oekotoxzentrum
centre ecotox
Schweizerisches Zentrum für angewandte Ökotoxikologie
Centre Suisse d'écotoxicologie appliquée

Ecotox hazards of tire particles

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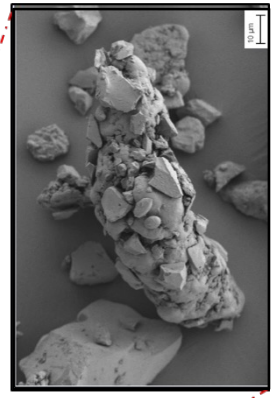
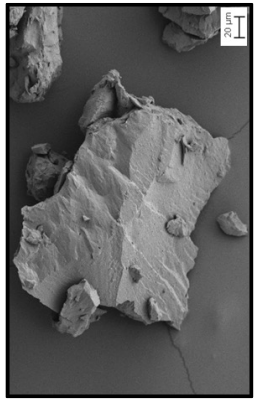
WBCSD World Business Council for Sustainable Development

Tire Industry Project

Narrowing the scope

Tire and Road Wear Particles (**TRWP**)

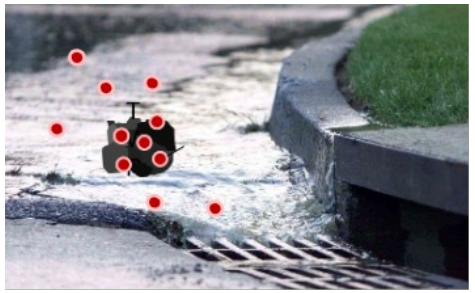


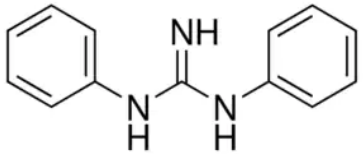


Tire Wear Particles (**TWP**)

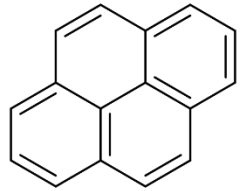
Tire Particles (**TP**)

Cryogenically Milled Tire Tread (**CMTT**)

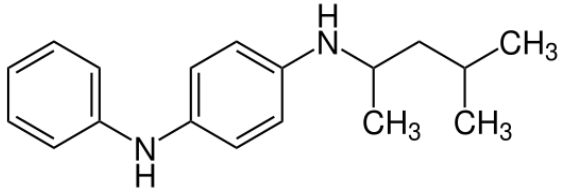




1,3-diphenylguanidine
Vulcanization accelerator

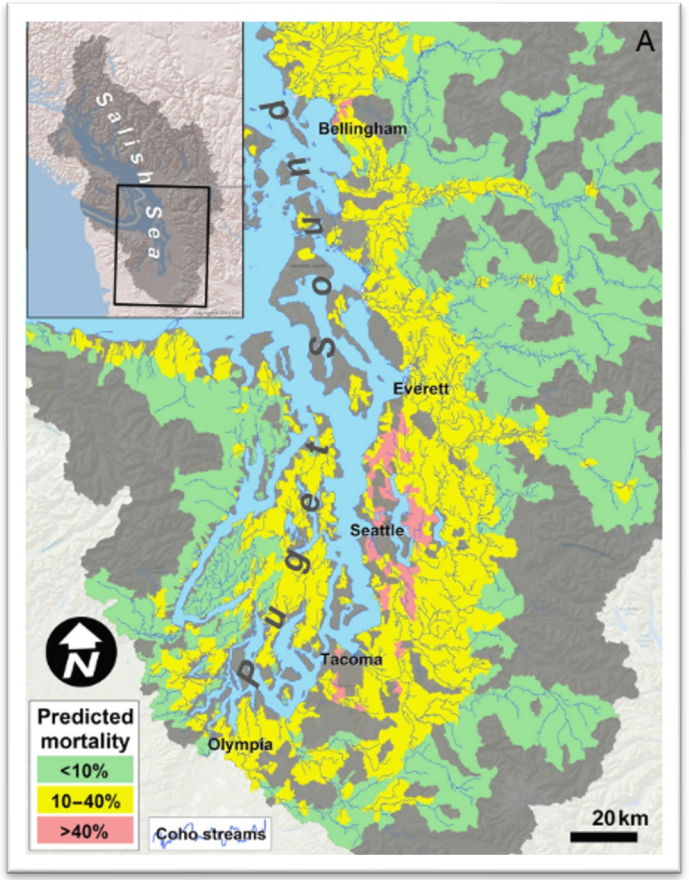


pyrene
PAH



6PPD
Antiozonant

Mortality associated with urban runoff



Feist et al. 2017. Ecological Applications.

