Protecting Salmonids from Tire Wear Toxins:
6-PPDQ Workshop 2024

Post-Workshop Summary

BRITISH COLUMBIA
CONSERVATION FOUNDATION

VANCOUVER ISLAND
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Protecting Salmonids from Tire Wear Toxins: 6-PPDQ Workshop 2024

Post-Workshop Summary

Nanaimo, British Columbia

Prepared by:

British Columbia Conservation Foundation's Aquatic Research & Restoration Centre

&

Vancouver Island University's Applied Environmental Research Labs

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BRITISH COLUMBIA CONSERVATION FOUNDATION

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AERL Applied Environmental Research Laboratories

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ACKNOWLEDGEMENTS

We are grateful that the *Protecting Salmonids from Tire Wear Toxins: 6-PPDQ Workshop 2024* was able to be hosted on the traditional and unceded territory of the Snuneymuxw First Nation at Vancouver Island University (VIU) in Nanaimo, British Columbia (BC). We would like to extend a special thank you to Joan Brown, Snuneymuxw First Nation Elder and Chief Administrative Officer, who provided a wonderful welcome prayer and opening remarks to start the workshop off in a good way. A further thank you to VIU President Dr. Deborah Saucier for welcoming all presenters and attendees to the university at the start of day one.

A special thank you to Dr. Rachel Scholes (University of British Columbia) and Jane Pendray (Pacific Salmon Foundation) for contributing their time and efforts to the planning, communication, and organization of the workshop. We'd also like to thank the Vancouver Island University's Applied Environmental Research Labs and BC Conservation Foundation's Aquatic Research and Restoration Centre's staff for assisting with the set up and take down of the event. In particular, we would like to thank Joseph Monaghan, Angelina Jaeger, Dylan Steenis, Misha Zvekic, Sebastian Cereno, Jamieson Atkinson, Danny Swainson, Thomas Negrin, Ally Badger, Aaron Androsoff, Kirsten Stochmal, Carter Kowalski, and Jessie Paras.

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Finally, a massive thank you to all of the presenters and attendees that were able to make their way to Nanaimo for this event – it would not have been the same without such an incredibly engaging group of people!

ACRONYM LIST

Acronym	Definition
6-PPD	N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine
6-PPDQ	N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine quinone
BC	British Columbia
BCCF ARRC	BC Conservation Foundation's Applied Research & Restoration Centre
BCSRIF	BC Salmon Restoration & Innovation Fund
BPA	Bisphenol A
CEPA	*Canadian Environmental Protection Act*
CP-MIMS	Condensed Phase Membrane Introduction Mass Spectrometry
DFO	Department of Fisheries & Oceans
DPA	Diphenylamine
ECCC	Environment and Climate Change Canada
ELS	Early life stage
eNGO	Environmental non-governmental organization
FGA	Fish Gut Alley
GI	Green infrastructure
LC50	Lethal concentration 50 (mortality in 50% of tested specimens)
LLTK	Long Live The Kings
PSF	Pacific Salmon Foundation
SFU	Simon Fraser University
TIE	Toxicity identification evaluation
TRWP	Tire and roadway particles
TWP	Tire wear particles
UBC	University of British Columbia
USask	University of Saskatchewan
URMS	Urban runoff mortality syndrome
VIU	Vancouver Island University
VIU AERL	Vancouver Island University's Applied Environmental Research Labs

EXECUTIVE SUMMARY

The *Protecting Salmon from Tire Wear Toxins: 6-PPDQ Workshop 2024* was hosted April 29 and 30, 2024 at Vancouver Island University, by the British Columbia Conservation Foundation's Aquatic Research & Restoration Centre (BCCF ARRC) and VIU's Applied Environmental Research Labs (VIU AERL).

Since 6-PPDQ was only identified in 2020, there are many unanswered questions. This workshop intended to bring together those working on understanding the fate and distribution of 6-PPDQ, its impacts on ecosystem health, and mitigation strategies. The workshop hosts see this workshop as an important knowledge-sharing gathering to ensure that science is robust, relevant, and accessible.

In total, approximately 150 people, representing 68 different organizations, attended the two-day workshop. The first day (April 29, 2024) had a public-focused approach and centered on the major issues and impacts, while the second day (April 30, 2024) was intended for an academic audience and included more technical details related to the chemistry of 6-PPDQ and different areas of current research.

The first day of the workshop began with an introduction to 6-PPDQ by Dr. Ed Kolodziej, including the discovery story and what ultimately lead to uncovering the toxin. Dr. Markus Brinkmann followed up with an overview of how far reaching and impactful 6-PPDQ is with regards to non-coastal species and varying effects on different life stages. Dr. Erik Krogh, Haley Tomlin, Dr. Tanya Brown, and Dr. Rachel Scholes rounded out the morning by providing a short overview of ongoing, local 6-PPDQ monitoring programs. The afternoon of the first day focused on the perspectives of local individuals/organizations and potential solutions that can be implemented (presentations by Tim Kulchyski, Kyle Miller, Justin Budyk, Dr. Sylvie Spaakman, and Keith Estes). The last portion of the first day involved an overview of the current state of 6-PPD and regulations in Canada by Daniel Cheater of Ecojustice Canada.

The second day of the workshop involved more in-depth overviews of current research; the day was divided into three panels: toxicity, occurrence, and fate and remediation. The toxicity panel presented on different approaches to quantifying, identifying, and monitoring for 6-PPDQ (Josh Baker), assessing toxicity in different life stages of multiple fish species (Katie Roberts and Bonnie Lo), and assessing the variability of 6-PPDQ toxicity based on varying habitat conditions, fish stocks, and life stages (Garrett Foster). Occurrence related research presentations involved

an overview of different analytical methods used to measure 6-PPDQ in water samples (Dr. Joseph Monaghan), how 6-PPDQ changes over time and space (Angelina Jaeger and Dr. Mason King), and an overview of the investigations into the physiochemical properties of PPDQs (Misha Zvekic). Finally, the day ended with ongoing research with regards to fate and remediation, including assessing the use of computational chemistry to inform questions regarding 6-PPDQ (Simon Maguire), investigating varying tire wear particle sources around Vancouver (Yanru Wang), and assessing different types of green infrastructure and their efficacy of removing 6-PPDQ (Dr. Tim Rodgers and Dr. Ani Jayakaran).

6-PPDQ OVERVIEW

It has been recognized for decades that stormwater runoff has been the cause of acute mortality, now referred to as 'urban runoff mortality syndrome' (URMS), in coho salmon (*Oncorhynchus kisutch*) in the Pacific Northwest (Tian et al., 2020). However, it wasn't until 2020 that the compound responsible for the death of 40 to 90% of Puget Sound's returning coho in its most urbanized watersheds (impacting ~40% of the Puget Sound area) was identified: N-(1,3-dimethylbutyl)-N-phenyl-p-phenylendiamine quinone, commonly referred to 6-PPDQ (Tian et al., 2020). Derived from N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6-PPD), 6-PPDQ is a transformative product (Figure 1). It is an antiozonant that has been added to tire rubber since the 1970s to preserve the lifespan of tires (Tian et al., 2020). Over time, tire treads break down and tire wear particles (TWP) are left to reside on the roadway until they are washed away by rainfall.

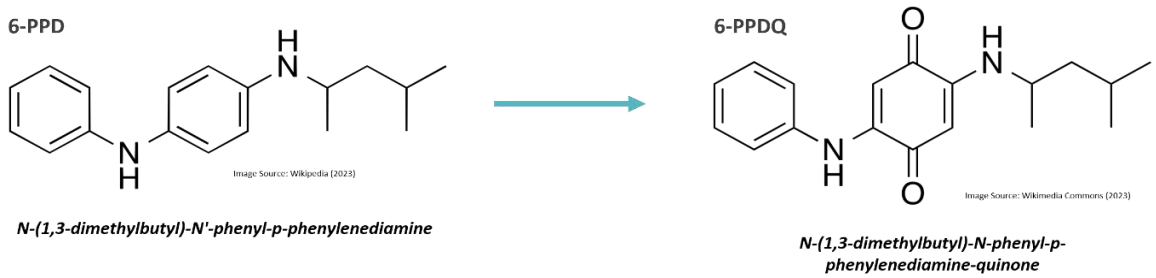

Figure 1. Compound added to tires as an antiozonant, known as 6-PPD (left), and its transformative compound, 6-PPDQ (right) that is toxic to salmonids.

Studies have identified that stormwater runoff is the greatest contributor of 6-PPDQ to urban waterways (Tian et al., 2022; Webowski et al., 2021). Stormwater runoff entering waterways with toxic concentrations (parts-per-trillion or ng/L) of 6-PPDQ can cause URMS to occur in numerous salmonid species in a matter of hours. Originally, identified to impact coho salmon (Tian et al., 2020), further studies have identified a similar fate to occur for numerous other species (Brinkmann et al., 2022; French et al., 2022).

WORKSHOP OVERVIEW

The *Protecting Salmon from Tire Wear Toxins: 6-PPDQ Workshop 2024*, was hosted at Vancouver Island University (VIU) on April 29 and 30, 2024, by the British Columbia Conservation Foundation's Aquatic Research & Restoration Centre (BCCF ARRC) and VIU's

Applied Environmental Research Labs (VIU AERL). Planning for the event was supported by the University of British Columbia (UBC) and the Pacific Salmon Foundation (PSF). Funding for the event was provided by the BC Salmon Restoration & Innovation Fund (BCSRIF) and PSF.

Since 6-PPDQ was only identified in 2020, there are many unanswered questions. This workshop intended to bring together those working on understanding the fate and distribution of 6-PPDQ, their impacts on ecosystem health, and mitigation strategies. The workshop hosts see this workshop as an important knowledge-sharing gathering to ensure that science is robust, relevant, and accessible. It is important that the many dimensions of this issue are thoroughly assessed, which will require a collective approach.

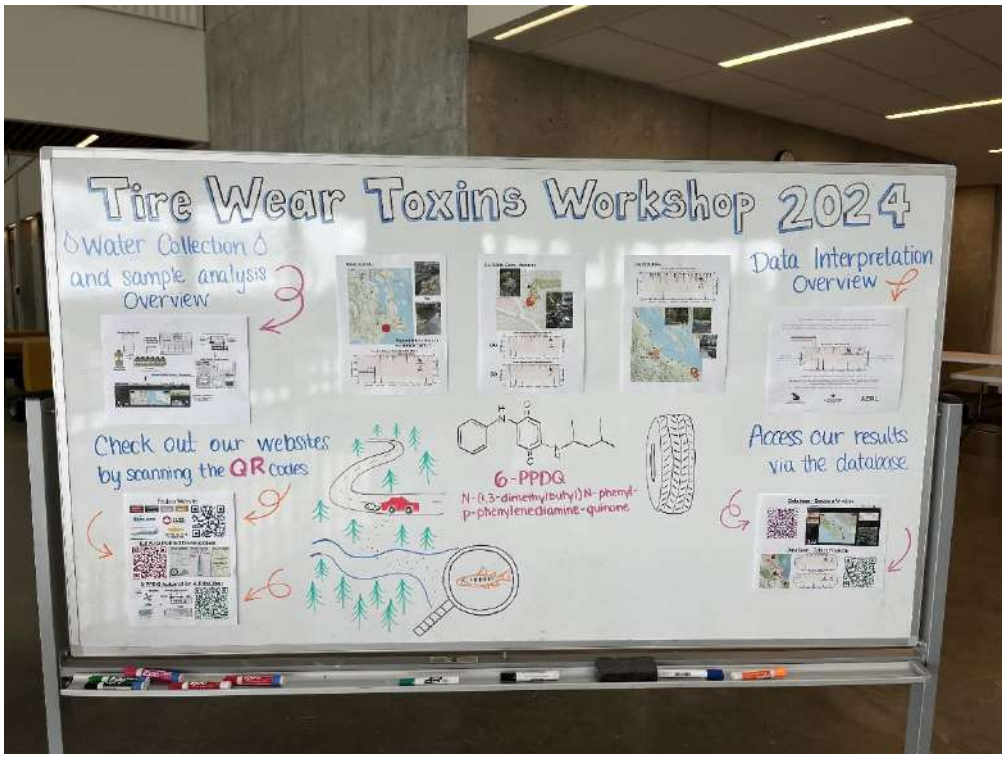

Figure 2. The welcome board that was displayed at the 2024 workshop.

ATTENDEE SUMMARY

In total, approximately 150 people representing 68 different organizations attended the two-day workshop. Most participants attended both days of the workshop. Organizations represented included environmental non-governmental organizations (eNGOs) (11), local First Nations and/or First Nations-based organizations (11), academic institutions (8), community stewardship groups (13), environmental consultants (9), provincial government

ministries/organizations (2), federal government departments (2), regional/municipal government staff (6), environmental working groups (2), and other miscellaneous organizations, including local media (4).

Figure 3. Dr. Erik Krogh welcomed workshop attendees on day 1.

WORKSHOP LAYOUT

The workshop occurred over two days, with each day planned for a different target audience. The first day (April 29, 2024) was meant to be for anyone interested and had a public-focused approach, while the second day (April 30, 2024) was intended for an academic audience.

The public-focused event was intended to provide participants with a background of 6-PPDQ, including how it was discovered, its known impacts, and ongoing local research. Additionally, the afternoon of the public-focused event included a panel of perspectives on why it is imperative to gain a better understanding of 6-PPDQ and its impacts, as well as an overview of known, effective mitigation strategies/solutions.

