Review

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Fernando Márcio Atroch and Maria João Santos *

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Review

Climate Change and Interference in Host-Parasite Interaction and Their Use as Environmental Bioindicators—A Review

Fernando Márcio Atroch [1,2] and Maria João Santos [1,2]*

[1] CIIMAR, Biology Department, Faculty of Sciences, University of Porto, Porto, Portugal.; fernandoatroch@hotmail.com; mjsantos@fc.up.pt
2 Interdisciplinary Centre of Marine and Environmental Research (CIIMAR), University of Porto, Matosinhos, Portugal; fernandoatroch@hotmail.com; mjsantos@fc.up.pt*.
* Correspondence: mjsantos@fc.up.pt

Abstract: Climate changes caused by anthropogenic actions can directly and indirectly affect living beings, including parasites and their hosts. Changes such as water temperature, pH, distribution of nutrients in the aquatic environment are some examples that can interfere with the fish community, whether in open water or in production systems. In this review, we will show how climate change can affect the adaptation of hosts and parasites in the aquatic environment and how these parasites can be used for environmental monitoring.

Keywords: climate change; host-parasite; bioindicators

Key Contribution: This article is a bibliographic review that contributes to the understanding of climate change and its interference in host-parasite interaction, interference in animal protein production and the use of parasites as environmental bioindicators.

1. Introduction

The threats of climate change to human society and natural ecosystems were highlighted in the fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2007. A scientific consensus has been reached, where human activity causes the accumulation of greenhouse gases in the atmosphere, increasing temperatures and causing environmental changes[1,2].

The theme on Climate Change has been addressed more frequently, due to the direct and indirect environmental impacts that affect the planet and causes several ecological changes, which cover all life forms[3–5]. Among the actions we can mention: the increase in the use of fossil fuels, deforestation, industrial activity and biomass burning, which results in an increase in the concentration of CO_2 and volatile organic compounds such as butane and propane among others[5,6].

Activities such as mining, livestock, agriculture, hydroelectric construction and highways are directly related to the occurrence of climate change, due to the environmental impacts generated[3,6–9]. Temperature rise, variations in other climate factors such as precipitation and humidity, result in climate change[6,10,11].

The effects mentioned above affect the most diverse groups of living beings, affects their ecological relationships with the environment and also between trophic levels, can lead to biodiversity loss in many taxonomic groups[3]. The resulting environmental changes, caused by both natural phenomena and human intervention, have a marked influence on the emergence and proliferation of zoonotic parasitic diseases[6,12]. Many infectious, vector organisms, non-human reservoir species, and rate of pathogen replication are sensitive to climatic conditions[13,14]. Both salmonella and cholera, for example, proliferate more rapidly at higher temperatures, salmonella in animal gut and food, cholera in water. In regions where low temperature, low rainfall, or absence of vector habitat restrict transmission of vector-borne disease, climatic changes could tip the ecological

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balance and trigger epidemics. Epidemics can also result from climate-related migration of reservoir hosts or human populations[15].

The relationship between climate change and the incidence/prevalence of infectious/parasitic diseases has been addressed by different authors, considering certain regions of the planet[7,8,16–21] or using more general approaches, without considering the spatial distribution or specific region[9–12,22].

Parasitic species are associated with their hosts, and these with their ecological niche, this ecological niche suffers from climate change, directly affecting the environmental behavior of host species, and consequently the adaptations of parasitic species associated with their hosts. Seasonal changes in the environment can cause modifications in the parasite-host relationship. The presence or abundance of parasites is directly influenced by both the environment within the host and the condition of the ecosystem[23].

One of the factors pointed out as temperature, directly influenced by species distribution patterns, favors the growth of host rates reservoirs of parasites and vectors, associated with the prevalence of parasites[17] besides affecting the life cycles of parasites[11] and consequently, something that can be linked to the emergence or reemergence of some parasitic diseases[21].

The interaction between climate change and the occurrence of diseases raise questions about the difficulties involved, highlights the fact of the cause-effect relationship between climate change and the incidence/prevalence of diseases, caused by parasites, where biotic or abiotic factors can interfere in host/parasite interaction and also in the vector, when applicable. Host-parasite systems with community-level interactions make them complex systems; in this complexity, it is difficult to assume climatic factors as the only cause, without taking into account the other related factors[24]. It is important to contextualize the difficulties raised by[24], in which climate change attributed to global warming, can interfere in the dynamics of disease transmission, including parasitic, vectors and host populations[11,21,22].

2. Materials and Methods

This article is a bibliographic review. The main platforms available for searching scientific references on the proposed topic, as Web of Science, Google Scholar, PubMed and Research Gate, were consulted. A survey of articles using the key words: "climate change", "host-parasite interaction" and "parasite bioindicators" was carried out from November 2022 to August 2023.

All articles with the theme of climate change, but which did not have as main focus the terms, fish, aquatic environment or fish parasites, were excluded from the bibliographic survey. The bibliographic review of this article is divided into topics referring to the understandings arranged on the proposed theme.

3. Effect of climate change on host fish

In ectothermic animals, such as fish, the impact of climate change, particularly global warming, is more severe, their body temperature and metabolism are closely regulated by circulating water that make them especially vulnerable to temperature fluctuations inducing organic responses at all levels of biological organization[25,26].

Aquatic organisms, and fish in particular, are affected by a variety of stressors caused by anthropogenic influences that lead to changes in environmental parameters. These in turn elicit stress responses of the organism in the sense that the affected organisms show reactions outside their normal range[27]. In a study on the impacts of multiple stressors in freshwater biota at spatial scales and ecosystems, was point out that anthropic actions can interfere in water quality dynamics, these include chemical pollutants (i.e. contaminants), nutrients, flow velocity, pH, dissolved oxygen, disturbances in light and temperature regimes, and many other physical-chemical variables that can be significantly altered[28].

Metabolic disorders and oxidative stress can be caused by increasing temperature, affecting the synthesis of release and actions of stress hormones[29]. Acute or prolonged exposure to high temperatures affects the functions of stress axes and responses to other stressors, compromising the long-term coping capacity of the animal[30].

In a study on the impacts of climate change on the functional diversity of freshwater fish, there was a change in the distribution of fish species, with some species being able to lose up to one hundred percent of the areas to which they are climatically adapted in the Paraná-Paraguay River basin[31].

