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FOCUSED REVIEW

Negatives and Positives: Contaminants and Other Stressors in Aquatic Ecosystems

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Abstract

Published research is reviewed to provide examples of both positive and negative interactions of contaminants and: climate change; habitat change; invasive and introduced species; and, eutrophication including harmful algal blooms. None of these stressor interactions results solely in negative effects. Research must shift from examining contaminants or other stressors in isolation to considering potential positive and negative effects of interactions, with the ultimate goal of providing the necessary information for the effective management of ecosystem services.

Keywords Contamination · Climate change · Habitat change · Invasive species · Harmful algal blooms · Eutrophication · Ecosystem services

With the publication of the 100th volume of the *Bulletin of Environmental Contamination and Toxicology*, it is appropriate to consider how contaminants may, in the future, interact with other stressors in aquatic ecosystems. The other stressors, in order of relative importance, are: climate change, habitat change, invasive species including introduced species, and eutrophication including harmful algal blooms (Chapman 2016a). Climate change causes a great number of changes to our world that affect us directly, as well as indirectly, by its effects on other stressors including chemical contaminants.

This short review of research on the positive and negative outcomes of chemical contamination and other stressor interactions in aquatic ecosystems is not intended to be comprehensive or complete. Rather, its purpose is to encourage researchers to fully assess future interactions of contaminants and other stressors, and the relevance of such positive and negative interactions to maintaining necessary ecosystem services.

Chemical contamination and climate change: climate change and resulting sea level rise will result in seawater inundation of nearshore areas, flooding, and salinification, all of which will alter the biogeochemistry of historically contaminated soils. Freshwater resources will change, affecting stream and river flows (Shrestha et al. 2017), with resulting effects on resident freshwater biota. In some cases climate change will not affect chemical contamination. For instance Freitas et al. (2017) found that, under predicted ocean acidification scenarios, mercury contamination did not induce higher impacts in polychaetes compared to present conditions. The interaction of chemical contamination and climate change on community structures is ecosystem and contamination-specific (Menezes-Oliveira et al. 2014).

In Memoriam: Peter M. Chapman Dr. Peter M. Chapman, author of this article, passed away on September 26, 2017. In a groundbreaking paper, Ed Long (Long and Chapman 1985) and he introduced the sediment quality triad. The sediment quality triad was one of the earliest examples of using a weight of evidence approach to the correspondence between chemical concentration and bioassay results to effects in infauna. The paper was a key in moving environmental toxicology from mere hazard assessment to an integration of exposure and effect for decision making that is the basis of ecological risk assessment. Dr. Chapman made important contributions to the study of metals in sediments and was a relentless advocate for the use of regression methods to describe exposure-response relationships. His interest in sediment toxicology continued throughout his career as evidenced by his recently published paper (Chapman 2016d) on when to either use or not use benthic organism gut contents to assess bioaccumulation. As a journal editor, he encouraged the publication of new methods, set up lively learned discourses, and was relentless in his search of accuracy and fairness. This paper illustrates those qualities.

Dr. Peter Michael Chapman is deceased.

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Some positives: inundation with salt water may lead to less contaminant release from soils than inundation with fresh water due to inhibition of oxide dissolution (LeMonte et al. 2017). Increasing salinity in fresh water will reduce the bioavailability and thus toxicity of many metals (Chapman 2008) and other contaminants (Duchet et al. 2010). Nanoparticles can protect organisms against ultraviolet light by scattering and sorption, and by accumulation within the bodies of organisms (Liu and Wang 2017).

Some negatives: climate change includes global warming, which will generally increase the toxicity of chemicals (Kimberly and Salice 2013; Laetz et al. 2014; Chapman 2016b) or, in cases where toxicity does not increase due to acclimation, adversely affect energy reserves. For example, Coppola et al. (2017) found that the mussel *Mytilus galloprovincialis* bioconcentrated less mercury with higher temperature, but this was because their valves closed for longer time periods at higher temperature. This resulted in reduced energy reserves contributing to higher oxidative stress. Conversely, chemical contaminants may reduce thermal tolerance (Little and Seebacher 2015).

Resident aquatic organisms may develop tolerance to chemical contaminants irrespective of climate change. Pedrosa et al. (2017) found that midge larvae acquired genetically inherited tolerance to cadmium with no apparent costs. In contrast, Jayasundara et al. (2017) found that contemporary evolutionary shifts in the fish *Fundulus heteroclitus* in response to polycyclic aromatic hydrocarbon contamination can compromise their ability to adapt to climate change.

Salting of freshwater bodies will adversely affect fish and other aquatic biota (Dugan et al. 2017). Contaminant toxicity will increase in some cases (Campbell et al. 2014). Sea levels rising above historical soil contamination will change redox conditions and release redox sensitive chemical contaminants such as arsenic (LeMonte et al. 2017) and mercury (Jacobson et al. 2012). Reduced river discharges will result in diminished dilution of chemical contaminants from point and non-point sources, resulting in decreased water quality (Sjerps et al. 2017). Carbon dioxide enrichment in aquatic systems can increase the mobility of sediment-bound metals with consequent increased toxicity (Passarelli et al. 2017), particularly in acidified oceans (Wang et al. 2015).

Chemical contamination and habitat change; some positives: microplastics introduce long-lived hard substrate into aquatic ecosystems that can be colonized (Anderson et al. 2016). For instance, water strider population increases in the North Pacific Subtropical Gyre may be due to increased abundances of microplastics (Goldstein et al. 2012).