The academic-focused event was still openly available for interested members of the public to attend. However, the intention of the second day was for current, ongoing research projects to

be presented, including more technical details that were omitted when discussing the major issues and impacts on day one.

Over both days of the workshop, information booths and project posters were set up in the area set aside for breaks and networking. In total, nine information booths were displayed by local eNGOs, regional district programs, and community stewardship groups. Additionally, 15 project posters were displayed and presented by current students and community group representatives.

Prior to the initial presentations given on the first day of the workshop, welcoming remarks and prayers were provided by Joan Brown, Snuneymuxw First Nation Elder and Chief Administrative Officer, to start the workshop off in a good way. Additionally, the President of VIU, Dr. Deborah Saucier, provided some words of welcome to those attending the workshop.

SUMMARY OF PUBLIC FOCUSED EVENT PRESENTATIONS: INTRODUCTION TO 6-PPDQ & ONGOING LOCAL PROGRAMS

Michael Meneer – Opening Remarks

President and CEO of the Pacific Salmon Foundation (PSF), Michael Meneer, provided some opening remarks highlighting the importance of the 6-PPDQ research, coming together for the workshop to share existing research and knowledge, and ultimately taking a collaborative approach to tackling the 6-PPDQ issue and strategies to support healthy waters for salmon.

Since the discovery of 6-PPDQ, PSF has been heavily involved in advocating for research and change locally and nationally. PSF is part of the group that put forth the request to the federal government to assess 6-PPD under section 76 of the *Canadian Environmental Protection Act*. Additionally, they have reached out to tire manufacturers in Canada, Environment and Climate Change Canada (ECCC), and the Department of Fisheries and Oceans (DFO) to get a better grasp on what is known and being undertaken in Canada to find solutions for 6-PPDQ issues. PSF has provided funding support to the BCCF ARRC/VIU AERL research, as well as supported through their Community Salmon Program to fund installation of mitigation measures, such as rain gardens. PSF is dedicated to continuing their support however they can to the 6-PPDQ issue moving forward.

Ed Kolodziej – 6-PPDQ: Introduction & Background

Dr. Ed Kolodziej, from the University of Washington and Center for Urban Waters, provided a background of the research undertaken to identify the cause of coho mortality events in Puget Sound and of the compound of concern, 6-PPDQ. Dr. Kolodziej runs an environmental mass spectrometry lab that was part of the research team that discovered 6-PPDQ and its impacts.

Extensive urban watershed restoration efforts in the 1990s resulted in more monitoring of urban waterways. It was these groups of people that started reporting high coho mortality during and following rain events. It was the observations of pre-spawn coho mortality that initiated research that ultimately found 6-PPDQ to be the culprit.

Between 2015 and 2017, the research team worked to identify the 'toxicant signature' of coho mortality. Working with citizen scientists, water samples were collected from waters where coho mortality was observed. The team found that there were 57 chemicals that were found in all of the collected water samples; of the 57 chemicals, 35 were related to tires. In the fall of 2017, Dr. Jen McIntyre exposed coho and chum to tire leachate and found that all coho exposed died, while the chum appeared unaffected.

Between 2017 and 2019, the research team worked to isolate the single toxic fraction from the ~2,000 chemicals that can be found in tire leachate, many of which are closely related. In late 2019, the team identified the toxic fraction ($C_{18}H_{22}N_2O_2$; 6-PPDQ), finding that it was actually not a compound added directly to tires, but one that occurs as a result of an additive (6-PPD) oxidizing. 6-PPD began being added to tires in the 1960s, prior to that, other techniques such as waxing were used to preserve the life of tires. Currently, there is approximately 1 lb of 6-PPD in ~100 lbs of rubber.

Once they identified the toxic compound, the research team then worked to evaluate its toxicity through comparison of field mortality and lab exposure experiments. Lab studies found that coho expressed the same symptoms (i.e., gaping, loss of equilibrium, etc.) that was observed in the field. Lab testing found that the most sensitive coho die at ~20 ng/L, whereas resistant 'super-coho' (1 – 2%) can survive 400 to 600+ ng/L exposures.

Unfortunately, 6-PPDQ may be the second most toxic compound to aquatic organisms ever identified and potentially the most toxic chemical ever identified for fish species. As a result, roadway runoff from busy highways will require approximately 20 to 25 times dilution to be considered safe for coho. Currently, most stormwater goes untreated, which is resulting in

~60% coho pre-spawn mortality in Seattle each fall. It is not currently known what the mortality rates of out-migrating juvenile coho are in the spring; higher water makes detections more challenging.

Further research is showing that stormwater exposure (non-lethal concentrations) are causing defects and may stunt growth of fish. Moving forward, mitigation strategies need to be prioritized, including high-performance impact treatment systems and salmon-safe tires, made with non-toxic chemicals.

Watch Ed's presentation here.

Markus Brinkmann – Toxicity of 6PPD-Quinone Across Fishes of Commercial, Cultural, & Ecological Importance

Dr. Markus Brinkmann, Director of the Toxicology Centre at the University of Saskatchewan (USask), provided an overview of his team's work that assessed a variety of fish species and their susceptibility to 6-PPDQ.

When initiating their work at USask, the only species known to be impacted by 6-PPDQ was coho salmon; therefore, there was a need to better understand how widespread the impacts of 6-PPDQ were. In total, they tested eight species of fish, including rainbow trout, brook trout, Arctic char, white sturgeon, brown trout, bull trout, lake trout, and westslope cutthroat trout; tests were conducted in collaboration by a number of different labs. A variety of exposure tests have been conducted by Brinkmann's team.

Initial studies looked to identify which species were vulnerable to 6-PPDQ. Sub-adult and juvenile life stages were exposed to 6-PPDQ for 12 to 96 hours. Test concentrations were informed by pilot studies, using single replicate high concentrations. Results indicated Arctic char, brown trout, bull trout, westslope cutthroat trout, and white sturgeon were unaffected by the highest concentrations of 6-PPDQ (> 13 µg/L). Mortality occurred in rainbow trout, brook trout, and lake trout; lethal concentrations (LC50) were between 0.33 and 1.0 µg/L. Results indicated variation in time required for mortality to occur for those impacted; brook trout died within a couple of hours, whereas rainbow trout mortality took longer. Earlier life stages appeared to be more sensitive than the sub-adults, with mortalities occurring quicker. All impacted species expressed the same behavioural symptoms as originally seen in coho salmon.

Overall, it appears there are two groups of fish: those that are sensitive at low concentrations and those that are unaffected; it is not clear what is causing the sensitivity for each species.

Further exposure studies looked at sub-lethal impacts in rainbow trout and lake trout over 28- and 45-day exposure tests. After 15 days, rainbow trout expressed multiple deformities, including yolk sac retention (not typical), spinal curvature, and blood pooling in the caudal (tail) fin.

Other studies undertaken by Markus' lab involved investigations of toxicity pathways; using *in vitro* and *in vivo* experiments, his team is looking at finding the mechanism(s) in which 6-PPDQ is causing mortality in select species. Cell lines from rainbow trout liver and gill cells were exposed to 6-PPDQ and assessed for cytotoxicity (i.e., if the cell died), oxygen consumption rate (i.e., was it impacting how oxygen is consumed), and biotransformation of 6-PPDQ (i.e., does it turn 6-PPDQ into something else). Results indicated that gills may be an important tissue to look at based on increased oxygen consumption rates when exposed to 6-PPDQ.

Overall, Markus' team showed that 6-PPDQ is not just a coastal issue and that there are many inland species that are impacted.

Watch Markus' presentation here.

Erik Krogh & Haley Tomlin – Mitigating Tire Wear Toxins to Protect Salmonids on Vancouver Island

Dr. Erik Krogh (VIU) and Haley Tomlin (BCCF) presented an overview of the BCCF/VIU monitoring program, funded by the BC Salmon Restoration & Innovation Fund (BCSRIF).

The primary objectives of the monitoring program include: [1] identifying the major sources of tire wear toxin inputs on Vancouver Island; [2] characterizing how 6-PPDQ concentrations change over time and space; and [3] evaluating how low-cost nature-based solutions can protect urban streams from tire wear toxins. Subsequent discussions focused on the first two objectives.

As there are over 10,000 points in which roadways intersect fish-bearing waterways along the East Coast of Vancouver Island, there is no shortage in sample locations. To have a greater reach, the BCCF/VIU team enlisted the help of local First Nations and stewardship groups. In 2023-2024, 30 different groups contributed to sampling 56 different waterways at 123 sites.

Sampling was directed by BCCF and was undertaken before, during, and after significant rainfall events from October 2023 to March 2024.

The novel method utilized for rapid sample analysis in this monitoring program, known as 'condensed phase membrane introduction mass spectrometry', was developed in-house at Vancouver Island University. The method and its analytical performance were expanded on in a further talk on day two by Joseph Monaghan. In anticipation of significant numbers of samples arriving at VIU's lab, a few innovations were adopted to reduce bottlenecks. First, a custom autosampler was built utilizing a reprogrammed 3D printer; this allows for automation of sample analysis, reducing any variation introduced by human operators and substantially increasing the number of samples that could be analyzed each day. Second, a sample collection app and associated materials (i.e., QR coded bottles and site location cards) were developed to standardize data collection and input. All data collected via the data collection app is automatically fed into a database in the VIU lab for inventory. Further, data processing and visualization tools were developed to automate data processing and generation of time series and geographical maps. All data from this program can now be viewed on an online data dashboard.

In addition to a wide-scale surveillance, the team has begun assessing how concentrations change over time and space. This topic was expanded on further in a talk on day two by Angelina Jaeger.

To date, the program and its volunteers have collected and analyzed over 2,000 samples over 6 rain events. Overall, 6-PPDQ was detected in approximately 33% of the samples collected. Approximately 100 of these samples were above the LC50 for coho salmon at an alevin life stage (41 ng/L) and approximately 50 were over the LC50 for coho salmon smolts (95 ng/L).

A full overview of this program can be found at the project website.

Watch Erik and Haley's presentation here.

Tanya Brown – Characterizing Runoff Associated 6-PPDQ Pulses & Effects in Pacific Salmon Habitat

Dr. Tanya Brown and her team from the Department of Fisheries and Oceans (DFO) and Simon Fraser University (SFU) have been conducting 6-PPDQ sampling in road runoff and salmon-bearing streams since 2021 to characterize concentrations and hotspots.

Efforts have involved sampling over 80 salmon bearing streams throughout the year around Metro Vancouver, Squamish, and throughout Vancouver Island since 2021. Methods involve sampling after a dry period of 48 hours or longer followed by at least 5 mm of rainfall. Sampling occurs before, during, and after the rainfall event.

In addition to analyzing water samples for 6-PPDQ, water quality parameters (i.e., dissolved oxygen, pH, etc.) are collected. Discharge and flow are being monitored at many of the sites to gain a better understanding of the relationship between discharge/flow and 6-PPDQ. The co-occurrence of other road runoff contaminants including, 6-PPD, diphenylamine (DPA), and various metals have also been studied. Results from initial data at the first 40 sites monitored indicate that 6-PPDQ concentrations during rain events generally approach or exceed the LC50 for coho salmon for the majority of sites monitored around Metro Vancouver and some within Victoria, Duncan, and the Comox area. Results show a 9- to 87-fold increase in 6-PPDQ between "before" and "during" samples.

Results are also indicating a direct relationship between DPA and 6-PPDQ. DPA is found in tires and other industrial chemical applications and is known to be toxic to rainbow trout. The elevated 6PPD-Q concentrations during rain events and the relationship between DPA and 6-PPDQ raise concerns about salmon habitat quality and the implications on their health.

Further research is underway to look at the relationship between land use/road density and 6-PPDQ. One of the objectives of this work is to develop a hotspot map using sample results along with land use/road density for predictive mapping purposes to help guide mitigative initiatives, as well as further site selection for 6-PPDQ monitoring.

Watch Tanya's presentation here.

Rachel Scholes – Identifying & Mitigating Hotspots of Salmon Exposure to Toxic Road Runoff Contaminants

Rachel Scholes and her research team's BCSRIF funded program is building off of sampling efforts conducted by Tanya's team over the past few years. The program is in collaboration with SFU/DFO, multiple Lower Mainland municipalities (Vancouver, Surrey, Burnaby), Salish Sea Indigenous Guardians Association, Salmon Safe BC, and A Rocha Canada.

The objectives of their program include: [1] identifying hotspots of salmon exposure to toxic road runoff contaminants, [2] assessing the removal of toxic road runoff contaminants from stormwater by green infrastructure (GI), and [3] how they can improve the design of GI for toxic road runoff contaminant removal.

Sample locations focus on the Metro Vancouver region (North Shore to Surrey/Whiterock) on the major salmon-bearing systems in the region. During each sample event, three teams head out to collect samples before, during, and after each rainfall; in 2023-2024 their teams sampled approximately 10 rain events. This data collection is meant to motivate where some interventions could be implemented in the future.

Further research from Rachel's lab is looking at better understanding how 6-PPDQ is mobilized into local waterways in the first place. Yanru Wang presented on day two regarding road dust from a variety of road types. This is building into a conceptual model on how different roadway types may be contributing to varying concentrations of 6-PPDQ in the environment.

Initial GI tests by Rachel's lab looked at bioretention systems. Their first assessment involved a spike test of a bioretention system in collaboration with the City of Vancouver. Results indicated that most 6-PPDQ (98%) that entered the bioretention cell was removed/sorbed to the soil and only about 2% of it came out through the underdrain that leads to the sewer. They have continued to look at how the design of GI influences how well they remove contaminants, including 6-PPDQ. Tim Rodgers spoke more on this on day two.

