[NTNU_IBI] [Case number 3]

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Biology (IBI)
Title of case study: **Research on emerging pollutants contributes to public awareness and regulation**
Period when the underpinning research was undertaken: 2007- 2021
Period when staff involved in the underpinning research were employed by the submitting institution: 2007 - ongoing
Period when the impact occurred: 2011 – 2021 (ongoing)

1. Summary of the impact (indicative maximum 100 words)

At IBI we study both exposure and effects to different types of pollutants in the natural environment. The growing amount of emerging pollutants Is enormous and most of them are not regulated. Our recent research on poly- and perfluorinated substances (PFASs) has received significant governmental. media and public attention. The Norwegian Environmental Agency has used our research in preparations for the regulation of PFASs in both firefighting foams (AFFFs) and skiwax within Europe. Our research on emerging pollutants and plastic pollution is also used for evaluation and inclusion in global regulations such as the Stockholm Convention (SC) and in the regulation of microplastics in Europe as well as in the ongoing negotiations of the global plastic treaty.

2. Underpinning research (indicative maximum 500 words)

Research on emerging organic pollutants, including PFASs, has been a main research focus at the ENVITOX group at IBI, including field observations in Norway, Europe and the Arctic, as well as exposure studies at NTNU. PFASs are used in many consumer products because of their water and fat repellant properties. Examples include goretex, Teflon pans, firefighting foams and skiwax. The Research Council of Norway (RCN) and NTNU funded fellesløfte project NewRaptor (RCN 230465, 2014-2018) found that PFASs in Norwegian raptors were the most prominent pollutants in these birds and that concentrations were higher around Trondheim than Tromsø. Higher human density and ski activity in Trondheim were suggested to play a role. In addition, exposure studies on chicken eggs showed that exposure to PFASs significantly lowered embryonic heart rate before hatching and that hatchlings exposed to a high dose of F-53B (an emerging PFAS compound) had a significantly enlarged liver (8%). Another exposure study on flame retardants, showed that within the incubation period, quail embryos were able to biotransform a chlorinated phosphorous flame retardant (TDCIPP), but not the chlorinated Dechlorane plus, which seems to be very persistent and could present a health risk. These results are used to inform restrictions in Europe and for the SC (see below).

In two other projects funded by RCN (two PhD-fellowships, RCN 268419, 268258, 2017-2022), we focused on bioaccumulation and biomagnification of PFAS and flame retardants in freshwater and marine ecosystems in Norway and the Arctic (Svalbard), and on thyroid related effects in gulls in the Arctic (Svalbard). The results documented that AFFFs (leaking from airports and paper factories) are significant sources for exposure in ecosystems, resulting in levels above safe guideline threshold for ecological effects and human food safety. Emerging flame retardants were reported in Arctic gulls. The results are important in documenting presence and effects of emerging contaminants that are candidates for inclusion in the SC.

Further work on PFASs was done in a NTNU-financed PhD project (2016-2021). Soil, earthworm and bank vole samples were collected from the Granåsen skiing area in Trondheim

(as a potential point source of PFASs contamination) and from a reference area with no skiing activities (Jonsvatnet, Trondheim). The summarized PFAS concentrations were significantly higher in bank voles from the skiing area, and 35% higher in earthworms from the skiing area, compared to the reference area. The perfluorocarboxylic acid (PFCA) profile in samples from the skiing area resembled that of the previously analyzed commercial ski waxes, dominated by long chained PFCAs, while the samples from the reference area were dominated by short-chained PFCAs. This indicates that animals inhabiting skiing areas are exposed to higher PFAS concentrations than animals inhabiting areas with no skiing activities, and that these PFAS most likely are derived from fluorinated ski wax. The bank voles from the skiing area had significantly higher brain dopamine concentrations, compared to the reference area. In addition, reduced testosterone concentrations were detected in the muscle tissue of male bank voles from the skiing area. The liver PFAS concentrations reported in the bank voles from the skiing area, were within the range of concentrations reported in the plasma of professional waxing technicians, which raised concerns for human health.