Habitat change, resulting in foraging ecology changes, is resulting in lower mercury concentrations in the tissues of southern Beaufort Sea polar bears even though mercury concentrations in the environment have not declined (McKinney et al. 2017). Areas contaminated from mining and processing of metal ores were reported to have relatively high species diversity in a terrestrial beech forest (Woch et al. 2017). Similar species richness from habitat heterogeneity related to aquatic chemical contamination is a possibility.

Microbial communities can rapidly acquire tolerance to metals and other contaminants (Hemme et al. 2010). Tolerant microbes can be used for bioremediation of contaminated habitat (Chakraborty et al. 2012).

Some negatives: microplastics can act as vectors and habitat for invasive species (Wagner et al. 2014) and can themselves be toxic (Peng et al. 2017). Foraging ecology changes may result in extended fasting periods for polar bears leading to reductions in body condition and the release of contaminants stored in fat (McKinney et al. 2017). Decreased wetlands will result in increased nutrient inputs to freshwater resources with resultant increased risks of eutrophication and harmful algal blooms (Cheng and Basu 2017).

Chemical contamination and invasive species; some positives: chemical contamination to which resident species have developed tolerance may inhibit invasive species. For example, De La Riva et al. (2017) found that native ant species in a selenium-contaminated site in California (USA) had a higher tolerance to selenium compared to invasive Argentine ants, whose native range was selenium-deficient.

There may be minimal interactions between water quality contaminants and non-native species as stressors; thus, it may be possible to manage these stressors independently (Maceda-Veiga et al. 2017). Invasive species can enhance ecosystem services (Tassin et al. 2017) and increase diversity with more stability and more resistance to further invasion (Briggs 2017).

Parrot's feather (*Myriophyllum aquaticum*) is native to the Amazon River in South America, but can now be found on every continent except Antarctica, rooting in freshwater streams, ponds, lakes, rivers, and canals that have a high nutrient content (http://eol.org/pages/486767/overview). Dense root systems can increase the stability of contaminated sediments.

Some negatives: chemical contamination and invasive species may cause reduced biodiversity, affecting ecosystem services (Daly and Matson 2008). They may reroute contaminant flows through food chains resulting in greater ecological and human health risks (Ng et al. 2008). Chemical contamination may favor their success (MacDougall and Turkington 2005; Varó et al. 2015; Bielen et al. 2016); they may acquire heritable tolerance to chemical contamination (McKenzie et al. 2011). Invasive plant species such as Parrot's feather may cause problems with drainage and alterations of aquatic ecosystems (http://eol.org/pages/486767/overview).

Chemical contamination and eutrophication including harmful algal blooms: climate change is expected to result in changes in the atmospheric deposition of nitrogen, specifically dominance of dry over wet deposition (Ochoa-Hueso et al. 2017), which can enhance eutrophication by increasing nutrients in water bodies. Eutrophication can result in harmful algal blooms adversely affecting ecosystem services (Dodds et al. 2009). Harmful algal blooms can sometimes be the greatest threat to water quality (Brooks et al. 2017), but their interactions with chemical contaminants have not been well studied to date.

Some positives: increased nutrients in aquatic ecosystems will result in increased concentrations of dissolved organic carbon, which can reduce the bioavailability of contaminants such as metals (Chapman 2008). The incidence of harmful algal blooms and of the toxins they produce may be reduced by chemical contamination (Li et al. 2017).

Some negatives: harmful algal blooms and chemical contamination may adversely affect biota to a greater extent than each individually.

Relevance to ecosystem services: ecosystem services comprise the benefits people obtain from ecosystems, including products such as food, fresh water, medicine; regulating services such as water purification, waste management, pest control; habitat for species and maintaining the viability of gene pools; and, non-material but important cultural services such as spiritual enrichment, intellectual development, recreation, and aesthetic values (Chapman 2012a). Loss of a species does not necessarily affect ecosystem services, provided there is appropriate replacement.

As is apparent from the examples above, there are no exclusively negative or positive effects of contaminants and other stressors. Evaluating the overall effects of stressor-induced changes that can affect the ecosystem services on which human beings rely is not a simple matter. Environmental complexity is a reality that is compounded by stressor-induced changes.

With global climate change we are facing irreversible ecological changes, which we must accept as we cannot prevent them (Chapman 2011), and because such change is not unique to modern times; evolutionary change is a continuing reality especially in this Anthropocene epoch (Ruddiman et al. 2015). Contemporaneous evolution may play a role in maintaining and enhancing ecosystem services (Kinnison and Hairston 2007; Rudman et al. 2017) .We need to more fully understand the changes that are occurring, how they might be affecting ecosystem services, and what we can do to maintain necessary ecosystem services through management actions that do not simply attempt to preserve the status quo (Chapman 2012b); for instance, by introducing selected invasive species into ecosystems rather than relying on chance to provide the necessary invasive species to maintain necessary ecosystem services (Chapman 2016c).

As Stephen Dobyns noted (http://www.azquotes.com/author/4019-Stephen_Dobyns) "Actions have consequences. Ignorance about the nature of those actions does not free a person from responsibility for the consequences." Too often researchers only focus on the negative aspects of contaminant interactions when there are also positive aspects. We need to attempt to understand all aspects of the interactions between chemical contaminants and other stressors to make appropriate management recommendations focused on the maintenance of ecosystem services in the face of ongoing environmental change and uncertainty (Polasky et al. 2011). Future research focused on both positive and negative stressor interactions is not only encouraged, it is essential information for appropriate adaptive management to our changing environment.

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