Research on how to enhance retention in GI has also been ongoing; this includes microcosm experiments assessing different soils and soil amendments. Part of what they're trying to test is if 6-PPDQ is breaking down in the soil or if it is just being stored. Ultimately, they are looking at the capture and degradation of 6-PPDQ in GI.

Watch Rachel's presentation here.

Panel Discussion

The panel discussion period was chaired by Dr. Erik Krogh. This portion of the workshop can be viewed here.

Question: Does 6-PPDQ bioaccumulate?

[Markus] Based on exposure studies, there were still a few survivors after 25 to 48 days. Therefore, it is thought that it does not bioaccumulate.

Question: Markus' study looked at westslope cutthroat trout and they appear to not be sensitive. Are coastal cutthroat trout sensitive to 6-PPDQ?

[Markus] These two cutthroat trout species are subspecies, and the genetics are challenging. Coastal cutthroat trout appear to be sensitive from some initial studies ongoing. Those testing the coastal cutthroat trout will be testing their strain of westslope cutthroat trout to compare studies with different strains.

Question: How frequently do we need to replace the materials in existing rain gardens and bioretention systems to maximize their capacity?

[Rachel] To my knowledge, the replacement of the material should occur on decade timescales (~20 years). We'll likely hear more from a municipal engineer about this later today.

[Ed] I worry a bit about the sorption capacity for the dissolved contaminant that will be used up first versus the continued trapping of TWP, which can act like a long-term source. I believe these sources can have toxins leach out for multiple years, potentially longer (i.e., decades). Therefore, I think gaining an understanding of how well they are capturing physical rubber particles and whether eventual removal of that rubber particle mass might be needed from detention basins or sedimentation tanks.

[Rachel] I think you would likely replace the surface media (e.g., mulching) on a more regular basis than having to actually remove all of the media from a system like that, which would be very infrequent.

Question: Are any of the bioretention systems looking at different setups that potentially have a first phase of filtration where tire particles are captured and more easily cleaned out?

[Rachel] Some existing systems have an inlet structure that allows some settling before it enters the main soil area. The idea is some of those solids settle out before going into the soil itself and those would likely be cleaned out more regularly.

[Erik] We've done preliminary lab studies, as well as others, that have looked at other potential 6-PPDQ sources (e.g., artificial turf fill). You can place artificial turf in water and watch the 6-PPDQ leach off for quite some time, so this is an important area for further research.

Question: There is a high school in the Colquitz watershed that wants to build an artificial turf field, which would drain into the Colquitz estuary. It takes 10,000 recycled tires to make enough tire crumb to cover a sports field. Someone said earlier that four tires equates to one pound of 6-PPDQ; that means there would be ~2,500 lbs of 6-PPDQ on one sports field. We have infrastructure in the Colquitz estuary where we count the salmon every year. Every year, for at least the last 20 years, we see salmon mortalities after the first flush. Is there a difference in the impact for the salmon in the ocean versus freshwater environment?

[Markus] The artificial turf fields are very interesting; we currently have a student working on this in a multi-year study. He is building an artificial turf on the top of their building. What comes off of it over long periods of time (currently in the third year of the study) is remarkable; these concentrations are really high. These releases occur for years and years. When it dries and continues to crumble overtime, the 6-PPDQ is replenished at the surface as newly exposed tire crumb is ozonated. So, I think that when you collect the effluent from a field like this it should not go directly into a body of water, it should have some type of treatment.

[Ed] If you have an artificial turf field in a sensitive environment, you need to look at non-rubber infill material. There are alternatives that do not rely on waste tires or rubber products. I believe there are some infills made with EPDM rubber, which doesn't use PPD ozonants. So, look for non-waste tire derived infills if you have to have that artificial turf fields there. We don't have a lot of data but the EPDM rubber does not have the PPD ozonants – there are alternatives out there.

Question: Considering other engineering mechanisms for mostly flow mitigation (i.e., oversized underground pipes) that have the intention of reduce initial runoff. Have we looked at how that longer exposure time would potential effect salmon in the creek? Does 6-PPDQ come out of solution as it sits in retention systems?

[Ed] I'm concerned with stagnant water-rubber contact times. Although, I have little scientific data to understand that. We have antidotal data that we think is best explained by stagnant waters bumping out of a storm drainage system, which is likely lots of rubber particles sediments in the bottom of concrete infrastructure that small volumes of water contact for a long time. We had an event in Miller Creek that had only 4 mm of rain, the hydrograph barely moved, no turbidity happened, and the water quality changed by two orders of magnitude. I think that was stagnant water transport. So, there is a data gap there.

[Rachel] Some of our leaching experiments with road dust show that within the first few hours, they are leaching. Concentrations continue to increase, stabilizing after around 24 hours.

[Markus] In the City of Saskatoon, we have 100 stormwater outfalls that shoot directly into the river and when we go measure them we see really high spikes show up really rapidly after a rain event. Saskatoon is beginning to spread out to the outskirts of the city. In these suburban areas, there are stormwater retention ponds, which seem to reduce 6-PPDQ concentrations (at the outfall). We haven't done a ton of detailed work – we're just about to start that. That said, semi-natural wetland areas that we design/construct may be part of the solution.

Question: Is there any understanding of a proxy (i.e., something that is directly correlated to 6-PPDQ) that could enable more readily accessible approaches rather than using a mass spectrometer?

[Erik] A number of people have been looking at proxies. Turbidity has been a good one in systems that we've been looking at. Turbidity is telling you there is a lot of runoff, but doesn't necessarily tell you that there is 6-PPDQ. Not all high turbidity samples have high 6-PPDQ, but it could be a good starting point.

[Tanya] Turbidity is definitely one that seems to be comparable. Conductivity is challenging as you'll get peaks and lows based on seasonality. I don't think there is a quick and easy solution yet from the monitoring perspective. My hope is that hotspot modelling will help reduce the

amount of monitoring we may actually need to do. It could be a way to define it on a larger scale. We're working on characterizing it on a smaller scale currently.

[Rachel] Part of what we're trying to do is identify where interventions should be installed. We want to identify the specific locations where GI should be implemented and have the greatest impact.

[Erik] Traffic density and stream flow are two characteristics that directly impact concentrations. Larger systems see greater dilution. Smaller, urban streams appear to increase much more quickly.

Question: Is there a difference in 6-PPDQ results for salt water versus freshwater samples?

[Erik] The few salt water samples we've looked at so far haven't really detected anything. That could just be a matter of dilution, but estuaries are a concern and should be investigated further.

[Tanya] We've been trying to avoid sampling in the tidal areas due to constant tidal flushes. However, if you're seeing known die off events after a rain event, it would be important to continue to monitor those sites – there may not be enough tidal flushing to dilute the 6-PPDQ in those cases. That said, I don't know of anyone that is looking directly at marine versus freshwater.

[Ed] I'm not aware of any marine waters ecotoxicology studies that compare marine/estuarine versus freshwater coho. I've been watching Commencement Bay in Tacoma get hit by storms and stormwater for a long time. I'm surprised by how much the different temperature, different salinity stormwater floats on the seawater in the tidal area. You get about a one-foot lens of really turbid stormwater move through the estuary – the water colour and water quality are totally different. I think in those estuary areas it might be surprisingly high concentrations, but I don't have enough data to actually say concentrations are high enough to result in acute toxicity. It's probably relatively short-term, maybe just a few hours.

Question: What kind of response has there been from tire companies?

[Ed] They are doing things but it's difficult to know the extent of what they're doing from the outside. We've been talking to them since 2019 and since then they haven't admitted any guilt

or find they have any issues themselves. They're likely comfortable with a long process of replacement, like 15 to 20 years. I'm not sure the 'why' of that – there are some approval, permitting, and safety standards to meet. At least in the US, there will likely be a legal decision at some point that might determine timelines, what gets replaced, and maybe who pays for updates. There is an argument to be made that tire companies should foot some of the bill for runoff treatment. Those are questions outside of the people in this room's hands. Something important to think about is that PPDs (even without making PPD-quinones) are highly toxic chemicals. I think the industry would prefer to put in a 7PPD or CPPD, and that might be incrementally more beneficial for sensitive salmonids, but I'm not sure that is a safe or smart decision over the long term. We should collectively think about what data should be generated or what we need in this space to prevent PPD alternatives to be what's used to replace 6-PPD.

[Rachel] I know that the US Tire Manufacturers Association put out a report on alternatives – their top choice is another PPD. If we're concerned about replacing 6-PPD with other PPDs, let's generate the data and make sure those that are reviewing such reports are aware of scientific concerns about doing that.

[Tanya] Ultimately to force the tire companies to replace these products, other than the amount of press and pressure that has been put on them is for regulators to step up and regulate this chemical. We've seen it time and time again, these replacement products (PCBs, PPDs, etc.) are just as toxic as previously used chemicals.

[Markus] To reiterate what Tanya said, time and time again we see those regrettable substitutions. If you look at your plastic water bottles, a lot of them will say Bisphenol A (BPA) free – we know a lot about BPA and how it might disrupt our endocrine systems. So, it has been swapped out with replacement chemicals such as Bisphenol S, which is arguably more toxic than BPA, but we didn't know about it to describe it at the time of the substitution. I was equally surprised by the list of substitutions provided by the US Tire Manufacturers Association, because these are all compounds that have been known a long time and have been tested by the tire companies regarding their efficacy of protecting tires from ozone. There are probably other things that we haven't learned about before. The US Environmental Protection Agency put out a request for any data related to anti-ozonants in tires that the tire industry will need to report to now.

Question: Erik and Haley presented that about 33% of their samples had 6-PPDQ detected, with about 100 samples having 6-PPDQ above the alevin coho LC50 and about 50 samples above the smolt coho LC50. Where were those samples collected and what does this mean for the local fish population?

[Erik] Samples were collected between last October (2023) and up until about a month ago (March 2024). These samples were collected on Vancouver Island.

[Tanya] We've been detecting 6-PPDQ in about 98-99% of our samples, which is likely only due to using a different method and having a slightly lower detection limit. The VIU method is designed for high throughput; we're using a more sensitive and more time consuming analysis, but you get a lower detection limit.

[Erik] The second half of your question – how it impacts fish. It's not a good news story, but the question that should be asked in tandem is what is the duration of those high concentrations. Some of the data that Markus showed us today, indicated health effects within a few hours in some cases and complete mortality within six hours.

Question: You've talked about GI as a potential solution, can you describe what GI solutions could look like?

[Rachel] When I say GI, I mean things like rain gardens, bioretention system, and potentially retention ponds – though there is some concern of continuous leaching in retention ponds. The replacement of 6-PPD by other compounds in tires is a very important move; however, this is the source control. Whereas, GI is treating runoff that contains contaminants.

Question: In our urban streams, we still have salmon. However, they are so susceptible to 6-PPDQ. Are they doing something behaviorally to avoid 6-PPDQ? How could we potentially change restoration techniques that could benefit salmonids?

[Markus] I think there are multiple aspects to this. Salmon species do migrate up into the streams to spawn. I visited Bellingham last fall and you could many of their small streams didn't have much flow and had a few steps in them that fish couldn't get past. As soon as it starts raining though, they start pushing upstream. It really depends on the geomorphology and how salmonids move in there. Another thing I think we can say is that around a lot of heavily

urbanized areas, you don't find the salmon anymore (i.e., San Francisco). Is this driven by 6-PPDQ or other water quality concerns? We can't say with certainty but there is definitely that correlation of presence/absence of some species.

[Ed] Two points: I think that straying accounts for a lot of coho returns throughout the Puget Sound region. Coho are returning to creeks with 60 to 90% mortality, with many of which are strays from elsewhere. Puget Sound has net pens that they use for releases, so those coho are just looking for any freshwater. Then there are a lot of artificial hatchery salmon that are released all over the place – these things can explain the consistent returns even in urban creeks with high mortality. The more important question regarding restoration – work by J. Davis – he thinks it was a mistake to do all the urban creek restoration; it created ecological traps by restoring physical habitat, but not chemical habitat. You've created spots that the salmon really liked and they hung out there, then it rained and they died. If those nice spots weren't there, they would've gone somewhere else. The ecological trap concept is critical where we have to align physical habitat restoration with chemical habitat restoration. I'm communicating someone else's ideas there as something to consider.

SUMMARY OF PUBLIC FOCUSED EVENT PRESENTATIONS: PERSPECTIVES & SOLUTIONS

The afternoon panel and associated discussion period was chaired by Jane Pendray, PSF's Salmon and Climate Adaptation Program Manager. This portion of the workshop can be viewed here.

Tim Kulchyski – 6-PPDQ Sampling in the Cowichan System

Tim Kulchyski is a is a member of Cowichan Tribes, works as a Natural Resource Consultant in the Cowichan Tribes Lands and Self-Governance Department, and serves as a member of the Cowichan Watershed Board.

Tim spoke about the two main areas where Cowichan Tribes has been focusing their sampling efforts: Fish Gut Alley (FGA), a tributary of the Cowichan River, and Bings Creek, which is part of the Somenos watershed that ultimately leads to the Cowichan. Both systems are important coho habitat in the Cowichan watershed.

Typically, the water quality in both systems is okay, with the water appearing quite clear. However, during rain events there are significant changes in the water quality in these systems. In particular FGA looks like greywater after a rain event, as it is where the drainage catchment for the City of Duncan spills into.

