State of play of the impact of chemical pollution on freshwater and marine wildlife in the UK

Report from conversations with UK academics between April and July 2020

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Summary

Globally, pollution, including chemical pollution, is one of the key drivers of the biodiversity crisis, which is a source of great concern for MCS and CHEM Trust. Concerningly, not one of England's 4,679 inland water bodies assessed by the Environment Agency in 2019 received good chemical status. All have levels of certain chemical contaminants related to human activities exceeding environmental standards. But what impact is chemical pollution having on biodiversity in the UK?

During 2020 we had conversations with 15 academics based in the UK to assess the evidence of the impacts of chemical pollution on freshwater and marine wildlife. The key message was that chemical pollution, from both historic and current day emissions, is still impacting the marine and freshwater environments, despite a significant decrease in pollution from certain contaminants since the last century.

From a freshwater perspective, recovery of certain freshwater species is still only partial (e.g. certain fish and invertebrate species). This is especially the case in areas with greatest urban cover, where pollution from legacy persistent organic pollutants (POPs) is hindering the full recovery of freshwater wildlife and ecosystems. Moreover, the scarcity of data regarding emerging contaminants makes it difficult to derive their trends and impacts on freshwater wildlife in the UK.

In terms of the marine environment, there is clear evidence of the impact of legacy POPs, in particular PCBs, on the immune system, reproductive system and lipid metabolism of marine mammals in the UK (e.g. killer whales, harbour porpoises, grey seals). This is a source of concern regarding the long-term impact of chemical pollution on marine mammal populations, with clear evidence of decline regarding killer whale populations. Also, there is evidence of chemical pollution induced tumours in some fish species, as well as disruption of the endocrine system of marine invertebrates.

The evidence highlights the particular concern of pollution from persistent anthropogenic chemicals, with severe adverse effects still reported decades after the phase out of certain POPs. However, our understanding of the impact of chemical pollution is incomplete as there is significantly less data available regarding emerging contaminants such as the very persistent chemicals PFAS and new generations of flame retardants, pesticides, pharmaceuticals, etc. Adverse impacts from a wider range of contaminants on freshwater and marine wildlife should therefore not be ruled out.

The academics also provided their views on what needs to be done differently in terms of chemical regulation, research, monitoring and funding in order to mitigate the impact of chemical pollution on freshwater and marine environments. The key message regarding chemical regulation is that a more proactive approach is required (e.g. preventing new 'problem' chemicals entering widespread use). Monitoring is recognised as vital in order to identify unforeseen adverse impacts on wildlife and ecosystems. However, longer-term monitoring integrating chemical, biological and ecological indicators is needed to better assess the real-world and long-term impact of chemical pollution on wildlife and ecosystems. Finally, the academics felt funding for both research and monitoring does not reflect the threat posed by chemical pollution.

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Background

The Marine Conservation Society, MCS, the UK's leading marine charity, works to ensure our seas are healthy, pollution free and protected. CHEM Trust, a collaboration between CHEM Trust, a UK registered charity and CHEM Trust Europe eV a charity based in Germany, works towards the protection of humans and wildlife from harmful chemicals. Together we share concerns about the impact of chemical pollution on wildlife and ecosystems and its role in the biodiversity crisis, concerns that we've expressed in various publications and public consultations over the years *(e.g. CHEM Trust, 2008, 2013a,b, 2014; MCS 2020, 2021)*.

The UK government, as of March 2021, is working on a new Chemicals Strategy. The first UK Chemicals Strategy was established in 1999 and *"set out the government policies to avoid harm to the environment and to human health through the environmental exposure of chemicals."* Chemical production and consumption has increased sharply in the past 20 years and is projected to double again globally by 2030 *(UNEP, 2019)*. The increase in use of synthetic chemicals is likely to lead to increased emissions into the environment. In England, none of the 4,679 rivers, lakes, estuaries and other surface water bodies assessed by the Environment Agency in 2019, according to the water quality standards set in the Water Framework Directive, received good chemical status *(EA, 2020)*. Meaning that 100% of English rivers, the path to the sea, have concerning levels of chemicals related to human activities. The new UK Chemicals Strategy presents a unique opportunity to develop actions to lower the chemical pollution burden in the environment and address the impact of chemical pollution on people, wildlife and ecosystems.

In 2020, we spent time listening to scientists' concerns regarding the impact of chemical pollution on UK freshwater and marine environments. This new MCS and CHEM Trust joint briefing is a report of these conversations with the aim to inform the development of the new UK Chemicals Strategy. It will feed into the evidence-based recommendations that both MCS and CHEM Trust will put forward to UK policy makers to better protect marine and freshwater wildlife and ecosystems from the impact of chemical pollution.

1. Introduction

Pollution, including chemical pollution, is recognised as one of the key drivers of the biodiversity crisis *(IPBES, 2019)*. But what is the state of play of the impact of chemical pollution on biodiversity in the UK?

