. Physiological Review, 1997, 77: 591-625.
[50] D. Hoole. The effects of pollution on the immune response of fish: implications for helminth parasites. Parasitology, 1997, 39: 219-225.
[51] M. Pietrock, D. J. Marcogliese. Free-living endohelminth stages: at themercy of environmental conditions. Trends in Parasitology, 2003, 19: 293-299.
[52] C. R. Kennedy. Freshwater fish parasites and environmental quality: an overview and caution. Parasitology, 1997, 39: 249-254.
[53] R. M. Overstreet. Parasitological data as monitors of environmental health. Parasitologia, 1997, 39: 169-175.
[54] B. Sures, N. Reimann. Analysis of trace metals in the Antarctic host-parasite system Notothenia coriiceps and Aspersentis megarhynchus (Acanthocephala) caught at King George Island, South Shetland Islands. Polar Biology, 2003, 26: 680-686.
[55] J. D. Smyth. Introduction to Animal parasitology, Cambridge, University Press, Cambridge, 1994, 549 pp.

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