Unfortunately, FGA has experienced multiple fish kills attributed to the stormwater treatment system. It was originally thought that the issue was due to low oxygen levels, as the catchment basin was not previously aerated. However, we're now wondering if the issue has been a combination of factors, as we've been seeing concentrations that are approximately four times the LC50 for coho salmon in samples collected just downstream of the outfall.

With increasing drought conditions and larger storm events, 6-PPDQ is very concerning for the small systems within the Cowichan watershed. 6-PPDQ really brings home how poorly we treat our water and our system.

Kyle Miller – Tseshaht First Nation 6-PPDQ Monitoring

Kyle Miller is a Fisheries Technician for the Tseshaht First Nation Fisheries Department.

Although Tseshaht territory spans from the Somass River to Great Central Lake and Barkley Sound, the most worrisome locations with regards to 6-PPDQ are Port Alberni and Highway 4. Port Alberni is located in a Mediterranean climate, where they see long dry summers, followed by extensive rainfall in the fall. Further, Highway 4 is the only road to Tofino, which sees about a million tourists every year.

When Kyle started in 2023, Tseshaht First Nation had already had 6-PPDQ on their agenda for 18 months – they were some of the initial groups to conduct 6-PPDQ monitoring on the Island. They will continue to monitor and work towards mitigating the issue in their territory.

Justin Budyk – 6-PPDQ Monitoring & Raingarden Construction in Partnership with Stewardship Groups in the Greater Victoria Area

Justin Budyk is the Environmental Stewardship Coordinator for Peninsula Streams & Shorelines, a not-for-profit that works in the Saanich Peninsula on 13 different watersheds. He works with volunteers, stewardship groups, and various other stakeholders in Greater Victoria to conduct restoration projects and environmental monitoring. He is specifically working with two groups

on the 6-PPDQ monitoring in collaboration with BCCF ARRC/VIU AERL. The groups are monitoring Millstream and Gabo Creeks. They're also helping with sampling some of the DFO/SFU sites on Vancouver Island with their partners. In all systems they've been monitoring, expect the Millstream, they have been seeing concentrations that are reaching or exceeding the coho salmon LC50.

Hot, fast, and toxic stormwater is another blow to the fragile situation in Victoria's small, urban streams. Justin sees citizen science as a powerful opportunity to engage and educate the local community – "People that don't see salmon, don't care about salmon".

Justin runs Peninsula Streams & Shorelines Raingardens for Headwaters Program, which involves installing mini urban wetlands throughout the Greater Victoria area to capture and hold stormwater. They are using bioactive soils, native plants, and biota to break down these contaminants (not just 6-PPDQ). These rain gardens aren't just good at filtering water, they are also great educational tools at schools and for the public.

Sylvie Spaakman – City of Vancouver's Green Rainwater Infrastructure

Sylvie Spraakman is a Senior Engineer at the City of Vancouver in the Green Infrastructure Implementation Branch.

The City of Vancouver implemented their Rain City Strategy in 2019, which is a high level, 30 year green rainwater infrastructure and rainwater management initiative that is aiming to protect and restore local waterways.

Sylvie introduced a number of different types of GI that are currently established in the City of Vancouver, including bioretention systems, laneway subsurface infiltration, rainwater tree trenches, and bioswale schematics. Bioretention systems include rain gardens, which can come in a variety of shapes and sizes. Laneway subsurface infiltration involves infrastructure installed underneath laneways that is meant to slow down runoff movement. Vancouver has 750 km of laneways, and these are strategically being used to soak water into the ground. Rainwater tree trenches are often combined with active transportation goals (i.e., bike lanes); the infrastructure releases water through perforated pipe, rather than directing it all away to stormwater systems. Bioswale schematics involves drainage from laneway/road/bike lanes;

often sections of a road are closed off for safer bike lanes and these divisions are built bioswales. These allow for water to percolate in a few different areas.

The City has conducted synthetic runoff tests, in which they add contaminants and water to each type of system. Results indicated a huge volume reduction and contaminants being absorbed into the soil. With these positive results, more GI needs to be installed in areas where it will make a big difference (i.e., where large inputs of 6-PPDQ occur).

The City of Vancouver has multiple design guidance documents that be used to plan for and implement GI of your own.

Keith Estes – 6-PPDQ & Salmon: Prioritization & Best Management Practices

Keith Estes is a Project Manager at Long Live The Kings (LLTK) working on salmon recovery by facilitating habitat restoration and stormwater management projects in Puget Sound. One of LLTK's objectives is to bring together stakeholders with regards to pressing issues surrounding salmon; currently 6-PPDQ is one of those issues. Additionally, LLTK has a couple of 6-PPDQ programs ongoing.

One of the key projects is their Ohop Creek Stormwater Management Pilot Project. This project is in partnership with the Nisqually Indian Tribe in Washington State. The Ohop Creek watershed is one of the most important and protected in the area. The project team has installed and is testing a containerized, modular biofiltration unit designed by Cedar Grove to assess its efficacy of removing contaminants, including 6-PPDQ. The mobile unit is filled with layers of compost-based filtration media. As compost contains extra nutrients that could be discharged, the unit has an external polishing layer with the purpose of removing excess phosphorous before water is discharged into the wetlands adjacent to the creek. The system has been tested during three storm events and had an average 6-PPDQ removal of 92.5%. This is still a small sample size so they are looking at conducting further testing this coming year, with the goal of evaluating at least 20 rain events over two years. However, this is a good launching off point. Read more about the pilot project here.

Another program on the go for LLTK is 6-PPDQ prioritization mapping. The ultimate goal of this program is to identify where retrofits would be most beneficial. They are in contact with the Washington Department of Transportation to share the data and information collected.

Panel Discussion

This panel discussion can be viewed via the same link as the presentations.

Question: With the LLTK biofiltration program, the toxins appear to become contained within the mobile unit. What do you do with them afterwards?

[Keith] Yeah, that's a good question. So, we have not reached a point where we've needed to change the soil media and so they're just captured within the biofiltration system. So that's a good question on removal and I think I'll probably be relying a little bit on Ed on figuring out the timeframe and mechanisms to do that.

Question: [With reference to Keith's presentation] There were a lot of negative values in your table that potentially through this system is mobilizing some of the things we do don't want in our water. Have you looked at why that's happening and what sort of media would prevent changing one for the other?

[Keith] I skipped over that we noticed a bit of nutrient export within that, but that's what we anticipated and that's why there was an inclusion of the polishing layer. So that adjustment of alumina, iron, and sand in the polishing layer could be adjusted to the point where that export of nutrients is not so much of a problem. That is something we are monitoring and making sure of. There was an export of dissolved organic carbon and total copper, which help with toxicity of water and so it was negative on the chart but not so much negative as far as our project results go.

Question: Do you have a readily available list of rain garden sites? If you were provided a large sum of funding, could you role out another 20 or so sites easily?

[Justin] Yes, that is something I meant to talk about. One thing we are doing is rain garden mapping, so have done a far bit of mapping in the Greater Victoria area about potential rain garden sites and stakeholders. The biggest barrier is funding and capacity to get these projects sorted through jurisdictions and site stakeholders. I couldn't make any promises in terms of the number of rain gardens that could be built in a certain timeframe. But given the right resources, we definitely could prioritize that. As I teach Grade 3's with the watershed model, everything that happens in one part of the watershed will trickle down into low lying areas. So, mitigating

these toxic compounds in our headwaters through things like rain gardens and different GSI solutions is incredibly important.

Question: A lot of municipalities have very good GIS databases of all kinds of things. Do you know of any municipalities that have their GI mapped?

[Sylvie] It is mapped in Vancouver. I would just say as potential, anywhere you see a catchbasin, that could be a piece of green infrastructure. That's mapped for sure in whatever city you're in. So, your potentials are there.

[Justin] We are working with the Friends of Bowker Creek and some others is having a live map online that members of the public can contribute to. Right now, it's just me driving around and pulling over when I see another site. It's like Ed was saying about not being able to see tires or stormwater the same way. I can't see city's without seeing potential rain gardens. This is something we're working on right now – we're trying to have a live database that members of the public can enter where they saw a rain garden or a potential rain garden site. Pretty much anywhere you see a stormdrain is a place you could place one of these.

Question: Tim, can you tell us more about the retention system that feeds into FGA? Potentially there are ways to convert historic stormwater retention systems to more impactful infrastructure.

[Tim K.] Dating back quite a few years, we had first-hand experience and missed an opportunity to actually talk about the development of the infrastructure that's there, which was over 25 years ago. Over the years, with the number of fish kills, we really pushed to try and start experimenting. Volume wise, it was thought that it wasn't possible with the physical footprint that we have. One of the big issues that makes FGA such a hotspot is that it is fed by the highway, the mall development, and a portion of Duncan. All of that material gets held in a big underground holding tank. All runoff is from a fairly dense commercial area. The holding tank is sitting next to the sewage lagoon treatment system. There was a thought that all that effluent could be put into the sewage treatment system and that would hopefully mitigate whatever compound was causing the problems. This was before we had a much better sense of what was going on. There was real worry that would impact the biota and the processes within the treatment system. That in itself, a number of years ago, was like a million and a half [dollars]. So

for the CVRD, for Duncan, for North Cowichan, you really have to be able to cross all your 't's and dot all your 'I's, as far as being able to demonstrate how well these systems work. That's why things like your work [referring to Keith's project] is so spot on because I remember in the mall development, that is on reserve, going through a huge push within our department to try and get them to put swales and vegetation within the parking system, we wanted to make that a prerequisite. But at the time, given that this was more than 20 years ago, they said that you had to prove that it works. Well, that work had been done, but being able to demonstrate that in a short timeframe was difficult. I think one of the biggest questions is, what do we do now. I think there's space and options there, but we feed such a major part of the developmental infrastructure for Duncan in such a tiny little system – it really compounds. That used to be the most profitable coho rearing habitat within the entire watershed, now there's very little coho there.

Question: Catalyst was pumping water into the Cowichan River. In the Colquitz watershed, the headwaters are Elk and Beaver Lakes. Some groups want to see water pulsed into the system from the headwaters. When you pulse water and you entice the salmon to come in, you haven't had the first flush. In drought conditions, fish will be exposed directly to the first flush. Is this a problem in other systems?

[Attendee Comment] This year in North Vancouver on the Coppola River, they did pulse water, but in that case they're bringing the fish up into the hatchery and they're in a 'safe zone'. So I think it's a pretty complicated question and you know if the first rains are going to come so late and these fish are over ripe, they're going to be dead anyway. So, I think there are a lot of factors and localized.

[Tim K.] In that, I would say that flows discussions are stressful. From the beginning, when I started 27 years ago, we've had drought after drought after drought. I think in that period, we've had 17 prominent drought periods in the last 25 years. Catalyst is extracting but during the lowest periods to keep extraction, they pump from the lake over top of the weir. So, you're absolutely right, it is so, so complicated. You learn one little piece of the puzzle and you kind of think you have a sense of what's going on and then everything shifts when new information comes. During some of our greater drought periods, we've noted that we're having issues with predation in our out-migration. As the water levels drop and the fish are cued either by temperature or drop in flows, we're seeing predation events that are as high as 1.5% per

kilometre, so upwards of 80% of out-migrating fish, before they get to the marine waters, which are then as high as 60-70% for Cowichan Chinook. They're hit really, really hard. You have to really try – and it's almost impossible to get a sense of what's really going on – and you have to keep making decisions and watch what's happening – that's the big thing. It's not possible in all systems. We probably have more eyes on the Cowichan than almost any other system and I don't feel like we really know what's going on with the returning adults. I would say in general, you're correct – you're trying to figure out how to adequately balance things and you don't have a way to evaluate that in real time. You have to look sometimes like three years later, or whenever the fish are coming back. We're learning with the returning adult migration that there's a pretty significant impact (~30%) from pinnipeds out in Cowichan Bay. It's trying to pull all of that together to make some sense of that and prioritize fish in that matrix – it's certainly not easy.

Daniel Cheater – 6-PPD & the Canadian Environmental Protection Act: Regulating Toxic Substances in Canada

Daniel Cheater is a lawyer with Ecojustice Canada, a non-profit organization that provides legal services to the environmental community and raises matters of environmental importance.

On behalf of PSF, Raincoast Conservation Foundation, and Watershed Watch Salmon Society, Ecojustice put forth a request to the Honourable Steven Guilbeault, Minister of Environment and Climate Change Canada (ECCC), that ECCC assess 6-PPD to determine whether it is toxic or capable of being toxic. This request was submitted in February 2024 under the *Canadian Environmental Protection Act* (CEPA), Canada's primary law for pollution prevention, which allows any person to submit a request to assess a substance under section 76.

The Canadian constitution provides no clarity about which level of government can regulate chemicals, including toxic substances. This creates two challenges for regulating these substances in Canada: (1) neither the federal government nor the provinces is required to regulate toxic substances, and (2) if they do attempt to regulate, they may be challenged in Court. In 1997, the Supreme Court of Canada found that the federal government can regulate substances through CEPA – but only if the substance is proven to be toxic or harmful. This means that the compound must be assessed and found harmful before regulation is possible.

The Minister is required to respond within 90 days of the submission date. If approved, this request would prioritize/fast-track the assessment of 6-PPD, and if listed under CEPA, the federal government could then regulate it as a toxic substance. One of the goals of the request was to kick-start the process.

On April 30, 2024 (after this lecture), Ecojustice's request was in fact granted – meaning 6-PPD is now prioritized for assessment. Unfortunately, 6-PPD can still not be regulated until the toxicity assessment is completed. Because there are no strict timelines to go from prioritization to the actual assessment, it is critical that Canada move as quickly as possible to start the assessment of 6-PPD and its quinone.

