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Review

Global warming and environmental contaminants in aquatic organisms: The need of the etho-toxicology approach

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HIGHLIGHTS

- Temperature affects distribution and toxicity of environmental chemicals in water.
- We assess papers, reviews and organizational reports available on this issue.
- Effects of warming in a contaminated world on aquatic organisms are reported.
- We propose an etho-toxicological approach to study chemical and thermal interplay.

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ABSTRACT

Environmental contaminants are associated with a wide spectrum of pathological effects. Temperature increase affects ambient distribution and toxicity of these chemicals in the water environment, representing a potentially emerging problem for aquatic species with short-, medium- and long-term repercussions on human health through the food chain. We assessed peer-reviewed literature, including primary studies, review articles and organizational reports available. We focused on studies concerning toxicity of environmental pollutants within a global warming scenario. Existing knowledge on the effects that the increase of water temperature in a contaminated situation has on physiological mechanisms of aquatic organisms is presented. Altogether we consider the potential consequences for the human beings due to fish and shellfish consumption. Finally, we propose an etho-toxicological approach to study the effects of toxicants in conditions of thermal increase, using aquatic organisms as experimental models under laboratory controlled conditions.

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1. Introduction

The increase of temperature is universally thought to be one of the main effects of climate change (IPCC, 2007). The Intergovernmental Panel on Climate Change (IPCC) reports a linear warming trend over the last 50 years at an average rate of 0.13 °C per decade, and foresees a further warming of about 0.1–0.2 °C per decade, even if greenhouse gases and aerosol emissions will be kept constant (IPCC, 2007).

Changes in temperature might entail a variety of consequences on the health status of millions people, in particular of vulnerable

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population groups such as pregnant women, infants, children and the elderly (Confalonieri et al., 2007; Sheffield and Landrigan, 2011). One of the effects of the increase of temperature is its influence on physical, chemical and biological properties of aquatic ecosystems, with predominantly adverse impacts on the water quality, as well as animal and plant communities' composition (IPCC, 2007). Indeed, temperature alteration could cause changes in planktonic production or timing of animal migrations, finally affecting the animal and plant structures at the higher trophic levels.

Furthermore, one of the consequences of the rising temperature recently attracting attention is its potential to alter the environmental distribution and characteristics of chemical toxicants, suspected to be endocrine disruptors at environmentally relevant levels of human exposure. Temperature is thought to have a large influence on the partitioning of environmental contaminants, such as Persistent Organic Pollutants (POPs) and pesticides, in soil, water and atmosphere (Noyes et al., 2009). Most of these substances bioaccumulate in food chains and persist in the environment for many years (EFSA, 2005; Evans et al., 2005; UNEP/AMAP, 2011).

The aquatic communities, despite showing resilience and buffering capacities to environmental changes, reach endpoints with irreversible or hardly-reversible detrimental consequences in chronic stress situations, such as the presence of toxic agents (Schramm and Nienhuis, 1996; Valiela et al., 1997). The tight interaction between environmental variation and behaviour has induced researchers to use behavioural indicators in fishes for ecologically relevant monitoring of environmental pollution (Atchison et al., 1987). Inappropriate behavioural responses to external stimuli, due to detrimental effects of aquatic contaminants, can have severe implications for survival at individual and population level (Weber, 1993; Webber and Haines, 2003).

The purpose of this review is firstly to provide a brief overview on what is known about potential or actual effects that temperature increase can exert on environmental toxicants' presence in aquatic organisms, thus indirectly on human health by fish and shellfish consumption. Then, we provide suggestions for future experimental approaches which could contribute to increase the knowledge on this issue. Specifically, we indicate the use of aquatic organisms as valid animal models to investigate the impact of the thermal conditions on neurobehavioural toxicity of environmental contaminants.