To discuss this question, CHEM Trust and MCS contacted UK academics researching the impacts of chemical pollution on marine and freshwater wildlife and ecosystems. We held a workshop in April 2020 and followed up with individual conversations to delve deeper into the available evidence.

In this paper, we report from the workshop and the subsequent conversations we had with a dozen academics. It was noted by academics that the marine and freshwater environments, although linked, were significantly different in the impacts caused by chemical pollution. This is mostly due to the difference in average species longevity and the implications for chemical bioaccumulation. For freshwater species life spans are around 1 to 10 years, but can be up to several decades for some marine mammals. Therefore, we have split the report into two sections, covering the separate environments for the purpose of this paper. The paper also does not cover terrestrial ecosystems.

Following the assessment of the state of play and its limitations (sections 2, 3 and 4), section 5 summarises the academics opinions regarding what should be done differently going forward.

2. Freshwater

2.1 Significant improvement, but recovery is lagging behind

Looking at freshwater first, the common message from the academics is that, compared to the previous century, there has been a clear improvement in water quality regarding certain biological and physicochemical indicators. With a significant reduction in historical pollution from certain contaminants such as heavy metals and ammonia, mostly due to a reduction in industrial activities, but also to regulatory actions *(e.g., 1991 European Urban Wastewater Treatment Directive)*.

As a consequence, several freshwater species, which showed significant decline until the mid-1990s due to chemical pollution, are now recovering, such as otter and Atlantic salmon *(Mawle and Milner, 2008)*. However, the recovery of certain freshwater species is only partial and lagging behind that of physicochemical conditions. Fish populations have still not fully recovered *(Mawle and Milner, 2008)*, freshwater mollusc occupancy is still in decline *(Outhwaite et al., 2020)* and otters are showing signs of a new decline, although the reason is unclear *(Kean et al., 2021a)*. In urban river systems, invertebrate communities remain impaired and present only 60% of the macroinvertebrate families found in non-urban catchments *(Vaughan and Ormerod, 2012; Windsor et al., 2019)*. Furthermore, it is recognised that poor habitat status may be preventing a return to ideal biodiversity.

2.2 Legacy, emerging and hidden contaminants; all a cause for concern

Although the situation in terms of gross historical pollution, as one academic put it, *"is like night and day compared to previous decades"*, not one river in England is in good chemical status according to the Water Framework Directive standards. And despite the good progress on certain fronts, there is continued, and for some contaminants, increasing concern around the effects of chemical pollution.

Legacy persistent organic pollutants (POPs) such as PCBs, PBDEs and PFOS[1] are still present in UK rivers *(EA, 2019)* and freshwater wildlife *(Keane et al., 2021b)* above currently estimated toxicity thresholds. This is due to their high persistence in the environment, and also because regulatory control measures were adopted only after many years of delay. And there is evidence that POPs are hindering the recovery of freshwater wildlife populations, especially in areas with a greater urban cover *(Windsor et al., 2019)*. However, there are concerns about emerging contaminants, including neonicotinoid insecticides *(Mason et al.,*

[1] PCBs: Polychlorinated biphenyls; PBDEs: Polybrominated diphenyl ethers; PFOS: Perfluorooctanesulfonic acid.

2013) and pharmaceuticals *(e.g. White et al., 2019)*, but it is difficult to derive trends and impacts on freshwater wildlife and ecosystems in the UK due to the scarcity of data. For instance, the potential role of chemical pollution in the decline of amphibian populations in the UK has yet to be fully investigated. Viral infection from *Ranavirus,* causing syndromes such as skin ulceration in amphibians, have been correlated with localised declines of common frog populations in Britain *(Teacher et al., 2010);* and laboratory studies are showing an association between chemical exposures, in particular pesticides *(e.g. Mann et al., 2009)*, and the weakening of immune function of amphibians, making them more susceptible to infectious disease.

There are also concerns about the more subtle, indirect effects of chemical pollutants that may be impacting the entire ecosystem through affecting the ways species interact with each other. When looking in detail at an ecosystem scale (at high taxonomic resolution) the picture is much more complex. *Windsor et al., 2019* studied a network of rivers in South Wales between 2016 and 2017 and showed that food webs at the most highly contaminated urban sites were characterised by: reduced diversity, both in terms of species and ecosystem functions; simplified food web structure with reduced network connectance; and reductions in the abundance of prey important for apex predators such as the Eurasian dipper. These changes in ecosystem structures, in part attributed to chemical pollution, impact the food web and therefore the function of the ecosystem.

3. Marine

3.1 At the end of the river is the ocean

The marine environment is the receiving end of land and river pollution, acting as the final sink. There is a common misconception that due to the vastness of the sea, contamination is diluted to the point of no effect. However, for some pollutants with bioaccumulative and/or persistent properties, the levels in the marine environment and wildlife are potentially higher and of greater concern than the same pollutants in freshwater. The most dramatic illustration of this is the fact that levels of some synthetic chemicals (i.e PCBs, PBDEs) in the deepest part of the ocean, the Mariana trench, are higher than in some of the most industrialised areas in the globe *(Jamieson et al., 2017)*.