The declining biodiversity could also bring food security problems. Climate change could lead to disruptions in ocean currents, which will stop bringing nutrients to Antarctica's shores, hampering the growth of krill, which is the base of the oceans' food chain. This could lead to a decrease in marine biota and a low supply of food to communities traditionally consuming fish and/or seafood[31].

The formation of reactive oxygen species (ROS) responsible for oxidative stress is a common aspect generated by stress. The term oxidative stress is used for the state of imbalance between the generation of oxidants (free radicals and ROS) and the availability of endogenous antioxidants to eliminate ROS[32]. The ROS react with lipids, proteins and DNA, an excessive production can be harmful leading to the onset of many pathologies and, in the last case, cell injury and death. Many studies show that ROS play a central role in the pathogenesis and progression of many infectious diseases and inflammatory disorders[33,34].

Inflammation is a host defense mechanism, generating immune response to physical stimuli, external chemicals or pathogen infiltration that plays a crucial role in the removal of host pathogens involving an increased generation of ROS by target cells and the immune system[35]. As part of the inflammatory response, ROS are produced that facilitate the elimination of invasive tissue pathogens, however when produced for prolonged periods promote oxidative stress and problems related to chronic inflammation[34]. Immune system cells such as mast cells and leukocytes are recruited during inflammation, they migrate to the site of infection, leading to a "respiratory burst" due to increased oxygen uptake and therefore greater release and accumulation of ROS at the site of infection that stimulate pathways that lead to inflammation activation[33].

The immune system of vertebrates comprises cells, tissues and organs that serve to protect a host organism from infections by bacteria, viruses or parasites. Innate immunity is the first line of defense against invading pathogens. This type of immunity involves physical barriers such as skin and mucus, cellular components and soluble components, including cytokines and complement[36,37]. Adaptive immune response is slower but more efficient, and includes humoral components, B lymphocytes, and cell-mediated components such as T lymphocytes. Adaptive immunity is very specific in its targets and has a memory component that allows a faster response to a reinfection[38].

Fish have both innate and adaptive immunity. In the innate immune response, pathogens are detected by recognition receptors, which induce specific responses to various molecular patterns associated with pathogens (PAMPs) in the infected animal[39]. Water temperature can affect the immune system of fish. Acute and chronic changes in temperature also have different impacts on animals, with short-term episodes being offset by processes such as heat-shock protein response (HSPs), while chronic temperature variations are less likely to be resolved by such responses and can still impact the physiology of the organism[40,41].

In a study on the projection of climate change in *Colossoma macropomum* (Characiforme) in the Amazon, a greater leukocyte immune response was found in the proportions of lymphocytes and granulocytes. The test determined a change in climate for the year 2100, where the increase in temperature closely influenced the immune response of the host in relation to the degree of monogenous parasites in the gills[42].

There is a limitation between the correlation of evidence that climate change is related to fish diseases[43]. Host-parasite relationships are affected by several factors, especially by environmental changes. For fish, changes in water temperature can lead to an increase in the intensity and virulence of the pathogen, decrease in immune resistance and increased frequency of disease outbreaks in the host. However, little attention has been paid to clarifying how dependence on fish temperature can directly affect parasites[44].

4. Climate change and fish production

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Aquaculture is defined as the cultivation of aquatic organisms under controlled conditions, with the objective of producing a marketable product in the most efficient and economical way possible. Aquaculture is among the most important sectors for food production, providing high quality animal protein and income generation and employment[45,46]. Aquaculture plays an important role in food production, in addition to a large international presence with an impact on the global economy[47].

Aquaculture can contribute to compensating for the negative impacts that climate change can have on fishing. However, mobile organisms, such as fish, may be tolerant of some environmental changes or may escape these changes by moving from one place to another, but aquaculture fish raised in cages or ponds cannot move to avoid these changes[48,49].

Climate changes can be considered stressful and promote the emergence of diseases in the growing environment[40,50], since temperature is an environmental factor that affects productivity in fish farming, it can affect the growth, reproduction and behavior of fish in nature and aquaculture, changing individual and population dynamics[1]. The increase in infectious diseases in aquaculture is associated with large economic losses. These diseases are controlled by the treatment of fish with chemicals and medications such as antibiotics. This seemingly stable state, in which the effective transmission of a disease is controlled by drugs, is highly delicate and can easily lose balance if environmental conditions change. One of these parameters is water temperature, which promotes the occurrence of diseases in nature and also in fish farms, since they obtain water from natural sources and the water temperature in the facilities accompanies environmental change[51–53]. Some studies have addressed the relationship between temperature modulation and fish susceptibility to pathogens[54,55].

The impact of climate change on aquaculture can vary in relation to both types (e.g. water temperature, saline water intrusion, ocean acidification) and extent of climate change, depending on climate zones (temperate, arid, tropical or Mediterranean), geographical areas (inland, sea or coastal), types of aquaculture production systems and aquatic species that are grown. In the Northern Hemisphere, rising temperatures can result in mild weather and positive effects on animal growth, but it can also introduce new diseases. In the Southern Hemisphere, the increase in temperature can result in heat stress, floods, droughts and extreme weather conditions[56]. In addition, ocean productivity decreases due to climate change and raw materials for fishmeal and fish oil may be affected[56,57]. In this circumstance, climate change indirectly puts more pressure on improving characteristics related to food efficiency, especially in carnivorous species.

The protozoan *Ichthyophthirus multifilis* is one of the main parasites that causes the most damage to fish farms. Due to lesions proven by these agents in intense infections combined with the enormous reproductive capacity of the protozoa, these can cause high mortality rates even in populations of native species[58]. This fact confirms the potential for dissemination of parasitological agents. In addition, these can act as vectors, bringing new pathogens from different regions and further intensifying the parasite load when it comes to introduced and farmed fish. The intensity of infestation was higher in polluted and eutrophicated lakes, demonstrating the importance of environmental characteristics in the proliferation of these agents. Thus, feed feeding on farmed fish contributes significantly to the eutrophication process of the environment. Associating this issue with rising temperatures, these environments are always susceptible to new pathogens and will never be completely free of parasites[59].