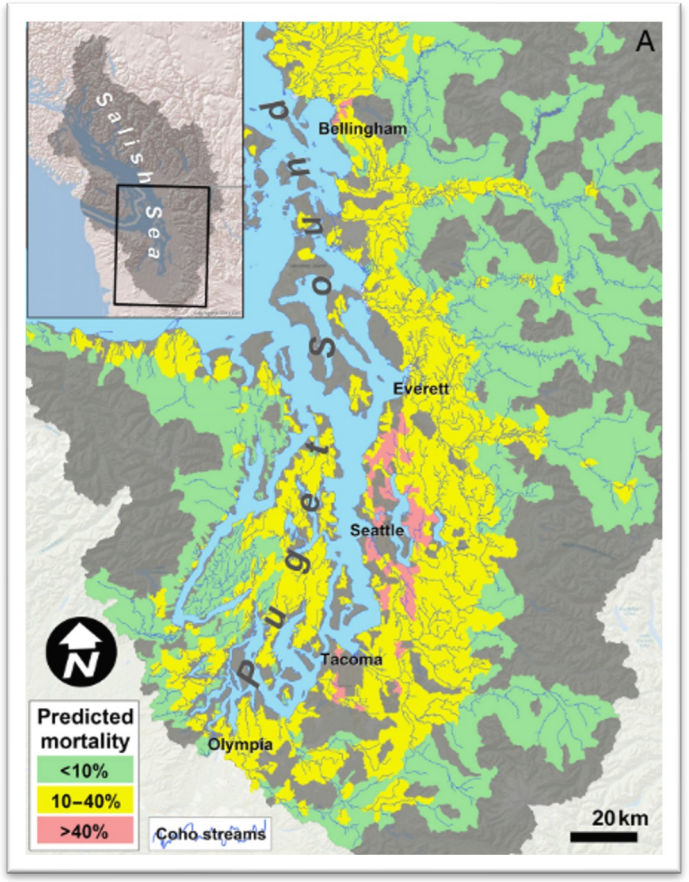
Pre-spawn mortality (PSM)

Urban runoff mortality syndrome

- surface swimming
- gaping
- loss of equilibrium
- pectoral fin splaying

Scholz et al. 2011. PloS one.

Mortality associated with urban runoff



Early studies ruled out:

- Common physical/chemical parameters
  - Temperature
  - Dissolved oxygen
  - Ammonia
  - pH
- Pathogens
- Common insecticides
- Metals

"The weight of evidence suggests that freshwater-transitional coho are particularly vulnerable to an **as-yet unidentified toxic contaminant** (or contaminant mixture) in urban runoff."

Scholz et al. 2011. PloS one.

Feist et al. 2017. Ecological Applications.