It is important to stress that there is already bias as to what is studied in the marine environment. By far, the most studied species in the UK are marine mammals (e.g., killer whales, harbour porpoises and seals) and the effects of POPs on these species. There are a handful of studies on other species such as flat fish. However, the vast majority of species in the UK marine environment are still understudied in terms of contamination. This includes other apex predators that are likely to have high contaminant levels, such as sharks *(Tiktak et al., 2020)*.

3.2 Evidence of chemical pollution impact on marine wildlife in the UK

Marine mammals: It is generally the case that persistent and bioaccumulative pollutants affect the animals at the top of the food chain the most due to biomagnification. The animals that mature late and have fewer offspring tend to have a larger build-up of contaminants. Disruption of the reproductive system, immune system and lipid metabolism are all causes for concern regarding the long-term impact of chemical pollution on marine mammal populations. Populations of killer whales have been studied in UK waters revealing that there have been no new calves in two decades; the populations are trending towards a complete collapse within the next 100 years, consistent with severe PCB-induced population-level effects *(Desforges et al., 2018)*.

PCB pollution impacts the immune system of marine mammals. 15 years ago, it was estimated that an increase of 1 mg of PCB per kg of lipid in the blubber was responsible for a 2% increase in risk of infectious disease mortality of harbour porpoise *(Hall et al., 2006)*. Now, adding 15 years of data, this value has more than doubled to 5% *(Williams et al., 2020a)*. For the average concentration reported in UK harbour porpoises in this study, it corresponds to a 41% increase in risk. Infectious disease is the first cause of death reported for harbour porpoise stranded on the UK coast *(CSIP, 2019)*.

POPs also disrupt the lipid metabolism of marine mammals, which impacts their energy balance and may affect their chance of survival. *Robinson et al. 2018* studied a population of grey seals on the coast of Scotland between 2015 and 2017. They found that 18 day old seal pups have already accumulated high enough levels of POP in their blubber to impact its function, which may negatively impact their ability to survive their first year of life at sea.

This highlights a reality common to all marine mammals: the young ones are already burdened with high levels of POPs a few weeks after birth; as these bioaccumulative synthetic chemicals are being passed from the mother to the young during breastfeeding as well as directly through the placenta.

Williams et al, 2020b showed that juvenile harbour porpoises in the UK were exposed to a more neurotoxic PCB mixture than adults at a time when they were most vulnerable to its effects. Early life is a time of rapid growth and development when the young may be particularly susceptible to the adverse effects of chemical pollutants.

Fish: A very worrying trend has been reported for flat fish in the North Sea. In some localities, e.g., Dogger Bank, liver cancer rate prevalence is > 20% *(Vethaak et al., 2009)* and can reach 40% in older fish over 7 years of age *(Stentiford et al., 2010)*. *Lerebours et al., 2014* showed that liver tumorigenesis in flat fish is associated with long term exposure to anthropogenic carcinogenic contaminants, in particular cadmium and PCBs.

Invertebrates: Imposex traits (female gastropod developing male sex organs) due to endocrine disruption related to POP exposure *(Oehlmann et al., 1996)* are still being observed in UK marine snails. These snails had only just started repopulating the coast around Portsmouth, and one academic told us that they were already shown to be imposex *(pers. comm.).*

It has also been reported that chemical pollution is impacting the sperm quality of marine crustaceans, with lower sperm counts recorded in the most polluted coastal areas in the UK *(Yang et al., 2008)*.

3.3 Persistence is a concern, especially with new unknown contaminants

POPs have been accumulating in the marine environment for decades and due to their persistence, are still present, and will still be present in high levels for many decades. The persistent nature of many chemical pollutants means that regulatory action has had a limited impact on the marine environment. After a significant decline between the 1970s and 1990s, POPs levels are now only declining slowly or plateauing (eg. *Robinson et al., 2019*). PCB levels in particular have been described to have *"potentially reached a 'steady state' between environmental input and degradation, meaning high PCB exposure is set to continue for long term" (Jepson et al., 2016)*.

Most of the academics we spoke to mentioned the 2001 Stockholm Convention international treaty as a positive example of regulation. One where countries across the globe came together to ban some of the most toxic chemicals on the planet. Signatory countries meet every two years to update the Convention and ban additional chemicals. To date, 30 POPs have been banned globally through the treaty, but thousands of highly persistent chemicals are still on the market and finding their way to the marine environment. Lessons have to be learnt.

The academics shared their concerns that the history of chemical regulation is unfortunately time and again, too little, too late. Action is needed now to prevent this cycle repeating with newer equally, if not more, persistent chemicals. In their 2020 paper, *Kwiatkowski et al.* noted that even if production of PFAS - a group of several thousands of highly persistent chemicals[2] - ceased today, the existing pollution would remain for centuries.

