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EDITORIAL

The legacy of pesticides and POPs stockpiles—a threat to health and the environment

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The unsustainable life cycle management of pesticides in the last 70 years has created large pesticide stockpiles. The two major working areas of the International HCH & Pesticides Association (IHPA; www.ihpa.info) partly address these legacies: (1) assess and support the management of the world's single largest persistent organic pollutants (POPs) stockpile: the 4 to 7 million tonnes (t) of hexachlorocyclohexane (HCH) wastes dumped globally from lindane production (Vijgen et al. 2011; Vijgen et al. 2013) and (2) support the management of the ~240,000 t of obsolete pesticides legacy in Eastern Europe, the Caucasus and Central Asia (EECCA) countries, where these pesticides are stored without adequate safety control, posing huge risks to the environment and human health (Vijgen et al. 2013).

As a major part of its approach, the IHPA organizes of the biannual "International HCH and Pesticides Forum" bringing together researchers, policymakers, government institutions, industry, civil society, and donors from different parts of the world for discussion on issues related to pesticide/POPs pollution and related solutions. This special issue of Environmental Science Pollution Research includes selected papers from the 13th HCH and Pesticides Forum held in Zaragoza, Spain, as well as selected contemporary case studies on POPs. The 13th Forum was organized in Zaragoza to draw international attention to the enormous environmental and financial problems in the region of Aragon (Spain) due to the former production of Lindane by Inquinosa and the unregulated dumping of more than 100,000 t of HCH-waste around Sabiñánigo and the Gállego River (Fernandez et al. 2013; De La Torre et al. 2018). From 2014 to 2016, a total of 65,000 t of HCH solid waste and 342,000 t of polluted soil were transferred to a new sanitary landfill with isolating measures beyond the Spanish legal requirements (De La Torre et al. 2018). The Forum agenda included disseminating the Aragon authorities' experiences with addressing this problem and transferring this knowledge to the EECCA countries and other interested countries with similar HCH-waste problems (Vijgen et al. 2011; IHPA 2015a, b).

Assessing the pollution situation, the relevance to human exposure, and possible improvements using available management and scientific measures remains a key challenge for developing and transition economies. In this special issue, three contributions (Toichuev et al. 2017a,b; Doolotkeldieva et al. 2017) document in detail the situation of POPs pesticide legacy in the Kyrgyz Republic. Toichuev (academy of science), together with the NGO Green Cross and TAUW company, describes the preliminary assessment and activities to secure the largest and most hazardous POPs pesticides dumping sites in Kyrgyzstan, where cattle died and the local population has high pesticide levels in blood, breastmilk, and placenta (Toichuev et al. 2017a). This study also reports on practical risk reduction measures carried out within a UN project and provides further recommendations on monitoring and assessment, including the suggestion to consider the findings of the study in the National Implementation Plan of Kyrgyzstan (Toichuev et al. 2017a).

Toichuev and colleagues from the National Academy of Sciences of the Kyrgyz Republic analyzed organochlorine pesticides (OCPs) in 241 placentas from cotton-growing regions, 121 placentas from an urban area (city of Osh), and 146 placentas from unpolluted mountain regions of Kyrgyzstan. The relative risk of health problems in both, mothers and newborns increased significantly, in a concentration-dependent manner, with increasing levels of total OCPs

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($p < 0.0001$). Health complications with increased incidence in OCP-exposed newborns included low birth weight, congenital malformations, infections, and stillbirths in OCP-exposed mothers pre-term delivery, (pre-)eclampsia/gestosis, and frequency of hospitalizations after delivery (Toichuev et al. 2017b). The study concluded that women living near former pesticide storehouses and agro airstrips are at risk, and exposure reduction is urgently needed.

The case of dismantling and relocation of the Sabiñánigo HCH-waste landfill indicates that industrial countries have the capacity to relocate large pesticide stockpiles when there is a high risk of polluting water reservoirs, or other unacceptable exposure risks. However, the funding needed for destroying the huge amount of waste (65,000 t of HCH waste and 342,000 t of contaminated soil) was unavailable and therefore the waste was transferred to a better secured landfill for the time being. On the other hand, the cases of the POPs pesticide dumpsites in Kyrgyzstan demonstrate the current challenges to manage such sites in developing countries and that often only small budgets and minimum mitigation measures are available (Toichuev et al. 2017a) to address the largest exposure risks (Toichuev et al. 2017a,b). This highlights the need for more integrated POPs management and improved destruction capacity for many countries, as discussed in the former special issues (Weber et al. 2013, 2015). In recent years, China has demonstrated that it is feasible to destroy more than 10,000 t of POPs pesticide stockpiles and 400,000 t of POP pesticide-contaminated soils in cement kilns including the development of management and monitoring capacity (Yan et al. 2014; Li et al. 2015).