Linking toxic waters to tire wear particles

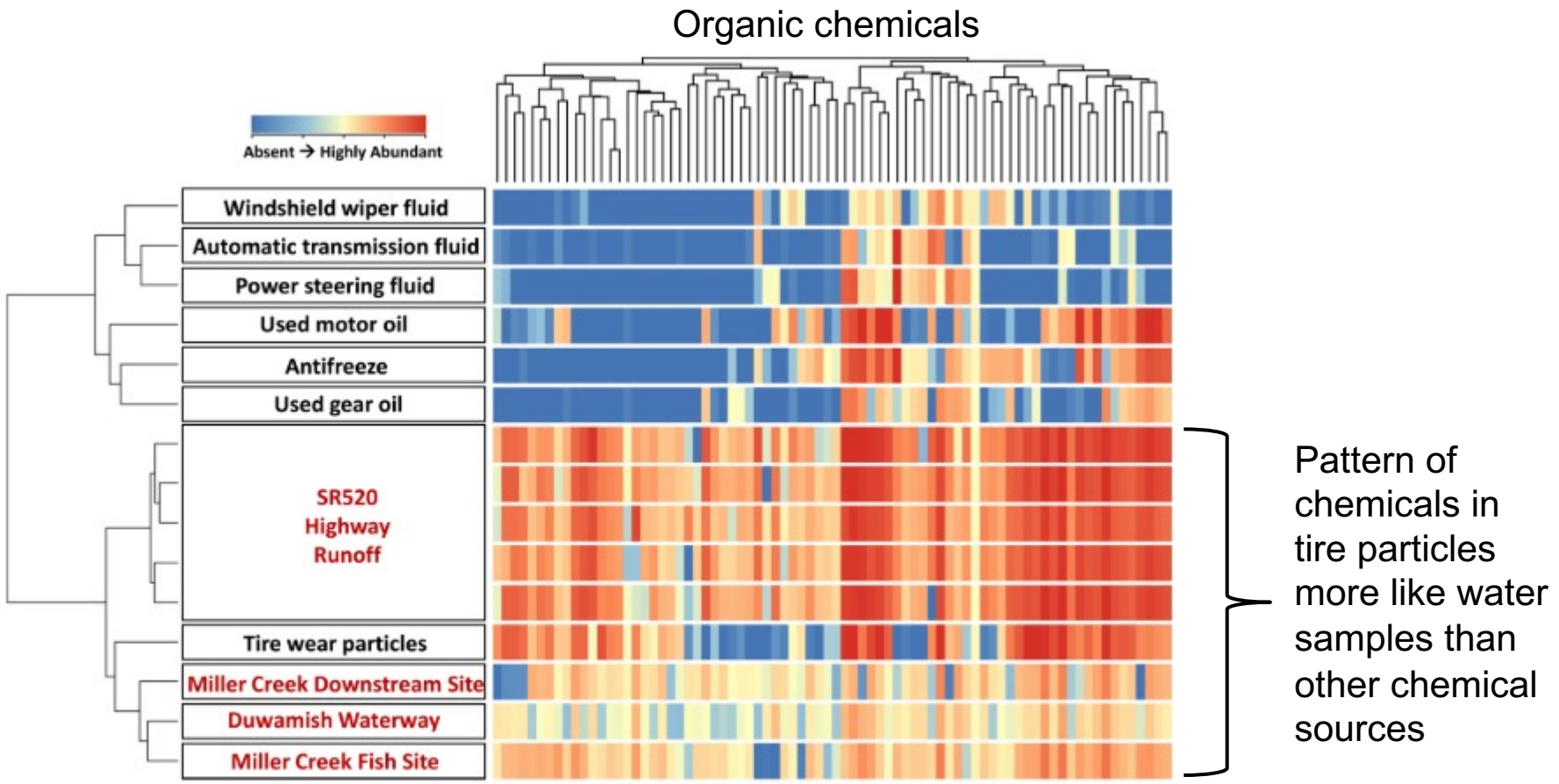
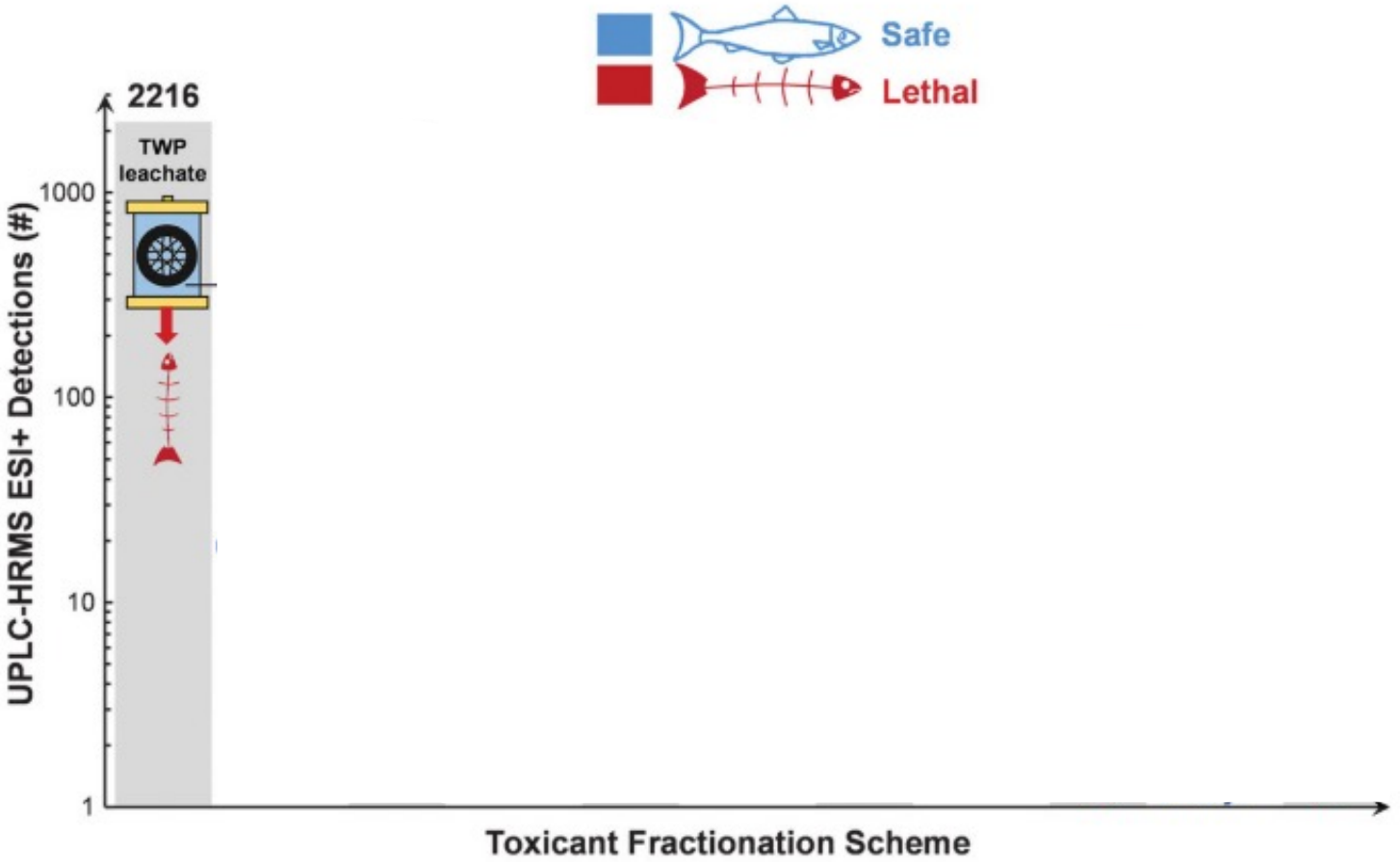


Figure: Hierarchical clustering of high-resolution mass spectrometry (HRMS) data

Peter et al. 2018. Environmental science & technology.

Fractionation



Most abundant candidate:
[M+H]+: 299.1752
RT: 11.0 min
Formula:
$C_{18}H_{22}N_2O_2$

Tian et al. 2021. Science.

Linking unknown to 6PPD

MECHANISMS OF OZONATION OF N-(1,3-DIMETHYLBUTYL)-N′-PHENYL-*p*-PHENYLENEDIAMINE*

R. P. LATTIMER, E. R. HOOSER, R. W. LAYER, AND C. K. RHEE

THE BFGOODRICH RESEARCH AND DEVELOPMENT CENTER, 9921 BRECKSVILLE ROAD, BRECKSVILLE, OHIO 44141

INTRODUCTION

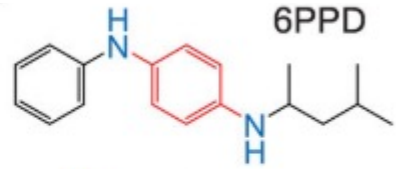
TABLE I

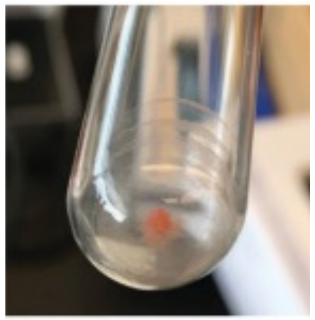
COMPOSITIONS OF OZONE-HPPD REACTION PRODUCTS