5. Climate change and parasites

The increase in temperature affects system transmission, with direct increase in the metabolism of the parasite, increasing the feeding or replication of the parasite in the host, increasing the damage and resulting in the production of a greater number of stages of transmission, as well as a faster spread of the disease in a single outbreak[53,60]. The increase in temperature can extend the duration of transmission windows, resulting in a general spread of the disease in the host population. Both mechanisms, alone or in combination, would result in a higher prevalence of the disease. However, some diseases could also show opposite effects with the increase in temperature if their ideal temperature for growth and transmission were lower[53,61].

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The fact that climate change mainly affects fish communities, whether in cold or hot waters with the determining factors: ocean acidification, increased temperature, salinity, disposal of pollutants, among others, has shown significant changes in the disposition of host species. These factors are also influencing the reproduction, fertility and feeding of fish species. Parasites can be acquired by their hosts in two ways: phylogenetic and ecological. By the phylogenetic route, the parasites are inherited from species or groups of ancestral species, and by the ecological route, the parasites are acquired from the environment or from other host species[62].

Monogenous (Platyhelminths: Monogenea) are the most common and most diverse ectoparasites of fish, usually live on external surfaces, such as the skin, fins, head, gills and eyes, oral and branchial cavities[63]. Haptor is the main organ for fixing these parasites to their hosts and is the main morphological characteristic used to distinguish these from cestoda and digenea parasites[64]. They have monoxenous life cycles and stages of rapid transmission, feed on mucus and epithelial cells, which results in damage to host tissue, such as deep wounds in the epidermis that can reach the dermis. The presence of these ectoparasites is correlated with increased susceptibility to secondary infections such as bacteriosis and disturbances in the host immune system[65]. They are widespread in aquaculture, including closed, semi-closed and open systems, and are responsible for economic losses. Therefore, the fight against infectious diseases, which is already considered one of the main current challenges of fish farming, can become an important issue in climate change scenarios[53,66].

In a senary of climate change until 2100, with the increase in temperature, a higher intensity of monogenetics *Notozothecium janauachensis* (Domingues and Martins, 2004), *Anacanthorus spathulatus* (Kritsky et al., 1979) and *Mymarothecium boegeri* (Cohen and Kohn, 2005) was observed in the host *C. macropomum*, with a 200% increase in mean intensity and a prevalence of 100% in the hosts. The authors concluded that the environment favours activity and increase in parasitic metabolism[42].

Several factors influence the responses of species to temperature rises, both intrinsic to each organism and extrinsic linked to the ecological niches in which they are inserted, which are directly subject to the environmental conditions existing in each geographic region and how these conditions are and will be affected or not by climate change[5,22].

Certain parasites may have a higher incidence with increasing temperatures, leading to a decrease in species or even their extinction. In the literature there are reports of massive deaths among lions, frogs, birds, wild dogs, snails, mussels, storks, eagles, corals and various types of plants, all caused by pathogens. Fungi and viruses are especially sensitive to climate change and can quickly grow when the temperature rises, especially if this elevation is accompanied by increased humidity. Fungi and insects have their activity increased and can be responsible for the elimination of entire species of trees. Parasitosis in both cattle and wild animals are also greatly increased with higher temperatures[67].

The same impact of climate change on the diversity of animals and plants is predicted for parasitic diversity. Parasites, such as helminths, are known as modulators of the immune system, can have a synergistic effect on the effects of climate change on hosts. The hypothesis "*old friends*" suggests that the reactivity of the immune system of vertebrates depends on exposure to parasites, which are important for the host to develop an adequate functional immune response. Parasitic-host interactions are the main force in the evolution of the immune system that is designed to maintain optimal basal immunity, minimizing the risk of developing potentially pathological reactions[50,68].

Modifications in environmental elements such as water bodies, soil moisture, vegetation cover, among others, interfere in parasites, vectors and their hosts, as well as in the interactions between them[69]. In the case of vectors of parasitic diseases, changes in temperature influence the life cycles of parasites. After all, a portion of them have part of the life cycle in the environment[10].

6. Fish parasites as bioindicators of environmental health

Parasitism is one of the most successful means of life presented by living beings[70], and is such an ancient relationship that it played a crucial role in the emergence of life on earth, through what is called molecular parasitism[71,72]. The term itself lives in the shadow of dualities, as parasites are

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intrinsically linked to the generation of diversity, while they can cause the extinction of species, can cause problems in the reproduction of hosts, but increase the rate of population growth, and can stimulate an immune response, while stimulating a secondary chronic infection[73]. The term parasitism is commonly associated with pathogenicity when in fact this is not always the final product of the relationship, and parasites are often harmless to the health of the host and extremely important for its survival[71].

Historically, the role of parasites in the functioning of the ecosystem has been considered of little importance, however, there is growing evidence that the effects mediated by parasites can be extremely significant in the modeling of ecosystem functions and in the structuring of food chains, being considered as important drivers of biodiversity[73]. In contrast to the undeniable importance of these organisms in maintaining ecosystems, parasites face some paradigms, especially linked to their conservation, because they suffer from the stigma of being causing negative impacts to hosts and are constantly targeted at eradication strategies[74]. Therefore, understanding parasitism as a crucial component in biodiversity, with the inclusion of these organisms in conservation strategies is extremely important to ensure the maintenance of ecosystems and the survival of host species.

Environmental impacts are a constant threat to global biodiversity, and as far as parasite biodiversity is concerned, they can cause the extinction of 5 to 10% of the species of the main known clades in the coming decades, some of which are not even described by the taxonomy[75,76]. These organisms respond to impacts in different ways depending on their taxonomic group, their host and the habitat it occupies[11], and can help us detect, identify and even predict such impacts on the environment[11,77].

In recent decades, studies evaluating the strength of environmental impacts on parasites and/or parasitism have increased significantly[27], which led to the establishment of the term "Environmental Parasitology"[78], which becomes an accepted discipline within parasitology and encompasses all studies that relate parasites and the environment, especially on the anthropogenic impact on them and the role of parasites as bioindicators of environmental quality. Currently, the two most studied areas within this spectrum are: parasites as bioindicators of accumulation and parasites as bioindicators of effect.

The ecological pathway is directly related to migratory movements, the conquest of new territories, changes in habits, cultural processes and contact with new host species and their pathogens. In this dynamic, climatic factors can determine the extinction of some species of pathogens and promote the dispersion of others[79].