Some articles in the special issue are also seeking cost effective solutions for (moderately) POPs pesticide-contaminated soils. Doolotkeldieva et al. (2017) carried out laboratory experiments to select active degraders from bacterial populations capable of degrading aldrin (*Pseudomonas fluorescens* and Bacillus polymyxa) isolated at major pesticide sites in Kyrgyzstan. Also, the study by Xie et al. (2018) demonstrates in pot experiments that specific bacteria (strain DXZ9 of Stenotrophomonas sp.) combined with ryegrass can likely bioremediate soil contaminated with DDT and DDE.

Miszczyk et al. (2018) describe the official quality control system of plant protection products in Poland, the analytical methods for testing pesticides suspected of adulteration, and some recent test results. The analysis of illegal and counterfeit plant protection products indicated that the majority of illegal pesticides detected in Poland are herbicides.

Another study in this special issue investigated the atmospheric contamination from OCPs in four West African countries - Togo, Benin, Nigeria, and Cameroon, assessing emission levels and the characteristic signatures of contamination (Isogai et al. 2016). Emerging evidence suggests that there are contemporary sources of OCPs in African countries, despite the global ban on these products. Significant evidence, based on chemical signatures of the contamination, indicated that DDT, aldrin, chlordane, and endosulfan had recently been applied at certain sites in these countries (Isogai et al. 2016). The study also demonstrated the benefit of North-South research cooperation for addressing questions of implementation of the Stockholm Convention where monitoring programs and data are needed.

Two articles from Chinese and Japanese research groups address POPs unintentionally produced as by-products, such as PCDD/F. Yamamoto et al. (2017) assessed the PCDD/F pattern under different conditions in chloralkali-electrolysis, which is a major historic source of unintentional POPs, including dioxin and mercury often associated with contaminated sites (Weber et al. 2008; Healthy Building Network 2018). The PCDD/F pattern in the laboratory tests dominated by the 1,2,7,8- and 2,3,7,8-TetraCDFs, 1,2,3,7,8-PentaCDF, and 1,2,3,4,7,8-HexaCDF marker congeners were identical with PCDD/F congener patterns in soil samples from a PCDD/F-contaminated site where chlor-alkali electrolysis had been operated for decades in Japan (Yamamoto et al. 2017), demonstrating the contamination potential and ongoing risks of these (historic) operations.

Li et al. (2016) assessed the destruction of unintentional POPs (PCDD/F, PCBs and HCB/PeCB) in a pilot-scale selective catalytic oxidative (SCO) system using a self-developed honeycomb catalyst in a typical municipal waste incinerator in China. Both temperature and the degree of chlorination influenced the removal efficiencies, with highest destruction efficiency for PCDD/F (Li et al. 2016).

Newly listed industrial POPs (PBDEs and PCNs) are also addressed in articles in this special issue. Babayemi et al. (2016) used the methodology of the Stockholm Convention PBDE inventory guidance (Secretariat of the Stockholm Convention 2015) to calculate commercial PentaBDE stock in vehicles in Nigeria. Based on a material/substance flow analysis using the STAN software ((http://www.stan2web.net/) combined with import and registration statistics, they estimate that the approximately 19 million passenger cars imported from 1980 to 2010 to Nigeria contained ca. 270 t of POP-PBDEs in ca. 401,000 t of polyurethane foam. Seventy-nine percent of those vehicles are still in use. The study highlights a range of other pollutants present in vehicles (e.g., heavy metals, other flame retardants, PCBs, chlorofluorocarbons, hydrofluorocarbons, and waste oil), and emphasizes the need for an integrated management of pollutants and resources from the transport sector (Babayemi et al. 2016). Aliyeva et al. (2017) measured PBDEs in air and soil at 13 urban and rural sites across Azerbaijan. Levels of BDE-47 and 99 (the two most abundant congeners in the widely used penta-formulation) were lower than levels reported elsewhere, suggesting limited use and import of the c-Penta-BDE in Azerbaijan (Aliyeva et al. 2017). The Nigerian study (Babayemi et al. 2016) reinforces the relevance of exports of