Measured mass[a]	Atomic composition	Calculated mass[b]
184.0997[c]	$C_{12}H_{12}N_2$	184.1000
198.0793[c]	$C_{12}H_{10}N_2O$	198.0793
214.0742[c]	$C_{12}H_{10}N_2O_2$	214.0742
268.1579[c]	$C_{17}H_{20}N_2O$	268.1576
268.1944[c]	$C_{18}H_{24}N_2$	268.1939
211.1235	$C_{14}H_{15}N_2$	211.1235
282.1734[c]	$C_{18}H_{22}N_2O$	282.1732
225.1023	$C_{14}H_{13}N_2O$	225.1028
296.1889[c]	$C_{19}H_{24}N_2O$	296.1888
298.1688[c]	$C_{18}H_{22}N_2O_2$	298.1681
534.3716[c]	$C_{36}H_{46}N_4$	534.3722
477.3011	$C_{32}H_{37}N_4$	477.3018
546.3356[c]	$C_{36}H_{42}N_4O$	546.3358
503.2819	$C_{33}H_{35}N_4O$	503.2811
489.2654	$C_{32}H_{33}N_4O$	489.2654

[a] Measured by peak matching in EI mode (Finnigan MAT 311A, $M/\Delta M$ ~10000).
[b] Based on given atomic composition.
[c] Molecular ion. (Other ions given are fragment ions.)

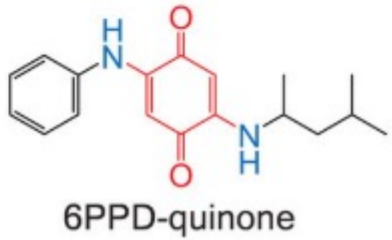
Lattimer et al. 1983.



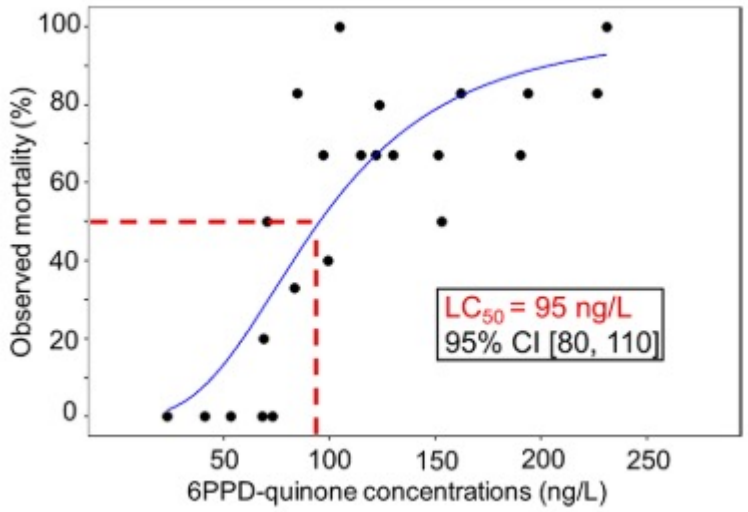


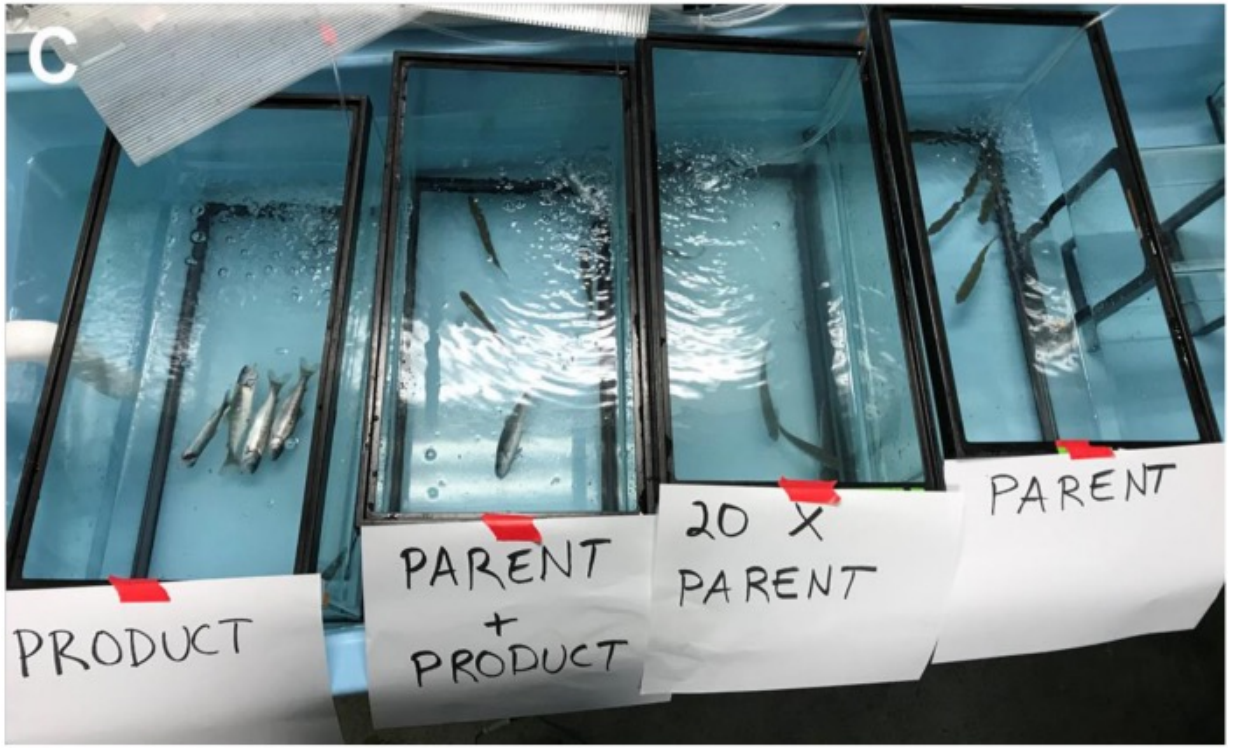
Tian et al. 2021. Science.