There is a direct link between parasite richness and life species richness free, resulting in the possibility of indicating changes in ecosystems[80]. This connection may be caused by the different types of parasite infection pathways. The Digenea, for example, involve molluscs as first intermediate hosts and a number of other organisms, crustaceans, other invertebrates and vertebrates, as second intermediate hosts[81]. These intermediate hosts are necessary to complete parasite ontogeny[82].

The first host is usually a defined species or a small group of close relatives[83]. With the loss of primary hosts, for example, caused by environmental change or pollution, the parasite will also disappear[80].

Environmental contamination and changes are stronger for parasites compared to their hosts[84]. The definitive host can adapt to new conditions and still occur, while the parasitic species can disappear[85]. A reduction in intermediate hosts alters the endoparasite fauna of the definitive host[86]. Several hosts are characteristic in the life cycle of endoparasites, however, ectoparasites have direct life cycles without the presence of intermediate hosts[87]. Direct life cycles can result in increased rates of ectoparasite infestation in the environment[83]. Endoparasite helminths decrease, while ectoparasites increase their numbers under increasing scenarios of environmental changes[83].

In the bioindication of accumulation, the potential of parasites is evaluated in accumulating a certain pollutant, usually compared to the tissues of its host. Trace metals (also designated as trace elements or heavy metals) are the most evaluated compounds in bioaccumulation studies[27], but some organic pollutants such as polychlorinated biphenyls (PCBs), organochlorinated pesticides (OCPs), polybrominated diphenyl ethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs),

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ftalates, insecticides, pyrethroids, N,N-diethyl metatomymides (DEET)[88] and even fragrances and UV filters (sunscreens) (Mille et al., 2020)[89] have also been studied. Many of these studies show that parasites can accumulate compounds in much higher amounts than their hosts or in relation to other free-life bioindicators, such as mussels[90–92].

The parasite groups most used for this purpose are the acanthocephalans, cestodes and nematodes[27], as they are the ones that generally meet the main requirements necessary for use in studies of this type, which are: ease of collection and identification, being large in size so that they have enough tissue for the analysis of the concentrations of compounds and with a vast amount of information about their available biology[93,94].

In a study carried out in floodplain lakes in the Amazon, a higher concentration of copper (Cu) was described in the tissue of the nematode *Procamallanus* (*Spirocamallanus*) *inopinatus* Pereira, 1958, collected from the host *Pygocentrus nattereri* (Kner, 1858). The concentrations in the parasite were 2.763 times higher than those found in the muscles of P. nattereri, 2.735 than those of the gills, 2.708 than those of the liver, and 2.730 times higher than the concentrations found in the waters of the lake. Also in the same research were found the metals, cadmium (Cd), Lead (Pb) and nickel (Ni), all elements showed higher concentration in the parasitic species. This determines which species of nematodes can be used as environmental bioindicators[95].

Other examples of bioaccumulation were found in nematoda larvae of the family Anisakidae (Railliet and Henry 1912) bioaccumulating lower concentrations of lead (Pb) and copper (Cu) than the host *Dicentrarchus labrax* (Linnaeus, 1758)[96].

In the bioindication of effect, the physiological, chemical, behavioral or numerical composition of the parasites in front of a stressor agent is studied[77]. These studies can be conducted at both the species level and the community level and the metrics used to assess responses to environmental impacts can be several, depending on the area of study, the type of pollutant or whatever the interfering variable, chemical or physical. The commonly used are, at the species level: changes in the prevalence, intensity and abundance rates of parasite according to changes in the environment, and at the community level: composition, richness and diversity of species according to the areas of study or concentration of pollutants or chemical and physical variables collected from the environment[97–102].

A significant positive correlation was found between the weight of the parasite *Acanthocephalus lucii* (Müller, 1776) and the concentration of heavy metals in Lake Mondsee, Austria. The correlation should reflect a longer time of exposure to the metal in older individuals and therefore a greater absorption[92].

The advance of environmental parasitology only further reinforces how important and extremely useful these small, peculiar and often forgotten organisms can be, not only for the maintenance of biodiversity, acting in food chains, but also by assisting in the detection and monitoring of environmental impacts caused by human beings. Research efforts, with the most varied groups of parasites in different regions of the globe, become of great importance for the creation of methodologies that include these organisms in an applied way in programs of environmental monitoring and biodiversity conservation (including parasites).

Fish in the environment play an important role in maintaining parasitic species, since parasites have an intimate relationship with their hosts. The lack of a host species in the environment can cause an environmental imbalance, host switching, with increasing the intensity, prevalence and abundance of parasitic species in other host species, which normally would not be parasitic by those species of parasites, whose natural host is no longer in the parasite environment.

Environments intensely affected by anthropogenic disorders may present structural and limnological degradation and invasion by non-native species, which results in negative consequences on the diversity of fish and their parasites. In a study on environmental degradation, there was a higher diversity of endoparasites in pristine streams and lower diversity in disturbed streams, which depends on the interaction between environmental degradation and host diversity. This result evidences complex ecological relationships, with factors that act simultaneously and result in the variations observed in the diversity and richness of fish endoparasites[103].

The occurrence of fish parasites is closely related to the distribution of their definitive and intermediate hosts[104]. Its abundance is also closely influenced by other biotic and abiotic factors, such as ecology, eating habits[105], water temperature[106], water depth and environment pollution[86]. The close relationship of a parasitic fauna with its hosts and the environment opens the opportunity to use these organisms as indicators of environmental changes.

7. Conclusion

Climate change may favor the emergence of infectious and parasitic diseases in fish in nature or in intensive, semi-intensive and open production systems. The increase in temperature can increase parasite metabolism, the adaptation of parasitic species to new hosts, the intensification of the most abundant parasitic species in the search for new hosts, contributing to greater economic loss due to parasitic lesions in these hosts, greater parasitic contamination in fish production leading to a higher dietary risk for consumers. In addition to directly affecting the physiological and immunological dynamics of the hosts. However, future studies need to be carried out to be able to understand more deeply how climate changes can interfere with host-parasite adaptations and interactions, and how these parasites can be used as bioindicators of the environmental health of the water and the host community.