PBDE-containing products and waste to environmental pollution (Breivik et al. 2011; Wong et al. 2007), while the Azerbaijan data show that EECCA regions with low imports of goods from the USA, where 90% of c-PentaBDE has been used, have low levels of contamination with c-PentaBDE congeners. This is also demonstrated by the PBDE data in the WHO global human milk study, which found very low levels of PBDEs in EECCA countries, as compared to the extremely high levels in the USA and the elevated levels in countries neighboring the USA such as Haiti, Mexico, Antiqua and Barbuda, Barbados (UNEP 2013), and Canada (Ryan and Rawn 2014). These high levels are driven by the flammability standards in the USA, which have resulted in products with high PBDE content, such as cars, furniture or baby products (Chicago Tribune 2012; Imm et al. 2009; Shaw et al. 2010; Stapleton et al. 2011).

Polychlorinated naphthalenes (PCNs) were added to the Stockholm Convention in 2015, and an inventory methodology draft has recently been published (Secretariat of the Stockholm Convention 2017). Yamamoto et al. (2016) conducted a series of verification tests to confirm that PCNs containing synthetic rubber products (Neoprene FB products) and aerosol adhesives, accidentally imported into Japan, could be thermally destroyed to a large degree in an industrial waste incinerator.

Due to the relevance of fertilizer application to heavy metal contamination of soils and food (Salo et al. 2018), the special issue included a study by Latifi and Jalali (2018) who analyzed 57 mineral fertilizers (nitrogen, potassium, phosphate, and compound fertilizers) used in Iran for their Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn, and Fe levels. All fertilizers were below the limits set by the German Fertilizer regulation, indicating minor risk (Latifi and Jalali 2018).

A special session of 13th IHPA Forum was devoted to health risks of exposure to POPs where contributions are not published in this special issue but presentations are available (http://www.hchforum.com/13/presentations.php). Dolores Romano gave an overview on the situation at the lindane dump site of Sabiñánigo and the toxicity of lindane. Mariana Fernandez presented a Spanish multicenter study on effects of POPs on children's development (INMA, Infancia y Medio Ambiente), including data on levels of POPs in placenta and adipose tissue from human breast. Juan Arrebola addressed the question of possible links between exposure to environmental chemicals and increased risk of obesity and metabolic syndrome. Joao Torres reported on internal human exposure to HCH, based on measurements in hair, in five regions of Brazil. Martin Forter discussed an example of lindane contamination in an industrial setting in Basle and solutions for large-scale dump site decontamination in Switzerland. Rina Guadagnini presented data of a comparative PAN investigation of pesticide exposure and poisoning symptoms in men, women, and children handling or not handling pesticides in Armenia, Belarus, Kyrgyzstan, Moldova, and Ukraine. Ahmad Mahdavi reported on the past and present situation of pesticide use in Iran. Peter Behnisch gave an overview of modern tools to identify toxic effects of environmental chemicals. The last two presentations emphasized the particular sensitivity of the developing organism to chemical insults. Henk van Loveren explained how the developing immune system can be affected by environmental chemicals (dioxins, PCBs, phthalates, methyl mercury) in utero and during childhood. Walter Lichtensteiger characterized the risk of exposure to environmental chemicals (PCBs, PBDEs, phthalates, bisphenol A, pesticides) for brain development, documented by epidemiological studies in children. Interactions with endocrine mechanisms appear to play a major role; they influence brain development at cortical levels (e.g., cognitive functions) as well as subcortical levels.

The Forum also had a film session where documentaries on contaminated sites and land grabbing were presented:

- "Forgotten Dumpsite," about the Kalush HCB dump in Ukraine (http://contaminatedfuture.org/video-the-forgotten-dumpsite/), by Contaminated Future http://contaminatedfuture.org/
- "DISCOVERING LINDANE – The legacy of HCH production" by Arturo Hortas http://www.ihpa.info/info/2016/01/11/discovering-lindane-the-legacy-of-hch-production/
- "When Elephants dance, the grass gets beaten" http://www.cultureunplugged.com/documentary/watch-online/play/53234/When-Elephants-dance%2D%2Dthe-grass-gets-beaten by Jan van den Berg, showing the dramatic situation of many small Cambodia family farms when large foreign companies are buying more of the agricultural land. The promised job opportunities fail to manifest, and the farmers find themselves without land or income.