6PPDQ reproduces coho mortality



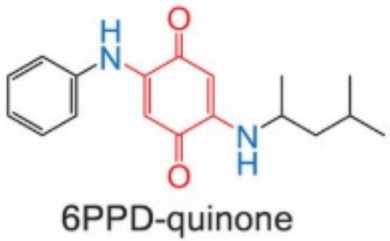
6PPD-quinone



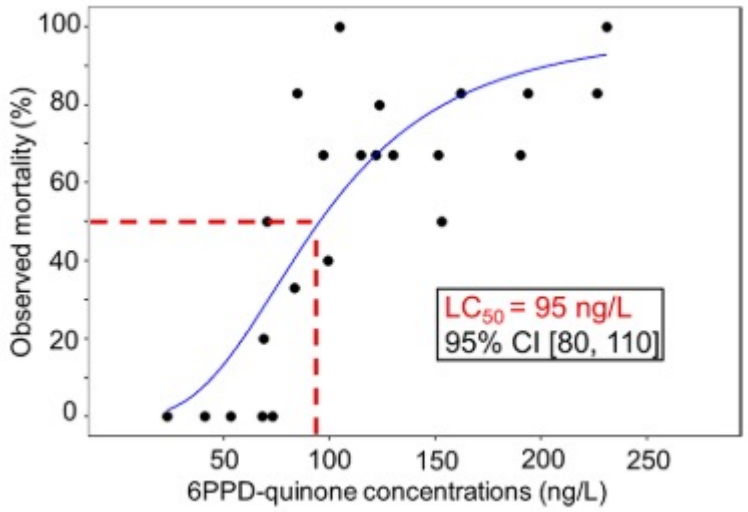


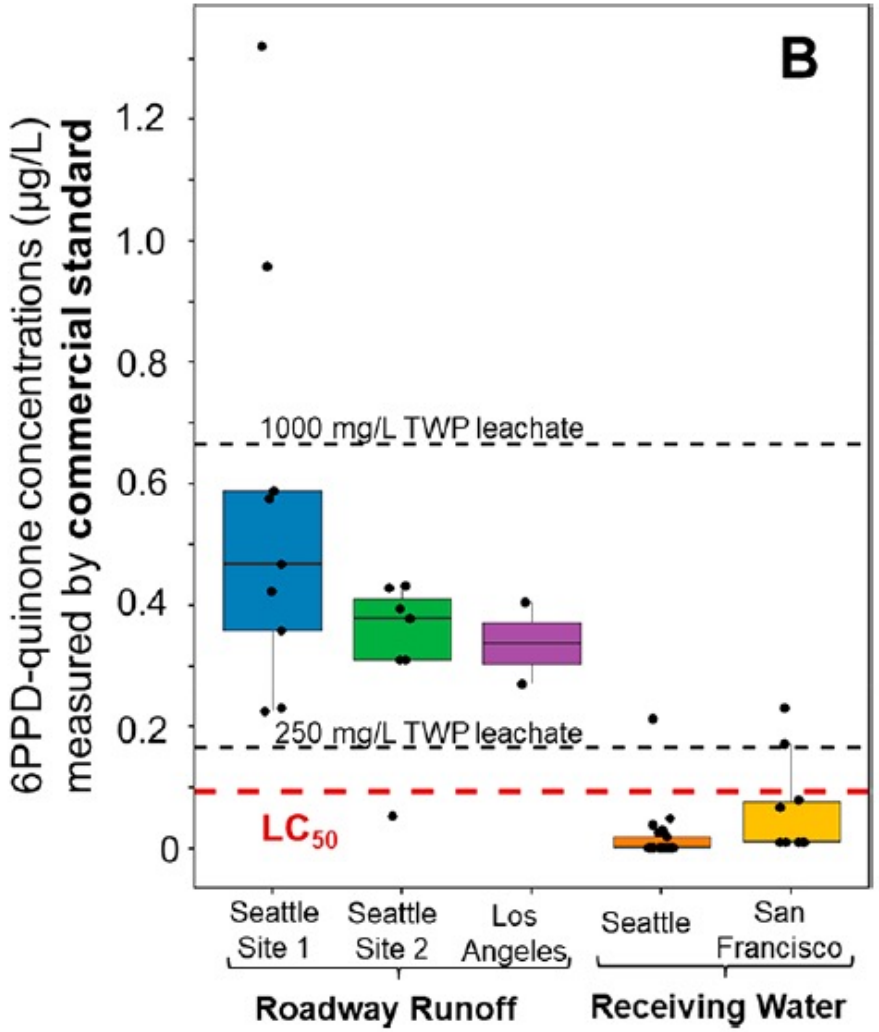
Tian et al. 2022. Environmental Science & Technology Letters.