Canada is falling behind on regulations related to car emissions. Regulation so far has focused on air emissions, allowing brake and tire manufacturers to escape scrutiny. Even once 6PPD is assessed, found toxic, and regulated, Canada needs to have broader action on tire and brake wear chemicals and products.

Watch Daniel's presentation here.

Question: Is there anything that can be done to replace 6-PPD with something that is less toxic?

[Daniel] There is ongoing alternative assessments coming out of the States. I think one of the speakers said it earlier but what's been proposed is other PPDs, like other equally or more toxic substances. I think it was the USEPA or State of Washington that set specific requirements about their alternatives assessment, which isn't out yet, and one of those is that it needs to be less harmful. I don't have the answer to what can replace 6-PPD, but it's important to ensure that whatever alternatives are eventually proposed are less toxic and well-studied before they are widespread. The CEPA does allow for class assessments, which is not just looking at one substance but at all related alternatives. I think that because the assessment of alternatives is still in its infancy, it would be a difficult ask at this point to look at the whole class. It may be an option in the future to say that when all alternatives are equally toxic to take a broader look and not prohibit one by one. That may be the case here, but we'll see what comes out of the various alternatives assessments in other jurisdictions.

Question: You've taken a compound specific approach. Do you think there's ever a point where stormwater is seen as a discharge that we can regulate or is it too complex to work to that goal?

[Daniel] How we've approached it initially is getting it assessed and potentially listed as a way to start regulations, but I think other measures could come from that. It might have be a joint provincial/federal effort if you're looking at stormwater and water quality regulations or the like. One of the difficulties is that tires are ubiquitous, the source of the pollution can't be tied back to one person or manufacturer. So typically with deleterious substances provisions that are engaged, it's when there is an obvious offender that has released a substance. This is a case where all vehicles are releasing it simultaneously, which makes it harder for us to leverage the Fisheries Act or something provincially, I suppose. One thing that's been tried in the United States is an interesting example but not something we could replicate here. There was an action brought by some fisheries groups/coalitions against tire manufacturers under their Endangered Species Legislation because coho and other salmonids are listed and because that act says citizens/groups can enforce the law. These groups have gone directly after tire manufacturers. There are two reasons we can't do that here: [1] our salmon populations aren't listed, they continue to not be listed as endangered under the Species at Risk law and [2] our law doesn't provide that mechanism for citizen enforcement. It's interesting to see and we'll have to wait and see what comes out of that action in the United States.

Question: I think we're a net importer of tires. Have you thought through that element of it yet?

[Daniel] A couple aspects to that. One reason we're asking the federal government to regulate this is because it does have trade implications. There is provincial ability to manage hazardous waste in some circumstances. Even municipalities have been successful at banning pesticides. But the federal government is responsible for ensuring international trade is possible and there are trade obligations under instruments like NAFTA that would be engaged by that. So, there is a need for global collaboration. That may be one concern coming from the federal government – they can't do it alone. That's not to say they can't list it as a toxic substance and regulate it. When prohibition, especially prohibition on trade, is at issue then there are those international trade concerns best dealt with through a coordinated effort from many jurisdictions at once.

We’re seeing that happen in the US and Europe, so there is potential for a global effort and a need for alternatives.

SUMMARY OF ACADEMIC FOCUSED EVENT PRESENTATIONS: PANEL 1 - TOXICITY

This panel and the following discussion were chaired by Dr. Erik Krogh.

Josh Baker – Aquatic Toxicity Testing Approaches to Identify, Quantify, & Monitor 6-PPDQ

Josh Baker is an Environmental Chemist with Nautilus Environmental, where he has been investigating causes of toxicity to aquatic organisms for over a decade. He has been testing Fraser Valley stormwaters to see if they are lethal to rainbow trout.

Working with the Cougar Creek Streamkeepers and Alouette River Management Society to collect some samples, water was collected from downspouts off the Alex Fraser Bridge and the Golden Ears Bridge, as well as from a local rain garden and from Cougar Creek during the first fall flush of 2022. All stormwater was used in 96-hour acute lethality tests on juvenile rainbow trout. Results indicated that the bridge downspout samples were toxic, rain garden water had reduced toxicity, and the creek samples were not lethal, likely due to dilution.

Toxicity Identification Evaluation (TIE) techniques were used to assess the acute lethality of the downspout samples. Results indicated that the Alex Fraser Bridge samples were toxic due to zinc. Based on the initial TIE manipulations, the Golden Ears Bridge samples were suspected to be toxic due to 6-PPDQ. Organic-methanol fractions of the stormwater suspected to be toxic due to 6PPD-Q were isolated and compared to those obtained with a commercial standard of 6PPD-Q to assist in the identification and quantification of 6PPD-Q toxicity. Condensed Phase Membrane Introduction Mass Spectrometry (CP-MIMS) was used as analytical support for 6PPD-Q quantification. Results indicated low recovery of 6-PPDQ from the columns; this poor recovery is thought to be due to the apparatus' composition (i.e., silicon in the equipment). Therefore, they couldn't conclusively say if the Golden Ears Bridge samples were toxic due to 6-PPDQ or not.

Further investigations considered if the addition of other water quality variables (i.e., aeration, harness, pH, DOC, additive toxicity, etc.) that might influence the toxicity of 6-PPDQ. Based on the factors tested, there was no apparent effect on the 6-PPDQs toxicity with the exception of additive toxicity with nitrite.

Another study Josh and his team worked on was with regards to which life stages of rainbow trout are most sensitive to 6-PPDQ. Hatched alevins were sensitive to 6-PPDQ which was similar to fry sensitivity; no lethality was observed prior to hatch. They conducted sub-lethal testing over seven days and did not see any impacts on growth to surviving larval trout. Josh proposed hatch boxes as an *in situ* tool to monitor development, hatch, and growth of salmonids until swim up; these hatch boxes are typically placed in the creek for three to five weeks depending on species.

Katie Roberts – Toxicity of 6-PPDQ to Early Life Stage Rainbow Trout & Lake Trout, & Putative Toxicity Pathways

Katie Roberts is a grad student of the Toxicology Centre at the University of Saskatchewan. Katie expanded on some of what Markus Brinkmann introduced on day one of the workshop.

Sensitivity within species and amongst life stages is variable amongst salmonids. In general, the early life stages of fishes are typically about 60% more sensitive than their adult counterparts to any given contaminant. This variability is likely a result of their increased surface area to volume ratio, presence of yolk sac, and ongoing changes to their metabolic activity and capacity.

Katie's research had three primary objectives: [1] determine the toxicity of 6-PPDQ to early life stage (ELS) rainbow trout and compare to adults; [2] determine toxicity of 6-PPDQ to ELS lake trout, and [3] determine sub-lethal effects of 6-PPDQ exposure to rainbow trout and lake trout (i.e., developmental changes, transcriptomic pathway disruption).

ELS of rainbow trout and lake trout were exposed to 6-PPDQ at varying concentrations upon hatch (40 tanks total per species: 6 concentrations of 6PPDQ, plus solvent and water controls, 5 replicates each). Rainbow trout were exposed for 28 days, which is past the point of swim up. Lake trout were exposed for 45 days as they take longer to reach the swim up stage. Results showed both species had similar symptoms, but impacts were observed at variable concentrations. Spinal curvature occurred at low concentrations. Yolk sac edemas occurred in both. Caudal fin hemorrhaging occurred in rainbow trout at much lower concentrations (0.44 µg/L) than lake trout (3.4 µg/L). Additionally, lake trout also experienced pooling blood in their eye between 1.3 and 7.6 µg/L.

Acute mortality tests exposed rainbow trout and lake trout juveniles for 96 hours. Both species' fry were sensitive to 6-PPDQ, with both exhibiting URMS symptomology. The fry 96-hr LC50s for both species were similar to sub-chronic exposures (rainbow trout: 0.47 µg/L; lake trout: 0.50 µg/L).

When assessing transcriptomic pathway disruption, rainbow trout and lake trout were sampled after only four days of exposure to limit any changes due to stress. Following exposure to 6-PPDQ, there was significant transcriptome disruption. Rainbow trout had 1,200 dysregulated genes, with the key pathways that were dysregulated being: cytokine-cytokine receptor, toll-like receptor, chemokine signaling, osteoclast differentiation, apoptosis, and necroptosis.

Bonnie Lo – Lethal & Sub-Lethal Health Effects of 6-PPDQ on Pacific Salmonids

Bonnie Lo is a Ph.D. candidate in the Department of Biological Sciences at Simon Fraser University.

When considering potential sub-lethal effects, there are a number of variables to test (i.e., the chain of potential): genes, RNA (transcriptomics), metabolites (metabolomics), proteins (proteomics), organs, and the organism as a whole. Bonnie has been taking the top-down approach, starting with the whole organism and working her way down.

Bonnie and team conducted 24-hour acute toxicity tests on approximately three-week, post swim up coho, Chinook, chum, and steelhead. She published the LC50 for coho (41 ng/L) in 2023; in this study she also found that Chinook were 3-orders of magnitude less sensitive (LC50 > 67,307 ng/L). Also presented were preliminary (unpublished) findings related to chum and steelhead 6PPD-Q sensitivity.

Additionally, the 6PPD-Q research team (led by Dr. Tanya Brown) has conducted sub-lethal effects studies for all four species. Histopathology is the diagnosis and study of diseases. Histopathologic anomalies were only observed (by Dr. Gary Marty) in juvenile steelhead and Chinook. In particular, there were anomalies in their gill cells (e.g., lamella fused together and blood clots) and liver cells (e.g., reduced glycogen). No histopathological anomalies were observed in coho gill and liver cells.

Metabolomics is the collection of endogenous small molecules that mark specific fingerprints of cellular biochemistry. Acute exposure to 6-PPDQ resulted in marked different profiles of altered metabolites in coho and Chinook.

Moving forward Bonnie will continue to work down the chain of potential sublethal effects.

Garrett Foster – How Habitat, Species, & Life Stage Alter 6-PPDQ Toxicity to Salmon

Garrett Foster is a master's student in Dr. Jen McIntyre's Aquatic Ecotoxicology Lab at Washington State University's Puyallup Research and Extension Center.

Longfellow Creek in West Seattle was one of the first locations where URMS was observed. It was only discovered because of the efforts to try and restore these small, urban creeks. Therefore, people were out conducting post-construction monitoring when they observed coho in distress or mortality had already occurred. 6-PPDQ can be used as an indicator for general car pollution.

The research team looked at assessing 6-PPDQ toxicity in coho embryos by mimicking the worst exposure of 6-PPDQ – pulsing 6-PPDQ every 24 hours. Results shows that survival reduced significantly shortly after hatch (95.5 to 37%). To assess variability of embryos pre- and post-hatch, a subsample of embryos were removed from their sac. When comparing the unhatched embryos to hatched embryos, there were significant differences in eye size and body length.

The team also looked at the concentration response curve for coho – looking at the different life stages to gain a better understanding of which life stages are most sensitive. Ultimately, there appears to be a gradual increase in toxicity from alevin to parr stages, with parr being slightly more sensitive than alevin. When comparing the parr life stage to an adult coho, there did not appear to be any statistical difference between them, both are highly sensitive.

Another study looked at the variation in sensitivity between different populations of coho. They studied coho from Bingham Creek and Voight Creek. Bingham Creek, a tributary of the Chehalis River, has coho arrive later to spawn and have eggs incubate later into the winter; the creek is a much more rural and unimpacted. Voight Creek flows into the Puyallup River, which runs

through a much more urban environment (Tacoma, WA). Results indicated that Bingham Creek coho were more sensitive than Voight Creek coho.

Garrett and his team have also been investigating if 6-PPDQ's toxicity is impacted by habitat factors. So far, they have found that salinity, organic matter, and pH do not appear to affect the toxicity of 6-PPDQ. However, temperature seems to make a difference with 6-PPDQ toxicity. When temperatures were between 5°C and 15°C, 6-PPDQ was more toxic. Whereas, when temperatures were at or above 20°C, coho had reduced toxicity to 6-PPDQ.

Panel 1 Discussion

Panelists responses were written based off notes taken at the workshop, not a transcript. All responses were approved by panelists prior to publishing.

Question: [With reference to Josh's presentation] Did you try adding solids to the solution to try and change toxicity?

[Josh] No solids were added in any of our experiments.

Question: [With reference to Katie's presentation] You mentioned the caudal hemorrhaging – is the 6-PPDQ staying within the fish tissues and does it bioaccumulate?

[Katie] From what we've seen, 6-PPDQ is metabolized pretty quickly. We see very little 6-PPDQ remaining in the fish; therefore, we presume that it's not likely that it's bioaccumulating.

Question: [With reference to Bonnie's presentation] Why do you think there weren't any histopathological anomalies for coho – is it because they were all dead?

[Bonnie] The timeframes of exposure are short-lived for coho as they are so sensitive – so that could be a reason.

Question: [With reference to Garrett's presentation] Did you look at dissolved oxygen?

[Garrett] Dissolved oxygen was kept at 100% saturation throughout the study. 100% saturation corresponds to different mg/L concentrations at different temperatures. Temperature and dissolved oxygen were directly correlated, so the effect of dissolved oxygen on toxicity is inherently tied to our temperature results.

Question: [With reference to Garrett's presentation] One population included late spawners. After the first flush, I would think that the concentrations would be lower. Why do you think they are more impacted?

