Potential effects of climate change on the chemical quality of aquatic biota

Mario Carere, Roberto Miniero, Maria Rita Cicero

Climate changes can alter and modify the distribution and the partitioning of contaminants in water bodies through several factors (e.g., rise in temperature, decrease in oxygen through water scarcity, acidification and remobilization of pollutants in sediments due to flooding). Other indirect effects can be linked to climate changes (e.g., increased use of pesticides due to the rise of plant diseases caused by new vectors and erosion of coastal areas due to rise in sea level). All these factors have the potential to enhance the bioavailability of dangerous pollutants with bioaccumulative properties with an increasing risk of transfer in the food chain.

The data available on aquatic species for compounds such as, polychlorinated biphenyls, dioxins and mercury show that the legislative standards for food are exceeded in some areas. These data also show that levels in aquatic biota of other emerging compounds with bioaccumulative properties (such as, perfluorinated octane sulfonate, polybrominated diphenyl ethers and hexabromocyclododecane can be relevant in some areas and at some trophic levels. In particular, the effect of climate changes can be relevant in vulnerable water bodies (e.g., estuaries of rivers or coastal lagoons), where fishing, extensive and intensive aquaculture activities and sites of high biodiversity value are often present.

For these reasons, there is a need to change the water-monitoring strategies with a focus on analytical methods for biota determination and to have monitoring programs that include detection of long-term trends and share procedures for the setting of quality criteria for biota.

Keywords: Acidification; Aquatic biota; Bioaccumulation; Chemical quality; Climate change; Contaminant; Dangerous substance; Flooding; Monitoring program; Temperature

Abbreviations: BAF, bioaccumulation factor; BCF, bioconcentration factor; BMF, biomagnification factor; CIS, common implementation strategy; EQS, environmental quality standard; WFD, water framework directive; WHO, World Health Organization

Mario Carere*,
Roberto Miniero,
Maria Rita Cicero
National Institute of Health,
Department of Environment,
Viale Regina Elena,
299, 00161 Rome,
Italy

1. Introduction

The global mean surface temperature has increased by 0.74 ± 0.18°C over the past 100 years, while the global average sea level has risen by 1.8 mm per year since 1961, and Arctic sea ice is shrinking by 2.7 ± 0.6% per decade. In addition, mountain glaciers are retreating at increasing rates, surface ocean waters are getting more acidic and more frequent extreme weather events have been observed. Changes in the water cycle are likely to increase the risk of floods [1,2]. An increase in intensive short-term precipitation in most of Europe is likely to lead to an increased risk of flash floods [3], particularly in the Mediterranean and Eastern Europe [4]. Palmer and Raisanen concluded that in Europe the risk of extreme precipitation and flooding would increase in the future because of rising levels of atmospheric carbon dioxide [5]. The same authors predicted that, in winter over Europe, the probability of extremely high seasonal precipitation will increase by about 2–5 times over the course of the next 50–100 years.

Potential impacts on water supply have received much attention, but relatively little is known about the concomitant changes in the chemical quality of water. Projected changes in air temperature and rainfall could affect river flows and, hence, the mobility and the dilution of contaminants [6].

Water quality may be impacted by climatic changes in temperature [7,8]. A rise in water temperature will affect the rate of biogeochemical and ecological processes

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*Corresponding author.
E-mail: mcarere@iss.it

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that determine water quality. The increase of water temperature in streams and lakes can reduce oxygen solubility and increase biological respiration rates, which may therefore result in lower dissolved-oxygen (DO) concentrations, particularly in summer low-flow periods and in the bottom layers of lakes.

In the Great Lakes in the USA, a study highlighted that increasing temperatures will also substantially impact physico-chemical processes, including thermal stratification, nutrient cycling and, importantly, contaminant dynamics [9]. Great Lakes sediments currently contain millions of cubic meters of contaminated material, including persistent, bioaccumulative substances [e.g., polychlorinated biphenyls (PCBs)]. Increasing temperatures, changes in precipitation, and seasonal patterns will affect contaminant transport, deposition, and remobilization, and thus could lead to enhanced reemission of legacy contaminants (e.g., PCBs) in such environments.