Finally, a Zaragoza declaration containing the key messages of the 13th International HCH & Pesticides Forum was compiled and published. Specifically, the participants identified and concluded the following regarding three areas of further development:

- First, the Roadmap developed under the EC-FAO partnership program project "Improving capacities to eliminate and prevent recurrence of obsolete pesticides as a model for tackling unused hazardous chemicals in the former Soviet Union (FAO/GCP/RER/040/EC)" was endorsed as an efficient framework for building the necessary leadership and capacity for sound environmental management of hazardous waste in the EECCA region. (The Roadmap and all country reports can be found at: http://www.ihpa.info/resources/library/improving-capacities/).
- Second, given the situation in Aragon, the HCH dump sites in Sabiñanigo and Sardas from the Lindane-plant of

Inquinosa, and previous reports to the IHPA Forum, it is clear that mega-sites exist, where the contamination is so large and complex that no region or country alone can fund the necessary remediation. The Inquinosa facility with the connected landfills in Aragon is such a mega-site.

- Third, reviewing the inventories and costs for eliminating POP pesticides, POPs and associated waste, it was noted that the total cost for cleaning up the known legacy sites is less than 0,1% of the 2014 GDP of the EECCA countries. Hence, elimination of the legacy of POP pesticides, POPs and associated waste should be affordable in all EECCA countries given that the political awareness and leadership are present. Prompt clean-up will prevent further cost increases due to in-action.

Based on the above points and on the discussion and recommendations from the Forum participants, the Zaragoza declaration brought forward individual "to do lists" for national Governments, specifically for the Governments in the EECCA region; for The European Parliament and The European Commission, and for International Organizations, specifically FAO and International Financial Institutions, Global Environment Facility (GEF) and cooperating agencies, and other relevant partners. The detailed actions suggested by the declaration along with key note speeches can be downloaded from the IHPA Website (IHPA 2015a, b).

The Forum and related contributions again stressed that there is an urgent need to further improve the management and exposure risk of the pesticide legacy in the EECCA countries, to protect public health. In order to make further advancements, activities to assess and secure pesticide-contaminated sites need to be further supported by United Nation/GEF activities, along with the development and strengthening of national research and management capacity.

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John Vijgen was born in 1951 in Heerlen, The Netherlands, and was educated as civil engineer at the Technical University of Aachen, Germany. He has been working for more than 40 years on the clean-up of contaminated sites and pesticide stockpiles including the elimination of 200,000 t of HCH and Lindane contaminated soils and wastes when working for TAUW. At present, he is the director of the International HCH & Pesticides Association (IHPA; www.ihpa.info), which he founded in 1998 with the objective of eliminating obsolete pesticides in Central and Eastern Europe, the Caucasus, and the Central Asia Republics (EECCA). Over more than 23 years, he has been organizing the biannual International HCH and Pesticides Forum including the 2013 forum in Kiev/Ukraine and the upcoming in Zaragoza in Spain 3–6 November 2015 (http://www.hchforum.com/). The Forum provides an international platform to solve obsolete pesticides problems, brings stakeholders together to exchange experiences, and involves donors, public and private problem owners, scientists, and civil society and dedicated politicians. In 2006, he published "The Legacy of Lindane HCH Isomer Production", a major contribution for the nomination of Lindane and HCH-isomers as POP in the framework of the Stockholm Convention. He was involved in a large number of pesticides clean-ups and has recently produced for UNEP 18 new Fact sheets for POPs destruction technologies that will be published before the end of 2015. From 2009 to 2013, with Green Cross and Milieukontakt Int., he has been managing the GEF-FAO project on capacity building on obsolete and POPs pesticides in EECCA countries. At present, he is finalizing within the EU financed and by FAO managed project on "Improving capacities for obsolete pesticides in the Former Soviet Union" the report "Road Map to Establishing Environmental Sound Management of POPs Pesticides and other Hazardous Waste in the EECCA region" plus national waste management and legal reports for the 12 countries that will be published towards the end of 2015.

