Contaminants of Concern in the Marine Environment: The Need for New Monitoring and Assessment Strategies

Geoffrey I. Scott*, Michael H. Fulton†, Stephen B. Weisberg*, Keith A. Maruya‡ and Gunnar Lauenstein†

More than 156 million people, over half of the U.S. population, live in the coastal zone [1]. Economic development within the coastal zone may result in the discharge of chemical contaminants into coastal ecosystems from sewage treatment plants, industrial point sources and urban and agricultural nonpoint source runoff [2,3]. Aquatic monitoring programs have long measured legacy contaminants such as DDT and PCBs, but are increasingly being asked to focus on modern commercial chemicals that as a group are referred to as Contaminants of Emerging Concern (CECs). CECs present many challenges, often because measurement methods don’t yet exist nor have toxicological studies yet been conducted to place monitoring results in proper context. This challenge is exacerbated because many CECs interact with hormone systems in wildlife to affect reproduction and development in ways that are not assessed through traditional toxicological evaluations.

Managing CECs represents a difficult challenge, as it is impractical to incorporate tens of thousands of new chemicals into monitoring and assessment programs. Two recent reports have addressed the issue of future assessments of CECs in both freshwater [4] and marine environments [5] and how to better deal with the uncertainty of their risks to the environment. The Anderson et al. [5] report was compiled by the Southern California Coastal Water Research Project (SCCWRP) for the California Water Resources Control Board and defines a process for evaluating the hazards of CECs, which was applied to several different coastal and marine habitat scenarios (effluent dominated watershed, coastal embayment and offshore coastal discharge). The approach involved categorizing CECs, defined in this context as contaminants that are not presently monitored for in a routine or systematic fashion, into three distinct areas in which the science needs to be enhanced and analyzed for risks based upon uncertainty.

1) **Known Knowns** – These are chemicals for which we have developed analytical methods, have begun collecting ambient data on environmental concentrations and/or developed laboratory toxicity data. The challenge for this group of chemicals is to better synthesize information across an array of studies and develop a consensus about those chemicals for which we have enough information to elevate to a priority pollutant level. Examples of Known Knowns include:

- **Flame Retardants** such as poly-brominated diphenyl ethers (PBDEs) and their replacements are a class of halogenated organic compounds used in commercial products, such as foams, paints, construction materials, textiles, carpets, furniture, electronics and firefighting chemical formulations. The persistence, bioaccumulation, and toxic potential of many of these chemicals in animals and in humans have been well documented [6,7]. Moreover, there is an increasing concern as the oceans are considered global sinks for PBDEs for example, since higher levels are found in marine organisms than in terrestrial biota [8-11].

- **Perfluorinated Compounds** (PFCs) are fluorine containing chemicals that have unique properties that make them stain and stick resistant. They have been used since the 1950s in the production of consumer goods that contain Teflon® and Scotchgard®. They are highly persistent in the environment and some are suspected human carcinogens. They have also been found to cause liver and kidney damage as well as reproductive problems in laboratory animals [12].

- **Pesticides** are the only class of commercial chemicals that are specifically designed to cause toxicity in selected target species. Although many of the more persistent pesticides such as DDT have been largely banned in most countries, new contemporary use pesticides are introduced each year and some (e.g. fipronil, pyrethroids) are considered CECs. In 2003 alone, more than 31 new active ingredients were registered in the U.S. [13]. Often, effects in non-target species may not be fully recognized until many years after registration.

Anderson et al. [5] recommended 12 new CECs which should be added to future monitoring and assessment efforts in coastal and marine ecosystems. This list includes contemporary use pesticides, industrial chemicals, flame retardants, and pharmaceuticals and personal care products. Currently SCCWRP, NOAA’s Mussel Watch and National Status and Trend Programs [14] and other national monitoring programs have efforts underway to add these chemicals to their current list of contaminants for coastal monitoring and assessment.