Ongoing work on plastic pollution includes characterizing the human and environmental toxicity of nano- and microplastics as well as of the chemicals present in plastics. We have assessed the environmental risks of nano- and microplastics using meta-analyses. We have estimated species sensitivity distribution using toxicity data from the published literature to derive toxicological thresholds for Norwegian policymakers (VKM) and for the State of California. These can be applied by regulators in multiple contexts (see below). Working with an international group of experts, we have also provided the first scientific definition of plastic debris in nature that has been used by regulators across the globe. Lastly, our work on chemicals in everyday plastic products has established that the plastics contain many more toxic chemicals than previously thought. This knowledge has contributed to making this aspect part of the international negotiations of the plastics treaty.

PhD students involved:

- Jenny Bytingsvik (RCN 175989, 2007-2012)
- Nathalie Briels, PhD student working on NewRaptor (RCN 230465, 2014-2019)
- Mari Løseth, PhD student working on NewRaptor (RCN 230465, 2014-2019)
- Randi Grønnestad (2016-2021)
- Håkon Langberg (RCN 268258, 2017-2021)
- Åse-Karen Mortensen (RCN 268419, 2017- ongoing)
- Essa Ahsan Khan (RCN 248840, 2016-2021)

Permanent staff at ENVITOX involved:

- Veerle Jaspers, project leader NewRaptor (RCN 230465), supervisor of Briels, Løseth, co-supervisor of Grønnestad
- Augustine Arukwe, supervisor of Grønnestad, Khan
- Bjørn Munro Jenssen, supervisor of Bytingsvik, Langberg, Mortensen, co-supervisor Grønnestad, Løseth
- Åse Krøkje , co-supervisor Grønnestad
- Martin Wagner, research on plastic pollution
- Tomasz M. Ciesielski, co-supervisor Briels, Mortensen

3. References to the research (indicative maximum of six references)

1. Briels N., Torgersen L.N., Castaño-Ortiz J.M., Løseth M.E., Herzke D., Nygård T., Bustnes J.O., Ciesielski T.M., Poma G., Malarvannan G., Covaci A., Jaspers V.L.B. (2019). Integrated exposure assessment of northern goshawk (*Accipiter gentilis*) nestlings to legacy and emerging organic pollutants using non-destructive samples, Environmental Research 178: 108678. https://doi.org/10.1016/j.envres.2019.108678

PFASs were the compounds found in the highest concentrations in blood plasma, suggesting that the nestlings were recently and continuously exposed to PFASs, likely through dietary intake.

2. Briels N, Løseth ME, Ciesielski TM, Malarvannan G, Poma G, Kjærvik SA, Léon A, Cariou R, Covaci A, Jaspers VLB (2018). *In ovo* transformation of two emerging flame retardants in Japanese quail (*Coturnix japonica*). Ecotoxicol Environ Saf. 149:51-57. DOI: 10.1016/j.ecoenv.2017.10.069

   In this in ovo experiment it was found that Dechlorane plus could not be biotransformed by the embryo.

References 1-2 and others were cited in Persistent Organic Pollutants Review Committee (POPRC) recommendations to nominate PFCAs and Dechlorane plus to the SC.

3. Bytingsvik J, van Leeuwen SP, Hamers T, Swart K, Aars J, Lie E, Nilsen EM, Wiig O, Derocher AE, Jenssen BM (2012). Perfluoroalkyl substances in polar bear mother-cub pairs: a comparative study based on plasma levels from 1998 and 2008. Environ Int. 15;49:92-9. https://doi.org/10.1016/j.envint.2012.08.004

Reference 3 and other relevant papers were cited in Risk profile on perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds. UNEP/POPS/POPRC.14/6/Add.1

4. Briels, N., Ciesielski, T. M., Herzke, D., & Jaspers, V. L. B. (2018). Developmental Toxicity of Perfluorooctanesulfonate (PFOS) and Its Chlorinated Polyfluoroalkyl Ether Sulfonate Alternative F-53B in the Domestic Chicken. Environ Sci Technol, 52(21), 12859-12867. doi:10.1021/acs.est.8b04749

Reference 4 and others are cited in the European Chemicals Agency (ECHA) restriction proposal on PFASs in firefighting foams.

