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DISCUSSION ARTICLE

An indispensable asset at risk: merits and needs of chemicals-related environmental sciences

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Abstract
Background Modern societies depend on environmental sustainability and on new generations of individuals well-trained by environmental research and teaching institutions. In the past, significant contributions to the identification, assessment, and management of chemical stressors with legal consequences have been made.
Main Features Within this article, we intend to elucidate the merits and the emerging challenges of chemicals-related environmental sciences. The manuscript is supported by more than 70 professors and university academics of leading institutions in Germany, Switzerland, Austria, and other countries in Europe, but addresses topics of global concern.
Results and Discussion Many environmental problems of pollutants remain to be addresses, since new chemical compounds or classes of new compounds are continuously developed and brought to the market and sooner or later "emerge" in the environment. Further issues are the inclusion of transformation products and chemical mixtures in environmental risk assessment, the long-term presence of xenobiotics bound to soils and sediments, as well as an understanding of the ecological relevance of ecotoxicological end points.

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Conclusion and Perspectives We point out the need for a strong academic research and education system in chemicals-related environmental sciences to ministries, politicians, and research funding institutions and we propose to create specific units in the national funding bodies that address basic and interdisciplinary research in this field.

Keywords Chemicals-related environmental sciences · Environmental research and teaching · Environmental risk assessment of pollutants

1 Achievements and societal needs

Modern societies depend on environmental sustainability, e.g. sustainable industrial and agricultural production, drinking water abstraction, and waste disposal, and therefore, depend continuously on new generations of individuals well-trained by well-furnished environmental research and teaching institutions.

Significant contributions to the identification, assessment, and management of chemical stressors with legal consequences have already been made with prominent examples such as dichlorodiphenyltrichloroethane and other organochlorine pesticides, chlorofluorocarbons, chlorinated dioxins and furans (Weber et al. 2008b), and organotin compounds. In Europe, important regulatory frameworks were established originating from such research, e.g., the European Water Framework Directive, the European Soil Framework Directive, and most recently, the European Regulation for Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). Figure 1 demonstrates the long way from early evidences on environmental impacts of such chemicals to regulatory decisions (EPA 2001), e.g., more than 35 years ago and more than 2,500 ecotoxicological publications from the first indication of ecotoxicological effects of tributyltin until its ban as an antifouling agent.

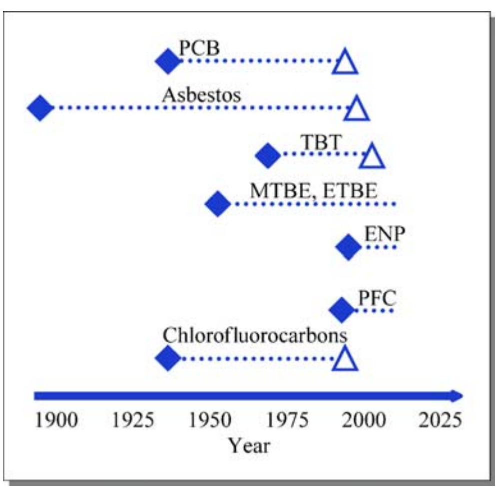

Fig. 1 First scientific evidence (*diamonds*) for the effects of pollutants to human health or environment and legal consequences (*triangles*). *PCB* polychlorinated biphenyls, *TBT* tributyltin, *MTBE* methyl tertiary-butyl ether, *ETBE* ethyl tertiary-butyl ether, *ENP* engineered nanoparticles, *PFC* perfluorinated chemicals

However, many environmental problems of pollutants remain to be addressed, since new chemical compounds or classes of new compounds are continuously developed and brought to the market (Daughton and Ternes 1999; Kaiser 2007; Kaykhaii and Mirbaloochzahi 2008; Kelly et al. 2007; Olsman et al. 2007; Skutlarek et al. 2006) and sooner or later "emerge" in the environment. The time lag is determined by emission strength, chemodynamics, and analytical sensitivity. Engineered nanomaterials (Fischer and Chan 2007; Nel et al. 2006; Scheringer 2008; Wiesner et al. 2006) may pose a new potential threat that is widely discussed but cannot adequately be assessed at present. Further issues are the inclusion of transformation products and chemical mixtures in environmental risk assessment, the long-term presence of xenobiotics bound to soils and sediments, as well as an understanding of the ecological relevance of ecotoxicological end points (Filser 2008; Jablonowski et al. 2008; Schwarzenbach et al. 2006). Besides synthetic chemicals, natural chemical stressors also have to be considered, such as *Bacillus thuringiensis* (Bt) toxin as a pesticide. The ecological consequences of corresponding transgenic crops, e.g., Bt maize, have been examined, but debates continue regarding the nontarget impacts of this technology (Marvier et al. 2007). The interaction of ecological, genetic, and evolutionary aspects of environmental pollution and its long-term effects is discussed (Theodorakis 1999; van Straalen and Timmermans 2002), but there is little consolidated knowledge.

