An Argument for Studying the Fate of 6PPD-Q in Bogs and Wetlands with Organic Soils in Washington State

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Introduction

Bogs are unique ecosystems, even amongst wetlands. Defined by the Environmental protection agency as being "characterized by spongy peat deposits, acidic waters and a floor covered by a thick carpet of sphagnum moss," bogs are carbon sinks, helping offset the effects of global warming (US EPA, 2015). They are sensitive to disturbance and are difficult, if not impossible to restore or recreate through mitigation efforts, which has led the Washington State Department of Ecology to give bogs the highest wetland conservation rating, Category I, in the Western Washington Wetland Rating System (Hruby, 2014).

In addition to serving as excellent carbon sinks, bogs may also serve as sinks for 6PPD-quinone (6PPD-Q). Little is known about 6PPD-Q, aside from its ubiquity in stormwater runoff and its toxicity to salmonids and other aquatic species. This essay discusses ongoing research into 6PPD-Q, introduce a hypothesis that large concentrations of 6PPD-Q accumulate in bogs and wetlands with organic soils, in order to propose a study to fill in the knowledge gaps regarding the fate of 6PPD-Q in Washington state bogs.

What is 6PPD-Q and why is it important?

6PPD is an antiozonant that has been used in car tires since the 1960s to protect tires from breaking down. In 2020, its oxidation product, 6PPD-quinone (6PPD-Q), was identified as the chemical causing acute mortality in coho salmon. 6PPD reacts with atmospheric ozone to form 6PPD-Q, and leaches into the environment when tire wear particles are washed into waterways via stormwater runoff (Tian *et al.*, 2021). 6PPD, and by extension 6PPD-Q, is globally ubiquitous, making this a worldwide environmental problem.

As a recently discovered chemical, there are several knowledge gaps regarding 6PPD-Q. Such gaps include: why coho salmon are so sensitive to the chemical, the extent of adverse health effects on mammals and aquatic species, and how best to filter or remove 6PPD-Q from the biosphere.

Current research into 6PPD-Q

Study of 6PPD-Q to date has focused on its impacts on health of coho salmon and other salmonids. A 2021 study found that 6PPD-Q is highly toxic to coho salmon, with a median lethal concentration (LC_{50}) in juvenile coho salmon of 95 ng/L (Thorp, 2022). In light of this finding, further tests have been performed to determine toxicity to other aquatic species. A 2022 study testing acute toxicity of 6PPD-Q in fish of ecological importance found LC_{50} in brook trout and rainbow trout of 0.59 µg/L and 1.00 µg/L respectively (Brinkmann *et al.*, 2022), the latter concentration being over 100 times greater than that of the coho salmon. By contrast, an earlier study testing a similar hypothesis did not detect acute toxicity in any of the tested species (*D. rerio*, *O. latipes*, *D. magna*, or *H. Azteca)*, even at maximum 6PPD-Q solubility (Hiki *et al.*, 2021). In addition, no acute toxicity was detected in Atlantic salmon or brown trout in concentrations up to 12.16 µg/L (Foldvik *et al.*, 2022). It is currently unknown why coho salmon are so sensitive to 6PPD-Q compared to other species.

In addition to acute toxicity in specific salmonid species, 6PPD-Q has also been found to cause non-lethal adverse effects in non-salmonid species. Long term exposure to 6PPD-Q in concentrations of 0.1-10 µg/L can cause motor neuron degradation in the nematode species *Caenorhabditis elegans* (Hua *et al.*, 2023). In zebrafish embryo and larvae it has been found to cause reductions in swimming performance and eye size, along with other physical deformities at concentrations of up to 25 µg/L (Varshney *et al.*, 2022). Bioaccumulation of both 6PPD and

6PPD-Q in mice can induce lipid metabolism disorder and lead to an inflammatory reaction (Fang *et al.*, 2023).

6PPD-Q's effects on humans are unknown, though it has been found in human urine. Studies of 6PPD and 6PPD-Q concentration in human urine found greater concentrations in pregnant women than in children and general adults (Du *et al.*, 2022).