[Garrett] This study involved an exposure in a lab. In their natural environment, they likely don't have much in the way of 6-PPDQ exposure naturally, so they likely don't have any built in tolerance to the compound. Rather, those that have to swim through Tacoma and under the I-5, they would have been exposed to 6-PPDQ on many occasions.

Question: [With reference to Bonnie's presentation] You saw a disruption of gas exchange, so that should account for the glycogen difference?

[Bonnie] I'm still unsure of this – we're working on some new pathways with more data at the moment.

Question: Is there any other research where you'll be looking at fish growth impacts due to 6-PPDQ?

[Katie] When we looked at surviving fish, we didn't see any differences in length. In higher concentrations, there was variability in length and weight, with some being quite small. This has been challenging to characterize, given that the surviving fish had fewer tankmates, and I think we'll need to tighten the exposure window to get a better idea of effects on growth.

Question: [With reference to Josh's presentation] You found that toxicity was due to zinc in one of your bridge samples – do you think this was from brakes? What were the copper concentrations?

[Josh] The assumption is that the zinc came from brakes/tire particles. Copper can be initially quite toxic and then become reduced over storage time. It's possible that some toxicity was from copper but was lost.

Question: Regarding organ abnormalities – what's the prognosis for the fish that survive? Do we know if they die or if they can heal?

[Bonnie] We can't definitively say at this point. After the study, they are euthanized. They weren't showing any signs or symptoms. If they had continued the exposure, they may have seen additional changes.

Question: [With reference to Bonnie's presentation] Did Gary Marty comment on the gill morphology – would they have recovered?

[Bonnie] Those changes were ranked as severe, they would not likely have survived.

Question: [With reference to Josh's presentation] You mentioned toxicity due to zinc, but with some suspected 6-PPDQ. At the three locations you collected from during the first flush, which location had the higher concentration? Also, with higher zinc concentrations does it come from TWP?

[Josh] The first day was a small rain event. The sample was more concentrated and we could see the particulate, which is why we suspected 6-PPDQ. The second flush (three days later), the toxicity was due to zinc.

Question: All studies appear to be completed in a lab – are there any similar studies in the wild or more natural conditions?

[Garrett] There are some ongoing exposures occurring, but we don't have any data from those yet.

Question: 6-PPDQ can be unstable, is there a set way to analyze the samples?

[Josh] There have been different responses from different labs.

[Bonnie] ECCC is coordinating an interlab study which may help with some of these findings.

SUMMARY OF ACADEMIC FOCUSED EVENT PRESENTATIONS: PANEL 2 - OCCURRENCE

This panel and the following discussion was chaired by Dr. Chris Gill, Co-Director of VIU AERL.

Joseph Monaghan – Condensed Phase Membrane Introduction Mass Spectrometry (CP-MIMS): A Scalable Tool for Environmental Analysis of Tire Wear Toxins

Joseph Monaghan is a recent Ph.D. graduate who undertook his work at the AERL under the supervision of Dr. Erik Krogh.

With such an extensive number of potential sample locations and sampling to occur before, during, and after rain events, with the intention of sampling multiple rainfalls, this will involve the analysis of a significant number of samples. In anticipation of this, AERL tested their CP-MIMS method to assess its ability to detect 6-PPDQ at environmentally relevant concentrations. To be well-suited for CP-MIMS analysis, the analytes need to be hydrophobic, small (high diffusion), and detectable by mass spectrometry. The method proved to work for 6-PPDQ analysis but did require some adjustments to increase sensitivity and speed (e.g., thinner membrane probe). After some comparison with the conventional analytical techniques (LC-MS/MS) showed great agreement for creek samples, sample collection at a larger scale was able to go ahead. High concentration samples are still a bit variable, which is suspected to be a result of free versus total (i.e., including particulate bound) 6-PPDQ in solution.

Now with a sensitive, high-throughput (2.5 mins/sample) method and plans for a large number of samples, there was a need for automation in order to minimize burden on the operator and improve sample capacity. Ultimately, he reprogrammed a 3D printer as it met all his criteria for what the autosampler needed (i.e., precise xyz positioning, stirring ability, open source and re-programmable, and low cost). This autosampler streamlines the data processing and allows for faster reporting.

Now with the autosampler removing the sample bottleneck, there were still bottlenecks associated with data collection and data processing/visualization. To solve the data collection bottleneck, the team developed a data collection app which utilizes QR-coded sample bottles to encode important information like sampling time and locations. The app has allowed for reduced transcription errors and ensured that a sample's associated data is readily available as soon as it arrives in the lab. In addition to the data collection app, Joseph also developed data processing and visualization tools that he translated into graphical interfaces, making the utilization of the autosampler and visualizing the data clear and simple for a wide range of users.

Angelina Jaeger – Intensive Temporal & Spatial Sampling for the Fate & Distribution of 6-PPDQ in Waterways

Angelina Jaeger began her master's in chemistry at the University of Victoria in fall 2023; she conducts all of her research at VIU's AERL under the supervision of Dr. Erik Krogh.

Building on the methods and programs that Joseph built, Angelina has been able to measure over 2,000 samples since September 2023 (~1,900 of these samples have been reported out currently). A couple of Angelina's primary questions involve: where should sampling occur and when is the opportune time for it to happen. To begin to answer some of these questions, increased spatial and temporal sampling began in September 2023. Sampling has been focused in Nanaimo on three systems: Northfield Creek, Millstone River, and Cat Stream (part of the larger Chase River watershed).

In order to best identify where to sample, multiple locations were established across each of these watersheds. All sites were located upstream and/or downstream of potential point sources (i.e., roads, stormwater outfalls). Multiple sample locations were sampled to assess if 6-PPDQ accumulates at the base of a stream and/or if it is variable throughout the system. Preliminary results indicated that concentrations are very site specific and don't just continue to accumulate as they move downstream. Additionally, results have shown the greatest concentrations in these systems have been observed early in the season (first fall flush) and decreased as we moved through the season.

In order to better grasp when the best time to sample is, the VIU AERL/BCCF ARRC team conducted sampling at one-to-six-hour increments (depending on weather conditions) at one site on each of the same three systems. Due to the timing of the high frequency sampling (late November), the Millstone River had higher water and is likely the reason that little to no 6-PPDQ was detected. Cat Stream and Northfield Creek had multiple pulses of 6-PPDQ occur throughout the week of sampling; the largest pulses occurred following the first few, smaller rainfalls (2 to 4 mm). Smaller pulses still occurred later in the week when a larger rainfall occurred. Results showed variation in the timeframe in which the first peaks occurred in Cat Stream and Northfield Creek, likely due to the differences in vegetative buffers and/or the number of direct point sources.

Next steps will involve bringing the mobile lab into the field and monitoring rain events continuously.

Mason King – 6-PPDQ Concentrations in Coho Salmon Stream Water During Rain Events

Dr. Mason King is a Post-Doctoral Fellow in the Brown Lab within Simon Fraser University's Department of Biological Sciences. The research Mason presented was undertaken in collaboration with Tanya M. Brown, Timothy F. M. Rodgers, Gopal Sharma, Rachel C. Scholes, Sonya Reger, Xiangjun Liao, and Andrew Ross.

Metro Vancouver is the largest population centre in BC and, despite heavy urbanization, contains numerous creeks that are vulnerable to stormwater runoff. Mason's two primary research questions are: do stream 6-PPDQ concentrations in the Metro Vancouver area exceed known toxicity thresholds? If so, for what duration? For this study, Mason and his team were evaluating the feasibility of 6-PPDQ monitoring with portable autosamplers in the field and beginning to characterize in-stream 6-PPDQ dynamics as they relate to the hydrologic state during rainfall events (i.e., dry periods under base flow, rainfall flush, and stormflow).

Their study occurred on the Serpentine River, which has wild and hatchery coho stocks. This system was selected due to previous grab sampling efforts that indicated high 6-PPDQ concentrations and documented fish kills of unknown cause there. The first sampling period with an autosampler was 60 hours in fall 2023. They collected a few grab samples at the same

time the autosampler was collecting for comparison. They repeated the autosampler collection in the spring (2024) but this time over multiple rainfalls (80 hours from the first rainfall to the last). Results indicate pulses of 6-PPDQ were detected that reflect the episodic period of rain. The concentrations detected were well above baseline for up to three days.

The team is still assessing how comparable autosamplers are to grab samples, but so far results are promising. Moving forward, they're looking to sample multiple streams from separate watersheds and replicate rain events.

Misha Zvekic – Physiochemical Properties & Environmental Partitioning of Para-Phenylenediamine Quinones (PPDQs) Measured With Direct Mass Spectrometry

Misha Zvekic is a recent Master of Chemistry graduate from Vancouver Island University.

Misha has been working on assessing the physiochemical properties of PPDQs. Physiochemical properties include the boiling point, melting point, aqueous solubility limit, aqueous stability, and sorption partitioning coefficient, which can tell you something about the fate and distribution of the compound in the environment and inform sample handling. These properties can vary across the different PPDQs.

CP-MIMS can be used to find the solubility limit, which refers to the maximum amount of solute (PPDQ) that can dissolve in an amount of solvent (water). CP-MIMS only measures the free-floating compound, so when detections flatten, you can note the solubility limit. Hu et al. (2023) found the solubility limit of 6-PPDQ to be 38 ± 10 µg/L, while CP-MIMS found it to be 31 ± 3 µg/L, which shows good agreement. Some trends identified included that the larger the solute, the less soluble it is.

When assessing sorption processes to sediments, plastics, and other materials, we were looking at how it could relate to environmental mobility (i.e., where it might be stored in the environment). When Misha assessed different materials, there was certainly some sorption occurring to sediments, but higher partitioning to plastic, and even higher to weathered plastic. The same assessment was done for other PPDQs and it was found that CPPDQ has similar behavior to 6-PPDQ while IPPDQ was less comparable.

The VIU AERL team also assessed the shelf-life and volatility of PPDQs. First assessing the aqueous stability in capped vials over two weeks. 6-PPDQ appears to remain fairly stable, which was different from other papers, as others saw loss overtime. Additionally, shelf-life was assessed in uncapped vials with various analogues and found that there was systemic loss overtime. Results indicated that 77PDQ was lost much more rapidly than 6-PPDQ.

Some future work to be done in this space is looking at what is driving the loss of the compound, as well as doing some pKa experiments.

Panel 2 Discussion

Panelists responses were written based off notes taken at the workshop, not a transcript. All responses were approved by panelists prior to publishing.

Question: [With reference to Angelina's presentation] How do you take the samples with the mobile lab?

[Angelina] We have a couple of options – we can either collect grab samples on site and analyze them in the van, or we could do continuous monitoring by pumping water to the van.

Question: What do we know about stability of 6-PPDQ in the sample bottle?

[Angelina] We know that we can see loss if the bottles are left uncapped or just over longer periods of time. That said, we keep them capped, refrigerated, and try to measure them within 24 hours of arrival at the lab.

Question: [With reference to Mason's presentation] Can you look at sediment concentrations to correlate to toxicity?

[Mason] SFU hasn't been looking at this, our efforts have been focused on water sampling. This could be something that's looked at in the future.

Question: [With reference to Misha's presentation] Your presentation makes it sound like weathered plastics may be something that could be used to keep 6-PPDQ contained – thoughts?

[Misha] Plastics may not be ultimately be the best option – I don't want to suggest putting more plastic into the environment. However, utilizing some recycled plastics for remediation maybe an option.

Question: Do we know how 6-PPDQ reacts with oxygen?

[Joseph] A couple of papers where they flood 6-PPDQ with oxygen or ozone show that it can further react and form into other transformative products.

Question: It seems we start to see effects when gill modifications and respiration stages are effected. I'm wondering what role oxygen may have. Is there a reactive intermediate that is causing the symptoms that we see?

[Mason] I'm not sure if we have the answer for this yet. It seems that it is 6-PPDQ at this point that we know of.

[Joseph] Quinones (such as 6-PPDQ) are pretty well-known for their ability to participate in oxidation-reduction reactions, so it is somewhat likely that it can react in the fish in this way. There is a recent preprint that implicates a 6-PPDQ metabolite as a contributor to the toxicity, but this work is still ongoing.

Question: What is with the persistence of pulse/tailing of 6-PPDQ? With reference to the variation between Angelina and Mason's work. Do you think that the fish can get away from or escape a pulse event?

[Mason] Our study was focused on one location so we only have the concentration data for this one specific site. There is a lot of variability between different sites, including what's upstream and downstream of the site.

[Angelina] We've found that there is a lot of variability between sites. How the pulse could travel is also a question for what fish could do.

[Joseph] It's important to consider the differences between analytical techniques too. The CP-MIMS has a higher limit of detection, so when concentrations are below ~5 ng/L, they're

indistinguishable from zeros. Therefore, this could make it look like the concentrations aren't tailing after the rain, when really it is just below the threshold.

[Mason] Fish biology is important – juveniles will hang out in specific portion of the stream. I don't know if we know if/how they get away or escape pulse events, if they do.

Question: Do you have any quantitative data on the solubility kinetics for 6-PPDQ to dissolve?

[Misha] I haven't done solubility kinetics studies yet. Some are more challenging to get into solution. DTPDQ was really challenging to get into water. What would be the benefit of kinetic studies?

[Ed] It can take a long time for 6-PPDQ to get into solution – different standards can dissolve at different speeds. We may have a lot of studies that are biased low or have particulate in there.

Question: [With reference to Angelina's presentation] Some of the concentration spikes were leading the rainfall spike, how would the water quality degrade so early in a rainfall?