1.1. Impact of temperature increase on the environmental contaminant characteristics

Studies on the impact of climate change on toxicity of environmental compounds describe the increase of temperature as possible cause of chemical and physical alterations in the behaviour of polluters, with influence in their distribution and toxicity (MacDonald et al., 2005; Dalla Valle et al., 2007; Noyes et al., 2009). Temperature variation may alter processes as polluting degradation, ambient partitioning, switching and depletion of solvent (MacDonald et al., 2002; Meyer and Wania, 2008). Specifically, rising temperature is expected to enhance the degradation, as well to alter partitioning of contaminants such as POPs into different phases (solid, liquid, gas), with increase of toxic concentration in a specific environmental compartment (sediment, water, biota, etc.) (Sweetman et al., 2005). Furthermore, it has been suggested that temperature enhancement may influence the degradation rate of many redox-sensitive organic pollutants, inducing changes in physicochemical characteristics of water such as redox conditions (Bourg and Bertin, 1993; Massmann et al., 2008).

Moreover, some authors underline as ice/snow melting will enhance wet deposition of polluting material to aquatic and terrestrial ecosystems, with consequent impact on toxicant biomagnifications pathways – the progressive increase in concentration of these substances through the food chain – by alteration in individual lipid dynamics, shifting in population size distribution and length and complexity of food chain (MacDonald et al., 2002, 2003; Meyer and Wania, 2008).

1.2. Impact of temperature increase on the environmental contaminant-linked effects on aquatic organisms

Methylmercury, polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins (PCDDs) and various organochlorine insecticides are commonly found in aquatic vertebrates (Muir et al., 2003; Borghesi et al., 2009; Webster et al., 2011). Environmentally relevant concentrations of pollutants studied under controlled laboratory conditions have been found to have an impact on aspect implicated in the survival capacity of aquatic animals such as body size, sex ratio and puberty onset (Berg et al., 2001).

Generally, the concentration of environmental toxicants depends on predatory nature, lifespan and body size of animals (EFSA, 2005; Alleva et al., 2006; Michelutti et al., 2010). Larger and longer-living predators show higher tissue toxicant concentration than smaller or shorter-living species; nevertheless the estimation of bioaccumulation and biomagnification processes is really difficult as numerous parameters such as large variability of food webs, compound's lipophylicity and toxicokinetic have to be considered in the mathematical models used (Alonso et al., 2008). Furthermore, patterns of fecundation and development of embryos may influence the presence of toxicants in animal tissue, as well as the spread and distribution of species or local populations. Organisms with external fecundation, where eggs are laid on algae or other substrates, can be more dangerously exposed to toxic agents and thus more affected by presence of toxicant at the population level than species retaining eggs inside until their hatching.

Many studies on interactions between thermal stress and chemicals have been conducted on heavy metals (e.g., nickel, copper, cadmium, lead and zinc) with main focus on aquatic organisms such as oysters, crayfish, zebrafish, isopods, and amphipods (Hallare et al., 2005; Perschbacher, 2005; Khan et al., 2006; Lannig et al., 2006; Furuta et al., 2008).

The interaction between thermal conditions and toxicants is complex and can occur at different levels (Richards and Beitinger, 1995; Gordon, 2003). Toxicity power of contaminants has been found to increase following the raising of water temperature (Gaunt and Barker, 2000); chronic thermal stress exacerbates the toxicity of the contaminants in aquatic species (Slotsbo et al., 2009). As a matter of fact, Buckman and colleagues (2007) described enhanced presence of toxicologically-active PCB metabolites in rainbow trout tissues upon temperature elevation, and a similar trend has been reported for copper toxicity (Boeckman and Bidwell, 2006; Khan et al., 2006). Further, a significant temperature-dependent increase in cadmium concentration in the isopod *Porcellio scaber tissues* has been found (Abdel-Lateif et al., 1998). Moreover, the presence of contaminants in the water environment affects the temperature tolerance of fishes (Mayer and Ellersieck, 1988; Patra et al., 2007).

The chemical–physical characteristics of environment (i.e., water temperature) play a relevant role in the response of organisms to external stressors (i.e. pollutant presence) (Holmstrup et al., 2010; Laskowski et al., 2010). Specifically, alterations in temperature or humidity influence the physiological responses of vertebrates to chemical toxicants (Mayer et al., 1991; Heugens et al., 2001).

So far there are relatively few studies addressed at understanding the mechanisms by which environmental stress modulates the