Roland Weber (Dr. rer. nat.) has been working since 2003 as an independent international consultant mainly for UN Organizations (UNEP, UNIDO, UNDP, UNITAR) and environmental ministries on the implementation of the Stockholm Convention on Persistent Organic Pollutants (POPs). His areas of particular expertise include dioxins, other unintentionally produced POPs and brominated and fluorinated POPs and POPs-like chemicals. He is drafter/co-drafter of several technical guidance documents for the Stockholm Convention and member of the UN Environment/Stockholm Convention BAT/BEP expert group. He co-authored the Mediterranean action plan for sustainable consumption and production (SCP) and the SCP toolkit for policy makers. (www.researchgate.net/profile/Roland_Weber3). He received his PhD in chemistry 1996 from Tübingen University and worked from 1997 to

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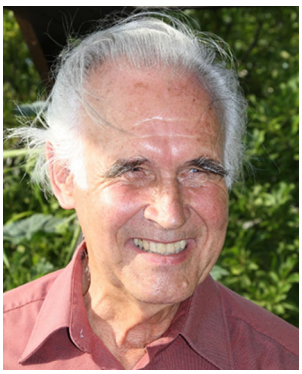

Walter Lichtensteiger (M.D., professor emeritus) has been teaching pharmacology and toxicology for students of the University of Zurich and of the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. In 2005, he founded GREEN Tox GmbH (Group for Reproductive, Endocrine and Environmental Toxicology http://www.greentox.org/), together with Margret Schlumpf (M.S.). Research of W. L. focuses on developmental toxicology of mammals, in particular developing neurotoxicology and development of neuroendocrine systems (sexual brain differentiation). He first worked on drugs of abuse; he was member and chairman of the Safety Surveillance Group of the Heroin-based Treatment Programs of the Swiss Health Office (1994–2002). Since the 1990s, the lab of W.L. and M.S. investigated endocrine activity of environmental chemicals. This led to the discovery of endocrine activity of cosmetic UV filters, which was complemented by an analytical study of xenobiotics in human milk. In 2002, the two researchers initiated the Swiss National Research Program (NRP) 50, "Endocrine Disruptors: Relevance to Humans, Animals and Ecosystems", together with other colleagues. Research was further supported by 3 European Union projects (PBDEs, PCBs, UV filters, endocrine disrupter mixtures). Ongoing transcriptomics research focuses on developing hippocampus as a target of endocrine disrupters. W.L. is working in several committees of the OECD Test Guidelines Program for chemicals: Endocrine Disrupter Testing and Assessment Advisory Group (EDTA AG), Extended Advisory Group on Molecular Screening and Toxicogenomics (EAGMST, Adverse Output Pathways), and Expert Group on Reproductive Toxicity.

Margret Schlumpf (PD Dr. sc. nat.) obtained her PhD in pharmaceutical sciences at the Swiss Federal Institute of Technology (ETH). She then worked in the Laboratory of Neuropharmacology of the National Institute of Mental Health at St. Elizabeth's Hospital in Washington, D.C., and at the Arthur Vining Davies Laboratory for Behavioral Neurobiology of the Salk Institute, La Jolla, on development of neurotransmitter systems in embryonic brain. M.S. subsequently joined the research group of Walter Lichtensteiger (W.L.) at the Institute of Pharmacology and Toxicology of the University of Zurich. The group started a program on developmental toxicity, where M.S. focused on developmental toxicity of benzodiazepines, in particular on developmental neuro-immunotoxicity. From the 1990s, M.S. and W.L. investigated endocrine activity of environmental chemicals, and discovered endocrine activity of cosmetic UV filters; other cosmetics such as fragrances were also investigated. In 2002, the two researchers initiated the Swiss National Research Program (NRP) 50, "Endocrine Disruptors: Relevance to Humans, Animals and Ecosystems", together with other colleagues. Research of M.S. on developmental neurotoxicity of UV filters and other endocrine disrupters was further supported by 2 European Union projects (UV filters, endocrine disrupter mixtures) and was complemented by comparative investigations of a large spectrum of xenobiotics in human milk. She also collaborated in a Swiss-Romanian cooperation program (ESTROM, 2006–2007) on heavy metal exposure and children's behavior. In addition to her work as docent of pharmacology and toxicology, M.S. engaged in the organization of continuous education at national and international levels. In 2005, M.S. and W.L. founded GREEN Tox GmbH (http://www.greentox.org/ Group for Reproductive, Endocrine and Environmental Toxicology).