1. Grønnestad, Randi; Vazquez, Berta Perez; Arukwe, Augustine; Jaspers, Veerle; Jenssen, Bjørn Munro; Karimi, Mahin; Lyche, Jan Ludvig; Krøkje, Åse. Levels, patterns, and biomagnification potential of perfluoroalkyl substances in a terrestrial food chain in a Nordic Skiing Area. Environmental Science and Technology 2019 ;Volum 53.(22) s. 13390-13397. DOI: 10.1021/acs.est.9b02533

   This study was cited in the Miljødirektoratet report: PFAS in the treatment of skis — Use, Emissions and Alternatives, M-2032 | 2021.

2. Grønnestad, Randi; Schlenk, Daniel; Krøkje, Åse; Jaspers, Veerle; Jenssen, Bjørn Munro; Coffin, Scott; Bertotto, Luísa Becker; Giroux, Marissa; Lyche, Jan Ludvig; Arukwe, Augustine. Alteration of neuro-dopamine and steroid hormone homeostasis in wild Bank voles in relation to tissue concentrations of PFAS at a Nordic skiing area. Science of the Total Environment 2021;Volum 756:143745. s. 1-8. DOI: 10.1016/j.scitotenv.2020.143745

References 5-6 intensified the discussion about the regulation of PFASs in skiwaxes for professional competition in 2021, which has been postponed.

3. Skåre, J.U., Alexander, J., Haave, M., Jakubowicz, I., Knutsen, H.K., Lusher, A., Ogonowski, M., Rakkestad, K.E., Skaar, I., Sverdrup, L.E., Wagner, M. et al. (2019) Microplastics; occurrence, levels and implications for environment and human health related to food. Scientific opinion of the Scientific Steering Committee of the Norwegian Scientific Committee for Food and Environment. 2019. VKM Report (2019:16).

4. Mehinto, A. C., Coffin, S., Koelmans, A. A., Brander, S. M., Wagner, M., Thornton Hampton, L. M., Burton Jr, A. G., Miller, E., Gouin, T., Weisberg, S. B., Rochman, C. M. (2022) Risk-based management framework for microplastics in aquatic ecosystems. Microplastics and Nanoplastics, 2, 17. DOI: 10.1186/s43591-022-00033-3

References 7 and 8 present species sensitivity distribution to estimate safe levels of nano- and microplastics in the aquatic environment.

4. Details of the impact (indicative maximum 750 words)

The published results of PFASs in both wildlife and effects found in exposure studies raised cause for concern for human health as well. In 2019, Krøkje and Grønnestad were approached by journalists from Dagbladet as they were making an investigation and large case on PFASs in skiwax. The research related to the findings found in ski areas was subsequently largely covered by the public media, national and internationally (15 media outlets registered in Cristin, including NRK, The Telegraph and Daily Mail) and Grønnestad was invited to give several talks regarding her findings from 2019-2021. The Norwegian Environmental Agency (Miljødirektoratet) also started looking into the studies and published a report in 2021 (M-2032). There was a plan to ban PFASs from all skiwax for professional competition in 2021, but this regulation was postponed. However, the current aim is to put a European wide legislation on PFASs into place by 2025 through REACH and Norway is a key player in the preparations towards the restriction report (to be delivered to ECHA in January 2023). The societal impact is already evident with several non PFASs alternatives now on the market and consumers being aware and asking about non PFASs skiwax when they buy skiwax. Our research, carried out and mainly drive by people at IBI (ENVITOX), has thus made a major impact on both the attention of regulators and the public attention towards PFASs in skiwax.