4. An incomplete picture

4.1 Limitations of current monitoring approach

An incomplete picture of chemical pollution is obtained if monitoring looks at only a limited number of contaminants (mostly legacy POPs), species and endpoints. With the current targeted monitoring practice, other threats remain invisible and are missed. One academic is of the opinion that it is the reason PFAS pollution was missed for so long. Some PFAS have only started to be *"seen"* via monitoring in the last couple of decades; but we are still *"blind"* to a large fraction of the PFAS group of chemicals. **This raises the question of what system can be put in place to prevent risks emerging from chemicals that aren't seen via routine monitoring?** Non-targeted monitoring is starting to reveal many substances that are entirely new to the scientific community: metabolites, breakdown and degradation products and new substances which have been put on the market.

Targeted monitoring alone doesn't allow a true picture of real-world exposure to chemical contaminants and what the pollution burden of wildlife is. **This brings limitations to our understanding of the impact of cumulative exposure to multiple anthropogenic substances**. Academics mentioned that, in several instances, it cannot be ruled out that adverse effects ascribed to the specific legacy contaminants studied in the field could, in reality, result from a combination effect of a wider range of legacy and emerging pollutants present in the environment.

Monitoring of biota is also very limited; both population monitoring, e.g., population density, demographic data etc. and for contaminants within the biota. Some academics were of the opinion that we currently don't hold enough data regarding chemical pollution on freshwater

[2] The US Environmental Protection Agency compiled a list of over 9,000 PFAS.
EPA. PFAS Master List of PFAS Substances (Version 2). Assessed 26/01/2021.
https://comptox.epa.gov/dashboard/chemical_lists/pfasmaster

species. They also pointed out that long term monitoring is often targeted at specific organisms that are widely dispersed and 'easy' to sample, but they may not be the most sensitive or biologically representative ones. Moreover, by looking only at the small suite of 'usual suspects', the contaminants that could be biologically relevant to certain species are potentially not being caught. Finally, the concern that some impacts of chemical pollution on the aquatic environment are being missed by not looking at the right endpoint using standard monitoring, was also expressed.

4.2 Limitations and challenges to the assessment of chemical pollution impact on aquatic wildlife

Lab observations vs real-world (field work): One of the main routes to understand the risk posed by chemical exposure to aquatic wildlife is via laboratory tests. These tests generally involve acute exposure of contaminants to tissues or a limited range of *"laboratory-friendly"* species. There is a long-standing concern that these tests do not properly replicate long term exposure to contaminants (chronic exposure) and are not predictive for all species and effects *(e.g., Johnson et al., 2020)***.** Overall, there is a critical lack of data for chronic exposure effects for most pollutants. One academic also said that *"it is also an open question as to whether these tests truly reflect impacts in the natural environment, certainly at the population level"*.

Mixture toxicity: In the real-world, aquatic wildlife is exposed to complex mixtures of known and unknown natural and anthropogenic substances. There is an increasing amount of evidence showing that the toxicity of a mixture of chemicals is not equal to the sum of its parts, and most worryingly that mixture toxicity could happen at levels below the toxicity of the individual single chemicals. This suggests that risk assessments based on single substances could underestimate the effect of 'real-world' contaminant exposure *(e.g., Desforges et al., 2017)*. Moreover, the lack of mixtures/'real-world' assessment potentially results in some specific chemicals looking like less or more of a threat than they truly are.

Multiple stressors: In the real-world, not only is wildlife being exposed to hundreds of contaminants, but also to multiple anthropogenic stressors. This includes climate-change, habitat loss, noise pollution, etc. Because of this complexity, it is a very challenging task to decipher what particular stressor is causing the adverse effect observed in the field. Moreover, combined exposure to multiple stressors can lead to complex ecological responses *(e.g., Birk et al., 2020)*. It has been shown for instance that combining stressful environmental conditions with high concentrations of pollutants may act additively or synergistically to disrupt energy metabolism in polar bears *(Tartu et al., 2017)*.

Population biology knowledge gaps: It was noted by academics that gaps in our knowledge of basic biology and population biology hampers our understanding of risks and make it difficult to assess if some field observations are abnormal or not. For instance, from a freshwater perspective we don't know the population dynamics of quite abundant species, such as the amphipod crustacean *Gammarus*.

The limitations expressed in this section (e.g., in monitoring, knowledge and research focus) are important to acknowledge in order to not interpret the absence of evidence as the evidence of absence of adverse impact.