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References

1. Brander, K.; Cochrane, K.; Barange, M.; Soto, D., Climate change implications for fisheries and aquaculture. *Climate change impacts on fisheries aquaculture: A global analysis* **2017,** *1*, 45-62.
2. Pachauri, R. K.; Allen, M. R.; Barros, V. R.; Broome, J.; Cramer, W.; Christ, R.; Church, J. A.; Clarke, L.; Dahe, Q.; Dasgupta, P., *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Ipcc: 2014.
3. Bellard, C.; Bertelsmeier, C.; Leadley, P.; Thuiller, W.; Courchamp, F., Impacts of climate change on the future of biodiversity. *Ecology letters* **2012,** *15* (4), 365-377.
4. Ojima, R.; Marandola Jr, E., *Mudanças climáticas e as cidades: novos e antigos debates na busca da sustentabilidade urbana e social*. Editora Blucher: 2013; Vol. 1.
5. Parmesan, C., Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.* **2006,** *37*, 637-669.
6. Patz, J. A.; Graczyk, T. K.; Geller, N.; Vittor, A. Y., Effects of environmental change on emerging parasitic diseases. *International journal for parasitology* **2000,** *30* (12-13), 1395-1405.
7. Charron, D. F.; Thomas, M. K.; Waltner-Toews, D.; Aramini, J. J.; Edge, T.; Kent, R. A.; Maarouf, A. R.; Wilson, J., Vulnerability of waterborne diseases to climate change in Canada: a review. *Journal of Toxicology Environmental Health, Part A* **2004,** *67* (20-22), 1667-1677.
8. Confalonieri, U. E.; Margonari, C.; Quintão, A. F., Environmental change and the dynamics of parasitic diseases in the Amazon. *Acta tropica* **2014,** *129*, 33-41.
9. Dantas-Torres, F., Climate change, biodiversity, ticks and tick-borne diseases: the butterfly effect. *International Journal for Parasitology: parasites wildlife* **2015,** *4* (3), 452-461.
10. Haines, A.; Kovats, R. S.; Campbell-Lendrum, D.; Corvalán, C., Climate change and human health: impacts, vulnerability and public health. *Public health* **2006,** *120* (7), 585-596.
11. Lafferty, K. D., Environmental parasitology: what can parasites tell us about human impacts on the environment? *Parasitology today* **1997,** *13* (7), 251-255.
12. McMichael, A. J.; Woodruff, R. E.; Hales, S., Climate change and human health: present and future risks. *The Lancet* **2006,** *367* (9513), 859-869.
13. Pascual, M.; Dobson, A., Seasonal patterns of infectious diseases. *PLoS Medicine* **2005,** *2* (1), e5.
14. Reeves, W. C.; Hardy, J. L.; Reisen, W. K.; Milby, M. M., Potential effect of global warming on mosquito-borne arboviruses. *Journal of medical entomology* **1994,** *31* (3), 323-332.
15. Hales, S.; Kovats, S.; Woodward, A., What El Niño can tell us about human health and global climate change. *Global Change and Human Health* **2000,** *1*, 66-77.

16. Araujo, A.; Rangel, A.; Ferreira, L. F. R., Climatic change in northeastern Brazil: paleoparasitological data. *Memórias do Instituto Oswaldo Cruz* **1993,** *88*, 577-579.
17. Dunn, R. R.; Davies, T. J.; Harris, N. C.; Gavin, M. C., Global drivers of human pathogen richness and prevalence. *Proceedings of the Royal Society B: Biological Sciences* **2010,** *277* (1694), 2587-2595.
18. Nava, A.; Shimabukuro, J. S.; Chmura, A. A.; Luz, S. L. B., The impact of global environmental changes on infectious disease emergence with a focus on risks for Brazil. *ILAR journal* **2017,** *58* (3), 393-400.
19. Queiroz, A. R. S. d.; Motta-Veiga, M., Análise dos impactos sociais e à saúde de grandes empreendimentos hidrelétricos: lições para uma gestão energética sustentável. *Ciência Saúde Coletiva* **2012,** *17* (6), 1387-1398.
20. Rosado-García, F. M.; Guerrero-Flórez, M.; Karanis, G.; Hinojosa, M. D. C.; Karanis, P., Water-borne protozoa parasites: the Latin American perspective. *International Journal of Hygiene Environmental Health* **2017,** *220* (5), 783-798.
21. Short, E. E.; Caminade, C.; Thomas, B. N., Climate change contribution to the emergence or re-emergence of parasitic diseases. *Infectious Diseases: Research Treatment* **2017,** *10*, 1178633617732296.
22. Fecchio, A.; Wells, K.; Bell, J. A.; Tkach, V. V.; Lutz, H. L.; Weckstein, J. D.; Clegg, S. M.; Clark, N. J., Climate variation influences host specificity in avian malaria parasites. *Ecology Letters* **2019,** *22* (3), 547-557.
23. Kadlec, D.; Šimková, A.; Jarkovský, J.; Gelnar, M., Parasite communities of freshwater fish under flood conditions. *Parasitology Research* **2003,** *89*, 272-283.
24. Rohr, J. R.; Dobson, A. P.; Johnson, P. T. J.; Kilpatrick, A. M.; Paull, S. H.; Raffel, T. R.; Ruiz-Moreno, D.; Thomas, M. B., Frontiers in climate change–disease research. *Trends in ecology evolution* **2011,** *26* (6), 270-277.
25. Burraco, P.; Orizaola, G.; Monaghan, P.; Metcalfe, N. B., Climate change and ageing in ectotherms. *Global Change Biology* **2020,** *26* (10), 5371-5381.
26. Pörtner, H. O., Climate-dependent evolution of Antarctic ectotherms: an integrative analysis. *Deep Sea Research Part II: Topical Studies in Oceanography* **2006,** *53* (8-10), 1071-1104.
27. Sures, B.; Nachev, M.; Selbach, C.; Marcogliese, D. J., Parasite responses to pollution: what we know and where we go in 'Environmental Parasitology'. *Aquatic Toxicology Vectors* **2017,** *10*, 1-19.
28. Birk, S.; Chapman, D.; Carvalho, L.; Spears, B. M.; Andersen, H. E.; Argillier, C.; Auer, S.; Baattrup-Pedersen, A.; Banin, L.; Beklioğlu, M., Impacts of multiple stressors on freshwater biota across spatial scales and ecosystems. *Nature Ecology Evolution* **2020,** *4* (8), 1060-1068.
29. Topal, A.; Özdemir, S.; Arslan, H.; Çomaklı, S., How does elevated water temperature affect fish brain?(A neurophysiological and experimental study: Assessment of brain derived neurotrophic factor, cFOS, apoptotic genes, heat shock genes, ER-stress genes and oxidative stress genes). *Fish Shellfish Immunology* **2021,** *115*, 198-204.
30. Alfonso, S.; Gesto, M.; Sadoul, B., Temperature increase and its effects on fish stress physiology in the context of global warming. *Journal of Fish Biology* **2021,** *98* (6), 1496-1508.
31. Novacek, M. J., Cleland, E. E, The current biodiversity extinction event: scenarios for mitigation and recovery, in: National Academy of Sciences Colloquium The Future of Evolution. *Irvine, California* **2002**.
32. Feidantsis, K.; Georgoulis, I.; Zachariou, A.; Campaz, B.; Christoforou, M.; Pörtner, H. O.; Michaelidis, B., Energetic, antioxidant, inflammatory and cell death responses in the red muscle of thermally stressed Sparus aurata. *Journal of Comparative Physiology B* **2020,** *190*, 403-418.
33. Chatterjee, S., Oxidative stress, inflammation, and disease. In *Oxidative stress and biomaterials*, Elsevier: 2016; pp 35-58.
34. Reuter, S.; Gupta, S. C.; Chaturvedi, M. M.; Aggarwal, B. B., Oxidative stress, inflammation, and cancer: how are they linked? *Free radical biology medicine* **2010,** *49* (11), 1603-1616.
35. Ko, E.-Y.; Cho, S.-H.; Kwon, S.-H.; Eom, C.-Y.; Jeong, M. S.; Lee, W.; Kim, S.-Y.; Heo, S.-J.; Ahn, G.; Lee, K. P., The roles of NF-κB and ROS in regulation of pro-inflammatory mediators of inflammation induction in LPS-stimulated zebrafish embryos. *Fish shellfish immunology* **2017,** *68*, 525-529.
36. Poynter, S.; Dixon, B., Bony Fish Immunology. *Elsevier Ltd* **2017**, 1–7.
37. Press, C. M.; Evensen, Ø., The morphology of the immune system in teleost fishes. *Fish shellfish immunology* **1999,** *9* (4), 309-318.
38. Alvarez-Pellitero, P., Fish immunity and parasite infections: from innate immunity to immunoprophylactic prospects. *Veterinary immunology imunopathology* **2008,** *126* (3-4), 171-198.
39. Tort, L.; Balasch, J. C.; Mackenzie, S., Fish immune system. A crossroads between innate and adaptive responses. *Inmunología* **2003,** *22* (3), 277-286.
40. Filipe, J. F.; Herrera, V.; Curone, G.; Vigo, D.; Riva, F., Floods, hurricanes, and other catastrophes: a challenge for the immune system of livestock and other animals. *Frontiers in veterinary science* **2020,** *7*, 16.
41. Makrinos, D. L.; Bowden, T. J., Natural environmental impacts on teleost immune function. *Fish Shellfish Immunology* **2016,** *53*, 50-57.
42. Costa, J. C. V., A. L, Extreme climate scenario and parasitism affect the Amazonian fish *Colossoma macropomum*. *Science of the Total Environment* **2020,** *726*.

