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Review

Interactive effects of infectious diseases and pollution in aquatic molluscs

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ABSTRACT

Aquatic molluscs are ideal invertebrate model systems for environmental monitoring and toxicology. However, like all animals, they are subjected to a wide range of infectious diseases that can have significant effects on host ecology and physiology and are therefore a source of natural stress to populations. Anthropogenic activities, especially involving chemical contaminants that pollute the environment, can also affect molluscan ecological and physiological parameters.

In combination, pollution and pathogens represent a serious threat to the health of aquatic communities that has been increasingly recognised. The present article reviews the interactive effects of viral, bacterial, protozoan, and trematode infections with toxic pollutants on aquatic molluscs. The interactions between pollution and other less well studied infectious diseases as well as the differing responses to pathogens and pollution between wild and cultured molluscan populations are also considered.

Contents

1. Introduction

Molluscs are common organisms in aquatic habitats and ecologically and commercially important on a global scale (Rittschof and McClellan-Green, 2005). Many species are sedentary, fairly resistant to chemical contamination, and often reside in regions where less hardy organisms cannot survive (O'Connor, 2002). Consequently they are ideal invertebrate model systems for aquatic environmental monitoring and toxicology (Rittschof and McClellan-Green, 2005). Nevertheless, like all animals, molluscs are subjected to a wide range of infectious diseases, which can affect host ecology, immunology, and physiology and may consequently be a source of natural stress to populations. Infectious diseases are caused by specific organisms that live in intimate associations with individual hosts and have detrimental effects on their biology. Disease causing organisms can have a significant negative impact on aquatic species and communities (Harvell et al., 1999).

Human activities, especially those that have resulted in chemical contamination of the environment, have also increased the potential stresses on molluscs in exposed habitats. Pollution, even

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at low concentrations can have drastic effects on the physiology, immunology and ecology of molluscan populations (Rittschof and McClellan-Green, 2005). The interactions between infectious diseases and pollutants in aquatic communities have therefore become an increasing area of concern (Khan and Thulin, 1991; Sindermann, 1995; Lafferty, 1997; Morley, 2009). In combination these two kinds of stressors potentially may be synergistically detrimental to affected population. Molluscs, due to their medical, veterinary and economic importance have been the subject of numerous investigations in recent years. Many of the important earlier studies on marine molluscs were reviewed by Sindermann (1990, 1995), although subsequently a much larger body of literature in both freshwater and marine systems has been published and it is now timely that this work is reviewed and evaluated.

The purpose of the present article is to summarise the work to date on viral, bacterial, protozoan and metazoan diseases of molluscs in polluted conditions. It is not intended to discuss those human diseases, such as *Cryptosporidium* and *Giardia*, whose cysts are found by accident in filter feeding molluscs and therefore act only as 'mechanical vectors' rather than genuine hosts. In addition the differences and similarities between wild and cultured molluscan populations response to pollution and pathogen stress is also assessed.

2. Interactions between infectious diseases and pollution

2.1. Viral diseases

The study of viral diseases that infect and replicate in molluscs is still in a largely embryonic state, limited by the lack of mollusc cell lines and the restricted application of molecular tools (Renault and Novoa, 2004). Viruses are known from both marine and freshwater molluscs (Johnson, 1984; Rondelaud and Barthe, 1992; Renault and Novoa, 2004) although so far studies in relation to pollution have been confined to marine species.

Stress is considered a major factor in the outbreaks of viral diseases in marine invertebrates (Johnson, 1984). Thermal pollution, in particular, has been considered as a stressor in viral epizootics of molluscs. Farley et al. (1972) found elevated levels of a Herpes-type virus in oysters from thermally heated effluent water of a power station. Laboratory studies on the pathology of a birnavirus to hard clams (*Meretrix lusoria*) under different temperature regimes found similar results. An increase in temperature after infection caused elevated mortalities, but decreasing the temperature after viral infection or changing the temperature prior to viral exposure had no affect on host mortality (Chou et al., 1994).