In a global context, both Dechlorane plus and long-chain PFCAs are currently under review for being listed on the Stockholm Convention for persistent organic pollutants. The Norwegian Environment Agency is routinely checking research articles and has also employed many of our studies to include for making proposals to ECHA and the Stockholm Convention (see references for some examples). As a results, in 2019 and 2022, two specific PFASs were added to the Stockholm Convention, PFOA and PFHxS, respectively. PFHxS was also one of the compounds found higher in the voles from the ski area as compared to the reference area by Grønnestad et al. 2019. Also the results from IPY project BearHealth (RCN 175989, 2007-2012) were presented for the SC in 2018 (POPRC-14) and contributed to regulations of PFHxS in the SC in 2022 (SC-10/13). Our research has made important contributions to these regulations, but this has to be seen as a part of the puzzle within the international research community that in total leads to a global impact.

Regarding the results on thresholds of nano- and microplastics in the environment: This research is being used by the Californian government to manage plastic pollution in their water bodies. The definition of plastic debris (recommendations formulated by the research group of Martin Wagners) has been used in ECHA's restriction proposal for intentionally used microplastics. Multiple other national regulations reference Wagner's work but are difficult to track down (1000+ citations). Research on plastic chemicals has been used to include the issue of hazardous chemicals in plastics in the ongoing negotiations of the global plastic treaty.

In summary, our research at IBI (ENVITOX) has contributed to many important regulations and is used in many proposals for new regulations. Regulations and restrictions of harmful chemicals are for the benefit of the global biosphere, including human health and society. Especially global regulations are of essence as chemical pollution crosses national and international borders.

5. Sources to corroborate the impact (indicative maximum of ten references)

Risk assessment and regulation:

1. Miljødirektoratet/ Norwegian Environment Agency PFAS in the treatment of skis — Use, Emissions and Alternatives - M-2032 | 2021
   PFAS in the treatment of skis - Use, Emissions and Alternatives - Miljødirektoratet (miljodirektoratet.no)

2. Restriction under REACH – proposal for a European wide regulation on PFASs:
   https://www.miljodirektoratet.no/ansvarsomrader/kjemikalier/reach/restriksjoner-under-reach/forbud-mot-pfas/

3. Persistent Organic Pollutants Review Committee (POPRC) recommendations UNEP-POPS-POPRC.17-7 (Canadian proposal for long chain PFASs) and UNEP-POPS-POPRC.17-13 (Risk profile for Dechlorane plus)
   http://www.pops.int/TheConvention/POPsReviewCommittee/Recommendations/tabid/243/Default.aspx

4. Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds listed in 2022 on Annex A without specific exemptions (decision SC-10/13) and perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds in 2019 on Annex A with specific exemptions (decision SC-9/12)
5. http://www.pops.int/TheConvention/ThePOPs/TheNewPOPs/tabid/2511/Default.aspxA MAP, 2018. AMAP Assessment 2018: Biological Effects of Contaminants on Arctic Wildlife and Fish. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. vii+84pp

6. Dietz R, Letcher RJ, …, Ciesielski TM, … Jenssen BM, et al (42 authors) 2022. A risk assessment review of mercury exposure in Arctic marine and terrestrial mammals. Science of the Total Environment 829: 154445.
   DOI: 10.1016/j.scitotenv.2022.154445

7. Definition of plastic debris: European Chemicals Agency (2019) ANNEX XV RESTRICTION REPORT PROPOSAL FOR A RESTRICTION
   https://echa.europa.eu/documents/10162/05bd96e3-b969-0a7c-c6d0-441182893720

8. Plastic chemicals: UNEP Preparation of an international legally binding instrument on plastic pollution, including in the marine environment - Plastics science, UNEP/PP/INC.1/7
   https://www.unep.org/about-un-environment/inc-plastic-pollution

International media:

9. Wax on skis could be harming the environment. The Telegraph (telegraph.co.uk) [Avis] 2019-11-06

10. Ski wax is being EATEN by animals at winter resorts and infiltrating the food chain at potentially toxic rates, scientists warn. Daily Mail (dailymail.co.uk) 2019-11-06