[Angelina] Northfield Creek is where we see this happen the most – it is a very unique situation. Most of that watershed is underground and collects in parking lots and highways nearby. We're likely seeing a rapid response just because of the direct input and how quickly water flows through those drains and to our sample location.

[Attendee comment] Northfield Creek watershed is about four to five square kilometres that is entirely urban. There are two artificial sports fields and an infilled lake. It's a really flashy watershed, as it all drains into one pipe ultimately.

Question: How 6-PPDQ forms through ozonation – what have you learned, what can we take from this to design the best mitigation?

[Joseph] That's a complicated question with complicated answers. The early emerging stories are ultimately saying there is a need to slow water down. In addition to slowing water, GI can remove 6-PPDQ, as well.

Question: With regards to 6-PPDQ partitioning to organic carbon – relative to other things it seems low. Was it low in comparison to what you expected?

[Misha] It was low relative to plastic (organic carbon), whereas soils have differing amounts of organic carbon. It makes sense that plastics can interact really well with 6-PPDQ.

Question: Let's not forget that as a species, we divert water off the land as fast as possible. In all of the urban streams, there is almost no complexity in the channels and that increases the time we can increase oxygenation. Is there a connection between oxygen and 6-PPDQ?

[Joseph] We all collect water quality data at our sample sites. We haven't seen a correlation between dissolved oxygen and 6-PPDQ, at least nothing systematic at this point.

[Mason] We haven't seen any variation in dissolved oxygen from typical streamwater.

Question: You've collected over 2,000 samples and have a great system for categorizing. Is it going to be public?

[Angelina] Yes, it is live now [here].

Question: When you're running your samples in the autosampler, you're putting it in something that rinses the previous sample. Are you testing the same sample multiple times?

[Joseph] Between every sample and standard the probe is cleaned with methanol. Every fifth sample we run is a calibration check solution to ensure that the equipment is running properly and a deionized water blank to ensure there is no carry over between samples. We do run all samples that have 6-PPDQ detected three times in total.

Question: [With reference to Mason's presentation] The streamside samples you're collecting, you're also collecting grab samples and taking them back to the lab? Also, how many sample bottles are in the autosampler?

[Mason] There are 24 glass bottles in the autosampler that get swapped out every 24 to 48 hours, as samples are collected every 1 to 2 hours. The autosampler can be set up to do a

higher interval of sampling – you can collect up to 50 samples per event. All samples are then sent to the lab.

Question: [With reference to Mason's presentation] Are you collecting field blanks in the field?

[Mason] We haven't been collecting field blanks. We have done some initial grab sample comparisons with the autosampler. The results correspond really well at low concentrations. We'll continue to collect at least one paired grab sample with the autosampler to compare.

Question: [With reference to Mason's presentation] Could you comment on what you draw into the glass bottle is what is in the river and are true concentrations?

[Mason] We have found a few sources of potential loss, but when comparing results to the grab samples there doesn't appear to be any significant loss. If you can clean the silicon/vinyl really well between samples, you don't seem to have much loss.

Question: Has anyone tested all the different types of nitrogen in terms of their impacts on 6-PPDQ toxicity?

[Josh] When nitrite exposure occurs, it can cause hemoglobinemia (i.e., blood can't carry oxygen). No other nitrogens have been tested.

SUMMARY OF ACADEMIC FOCUSED EVENT PRESENTATIONS: PANEL 3 – FATE & REMEDIATION

This panel and the following discussion were chaired by Dr. Rachel Scholes.

Simon Maguire – Computational Chemistry for Understanding the Properties of 6-PPDQ

Simon Maguire is a Bachelor of Science graduate from VIU. They work for Dr. Heather Wiebe in the Molecular Modelling Lab and Dr. Erik Krogh in the AERL.

Computational chemistry utilizes computer simulation to assist with solving complex chemical problems. It is a useful tool if the compound is not readily available, present in complex mixtures, and/or is toxic, dangerous, or unstable. Advantages of computational chemistry are that it can be fast, applied to groups of similar compounds, and used to predict the properties of compounds and degradation products before putting them in the environment. The properties of a compound provide an understanding of the compound's fate, distribution, and toxicity in the environment. The main limitation of computational chemistry is that some simplifying assumptions may need to be made about a system to avoid being too computationally expensive (can take days to run); therefore, it may not be as accurate as experimental conditions. Some computational methods may be more accurate than others for predicting the properties of 6PPDQ. For example, *ab initio* (quantum) methods may be more accurate than Quantitative Structure Activity Relationship models, like EPI Suite. Ultimately, computational models need to be tested with experiments – it is not a replacement for experimental data/testing.

Simon has used *ab initio* calculations to show that 6-PPDQ may be able to tautomerize, meaning it may be readily able interconvert between two slightly different structures by moving a hydrogen from one part of the molecule to another. *Ab initio* methods have also been used to calculate the properties of these two tautomers, as they may have different properties and therefore different behaviour in the environment.

Yanru Wang – Occurrence & Leaching Potential of 6-PPD & 6-PPDQ from Vancouver Road Dust

Yanru is a Ph.D. student at UBC's Civil and Environmental Engineering Department.

Pollution potential regarding 6-PPD/6-PPDQ is related to the amount of tire and road wear particles (TRWP) present on roadways and surfaces from which runoff can mobilize. Factors that generate TWP include tire design, vehicle characteristics (i.e., weight, load distribution,

etc.), road surface (i.e., material, runoff design, roughness), weather, road topography, and driving behavior. Yanru's study is looking to assess the occurrence and leaching potential of 6-PPD and 6-PPDQ from TRWPs under various traffic and climate conditions in the Vancouver area.

Road dust samples were collected using a Dyson vacuum at one site located on Southwest Marine Drive next to UBC, and the other four are concentrated in downtown Vancouver. Collected road dust was sieved to remove large particles/rocks and stored in amber glass bottles. Samples were taken back to the lab for leaching experiments, which involved mixing about 0.5 g of road dust and 500 mL of deionized water in bottles and shaking these bottles. The pH and temperature were monitored at the designed time points, and two 10 mL water samples were taken. Orbitrap LC-MS/MS was used to quantify the concentrations of 6PPD and 6PPDQ.

To identify and quantify the TRWP in the sample, road dust is separated by gravity, and supernatant materials are dried and deposited on barium-fluoride slides. Applying uFTIR would enable TRWP identification and quantification of samples. The proposed method is still in progress.

Judging from the current data, the leaching potential of 6-PPD and 6-PPDQ shows seasonal changes might be due to temperature, which showed a relatively strong positive correlation between temperature and the leaching potential of 6-PPDQ, and an increase in temperature may be accompanied by a higher risk of 6-PPDQ toxicity. Ground-level ozone concentration does not show a strong linear relationship with the leaching concentration of 6-PPD and 6-PPDQ. The other influencing factors need to be further explored and understood.

Tim Rodgers – Design Guidelines to Reduce 6PPD-Quinone Loading Using Stormwater Bioretention Cells

Tim is a postdoctoral fellow in the Department of Civil Engineering at UBC.

Rain gardens and bioretention cells are different types of stormwater management technologies that are working toward restoring pre-development hydrology and improve stormwater quality. Tim's primary research questions with regards to stormwater biorentention

cells are: [1] how well do rain gardens protect salmon from 6-PPDQ? and [2] can we improve the rain garden to remove more 6-PPDQ?

In order to assess the efficacy of rain gardens with regards to 6-PPDQ, Tim and the UBC team worked with the City of Vancouver to conduct a spike and recovery test. They pumped water from a water truck into a barrel where they mixed it with 6-PPDQ. The spike test saw really good capture – of the 860 µg/L added, only about 2% made it entirely through the rain garden. The effluent that made it through was still a high concentration (above coho LC50), however it was very short-lived.

Tim has been using modeling to assess how rain gardens can be improved to remove more 6-PPDQ. Conditions typically conducive for rain gardens to work are longer, less intense storm events. Modelling results indicate that under two-year events have great capture (>95%), whereas a 100-year storm (1 hour) has about 61% of 6-PPDQ lost to overflow, flowing directly into the sewer.

Potential means of improving rain gardens to treat 6-PPDQ could include no underdrain, lots of compost, deeper/greater capacity, and spread across the largest area possible.

Ani Jayakaran – The Promise of Permeable Pavements in Treating Tire Particles & Associated Leachable Contaminants

Ani Jayakaran is a professor at Washington State University Extension. He is presenting a project that one of his master's students, Chelsea Mitchell, recently published in January 2024.

Permeable pavement is a type of pavement that have interconnected voids that allow rainwater to percolate through into a reservoir course below. They are showing promise of retaining TWP and microplastics, which could be removed during routine maintenance. One of the downsides of permeable pavement is that it does not hold up well to tire traffic; they are better for side streets with lower traffic roadways, rather than highways.

The research team tested two types of pavement: asphalt and concrete. They did three experiments over three days: [1] flushing experiment; [2] exposed TWP to the pavement and irrigated them; and [3] another flushing experiment. The first and third experiments were meant to establish a baseline for TWP and assess continued TWP release, respectively. Results

indicated that >96% of TWP were retained by the pavement, which provided an estimated 52 to 100% mass reduction of 6-PPDQ. Retained particles appeared to leach the majority of available 6-PPDQ following TWP deposition.

This study was only conducted one time so it would be beneficial to do this a few more times to confidently state this.

Panel 3 Discussion

Panelists responses were written based off notes taken at the workshop, not a transcript. All responses were approved by panelists prior to publishing.

Question: [With regards to Simon's presentation] What is the environmental role of the tautomer?

[Simon] Tautomerization means that the molecule is changing slightly, so the properties could also change slightly. If 6-PPDQ were to tautomerize, that means that the properties that we see in the environment would be a weighted average between the tautomers based on which structure is the most common. Our goal is to be able to calculate the contribution of each of the two tautomers to the overall observed properties.

Question: [With reference to Yanru's presentation] How did you go about ensuring you did not have any carry over between samples?

[Yanru] After sampling at each site, all the parts of the Dyson vacuum that could be cleaned, were cleaned. There were some small parts that were challenging to clean, so there is potential there were some left over particles.

Question: [With reference to Tim R.'s presentation] Has there been anything testing done on the trapping of these compounds by rain gardens and having a subsequent rain event?

[Tim R.] During the spike test, we returned and ran more water through the system a week later. When we did this, nothing came out, so it appears that once the system holds it, they aren't releasing it.

Question: [With reference to Ani's presentation] How long would it take for permeable pavement to reach saturation before replacement?

[Ani] Permeable pavement requires maintenance regularly. It's believed that general maintenance every one to six months would be suitable. Maintenance involves street sweeper and wet equivalents of it that do the same thing but clean the water too.

Question: What is the timing of the peaks you're seeing 6-PPDQ come out? Why do we see a spike coming through it early on?

[Ani] TWP are very hydrophobic and will move quickly with the water, so I'm speculating that they get pushed out pretty quickly, which may be why we're seeing those first pulses.

[Tim R.] Our experiment involved adding a spike of 6-PPDQ to the rain garden. When modelling, it's more of a continuous flush. Residence time in these systems is relatively short.

[Ani] These are also contaminant limited systems; they can only hold/move a finite amount of materials.

Question: With the organics in a rain garden it will make it more effective. Do you need to replenish the compost?

[Sylvie] Regular landscaping practices are good to keep organic content, including adding mulch each year. Plants die and add organics naturally, as well.

Question: The Town of Comox is interested in bioretention systems. In particular on Brooklyn Creek, there is a site with two stormwater inputs – at one, there is no room for a bioretention

system – would street sweeping and/or removal of top layer of sediment catchment be enough? Is this normal/common?

[Tim R.] Catchments are mass limited typically. What the Town is doing sounds like it would help reduce 6-PPDQ input as they are preventing many TWP from making their way into the creek. Sinks before retention ponds would also likely help it.

Question: A proposal that would have 58,000 transits of big rigs to drop off construction materials at a specific site has been put forward. In transit, they are crossing an important slough. Two First Nations have opposed the proposal and said there should be a reduction in the amount of transit required. Would street sweeping be effective in any regard along these road that may see heavy traffic?

[Ani] Street sweeping has been shown to be effective at managing road pollutants – primarily metals. A study is going to be starting soon that is looking at effects specifically to 6-PPDQ, so it's still an open question.

Question: With regards to the impacts of climate change, in particular precipitation. What design recommendations would you have for rain gardens to accommodate these larger precipitation events?

[Tim R.] Retrofits that add compost, increase infiltration capacity, and/or increase the ponding zone could increase rain garden's capacity to accommodate larger rain events. Undersized infrastructure is challenging due to space constraints.

Question: How are the TWP that are collected in any system disposed of?

[Ani] As far as I know, at the landfill. Street sweeper trucks are deposited at the landfill – it may be at a specific hazardous waste facility. It may be different in different jurisdictions.

Question: [With reference to Simon's presentation] Can the same method be used on the analogs of 6-PPD and help make decisions about other potential compounds to use?

[Simon] Yes, the hope is to do this for all the analogs.

Question: [With reference to Yanru's presentation] Have you tried drying materials off and exposing to new water to see how many cycles it persists for? Just curious about regeneration.

[Yanru] I haven't done this year. The purpose of the study originally was to assess the 'first flush'.

Question: Do you ever see any designs where rain gardens can be implemented at road crossing or divert water away from a stream?

[Tim R.] High traffic intersects near streams are the most concerning locations. It is definitely possible that you could direct multiple pipes into GI; however, regrading a bridge would be very expensive.

