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Editorial

Per- and Polyfluoroalkyl Substances, Microplastics, and COVID-19: Will We Ever Learn?

At the time of this writing, the coronavirus pandemic has the attention of the entire world. It has been aptly referred by many scientists as the ultimate Black Swan event; that is to say, an extremely surprising random occurrence that is having a huge impact on the world economy and that experts try to explain away as something that was predictable, if only we had had the imagination to foresee it.

The rapid spread of the virus to all corners of the globe, the number of infections, and the death toll are beyond belief in a world that unwittingly celebrated the beginning of a new decade just a few months ago. This global health emergency reminds us that we live in a deeply interconnected world. It focuses our attention on the most vulnerable in society, on the need for global cooperation, and on the importance of professional leadership and expertise.

Sound familiar? Coronavirus disease 2019 (COVID-19) is preceded by several environment and health emergencies that we felt, at that time, would also remind us of a shared humanity, our inseparable connection to the environment, and the need for unity. Perhaps most prominent prior to the emergence of the coronavirus were the alarms sounding about the pervasive presence of plastic debris in our oceans, microplastics in the food chain and consumed by people, and the widespread use of the newly designated class of forever chemicals called per- and polyfluoroalkyl substances (PFAS). In fact, these are the latest in a long list of emergencies and calls for action dating back to recognition in the 1960s of the dangers posed by DDT and pesticides and, thereafter, by Hg, PCBs, dioxins, and flame retardant substances.

In hindsight, each time our response has been predictable. Shock and horror are soon replaced by laying blame and finger pointing, filing lawsuits (certainly true in the United States), and regulatory bans. With respect to chemical hazards, early reactions reflect our concerns for public health and as time passes migrate to the possible consequences for the environment and for wildlife. Scientific studies are commissioned, investigation methods are devised, and work is conducted around the world. The results arrive, and scientific and legal arguments ensue, claiming bias in the study methods, analysis, and interpretation of the data used to support certain points of view. Meanwhile, the onslaught of laboratory experiments and environmental monitoring continues, taking full advantage of the sudden availability of financial resources and opportunities to claim leadership and capture the public's worried attention. Concurrent with this sequence of events is the deluge of papers submitted to scientific review panels and technical journals for peer review where the information is debated and more often than not found to be incomplete and requiring further investigation. The cause of the crisis is rarely understood. The scientific process takes years to clarify and at a snail's pace; all the while politicians formulate regulatory policy and move forward to appease a panicked public.

And, so it goes…until the next Black Swan event.

Society should be increasingly immune to surprise by Black Swans. The ability to predict the consequences of human activities and technological inventions—both chemical and mechanical—have improved immensely during our professional lives. Scientists understand well the consequences of human intervention in nature and subsequent cause-and-effect relationships. This has been our life's work.

Should we have been surprised that halogens bound to aromatic rings are persistent and resistant to degradation? That materials with high logP values bioaccumulate or biomagnify? Should we have been caught unawares that volatile materials are transported by the atmosphere for long distances? If materials are made resistant to chemical, temperature, or biological degradation, then should we be surprised to find those same materials in our drinking water, soil, sediment, or biota? Chemical structures and structure–activity relationships are well understood; so should we not be surprised, for example, when certain substances behave as predicted and affect metabolic pathways or disrupt endocrine functions?

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The fundamental question society faces today, and most certainly the scientific community, as a consequence of the ongoing coronavirus pandemic, is not whether we have sufficient knowledge of the fate and effects of chemicals or plastics or even viruses on the environment and human health; it is whether we are able to connect scientific observation and theoretical study to real-life consequences.

We appear to suffer from a grand “not-in-my-backyard” attitude, wherein we have a void in our imaginations and ingenuity that inhibits our ability to translate science safely

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to the function and enjoyment of our daily lives. We simply do not have sufficient knowledge of our place in nature or control of our imaginations to foresee consequences, ask key questions, and to put a process in place. Can it be that we fundamentally misunderstand cause and effect?

Pearl and Mackenzie (2018) describes 3 levels on the ladder of causation. The ladder is a metaphor for understanding potential realities. The lowest step of the ladder is what he calls "seeing," that is, observing how variables may be associated. In statistics this level corresponds to observing associations. And although the late Peter Chapman would gladly remind us all that "association is not causation," associations can suggest places to investigate. The second step of the ladder is "intervention." Experiments are interventions; the classic before-and-after control field design is another excellent case. However, experiments may lead to an understanding that after *x*, then *y* occurs, but not lead to the understanding of the mechanism. It is not the why or how question that is key to predicting a previously unrecognized or unobserved event.

The third step of Pearl's causation ladder is perhaps the rung scientists rarely step upon. It is labeled "counterfactual." Here we must ask "what if" and "so what" questions. We must imagine new situations and retrospectively examine prior experiments and experiences to gain insight into causal mechanisms. An understanding of mechanisms helps us to explore more critical questions. For example, when Hooper et al. (2013) ask how climate change affects biochemical pathways that regulate toxicity, Carriger and Barron (2011) imagine a variety of scenarios and the effects of different management options to mitigate the possibility for enhancing toxicity. Graham et al. (2019) imagine even larger scale consequences for an entire region of the continent of Australia. And by so imagining, we collectively avoid Black Swans.

Are we enlightened by the current events of COVID-19 and are we likely to witness another global pandemic of biological or chemical origin in the future? Most certainly, on both accounts. Scientists need to be better at imagining new conditions, unexpected observations, assimilating experimental and field research into a series of mechanistic questions. Scientists need to have an investigatory and management plan for plausible Black Swans. Then when such an event occurs, it may have already been imagined and we have a process to understand the observation. For now, current events are an opportunity for discovery and to devise a strategic viewpoint, a careful process, and clear reporting.

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