Contaminant uptake in organisms will also be subject to altered exposure and transfer pathways [10–12]. In Italy, there are contaminated sites in marine-coastal and transitional waters in which there are high levels of bioaccumulative compounds in sediments {e.g., mercury, polyaromatic hydrocarbons (PAHs), PCBs, dioxins and dichlorodiphenyltrichloroethane (DDT) [13]}.

The environmental impact of floods occurring in large rivers includes clogging up water-treatment plants (potentially leading to the release of large quantities of contaminants), damage to vegetation and the mobilization of contaminants present in the soil. Increased incidence or severity of floods has the potential to cause widespread chemical contamination. Floods may have the capacity to re-mobilize and to re-distribute large amounts of contaminants and could cause overflow from toxic-waste sites.

Acidification of the oceans, resulting from increased levels of carbon dioxide in the atmosphere, is one of the main effects of climate change [14]. The magnitude and the consequences of acidic deposition across the landscape are influenced by a variety of factors including the distribution and the concentration of acids in wet and dry deposition, elevation, precipitation volume, vegetation type and biogeochemical processes that neutralize acidic deposition [15,16]. Oxygen solubility in water has an inverse relationship with water temperature. An increase in temperature both decreases the DO supply (through reduced saturation concentrations relative to air) and increases the biological oxygen demand (BOD).

Intense rainfall and wetter winter conditions favor acidic episodes [17,18]. Droughts can further exacerbate acidification by creating lower water tables and enhanced oxidation of sulfur to sulfate [19,20]. Acid anions are exported during subsequent storm events, along with heavy metals [21]. With increased intensity of storms, dilution of basic cation concentrations during storm events should also increase [22]. Increasing CO_2 in the surface ocean causes major shifts in seawater-carbonate chemistry and is likely to reduce pH by 0.2–0.4 units over the course of this century [23].

Bloomfield et al. [24] have undertaken a review of climate-change impacts on pesticides in surface waters and groundwaters and concluded that changes in temperature, rainfall intensity and seasonality will affect pesticide release and transport. In specific water bodies (e.g., coastal lagoons), temperature increases will influence organism metabolism and niche distribution, affect species interactions, and modify the structure of the food web, biogeochemical cycles and primary production [8].

The situation described and the changes of the physico-chemical properties of water bodies can have a significant effect on the bioavailability of the compounds that are present in water bodies. Warming temperatures and changing weather patterns, acidification and reduced DO can remobilize and modify chemical partitioning. Climate changes can exacerbate the effects of the bioaccumulative compounds in water bodies with an increasing risk for the trophic chains, in particular for the top predators and humans that consume fish products. Fish can make a major contribution to dietary human exposure to environmental contaminants, particularly polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran (PCDD/F), dioxin-like PCBs (DL-PCBs) and methylmercury. Species, season, location, diet, life stage and age have a major impact on the levels of contaminants in fish. These levels vary broadly within species and between species [25].

2. Existing data on bioaccumulative compounds

Although some of the most persistent, bioaccumulative and toxic substances introduced into the environment by human activity have been banned or restricted in use, many persist, especially in soils and sediments, and remain in contact with food chains or can be remobilized and taken up by aquatic biota. The list of dangerous substances that are managed by the environmental policy-makers for the aquatic environments usually include several compounds with bioaccumulation properties. An example is given by the list of priority and priority hazardous substances selected in the context of the Common Implementation Strategy (CIS) of the European Water Framework Directive (WFD) [26,27] that comprises mainly substances with bioaccumulation properties. In the context of the CIS, there is in course a review for a new list of compounds and most of the compounds reviewed have strong bioaccumulation properties [e.g., PFOS, HBCDD, PCB,