2) **Known Unknowns** – These are chemicals for which there is a potential for effects, but for which there are inadequate biomonitoring and bioeffects data to make a determination. Here the research focus is on developing analytical methods and expanding bioeffects tools to enhance knowledge about whether they pose significant environmental risks. Examples of Known Unknowns include:

- **Chemicals that induce antimicrobial resistance**, broadly defined as the development of adaptive physiological responses to chemicals, primarily pharmaceuticals used to kill or inhibit the growth of pathogenic microorganisms (bacteria, viruses, fungi and protozoa) and include antibiotics (antibacterials), antifungals, antivirals, and antiparasitic drugs. Wise [15] estimated that between 1 and 2 x 10⁸
kg of antibiotics are consumed annually worldwide with the majority being used in agriculture and clinical medicine [16,17]. Antibiotic resistance can be conferred not only from chemical exposure to antibiotics, but from gene mutation associated with plasmid (packets of external DNA) exchange with naive and antibiotic resistant bacteria. Effluents from wastewater treatment plants are often implicated as a major source for factors that may stimulate antimicrobial resistance in marine waters [18,19]. Increasing antibiotic resistance in microbes within marine ecosystems is a potential major ocean health concern for both seafood safety and contact recreation [20-22].

- **Nanoparticles** are single particles with a diameter < 100 nm [23] that are increasingly being used in the manufacture of industrial items, such as antibacterial surface coatings and semiconductors as well as white paint, paper, sunscreens, window coatings and plastics and cosmetics [24]. Materials synthesized at the nanoscale may behave differently than conventional materials because they have extraordinarily high surface to-volume ratios (over 80% of the atoms are located at the surface of 1-2 nm particles). This often results in much higher chemical reactivities. Their small size will allow nanomaterials to be absorbed by plants, across cell membranes and/or the blood-brain barrier enhancing the possibility that these materials are toxic to marine organisms. Currently, few systematic toxicity or uptake and bioaccumulation studies of nanomaterials have been conducted using marine species [25].

- **Transformation products** of known and unknown chemicals. Classic examples of this diverse class of chemicals are disinfection by-products resulting from chlorination of treated wastewater effluent discharged into coastal and marine waters. A committee of experts recently convened by the National Research Council on water reuse highlighted the importance of understanding the health risks associated with this class of CECs in drinking water supplies derived from treated municipal wastewater effluent [26]. The potential impact of transformation products on ecological receptors in coastal and marine environments is an understudied topic that warrants attention.

3) **Unknown Unknowns** – These are chemicals being rapidly developed for commercialization which there is little information on both potential environmental concentrations and possible adverse ecotoxicological effects. Unknown unknowns also include synergistic effects of multiple new contaminants that have not been previously investigated. For this group, the research need is for high-throughput in vitro bioassays that target CEC exposure in ecological receptors based on a common mode of biological activity (e.g., endocrine disrupting activity). Using this approach, a single assay can screen for multiple CECs, reducing the need for chemical-specific monitoring and affording a new, more efficient monitoring and assessment paradigm. However, this approach also requires research to identify how adverse outcome pathways at the molecular level are linked to higher order ecological effects (e.g., fish reproduction) to make the response managerially relevant.

Anderson et al. [5] present a comprehensive and grounding framework, but they also illustrate how much science remains to be conducted for effective monitoring and management of CECs. The Journal of Marine Biology and Oceanography welcomes research articles submitted on coastal pollution, such as CECs, particularly those that will focus both on development and application of new chemical contaminant monitoring methods and bioeffects processes. Also studies that integrate information on different classes of CECs (Known Knowns, Known Unknowns, and Unknown Unknowns) to provide a better context for risk assessment, enhance the current risk assessment framework and provide analysis for further consideration of the environmental hazards posed by CECs within the marine environment, are welcomed. The Journal also encourages discourse on the linkage of molecular endpoints with effects at higher levels of biological organization, the so-called “adverse outcome pathway” development and analysis. We encourage submissions for publication on this important environmental topic, helping the management community to understand this issue so that they can better protect, conserve and sustain the marine environment.

References


Author Affiliations

1NOAA/NOS National Centers for Coastal Ocean Science, Center for Coastal Environmental Health and Biomolecular Research, Charleston, SC 29412, USA
2Southern California Coastal Water Research Project, 3535 Harbor Blvd. Suite 110, Costa Mesa, CA 92626, USA
3NOAA/NOS National Centers Coastal Ocean Science, Center for Coastal Monitoring and Assessment, 1305 East West Highway, Silver Spring, MD 20910, USA

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