5. What should be done differently? Recommendations from the academics

During the workshop we held in April 2020 and subsequent conversations, we started discussing what should be done differently in terms of chemicals regulation, research, monitoring and funding for the purpose of achieving a higher level of protection for wildlife and ecosystems. This discussion will continue, however, we have included a summary of the opinions so far:

5.1 Chemicals regulation:

- Academics shared the common opinion that the approach to **chemicals regulation needs to be proactive and not reactive**. The shared feeling is that we are *"constantly playing catch up"* with 10-20 years cycles of what the industry has put on the market and currently *"just mopping up prior mistakes"*. There is a need to *"find a way to be ahead, not behind"*.
- This means, ***"getting better at predicting chemicals' toxicity before new chemicals are put on the market"*** to *"prevent new 'problem' chemicals entering widespread use"*.
- **The burden of proof should fall truly on the industry side**, *"not on the side of scientists scrambling to show a problem after chemicals have been approved for use"*. This involves **greater producer responsibility**: *"The onus should fall on producers to prove chemicals are safe"*.
- It was also noted that there is a need to *"close the loophole that allows demonstrated toxic chemicals to be substituted for something similar"* (aka **regrettable substitution**).
- One academic also suggested that the principle of chemical regulation should be much more on *"do we need these chemicals at all?"* even before *"is there an alternative?".* This echoes the concept of **'essential uses'** put forward by a group of scientists as a way to deal with the class of highly persistent chemicals PFAS *(Cousins et al., 2019)*.
- On **risk assessment**, it was noted that currently they *"**don't integrate enough biology and ecology**"*. That there are *"other concerns than direct toxicity regarding chemicals"*.
- Also, on **risk assessment**, there is a need to **break the silos** to account for mixture toxicity and for exposure to the same compound via routes that are regulated in different silos. For instance, pesticides and industrial chemicals should be assessed together. If a pesticide has similar effects or mode of action, it should not be considered separately, it *"doesn't make sense"*.
- Several academics were of the opinion that **a practical way to address mixture toxicity is to apply a Mixture Assessment Factor** (MAF) in the risk assessment of an individual chemical.
- Finally, one academic expressed his wish for ***"consideration of impacts on biodiversity to be included in future chemical regulation"***, *"beyond the usual lab testing"*.

5.2 Funding:

- It was noted that the gaps in knowledge regarding the impact of chemical pollution on wildlife result from *"a two part problem"*: On one side, *"analysis protocols per sample are relatively expensive"*. On the other side, there is a *"lack of interest by funding bodies to fund things like monitoring studies"*. One academic said, ***"I don't think the funding reflects the threats"***. This relates to funding for research and monitoring.
- There is also an **issue around resource allocation and prioritisation**: resource allocation often goes on what is 'fashionable', with a **'bandwagon effect'** where new research is proving what we already know *(see Johnson et al., 2020)*.
- Finally, several academics expressed their **worries about funding post Brexit**.

5.3 Assessing the 'real-world', looking at the big picture:

- One academic expressed that he *"would like to see a **more holistic approach to environment protection from chemical impacts**"*. Suggesting that *"rather than looking at individual organisms (e.g., daphnia, algae etc.), the ecosystem and ecological processes should be looked at. In addition to this, a wider range of testing that includes more subtle effects are needed"*.
- There is a need to **break the silos between ecotoxicology, environmental chemistry and ecology** as there is currently limited collaboration between the three groups. *Johnson et al., 2020* noted that ecologists have *"much to offer, in theory, in assessing chemical impacts on wildlife."*
- It was noted that *"**getting the balance between both lab and environment-based work is key**"*. One academic said that *"trying to study biologically relevant levels in environments that replicate ecological systems is really important"* and that even though long-term monitoring studies are essential, *"not all studies that work within the natural environment have to be focussed on long term monitoring"*. Further suggesting that *"developing new methods to move lab work into environments would help with this*".
- As expressed above, wildlife is exposed to a mixture of many synthetic substances. There is a need for Environmental Quality Standards (EQS) to reflect this reality by **deriving EQS for mixtures of chemicals** and **more effect-based monitoring**.
- Moreover, effect-based **mixture toxicity thresholds** are needed to **reflect the full pollutant burden of aquatic wildlife**.
- The findings of a horizon-scanning exercise to identify **key research questions to better assess and manage chemicals in the natural environment** are exposed in *Van Den Brink et al., 2018*.

5.4 Holistic monitoring integrating chemical, biological and ecological monitoring:

- It was noted that there is a *"lack of large consistent monitoring programs"* in the UK as opposed to *"lots of scientific data from discrete studies"*. The general agreement is that **more long-term monitoring is needed** in order to establish a clear baseline and be able to identify negative, but also positive changes.

- On long term monitoring, it was suggested that a **clearer dialogue** about what the Environment Agency and CEFAS[3] (and equivalent bodies in the devolved administrations) do in terms of their long-term monitoring would be beneficial.
- Monitoring programs should integrate **monitoring of chemicals in the environment, biomonitoring of chemicals in biota and ecological monitoring of wildlife populations**.
- **Ecological monitoring** is about acknowledging that *"we can't test all chemicals for all endpoints on all species"*; that *"we might be wrong sometimes"*. Therefore, we need to have a system in place to be able to catch an issue and correct the mistake. Ecological monitoring is therefore of critical importance to *"look at the end of the line"*, the start of the line being lab testing of chemicals to prevent dangerous ones from being put on the market and 'clean' the chemical universe. It is about ***"looking at the bigger picture and making sure we don't miss a bigger issue"***.
- It was also noted that many of the deficiencies in current monitoring could potentially be addressed in the future if **tissue from biomonitoring was routinely archived**. This would make it possible to re-examine the material for new chemicals of concern for which funding or methodology did not exist at the time.
- Finally, regarding monitoring of chemical contaminants in the environment, it was stressed that **the list of chemicals routinely monitored should be expanded** and **completed by wide screening non-targeted monitoring** to identify overlooked contaminants.