[Attendee comment] They are rebuilding bridges in the Colquitz watershed and part of this project is to redirect water into a rain garden that will be underneath the bridge.

[Attendee comment] The cost of retrofitting existing infrastructure is very costly. However, there are a lot of new developments going in now, where we should be advocating for these types of things now.

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APPENDIX A – SPEAKER BIOGRAPHIES

Speaker biographies are listed in alphabetical order.

Angelina Jaeger – Vancouver Island University

Angelina began her master's in chemistry in the fall of 2023. Her research will focus on continued rapid-detection 6-PPDQ monitoring and method development, as well as investigating chemical characteristics and reactions of 6-PPDQ.

Contact: angelina.jaeger@viu.ca

Ani Jayakaran – Washington State University

Ani Jayakaran is a professor at Washington State University Extension. His role is to meet education and research needs in a region experiencing the impacts of rapid urbanization, a changing climate, and increasingly diverse communities. He develops tools to manage water resources using Green Stormwater Infrastructure and ecological engineering principles. He aims to positively influence stormwater management decisions that impact under-resourced communities. Ani holds bachelor's and master's degrees in civil engineering and a doctoral degree in biosystems engineering. He is a registered engineer in Washington and South Carolina.

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Bonnie Lo – Simon Fraser University

Bonnie Lo is a Ph.D. candidate in the Department of Biological Sciences at Simon Fraser University, British Columbia, Canada. Her senior co-supervisors are Drs. Tanya Brown and Vicki Marlatt. Bonnie's current research employs a combination of 'omics and traditional toxicity evaluation techniques to assess contaminant related health effects in juvenile salmon present in the lower region of the Fraser watershed. Bonnie's previous research interests include selenium toxicity and amphibian toxicity test method development.

Daniel Cheater – Ecojustice

Daniel Cheater is a lawyer with Ecojustice Canada, a non-profit organization that provides legal services to the environmental community. Since joining Ecojustice in 2019 he has appeared

before the Federal Court, Federal Court of Appeal, and Supreme Court of Canada. As a member of Ecojustice's Healthy Communities and Nature teams, Dan's practice focuses on protecting Canada's biodiversity and ensuring industry is held to account.

Ed Kolodziej – University of Washington

Ed Kolodziej is a Professor at the University of Washington with joint faculty appointments at Environmental Sciences at UW-Tacoma and in Civil and Environmental Engineering at UW-Seattle. He also is a Principal Investigator at the Center for Urban Waters (Tacoma, WA) where Ed and his research group use advanced mass spectrometry and hard work to investigate contaminant fate and transport, build effective treatment systems, and ensure ecosystem health.

Contact: koloj@uw.edu

Erik Krogh – Vancouver Island University

Dr. Krogh completed his undergraduate studies in at the University of Toronto with a specialization in Physical Organic Chemistry and Environmental Studies. He went on to obtain his Ph.D. in Chemistry at the University of Victoria, where he focused on structure-activity relationships in the photochemistry of organic molecules in aqueous media. He is currently a faculty member in the Department of Chemistry at Vancouver Island University and co-Director of the Applied Environmental Research Laboratories. He teaches environmental and analytical chemistry courses and maintains an active group of undergraduate and graduate student researchers. He has published over 60 papers in the areas of environmental analytical chemistry. His current research interests include the development and application of real-time, on-line mass spectrometry to directly investigate environmental chemical processes in complex and reactive media.

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Garrett Foster – Washington State University

Garrett is an outdoor enthusiast and master's student in Dr. Jen McIntyre's Aquatic Ecotoxicology Lab at Washington State University's Puyallup Research and Extension Center. Garrett has worked with coho, chinook, and pink salmon in laboratory, field, and hatchery

settings with an interest focused on how chemistry and habitat impact fish, human, and ecosystem health. Garrett is approaching graduation and eager to start a career conserving the fisheries vital to the Pacific Northwest way of life!

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Haley Tomlin – British Columbia Conservation Foundation

Haley began her education at Yukon College before transferring to Vancouver Island University to finish her studies. She has been a biologist with the British Columbia Conservation Foundation's Aquatic Research & Restoration Centre since 2022. Haley works on a variety of BCCF ARRC's projects and has been co-leading the Tire Wear Toxin Monitoring Program with Erik at VIU AERL.

Contact: htomlin@bccf.com

Joseph Monaghan – Vancouver Island University

Joseph is a Nanaimo local who completed his B.Sc. (major in Biology; minor in Chemistry) at Vancouver Island University in 2019. At VIU, he received the Governor General's Silver Medal for earning the highest graduating GPA of the institution. Joseph began pursuing his PhD in fall 2019 under the supervision of Dr. Erik Krogh, where they would develop and apply direct mass spectrometry techniques for trace environmental analysis. Throughout his Ph.D., Joseph has published five peer-reviewed research articles covering applications of online membrane sampling for analysis of oil & gas related contaminants and tire-wear toxins and will defend his PhD in summer 2024.

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Josh Baker – Nautilus Environmental

Josh Baker has been investigating causes of toxicity to aquatic organisms for over a decade at Nautilus Environmental. These investigations have identified toxic constituents in a variety of discharges, including those originating from mining, oil and gas, municipal wastewater treatment, pulp and paper, amongst other operations. He has also been an active volunteer with streamkeeper and conservation groups, most notably the Alouette River Management Society and the British Columbia Wildlife Federation. This has led to outreach on pollutants, and

the possible adverse effects of stormwater on aquatic communities. As an advocate for salmon restoration and an experienced toxicity investigator, when in 2020 the remarkable results of detailed investigations into the cause of coho salmon mortality in tire leachate were published, he naturally became keenly interested in the 6PPD-Q science. He has recently used his in own unique experience and skills to investigate causes of toxicity in municipal stormwater, and to further explore the toxicity of 6PPD-Q.

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Justin Budyk – Peninsula Streams Society

Justin Budyk is the Environmental Stewardship Coordinator for Peninsula Streams & Shorelines. He works with volunteers, stewardship groups, and various other stakeholders in Greater Victoria to conduct restoration projects, environmental monitoring, and facilitate citizen science to protect and restore fish populations and their habitat. Originally from Winnipeg, he has considerable experience working in fisheries and freshwater ecology across Western Canada and the Subarctic.

Contact: justin.budyk@peninsulastreams.ca

Katie Roberts – University of Saskatchewan

Katie has been a grad student of the Toxicology Centre at the University of Saskatchewan since 2022, and is currently finishing her master's degree and planning to start a subsequent PhD program. Katie's research focuses on the effects of 6PPD-quinone on early-life stage salmonids, in both sub-chronic and acute exposures. She also looks at effects at the transcriptome level, with a goal to further elucidate both sub-lethal effects, as well as mechanism(s) of action of 6PPD-quinone.

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Keith Estes – Long Live The Kings

Keith Estes is a Project Manager at Long Live The Kings working on salmon recovery by facilitating habitat restoration and stormwater management projects in Puget Sound. Keith joined LLTK in 2023 after working for New York State's Department of Environmental Conservation as an Environmental Analyst in their Bureau of Water Resource Management.

Having grown up in Washington State, he has always been passionate about water systems and has a particular affinity for the Salish Sea. Keith holds a Masters of Natural Resources with a focus in Water and Marine Systems from Virginia Tech and a B.B.A in Marketing and Communications from Texas State University.

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Kyle Miller – Tseshaht First Nation

Kyle Miller is the fourth generation of this family to work in fisheries. He is currently the Fisheries Technician for the Tseshaht First Nation Fisheries Department, having previously held the position of RMOT (Resource Management Office Technician). Kyle's grandfather and father also worked in coordination with the Musqueam and Nis'gaa First Nations fisheries, and for four decades managed some of the largest commercial gillnet fleets in BC.

Markus Brinkmann – University of Saskatchewan

Dr. Markus Brinkmann is an associate professor and the Centennial Enhancement Chair in Mechanistic Environmental Toxicology in the School of Environment and Sustainability at the University of Saskatchewan, the director of the university's world-renowned Toxicology Centre, and a member of the Global Institute for Water Security. He is an award-winning toxicologist whose academic journey has focused on the exploration of environmental contaminants, including those that are discharged through municipal wastewater, and their impacts on environmental and human health.

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Mason King – Simon Fraser University

Dr. Mason King is a Post-Doctoral Fellow in the Brown Lab within Simon Fraser University's Department of Biological Sciences. His current research focuses on road runoff in salmon streams and its effects on salmon. Mason's past research examined persistent contaminants in seabirds, avian petroleum ecotoxicology, flame retardant effects in raptors, coastal watershed nutrient pollution, and ocean acidification. He is an active member of the Society of Environmental Toxicology and Chemistry and sits on the Wildlife Ecotoxicology Interest Group Steering Committee.

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Misha Zvekic – Vancouver Island University

Misha Zvekic is a Master of Chemistry graduate, with a background in biology and chemistry from Vancouver Island University. Misha has worked in the Applied Environmental Research Laboratories for 6 years and has enjoyed working on a number of projects including studying plastic weathering, microplastic-chemical interactions, and maternal transfer of toxic metals and organic contaminants in sixgill sharks. Misha's current work involves studying the physicochemical properties of PPDQ compounds.

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Rachel Scholes – University of British Columbia

Dr. Rachel Scholes is an Assistant Professor of Environmental Engineering at the University of British Columbia. Her research focuses on emerging contaminants in wastewater and stormwater, with an emphasis on nature-based treatment systems. She has conducted research on emerging contaminants as a Hollings Scholar for the National Oceanic and Atmospheric Administration, and as a Fulbright Graduate Research Fellow at the University of Otago, New Zealand. She earned an M.S. and Ph.D. in Environmental Engineering from the University of California, Berkeley, and a B.S. in Chemical Engineering from Northwestern University. Prior to joining UBC, she conducted postdoctoral research at the United States Department of Agriculture, where she focused on green chemistry approaches to mitigate emerging environmental contaminants. As an early-career faculty member, she has been highlighted as an Emerging Investigator by the Royal Society of Chemistry, and was appointed by the Peter Wall Institute for Advanced Studies at UBC as a Catalyst Scholar addressing the Climate and Nature Emergency.

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Simon Maguire – Vancouver Island University

Simon Maguire is a fourth year undergraduate Chemistry student at VIU who will be graduating in June. They work for Dr. Heather Wiebe in the Molecular Modelling Lab and Dr. Erik Krogh in the Applied Environmental Research Laboratories applying Computational Chemistry to

environmental concerns. Their undergraduate research project focuses on the potential tautomerization of 6-PPDQ and its analogs.

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Sylvie Spaakman – City of Vancouver

Sylvie Spraakman is a Senior Engineer at the City of Vancouver in the Green Infrastructure Implementation Branch. She has a PhD in Civil Engineering from the University of Toronto where her research focused on the long-term performance of bioretention systems.

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Tanya Brown – Simon Fraser University

Dr. Tanya Brown is an Assistant Professor in the Department of Biological Sciences at Simon Fraser University, British Columbia, Canada. She holds an Adjunct Professor position in the School of Environment at the University of Windsor, Ontario. Prior to her current position, she was a Research Scientist at Fisheries and Oceans Canada (DFO) with the Ocean Sciences Division from 2019-2023, where she led DFO's Whale Contaminants Program in support of the Government of Canada's Whales Initiative. She has 20 years of experience in the study of the ecology and ecotoxicology of marine mammals and fish. Her research has focused largely on understanding the influence of habitat use and feeding ecology on contaminant exposure, accumulation, and health effects in a changing marine environment. She leads a team of graduate students and researchers seeking to identify principal routes of exposure to priority contaminants and to understand how environmental changes and anthropogenic stressors are impacting valued ecosystem components, such as killer whales, beluga whales, ringed seals, Arctic char, and Pacific salmonids. She employs a combination of habitat use modelling, dietary tracers, and ‘omics technologies to characterize contaminant pathways and assess the health of fish and marine mammals. Dr. Brown has applied her expertise in support of contaminant site remediation, green infrastructure, and the recovery of at-risk species.

Tim Kulchyski – Cowichan Tribes

Tim Kulchyski is a member of Cowichan Tribes, works as a Natural Resource Consultant in the Cowichan Tribes Lands and Self-Governance Department, and serves as a member of the Cowichan Watershed Board. He has worked with a variety of clients assessing upland,

freshwater, and marine ecosystems for over 20 years. His work often involves examining the impacts of development on cultural values.

Tim Rodgers – University of British Columbia

Tim is a postdoctoral fellow in the Department of Civil Engineering at UBC. His research looks at the fate and behaviour of toxic chemicals in the environment, with a focus on chemicals emissions and human/environmental exposures. Tim is currently working on understanding how the tire wear product "6PPD-quinone", which is extremely toxic to coho salmon, moves through urban watersheds in the Metro Vancouver area. The goal of this project is to help design and implement engineered systems or policy interventions that can protect coho salmon and other aquatic organisms from 6PPD-quinone and other toxic road runoff compounds.

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Yanru Wang – University of British Columbia

Yanru is a Ph.D. student at UBC's Civil and Environmental Engineering Department. She completed her M.Eng. (2020) in Environmental Engineering at the University of Alberta and analyzed the flood mitigation capacity of bioretention. Currently, her research involves identifying and quantifying the fate and transformation pathways of a trace organic contaminant in stormwater, namely 6PPD-quinone, which is a transformation product that forms when the tire rubber additive 6PPD reacts with ozone in the air. She is now working on investigating under which environmental conditions more 6PPD-quinone will be produced, such as sun exposure or rain erosion, and its treatment and fate in green infrastructure systems.

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