Estimated environmental concentrations



6PPD-quinone



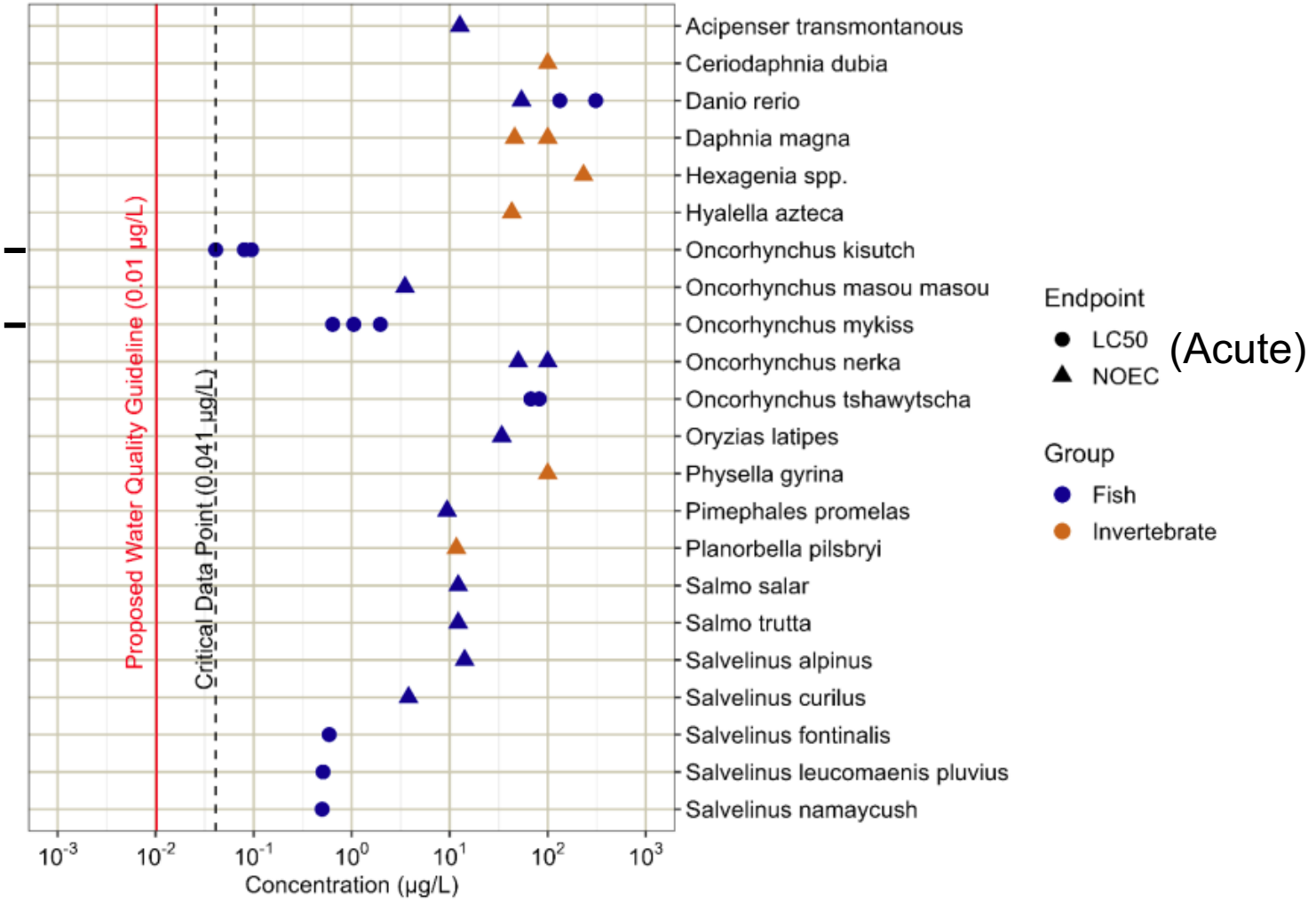


Tian et al. 2022. Environmental Science & Technology Letters.

Proposed water quality guideline: British Columbia

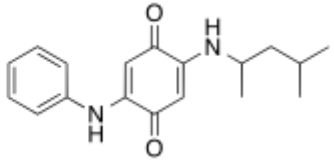
coho

rainbow trout



B.C. Ministry of Water, Land, and Resource Stewardship. 2025. 6PPD-quinone Water Quality Guidelines – Freshwater Aquatic Life. Water Quality Guideline Series, WQG-24. Prov. B.C., Victoria B.C.

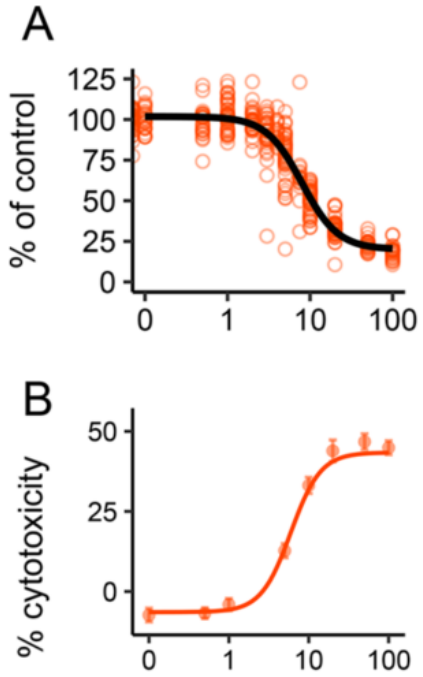
In vitro toxicity corresponds to in vivo