6. Conclusion

There was generally agreement among the academics that chemical pollution was still impacting the marine and freshwater environments, although to different degrees, despite a significant decrease in pollution from certain contaminants since the last century.

The main chemical pollution threat identified comes from legacy persistent organic pollutants (POPs) such as PCBs. There is strong evidence of their, sometimes dramatic, impact on marine mammals, and more subtle evidence of their impact on freshwater ecosystems, where their presence is thought to be responsible for the only partial recovery of freshwater ecosystems.

However, the impact from legacy POPs is also by far the most studied in the UK. Due to this bias, it would be incorrect to rule out negative impacts from other types of synthetic substances on UK marine and freshwater wildlife and ecosystems, as they have been much less studied (e.g., emerging contaminants such as PFAS and new generations of flame retardants, pesticides, pharmaceuticals etc.).

From environmental monitoring there is a very incomplete picture of the true pollution burden of aquatic wildlife and ecosystems because it has been mainly focussed on persistent pollutants from the past. The chemical landscape has evolved significantly in the past decades, with thousands of new substances put on the market and a strong diversification of the compounds. As a result, a much wider range of synthetic substances are present in the aquatic environment, albeit at lower levels, and the combined impact of this myriad of synthetic substances (e.g., cocktail or mixture effect) on aquatic wildlife and ecosystems is one of the big unknowns of our time.

[3] Centre for Environment Fisheries and Aquaculture Science

7. Acknowledgements

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8. References

Birk, S., Chapman, D., Carvalho, L., Spears, B.M., Andersen, H.E., Argillier, C., Auer, S., Baattrup-Pedersen, A., Banin, L., Beklioğlu, M. and Bondar-Kunze, E., 2020. Impacts of multiple stressors on freshwater biota across spatial scales and ecosystems. *Nature Ecology & Evolution*, 4(8), pp.1060-1068. https://doi.org/10.1038/s41559-020-1216-4

CHEM Trust, 2014. Pharmaceuticals in the Environment: A growing threat to our tap water and wildlife. A CHEM Trust report by Gwynne Lyons. 36p. https://www.chemtrust.org/wp-content/uploads/CHEM-Trust-Pharma-Dec14.pdf

CHEM Trust, 2013a. Frogs at risk and possible implications for humans. A CHEM Trust briefing by Professor Susan Jobling, Dr Alice Baynes and Dr Trenton W.J Garner. 10p. https://www.chemtrust.org/wp-content/uploads/CHEM-Trust-Frogs-Immune-Report-FINAL.pdf

CHEM Trust, 2013b. Persistent organic pollutants and indicators of otter health: other factors at play? A CHEM Trust report by Dr Eleanor Kean, Gwynne Lyons and Dr Elizabeth Chadwick. 28p. https://www.chemtrust.org/wp-content/uploads/Otter-Health-Pollutants-V8-DesignedV4-FINAL.pdf

CHEM Trust, 2008. Effects of Pollutants on the Reproductive Health of Male Vertebrate Wildlife – Males Under Threat. A CHEM Trust report by Gwynne Lyons. 48p. https://www.chemtrust.org/wp-content/uploads/Male-Wildlife-Under-Threat-2008-full-report.pdf

Cetacean Strandings Investigation Programme CSIP, 2019. Final Contract Report 1st January 2011 to 31st December 2017. Contract number MB0111. 81p. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17835&FromSearch=Y&Publisher=1&SearchText=strandings&SortString=ProjectCode&SortOrder=Asc&Paging=10&fbclid=IwAR2ZtxWK2uGG2AH3EOx4ChHSSMmPbAxkR3Tyf7xV6YxWsG58-QNhQZIvBR8#Description

Desforges, J.P., Hall, A., McConnell, B., Rosing-Asvid, A., Barber, J.L., Brownlow, A., De Guise, S., Eulaers, I., Jepson, P.D., Letcher, R.J. and Levin, M., 2018. Predicting global killer whale population collapse from PCB pollution. *Science*, 361(6409), pp.1373-1376. https://doi.org/10.1126/science.aat1953

Desforges, J.P., Levin, M., Jasperse, L., De Guise, S., Eulaers, I., Letcher, R.J., Acquarone, M., Nordøy, E., Folkow, L.P., Hammer Jensen, T. and Grøndahl, C., 2017. Effects of polar bear and killer whale derived contaminant cocktails on marine mammal immunity. Environmental science & technology, 51(19), pp.11431-11439. https://doi.org/10.1021/acs.est.7b03532

