Integrated Environmental Assessment and Management — Volume 10, Number 4—pp. 483–484

Global Climate Change and Contaminants, a Call to Arms Not Yet Heard?

A consensus has existed from the mid-2000s that climate change is occurring and is the result of anthropogenic causes (Oreskes 2004). Noyes et al. (2009) published the first description of the potential interactions between a warming environment and toxicology. Four years ago, an editorial in *Integrated Environmental Assessment and Management* (Wenning et al. 2010) called upon members of the Society of Environmental Toxicology and Chemistry (SETAC) to develop research on the potential interactions between global climate change (GCC) and environmental contaminants. An international, Pellston-style SETAC workshop in 2011 focused on the potential influence of GCC on the foundations (chemical fate, mechanistic/population ecotoxicology) and applications (human and ecological risk and injury assessments) of environmental toxicology and chemistry. This workshop resulted in 7 articles published in *Environmental Toxicology and Chemistry* in 2013 (Climate Change Series [CCS]) and 3 of these have achieved "SETAC top article" status as determined by internet downloads.

Despite the Pellston Workshop and several SETAC calls for research, there continues to be a lack of studies seeking to understand the interactions between climate change, contaminants, and environmental risk. We were hoping for more but recognize that these are early days.

We can point to several national and international reports on climate change highlighting specific plans and needs for adapting to and mitigating impacts of GCC. In 2013, the European Environment Agency (EEA) published the reports *Climate Change, Impacts and Vulnerability in Europe 2012* and *Adaptation in Europe—Addressing Risks and Opportunities from Climate Change in the Context of Socio-Economic Developments* (EEA 2012, 2013), and in May 2014, the United States published the Third National Climate Assessment: *Climate Change Impacts in the United States* (USGCRP 2014). The comprehensive 2014 report from the Intergovernmental Panel on Climate Change Working Group II on Impacts, Adaptation, and Vulnerability (IPCC 2014) documents a number of observed and predicted effects. The interactions of GCC with land-use change, water resource development, invasive species, increased economic activity, and biofuel crop cultivation are explicitly recognized. However, these reports do not explicitly recognize how xenobiotics can be a critical contributing factor to the risks that GCC presents to the environment.

On the other hand, why would the climate change community acknowledge the importance of the altered mobility and toxicity of contaminants if the field of environmental toxicology, chemistry, and risk assessment does not advance this area of research and articulate its importance to the broader scientific community?

The fundamental assumption of the Pellston work is that chemicals and climate change co-occur and what is done to manage one affects the impacts of the other, or has already. Stahl et al. (2013) points to 5 consensus observations.

The first point of consensus is that human actions, including mitigation of and adaptation to GCC, might have as much influence on the fate and distribution of chemical contaminants as does GCC, and modeled predictions should be interpreted cautiously. Mitigation for the causes and adaptation to the effects GCC can include the movement of sediment, the creation of dikes, flood control, the search for new energy sources, and changes in agricultural practices. Because of the ubiquity of anthropogenic chemicals, each of these mitigation and adaptation strategies could also include changes in the fate and transport of chemicals.

The second point of consensus is that climate change affects the toxicity of chemicals, but stress from chemicals can also affect organisms' ability to acclimate to GCC. Environmental changes caused by climate change might limit the molecular and physiological adaptation of an organism to intoxication by altering rates of uptake, detoxification, and excretion. Similarly, the physiological burden of exposure to a chemical might alter temperature regulation, responses to acidification, or responses to water availability. At a population scale, these molecular and physiological interactions alter the fitness landscape, limiting or enhancing evolutionary adaptation to changing conditions and potentially leading to enhanced risks to human health.

The third point is that the effects of GCC are slow, variable, and difficult to detect, although some populations and communities of high vulnerability might exhibit responses sooner and more dramatically than others. Just as the rates and trajectory of climate change vary depending on location, so will its effects. The ecological effects will also vary depending on the life-history strategies of the organisms, exposure to current stressors, the patchiness and isolation of the environment, and the genetic plasticity of the population. Previous and current chemical or nonchemical stressors might also affect the response of populations and communities to future events. GCC may ameliorate the effects of chemicals by reducing exposure, altering habitats, making the prediction of impacts and their probabilities challenging.

The fourth point of consensus is an integration of the first 3 applied to risk assessment. Human and ecological risk assessments need to incorporate multiple stressors and cumulative risks that consider the wide spectrum of potential impacts stemming from concurrent GCC and toxicant stressors. Predictions of risk associated with contaminant exposure that do not incorporate change driven by GCC and the mitigation efforts will be less accurate and include an increasing uncertainty. Risk assessments not including GCC stressors will result in incorrect distributions of risk, under predicting or over predicting the severity and probability of effects.

The fifth point is that baseline, or reference environmental conditions for estimating resource injury, restoration, or rehabilitation will continually shift because of GCC. Findings from the IPCC and other organizations identify that climate change and its effects are ongoing phenomena that date back several decades. Baseline conditions derived from even 30 years of environmental data to represent variability around an equilibrium value and without an anthropogenic forcing

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Published online in Wiley Online Library
(wileyonlinelibrary.com).
DOI: 10.1002/ieam.1568

function are not viable for projecting goals for future environmental work. Given suspected rates of change in climate and the cultural rate of adaptation expected in the future, the notion of an equilibrium or "natural" state needs to be replaced by a more dynamic concept of a "moving reference condition" (Johnson et al. 2010; Moe et al. 2014), or a reference condition based on societal goals and ecological attainability.

Stahl et al.'s (2013) 5 points of consensus are a call to arms for research to advance our understanding of environmental chemistry and toxicology in the context of GCC. Awareness needs to be nurtured in the fields of environmental chemistry and GCC about the importance of interactions between anthropogenic chemical mobility and persistence and GCC. Research efforts in environmental toxicology and GCC need to investigate the interactions among altered climate, chemical exposure and species susceptibility to bioaccumulation and toxicity, including human susceptibility. Regulatory organizations charged with environmental assessment, monitoring, and management must encourage the research on and development of effective risk assessment tools that incorporate GCC.

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