Cell lines: coho salmon embryo

metabolic activity

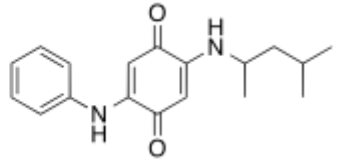
cytotoxicity

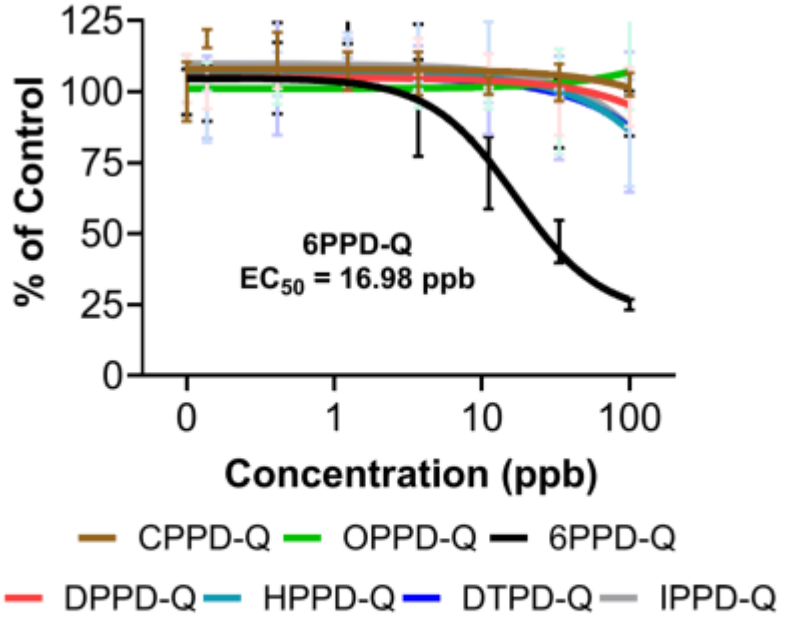


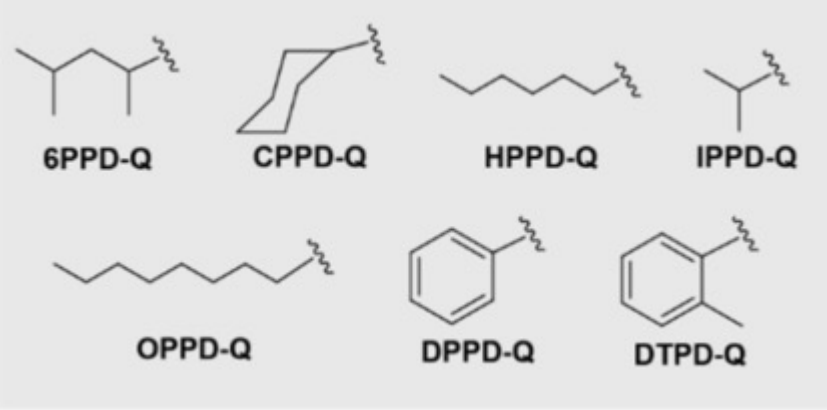
Greer et al. 2023. Envrion. Sci. Technol. Letters