2 Research and education for a sustainable future?

In a recent article, Debra Rowe pointed out the need for education in environmental sustainability and listed ongoing efforts in the U.S. (Rowe 2007). Clearly, there is an urgent need to create awareness for pressing environmental problems and to develop solutions in close cooperation between science, governments, industry, and other relevant stakeholders. Science is essential to navigate a transition toward sustainability on all scales (Kates et al. 2001). Environmental risk assessment covers spatial and temporal scales according to chemodynamics, environmental mobility, and ecosystem response. On the occasion of the chlorofluorocarbons and the "ozone hole," nowadays almost a stereotype for bad surprises from chemicals, environmental risk assessment has made key contributions to cope with global environmental change. Also many other persistent chemicals cycle regionally or globally. Due to their impact on ecosystem functions, natural and man-made chemicals' fate and effects will more and more emerge as an integrated part of interdisciplinary Earth system science. Biodiversity is intimately linked (Ehrlich and Wilson 1991) to the field of chemicals-related environmental risk assessment, for which the academic basis, however, has been increasingly cut back in the past decades.

Under the impression that something is going wrong during the "Decade of Education for Sustainable Development" declared by the United Nations (UN 2005), more than 70 academics from Germany, Austria, and Switzerland with a research focus on the environmental chemistry, ecotoxicology, and ecology of chemical pollutants in soil, water, and atmosphere have expressed their concerns about the decrease in political and financial support for academic environmental research and education. To emphasize the need for continuing support in this field and to discuss this need with policy makers and funding institutions, we have established an association of environmental university scientists in research and education (UFoH, in German "Verbund Umweltforschender Hochschulinstitute"). We are more than concerned that, in the future, both research and education will severely suffer with the ongoing budget reductions in environmental sciences at universities.

3 Need for a comprehensive scientific approach

The first period of ecotoxicology was initiated by major problems caused by environmental pollution and was strongly steered by the chemical industry. This period was mainly application-oriented. Practical concepts and scientific theories were developed separately. In contrast to other countries, a funding category for environmental pollution research does not exist in the German Research Foundation (DFG) and in the Swiss (SNF) National Science Foundation, the main sponsors of basic research in Germany and Switzerland. In Austria (FWF), funding for environmental research seems somewhat better off but still needs more active support, particularly with respect to the number of university chairs in this field.

In the past, research on environmental pollutants often tackled individual problems in a one-sided manner, i.e., from environmental chemistry and ecotoxicological or ecological viewpoints. However, the complex character of environmental issues is nowadays recognized as a multidisciplinary research challenge with interdependent variables comprising, beside other issues, the chemodynamics of pollutants and the ecological response on all levels of biological systems, from molecules to population and community level (Van den Brink 2008; Yeston et al. 2006), fields that are furthermore impacted by global trends, e.g., overriding scenarios such as global climate change. From the other end, Earth system science is more and more extending into smaller spatial scales. Only by applying a holistic experimental and modeling approach involving different disciplines within environmental sciences results can be transferred from a local scenario to the regional, transregional, or the global scale. As an example, the increasing worldwide contamination of freshwater systems with thousands of industrial and natural chemical compounds is one of the key environmental problems of the twenty-first century (Schwarzenbach et al. 2006; UN 2005). Also, soil contamination with highly toxic compounds has increased with negative, partly irreversible, effects on chemical, biological, and biochemical soil properties, leading to a continuous loss of soil functions in sustaining soil biota (Gianfreda and Rao 2008). Although effective strategies have been implemented to remediate contaminated sites (Weber et al. 2008a), a substantial amount of work will be needed to cope with the numerous compounds that are present at low concentrations with potential synergistic toxicity (Backhaus et al. 2004).

The scientists within UFoH see a strong need to strengthen basic environmental research by developing novel methods (Ahlers et al. 2008; Schwarzenbach et al. 2006; Schaffer et al. 2008), extending the environmental data base in the various fields, and by developing probabilistic risk assessment models (Schulz et al. 2009) to predict the fate and the effect of environmental pollutants at the ecosystem level. The analysis presented here is in high accordance to a recent initiative supported by over 40 Swedish scientists (Albin 2006). They clearly addressed the need for additional external funding in the fields of environmental toxicology and chemistry in order to guarantee the scientific expertise required to solve upcoming environmental issues for future generations.

4 Higher demands, dwindling resources, and proposals for improvement

Although qualified young environmental scientists are in great demand by industry and authorities, the number of university chairs in this field is steadily and disproportionately declining. Also, the financial support for research projects has been significantly shortened, unlike in other research areas, such as biotechnology or nanotechnology.

UFoH points out the need for a strong academic research and education system in environmental chemistry, ecotoxicology, and ecology to ministries, politicians, and research funding institutions in Germany, Austria, and Switzerland. We propose to create specific units in the national funding bodies that address basic and interdisciplinary research in chemicals-related environmental sciences in addition to the well-established classical categories such as chemistry, biology, agriculture, and geological sciences. As a consequence, funding for research excellence clusters should be boosted so that successful young scientists will have access to tenure track positions at the participating universities. On that basis, a completive and synergistic cooperation on par with nonuniversity research institutes, such as the German centers of Fraunhofer, Max-Planck, Helmholtz, Leibniz, and others, as well as with engineering sciences to develop sustainable technologies, could be accomplished.

To encourage young scientists interested in academic research and to sustain environmental research and teaching, long-term political and financial support is indispensable.

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