Additional laboratory studies using the same host–virus system investigated the effects of heavy metals (cadmium, copper, zinc, mercury) on clam susceptibility to viral infection. Exposure to virus followed by metals resulted in increased clam mortalities compared to controls of up to 52% after 5 weeks. However, exposure to metals for 1 week followed by viral inoculation resulted in greater mortalities of up to 90% 5 weeks post-inoculation (Chou et al., 1998).

Data derived from this study have subsequently been used as a basis for modelling the predicted interactions between clams and birnavirus under metal stress. Liao et al. (2006) and Liao and Yeh (2007) concluded that the immunomodulating effects of metal pollution is an important determinant influencing population dynamics of disease transmission, increasing susceptibility of molluscs to infection. However, host population size, life stage or density and the manner of stress exposure (virus + metal or metal + virus) are important factors in disease dynamics. Additional modelling by Liao et al. (2008) on the impact of predation to this metal exposed host–virus system concluded that a relatively low predation rate where predators captured only infected clams resulted in an increase in *M. lusoria* abundance because predation caused an increase in the number of healthy individuals in the mollusc population and reduced the incidence of pathogenic infection.

Viruses are known to cause many kinds of cancers in both infected humans and wildlife (Sindermann, 1990; McLaughlin-Drubin and Munger, 2008) and in mammals a number of studies have found synergistic cancer causing interactions between viruses and toxic chemicals (Sattar et al., 2007). For molluscs, cancerous tumours have been widely reported (Sindermann, 1990), particularly associated with pollution (Mix, 1986), although the potential interactions between viruses, pollution, and cancer have yet to be fully elucidated. Nevertheless for disseminated neoplasia, a cancerous condition of bivalves, some intriguing findings have been revealed.

Disseminated neoplasia has been reported from many species of bivalves and is a proliferation of abnormal circulating cells of unknown origin (Barber, 2004). A viral agent has been implicated in the aetiology of the disorder for many species e.g. Barber (2004), Romalde et al. (2007), although this interpretation is not without controversy because of the difficulties in repeating experiments by other researchers (Barber, 2004). Nevertheless experimental studies appear to indicate that any viral agents are likely to be host species specific (Kent et al., 1991). The impact of pollution on the occurrence of disseminated neoplasia has been extensively studied in the field with mixed conclusions (Barber, 2004). Although many studies found a correlation between the prevalence of the condition and pollution (Yevich and Barszcz, 1976, 1977; Hillman, 1993) equally a number of studies could find no relationship between neoplasia and environmental contamination (Brown et al., 1977; Krishnakumar et al., 1999). Mix (1986) considered such results were not unexpected when most studies were of insufficient size and scope or lacked reliable chemical data to address the issue. Laboratory studies also provide mixed results indicating that xenobiotic toxicity alone was insufficient to induce cancer (Barber, 2004). It is therefore likely that pollution is probably not a specific cause of disseminated neoplasia but may act to exacerbate pre-existing conditions induced by an infectious (viral) agent leading to increased molluscan stress and enhanced cancer development (Barber, 2004).

Interactions between contamination and viruses in the molluscan host obviously may not always lead to cancer. Nevertheless a number of mammalian studies have demonstrated that chemical exposure can cause reactivation of latent viral infections or that viruses may modify the detoxification of other pollutants (Sattar et al., 2007).

An important factor in viral transmission in polluted conditions is the potential impaired viability of any pathogen free-living stages. Viruses represent the most abundant component in aquatic ecosystems (Fuhrman, 1999) although little is known about their own susceptibility to xenobiotic toxicity. Studies on the exposure of a water-borne free-living stage of a birnavirus of clams demonstrated no susceptibility to zinc or cadmium, however exposure of both copper and mercury resulted in a reduced viral stability in seawater over a 28-day period (Chou et al., 1998). In contrast, exposure of the free-living stage of the fish virus VHSV (viral heamorrhagic septicemia virus) to crude oil did not impair survival compared to controls (Kocan et al., 2001). It therefore seems likely that survival and transmission of free-living viral stages in polluted conditions is influenced by the specific contaminants present.

2.2. Bacterial diseases

Bacterial infections of molluscs have been widely reported (Malek and Cheng, 1975; Sindermann, 1990) although there are