43. Lõhmus, M.; Björklund, M., Climate change: what will it do to fish—parasite interactions? *Biological Journal of the Linnean Society* **2015,** *116* (2), 397-411.
44. Morley, N. J.; Lewis, J. W., Temperature stress and parasitism of endothermic hosts under climate change. *Trends in Parasitology* **2014,** *30* (5), 221-227.
45. Stankus, A., State of world aquaculture 2020 and regional reviews: FAO webinar series. *FAO Aquaculture Newsletter* **2021,** (63), 17-18.
46. Tacon, A. G. J., Trends in global aquaculture and aquafeed production: 2000–2017. *Reviews in Fisheries Science Aquaculture* **2020,** *28* (1), 43-56.
47. Valladão, G. M. R.; Gallani, S. U.; Pilarski, F., South American fish for continental aquaculture. *Reviews in Aquaculture* **2018,** *10* (2), 351-369.
48. Jesus, T. F.; Moreno, J. M.; Repolho, T.; Athanasiadis, A.; Rosa, R.; Almeida-Val, V. M. F.; Coelho, M. M., Protein analysis and gene expression indicate differential vulnerability of Iberian fish species under a climate change scenario. *PLoS One* **2017,** *12* (7), e0181325.
49. Methling, C.; Aluru, N.; Vijayan, M. M.; Steffensen, J. F., Effect of moderate hypoxia at three acclimation temperatures on stress responses in Atlantic cod with different haemoglobin types. *Comparative Biochemistry Physiology Part A: Molecular Integrative Physiology* **2010,** *156* (4), 485-490.
50. Scharsack, J. P.; Wieczorek, B.; Schmidt-Drewello, A.; Büscher, J.; Franke, F.; Moore, A.; Branca, A.; Witten, A.; Stoll, M.; Bornberg-Bauer, E., Climate change facilitates a parasite's host exploitation via temperature-mediated immunometabolic processes. *Global Change Biology* **2020,** *27* (1), 94-107.
51. Borgwardt, F.; Unfer, G.; Auer, S.; Waldner, K.; El-Matbouli, M.; Bechter, T., Direct and indirect climate change impacts on brown trout in central Europe: How thermal regimes reinforce physiological stress and support the emergence of diseases. *Frontiers in Environmental Science* **2020**, 59.
52. Bruneaux, M.; Visse, M.; Gross, R.; Pukk, L.; Saks, L.; Vasemägi, A., Parasite infection and decreased thermal tolerance: impact of proliferative kidney disease on a wild salmonid fish in the context of climate change. *Functional Ecology* **2017,** *31* (1), 216-226.
53. Karvonen, A.; Rintamäki, P.; Jokela, J.; Valtonen, E. T., Increasing water temperature and disease risks in aquatic systems: climate change increases the risk of some, but not all, diseases. *International journal for parasitology* **2010,** *40* (13), 1483-1488.
54. Hwang, J. Y.; Markkandan, K.; Han, K.; Kwon, M. G.; Seo, J. S.; Yoo, S.; Hwang, S. D.; Ji, B. Y.; Son, M.; Park, J., Temperature-dependent immune response of olive flounder (Paralichthys olivaceus) infected with viral hemorrhagic septicemia virus (VHSV). *Genes genomics* **2018,** *40*, 315-320.
55. Kayansamruaj, P.; Pirarat, N.; Hirono, I.; Rodkhum, C., Increasing of temperature induces pathogenicity of Streptococcus agalactiae and the up-regulation of inflammatory related genes in infected Nile tilapia (Oreochromis niloticus). *Veterinary microbiology* **2014,** *172* (1-2), 265-271.
56. De Silva, S. S.; Soto, D., Climate change and aquaculture: potential impacts, adaptation and mitigation. *Climate change implications for fisheries aquaculture: overview of current scientific knowledge. FAO Fisheries Aquaculture Technical Paper* **2009,** *530*, 151-212.
57. Schmittner, A., Decline of the marine ecosystem caused by a reduction in the Atlantic overturning circulation. *Nature* **2005,** *434* (7033), 628-633.
58. Eiras, J. C., *Elementos da Ictioparasitologia* Porto, 1994.
59. Koskivaara, M. V., E. T.; Prost, M, Dactylogyrids on the gills of roach in central Finland: features of infection and species composition. *International Journal of Parasitology* **1991,** *21*, 565 - 572.
60. Byers, J. E., Marine parasites and disease in the era of global climate change. *Annual Review of Marine Science* **2021,** *13*, 397-420.
61. Pounds, J. A.; Bustamante, M. R.; Coloma, L. A.; Consuegra, J. A.; Fogden, M. P. L.; Foster, P. N.; La Marca, E.; Masters, K. L.; Merino-Viteri, A.; Puschendorf, R.; Ron, S. A.; Sánchez-Azofeifa, G. A.; Still, C. J.; Young, B. E., Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature* **2006,** *439*, 161-167.
62. Chame, M.; Batouli-Santos, A. L.; Brandão, M. L., As migrações humanas e animais ea introdução de parasitas exóticos invasores que afetam a saúde humana no Brasil. *FUMDHAMentos* **2008,** *7*, 47-62.
63. Buchmann, K.; Lindenstrøm, T., Interactions between monogenean parasites and their fish hosts. *International journal for parasitology* **2002,** *32* (3), 309-319.
64. Ogawa, K., Diseases of cultured marine fishes caused by Platyhelminthes (Monogenea, Digenea, Cestoda). *Parasitology* **2015,** *142* (1), 178-195.
65. WOO, P. T.; GREGORY, D. W. B., Diseases and disorders of finfish in cage culture. *CABI* **2014**.
66. Macnab, V.; Barber, I., Some (worms) like it hot: fish parasites grow faster in warmer water, and alter host thermal preferences. *Global Change Biology* **2012,** *18* (5), 1540-1548.
67. Harvell, C. D. e. a., Climate Warming and Disease Risks for Terrestrial and Marine Biota. *Science's Compass Review* **2002,** *296*.