Treatments to remove 6PPD-Q from water are experimental and have not been widely adopted. As recently as 2023, King County reported that it had developed a High Performance Bioretention Soil Mix (HPBSM) efficient in removing 6PPD-Q from stormwater, and expects the 2021 Surface Water Design Manual to allow the new treatment as a filtration option for 6PPD-Q (King County, 2023).

The benefits of studying bogs in relation to 6PPD-Q

6PPD and 6PPD-Q interactions with soils are currently poorly understood. A 2023 study of tire wear particle degradation in soils saw 3.8 times higher accumulation of 6PPD-Q in flooded soils than in wet soils (Xu et al., 2023). Any wetland subject to long-term inundation would thus be susceptible to heavy accumulation of 6PPD-Q. 6PPD-Q may also be toxic to soil-dwelling organisms.

Bogs in particular make excellent candidates for 6PPD-Q studies. Per former Washington State Department of Ecology personnel Lisbeth Seebacher, as an organic contaminant, 6PPD-Q will be absorbed into the organic matter in a wetland (L. Seebacher, personal communication 2024). Bogs, which are entirely composed of organic soils, are likely to serve as high-density reservoirs for the chemical.

Bogs surrounded by high-intensity land use, such as dense residential, commercial, and industrial land uses, are of particular interest to this kind of study because their proximity to roadways and other land uses with impervious surfaces means the bogs are more likely to receive from 6PPD-Q-contaminated runoff. Because bogs get most of their water from precipitation, sphagnum moss and plants such as bog labrador tea (*Rhododendron groenlandicum*) have developed adaptations to retain water during drier periods (Hébert and Thiffault, 2011). These adaptations may also force native bog vegetation to retain 6PPD-Q. Since bogs are often nutrient-deficient environments, 6PPD-Q may also take the place of nutrients within the plant and affect it in adverse ways.

A 2022 study by Ouyang *et al.* found that microplastics accumulate in coastal wetlands at a rate 528 times greater than in the water column, and 10 times greater than on sandy beaches (Ouyang *et al.*, 2022). This data could inform 6PPD-Q accumulation in bogs and wetlands by giving scientists a general idea of how much greater the accumulation is of 6PPD-Q and other tire wear particles than in stormwater systems and other waterways.

Considering all these factors, this essay proposes the hypothesis that 6PPD-Q may accumulate in bogs and wetlands with organic soil components in much greater concentrations than in wetlands with mineral soils and non-wetland waterways.

Recommendations and Conclusion

In order to test this hypothesis, a proposal has been outlined for a study of 6PPD-Q fate and impacts on bogs and wetlands with organic soils. Any studies into this topic should consider incorporating ideas from this proposal:

Over a period of at least one year, a bog or wetland with organic soils in western Washington should be selected for study, ideally surrounded by high-intensity land use and subject to inundation for most of the year. A non-wetland waterway or wetland with mineral soils should also be selected as a control. This study should also collaborate with the Washington State Department of Transportation (WSDOT) to collect more accurate vehicle counts near the study area. WSDOT only records vehicle traffic along state highways, so direct collaboration to set up vehicle count monitoring will be required if the study site is not situated along a state highway.

Soil samples and water samples should be taken weekly from the study area and from the control site and analyzed to determine concentrations of 6PPD-Q. Water samples should also be tested for pH to determine how much, if at all, 6PPD-Q is affected by acidic bog conditions. Ideally, studies should also be performed on 6PPD-Q uptake and potential sequestration in native bog vegetation, and how it compares to vegetation outside of wetlands.

Studies performed into the fate of 6PPD-Q in bogs could shed light on new methods of 6PPD-Q sequestration and removal from the biosphere, develop a deeper understanding of how 6PPD-Q interacts with soils, and provide more evidence towards the need to conserve bogs by pushing against commercial use of 6PPD in tires. Since research into 6PPD-Q is still new, it is important for wetland scientists and toxicologists alike to fill these knowledge gaps and collect information necessary to shape new environmental regulations.

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