Environment Agency, 2020. Catchment Data Explorer. Data updated 17th September 2020. https://environment.data.gov.uk/catchment-planning/

Environment Agency, 2019. 2021 river basin management plans. 36p. https://consult.environment-agency.gov.uk/environment-and-business/challenges-and-choices/user_uploads/chemicals-in-the-water-environment-challenge-rbmp-2021-2.pdf

Hall, A. J., Hugunin, K., Deaville, R., Law, R. J., Allchin, C. R. and Jepson, P. D., 2006. The Risk of Infection from Polychlorinated Biphenyl Exposure in the Harbor Porpoise (Phocoena Phocoena): A Case- Control Approach. *Environ. Health Perspect*, 114 (5), 704– 711. https://doi.org/10.1289/ehp.8222

IPBES, 2019. Global assessment report on biodiversity and ecosystem services. https://ipbes.net/global-assessment

Jamieson, A.J., Malkocs, T., Piertney, S.B., Fujii, T. and Zhang, Z., 2017. Bioaccumulation of persistent organic pollutants in the deepest ocean fauna. *Nature ecology & evolution*, *1*(3), pp.1-4. https://doi.org/10.1038/s41559-016-0051

Jepson, P.D., Deaville, R., Barber, J.L., Aguilar, À., Borrell, A., Murphy, S., Barry, J., Brownlow, A., Barnett, J., Berrow, S. and Cunningham, A.A., 2016. PCB pollution continues to impact populations of orcas and other dolphins in European waters. *Scientific reports*, 6, p.18573. https://doi.org/10.1038/srep18573

Johnson, A.C., Jin, X., Nakada, N. and Sumpter, J.P., 2020. Learning from the past and considering the future of chemicals in the environment. *Science*, *367*(6476), pp.384-387. https://doi.org/10.1126/science.aay6637

Kean, E., Clews-Roberts, R., Chadwick, E.A. and Halliwell, L., 2021a. Otter Survey of Wales 2015-2018. Arolwg Dyfrgwn yng Nghymru 2015-2018. Published by Natural Resources Wales, 2021.

Kean, E.F., Shore, R.F., Scholey, G., Strachan, R. and Chadwick, E.A., 2021b. Persistent pollutants exceed toxic thresholds in a freshwater top predator decades after legislative control. *Environmental Pollution*, 272, 116425. https://doi.org/10.1016/j.envpol.2020.116415

Lerebours, A., Stentiford, G.D., Lyons, B.P., Bignell, J.P., Derocles, S.A. and Rotchell, J.M., 2014. Genetic alterations and cancer formation in a European flatfish at sites of different contaminant burdens. *Environmental science & technology*, *48*(17), pp.10448-10455. https://doi.org/10.1021/es502591p

Mann, R.M., Hyne, R.V., Choung, C.B. and Wilson, S.P., 2009. Amphibians and agricultural chemicals: review of the risks in a complex environment. *Environmental pollution*, 157(11), pp.2903-2927. https://doi.org/10.1016/j.envpol.2009.05.015

Mason, R., Tennekes, H., Sánchez-Bayo, F. and Jepsen, P.U., 2013. Immune suppression by neonicotinoid insecticides at the root of global wildlife declines. *Journal of Environmental Immunology and Toxicology*, 1(1), pp.3-12. https://www.boerenlandvogels.nl/sites/default/files/JEIT%20Immune%20Suppression%20pdf_7.pdf

Mawle, G.W. and Milner, N.J., 2008. The return of Salmon to cleaner rivers - England and Wales. In: Mills, D. (Ed.), Salmon at the Edge. Blackwell Publishing, Oxford, UK, pp. 186e199. http://www.hwa.uk.com/site/wp-content/uploads/2017/12/Mawle-and-Milner-The-return-of-salmon-to-cleaner-rivers.pdf

MCS, 2021. A pollution time bomb heading to the coast. https://mcsuk.org/news/chemical-pollution-rivers

MCS, 2020. MCS calls for ban of ‘forever chemicals’ lurking in bathroom cabinets. https://www.mcsuk.org/news/pfas

Oehlmann, J., Fioroni, P., Stroben, E. and Markert, B., 1996. Tributyltin (TBT) effects on Ocinebrina aciculata (Gastropoda: Muricidae): imposex development, sterilization, sex change and population decline. *Science of the Total Environment*, 188(2-3), pp.205-223. https://doi.org/10.1016/0048-9697(96)05173-X

Outhwaite, C.L., Gregory, R.D., Chandler, R.E., Collen, B. and Isaac, N.J., 2020. Complex long-term biodiversity change among invertebrates, bryophytes and lichens. *Nature Ecology & Evolution,* 4(3), pp.384-392. https://doi.org/10.1038/s41559-020-1111-z

Robinson, K.J., Hall, A.J., Scholl, G., Debier, C., Thomé, J.P., Eppe, G., Adam, C. and Bennett, K.A., 2019. Investigating decadal changes in persistent organic pollutants in Scottish grey seal pups. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 29, pp.86-100. https://doi.org/10.1002/aqc.3137