68. Peuß, R.; Box, A. C.; Chen, S.; Wang, Y.; Tsuchiya, D.; Persons, J. L.; Kenzior, A.; Maldonado, E.; Krishnan, J.; Scharsack, J. P., Adaptation to low parasite abundance affects immune investment and immunopathological responses of cavefish. *Nature ecology evolution* **2020,** *4* (10), 1416-1430.
69. Haines, A. P., J. A, Health Effects of Climate Change. *Journal of the American Medical Association* **2004,** *291*, 99 - 103.
70. Poulin, R.; Morand, S., The diversity of parasites. *The quarterly review of biology* **2000,** *75* (3), 277-293.
71. Araújo, A.; Jansen, A. M.; Bouchet, F.; Reinhard, K.; Ferreira, L. F., Parasitism, the diversity of life, and paleoparasitology. *Memórias do Instituto Oswaldo Cruz* **2003,** *98*, 5-11.
72. Nee, S.; Smith, J. M., The evolutionary biology of molecular parasites. *Parasitology* **1990,** *100* (S1), S5-S18.
73. Hudson, P. J.; Dobson, A. P.; Lafferty, K. D., Is a healthy ecosystem one that is rich in parasites? *Trends in ecology evolution* **2006,** *21* (7), 381-385.
74. Dougherty, E. R.; Carlson, C. J.; Bueno, V. M.; Burgio, K. R.; Cizauskas, C. A.; Clements, C. F.; Seidel, D. P.; Harris, N. C., Paradigms for parasite conservation. *Conservation biology* **2015,** *30* (4), 724-733.
75. Carlson, C. J.; Burgio, K. R.; Dougherty, E. R.; Phillips, A. J.; Bueno, V. M.; Clements, C. F.; Castaldo, G.; Dallas, T. A.; Cizauskas, C. A.; Cumming, G. S., Parasite biodiversity faces extinction and redistribution in a changing climate. *Science advances* **2017,** *3* (9), e1602422.
76. Carlson, C. J.; Hopkins, S.; Bell, K. C.; Doña, J.; Godfrey, S. S.; Kwak, M. L.; Lafferty, K. D.; Moir, M. L.; Speer, K. A.; Strona, G., A global parasite conservation plan. *Biological Conservation* **2020,** *250*, 108596.
77. Vidal-Martinez, V. M.; Pech, D.; Sures, B.; Purucker, S. T.; Poulin, R., Can parasites really reveal environmental impact? *Trends in parasitology* **2010,** *26* (1), 44-51.
78. Nachev, M.; Sures, B., Environmental parasitology: Parasites as accumulation bioindicators in the marine environment. *Journal of Sea Research* **2016,** *113*, 45-50.
79. Araújo, F., Adaptation of the index of biotic integrity based on fish assemblages in the Paraiba do Sul River, RJ, Brazil. *R e v. Bras. Biol* **1998,** *58*.
80. Lafferty, K. D., Biodiversity loss decreases parasitediversity: theory and patterns. *Philosophical Transactions of the Royal Society B: Biological Sciences* **2012,** *367(1604)*, 2814-2827.
81. Cribb, T. H.; Chisholm, L. A.; Bray, R. A., Diversity in the Monogenea and Digenea: does lifestyle matter? *International Journal for Parasitology* **2002,** *32(3)*, 321-328.
82. Poulin, R.; Cribb, T. H., Trematode life cycles: short is sweet? *Trends in parasitology* **2002,** *18(4)*, 176-183.
83. MacKenzie, K., Parasites as pollution indicators in marine ecosystems: a proposed early warning system. *Marine Pollution Bulletin* **1999,** *38 n. 11*, 955-959.
84. Møller, A. P., Intraspecific nest parasitism and anti-parasite behaviour in swallows, Hirundo rustica. *Animal Behaviour* **1987,** *35(1)*, 247-254.
85. Lafferty, K. D.; Shaw, J. C., Comparing mechanisms of host manipulation across host and parasite taxa. *Journal of Experimental Biology* **2013,** *216(1)*, 56-66.
86. Palm, H. W., Fish parasites as biological indicators in a changing world: can we monitor environmental impact and climate change? *Progress in parasitology* **2011**, 223-250.
87. Marcogliese, D. J., Transmission of marine parasites. *Marine parasitology* **2005**, 280-286.
88. Molbert, N.; Alliot, F.; Leroux-Coyau, M.; Médoc; Biard, C.; Meylan, S.; Jacquin, L.; Santos, R.; Goutte, A., Potential benefits of acanthocephalan parasites for chub hosts in polluted environments. *Environmental science technology* **2020,** *54* (9), 5540-5549.
89. Mille, T.; Soulier, L.; Caill-Milly, N.; Cresson, P.; Morandeau, G.; Monperrus, M., Differential micropollutants bioaccumulation in European hake and their parasites Anisakis sp. *Environmental Pollution* **2020,** *265*, 115021.
90. Sures, B.; Siddall, R.; Taraschewski, H., Parasites as accumulation indicators of heavy metal pollution. *Parasitology Today* **1999,** *15* (1), 16-21.
91. Sures, B.; Steiner, W.; Rydlo, M.; Taraschewski, H., Concentrations of 17 elements in the zebra mussel (Dreissena polymorpha), in different tissues of perch (Perca fluviatilis), and in perch intestinal parasites (Acanthocephalus lucii) from the subalpine Lake Mondsee, Austria. *Environmental Toxicology Chemistry: An International Journal* **1999,** *18* (11), 2574-2579.
92. Sures, B.; Taraschewski, H.; Rydlo, M., Intestinal fish parasites as heavy metal bioindicators: a comparison between Acanthocephalus lucii (Palaeacanthocephala) and the zebra mussel, Dreissena polymorpha. *Bulletin of Environmental Contamination Toxicology* **1997,** *59*, 14-21.
93. Sures, B., Accumulation of heavy metals by intestinal helminths in fish: an overview and perspective. *Parasitology* **2003,** *126* (7), S53-S60.
94. Sures, B., Environmental parasitology: relevancy of parasites in monitoring environmental pollution. *Trends in parasitology* **2004,** *20* (4), 170-177.
95. Morais, A. M. Biodiversidade de parasitos da piranha vermelha Pygocentrus nattereri (Kner, 1858) (Characiformes; Serrasalmidae) e sua avaliação como bioindicadores na Amazônia Central. Instituto Nacional de Pesquisas da Amazônia, 2011.