Robinson, K.J., Hall, A.J., Debier, C., Eppe, G., Thomé, J.P. and Bennett, K.A., 2018. Persistent organic pollutant burden, experimental POP exposure, and tissue properties affect metabolic profiles of blubber from gray seal pups. *Environmental Science & Technology*, 52(22), pp.13523-13534. https://doi.org/10.1021/acs.est.8b04240

Stentiford, G.D., Bignell, J.P., Lyons, B.P., Thain, J.E. and Feist, S.W., 2010. Effect of age on liver pathology and other diseases in flatfish: implications for assessment of marine ecological health status. *Marine Ecology Progress Series*, 411, pp.215-230. https://doi.org/10.3354/meps08693

Tartu, S., Lille-Langøy, R., Størseth, T.R., Bourgeon, S., Brunsvik, A., Aars, J., Goksøyr, A., Jenssen, B.M., Polder, A., Thiemann, G.W. and Torget, V., 2017. Multiple-stressor effects in an apex predator: combined influence of pollutants and sea ice decline on lipid metabolism in polar bears. *Scientific reports,* 7(1), pp.1-12. https://doi.org/10.1038/s41598-017-16820-5

Teacher, A.G.F., Cunningham, A.A. and Garner, T.W.J., 2010. Assessing the long- term impact of Ranavirus infection in wild common frog populations. *Animal Conservation*, 13(5), pp.514-522. https://doi.org/10.1111/j.1469-1795.2010.00373.x

Tiktak, G.P., Butcher, D., Lawrence, P.J., Norrey, J., Bradley, L., Shaw, K., Preziosi, R. and Megson, D., 2020. Are concentrations of pollutants in sharks, rays and skates (Elasmobranchii) a cause for concern? A systematic review. *Marine Pollution Bulletin*, *160*, p.111701. https://doi.org/10.1016/j.marpolbul.2020.111701

UNEP, 2019. Global Chemicals Outlook II. 102p. https://www.unep.org/explore-topics/chemicals-waste/what-we-do/policy-and-governance/global-chemicals-outlook

Van den Brink, P.J., Boxall, A.B., Maltby, L., Brooks, B.W., Rudd, M.A., Backhaus, T., Spurgeon, D., Verougstraete, V., Ajao, C., Ankley, G.T. and Apitz, S.E., 2018. Toward sustainable environmental quality: Priority research questions for Europe. *Environmental toxicology and chemistry*, *37*(9), pp.2281-2295. https://doi.org/10.1002/etc.4205

Vaughan, I.P. and Ormerod, S.J., 2012. Large- scale, long- term trends in British river macroinvertebrates. *Global Change Biology*, 18(7), pp.2184-2194. https://doi.org/10.1111/j.1365-2486.2012.02662.x

Vethaak, A.D., Jol, J.G. and Pieters, J.P., 2009. Long-term trends in the prevalence of cancer and other major diseases among flatfish in the southeastern North Sea as indicators of changing ecosystem health. *Environmental science & technology*, 43(6), pp.2151-2158. https://doi.org/10.1021/es8028523

White, D., Lapworth, D.J., Civil, W. and Williams, P., 2019. Tracking changes in the occurrence and source of pharmaceuticals within the River Thames, UK; from source to sea. *Environmental pollution,* 249, pp.257-266. https://doi.org/10.1016/j.envpol.2019.03.015

Williams, R., Doeschate, M.T., Curnick, D.J., Brownlow, A., Barber, J.L., Davison, N.J., Deaville, R., Perkins, M., Jepson, P.D. and Jobling, S., 2020a. Levels of Polychlorinated Biphenyls Are Still Associated with Toxic Effects in Harbor Porpoises (Phocoena phocoena) Despite Having Fallen below Proposed Toxicity Thresholds. *Environmental Science & Technology*, 54(4), pp.2277-2286. https://doi.org/10.1021/acs.est.9b05453

Williams, R.S., Curnick, D.J., Barber, J.L., Brownlow, A., Davison, N.J., Deaville, R., Perkins, M., Jobling, S. and Jepson, P.D., 2020b. Juvenile harbor porpoises in the UK are exposed to a more neurotoxic mixture of polychlorinated biphenyls than adults. *Science of the Total Environment*, 708, p.134835. https://doi.org/10.1016/j.scitotenv.2019.134835

Windsor, F.M., Pereira, M.G., Tyler, C.R. and Ormerod, S.J., 2019. Persistent contaminants as potential constraints on the recovery of urban river food webs from gross pollution. *Water research*, *163*, p.114858. https://doi.org/10.1016/j.watres.2019.114858

Yang, G., Kille, P. and Ford, A.T., 2008. Infertility in a marine crustacean: Have we been ignoring pollution impacts on male invertebrates?. *Aquatic Toxicology*, *88*(1), pp.81-87. https://doi.org/10.1016/j.aquatox.2008.03.008

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