 doi:10.20944/preprints202309.0332.v1

96. Morsy, K. A.-R., B.; Abdel-Ghaffar, F.; Mehlhorn, H.; Quraishy, S.; El-Mahdi, M.; Al-Ghamdi, A.; Mostafa, N., First record of anisakid juveniles (Nematoda) in the European seabass Dicentrarchus labrax (family: Moronidae), and their role as bioindicators of heavy metal pollution. *Parasitology Research* **2011**.
97. Blanar, C. A.; Munkittrick, K. R.; Houlahan, J.; MacLatchy, D. L.; Marcogliese, D. J., Pollution and parasitism in aquatic animals: a meta-analysis of effect size. *Aquatic Toxicology* **2009,** *93* (1), 18-28.
98. Falkenberg, J. M.; Golzio, J. E. S.; Pessanha, A.; Patrício, J.; Vendel, A. L.; Lacerda, A. C., Gill parasites of fish and their relation to host and environmental factors in two estuaries in northeastern Brazil. *Aquatic Ecology* **2019,** *53*, 109-118.
99. Gilbert, B. M.; Avenant-Oldewage, A., Parasites and pollution: the effectiveness of tiny organisms in assessing the quality of aquatic ecosystems, with a focus on Africa. *Environmental Science Pollution Research* **2017,** *24*, 18742-18769.
100. Igeh, P. C.; Gilbert, B. M.; Avenant-Oldewage, A., Seasonal variance in water quality, trace metals and infection variables of Cichlidogyrus philander Douëllou, 1993 (Monogenea, Ancyrocephalidae) infecting the gills of Pseudocrenilabrus philander (Weber, 1897) in the Padda Dam, South Africa. *African Journal of Aquatic Science* **2021,** *46* (1), 88-99.
101. Lacerda, A. C. F.; Roumbedakis, K.; Junior, J. G. S. B.; Nuñer, A. P. O.; Petrucio, M. M.; Martins, M. L., Fish parasites as indicators of organic pollution in southern Brazil. *Journal of Helminthology* **2018,** *92* (3), 322-331.
102. Poulin, R., Meta-analysis of seasonal dynamics of parasite infections in aquatic ecosystems. *International journal for parasitology* **2020,** *50* (6-7), 501-510.
103. Gomes, E. S. Efeitos da degradação ambiental sobre relações parasito hospedeiro em riachos urbanos na amazônia. Instituto Nacional de Pesquisas da Amazônia – INPA, **2020**.
104. Hine, P. M.; Kennedy, C. R., Observations on the distribution, specificity and pathogenicity of the acanthocephalan Pomphorhynchus laevis (Müller). *Journal of Fish Biology* **1974,** *6* (4), 521-535.
105. Palm, H. W.; Poynton, S. L.; Rutledge, P., Surface ultrastructure of plerocercoids of Bombycirhynchus sphyraenaicum (Pintner, 1930)(Cestoda: Trypanorhyncha). *Parasitology Research* **1998,** *84*, 195-204.
106. Rohde, K.; Hayward, C.; Heap, M., Aspects of the ecology of metazoan ectoparasites of marine fishes. *International journal for parasitology* **1995**, *25* (8), 945-970.