Structure specific toxicity

coho salmon embryo cell line



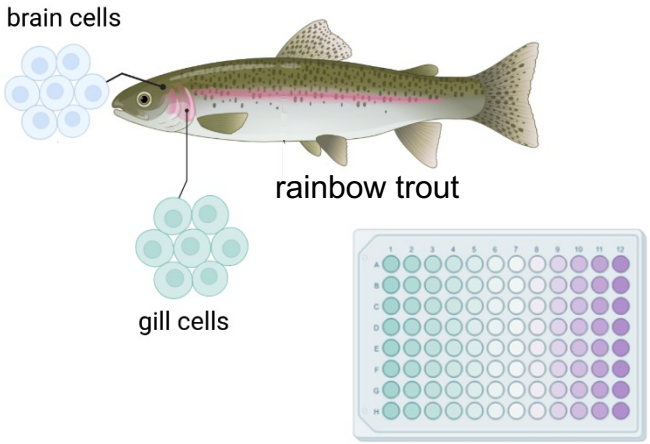


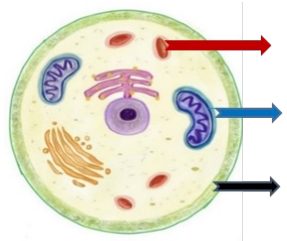


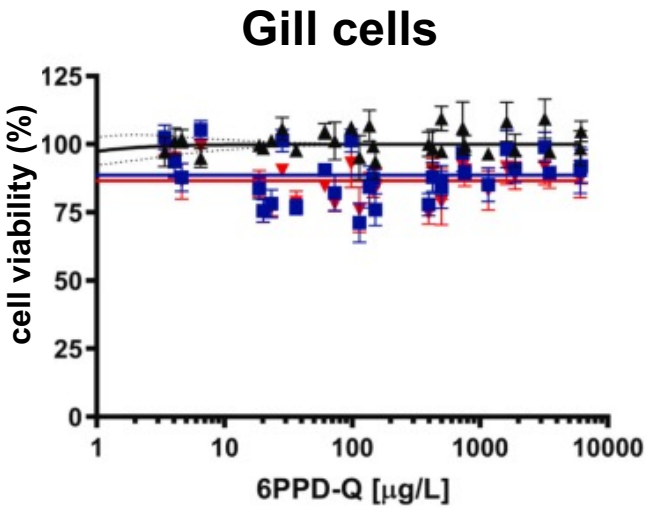
Tissue specific toxicity

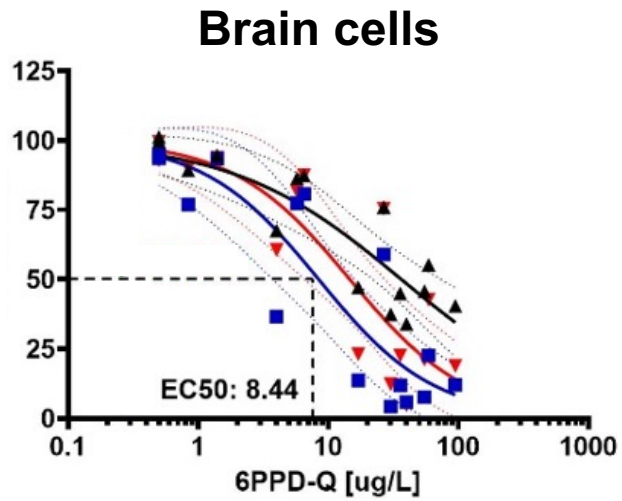

Marie Pigneres

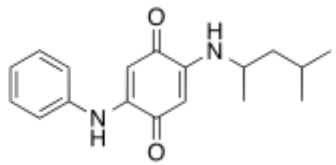

William Dudefoi




3 metrics of viability

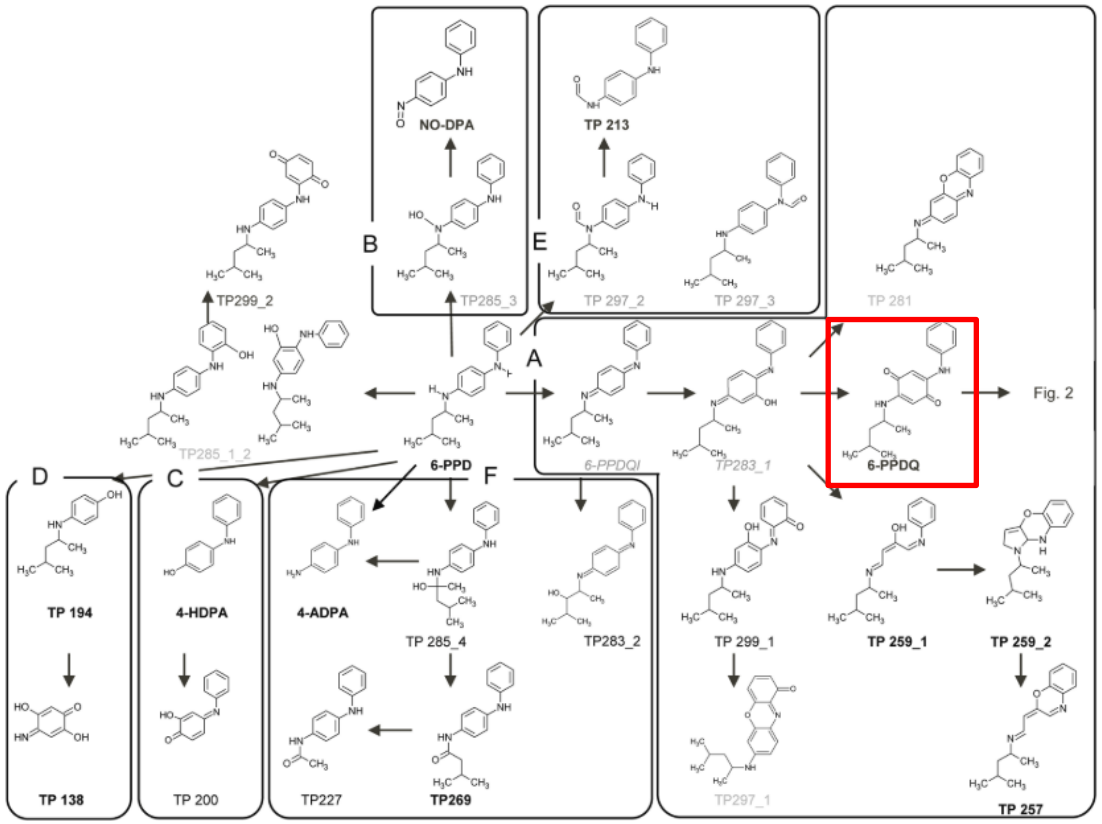




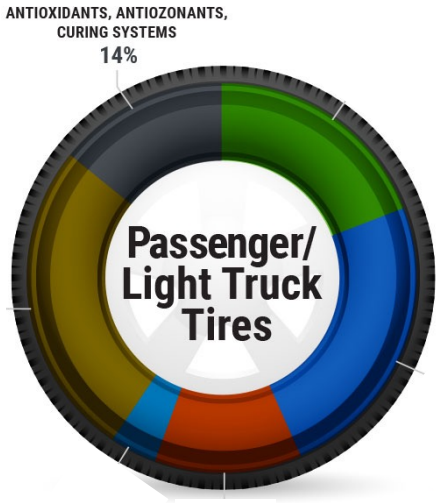


Dudefoi et al. 2024. Sci. Total Environ.
Pigneres M, Dudefoi W, Schirmer K et al. In preparation

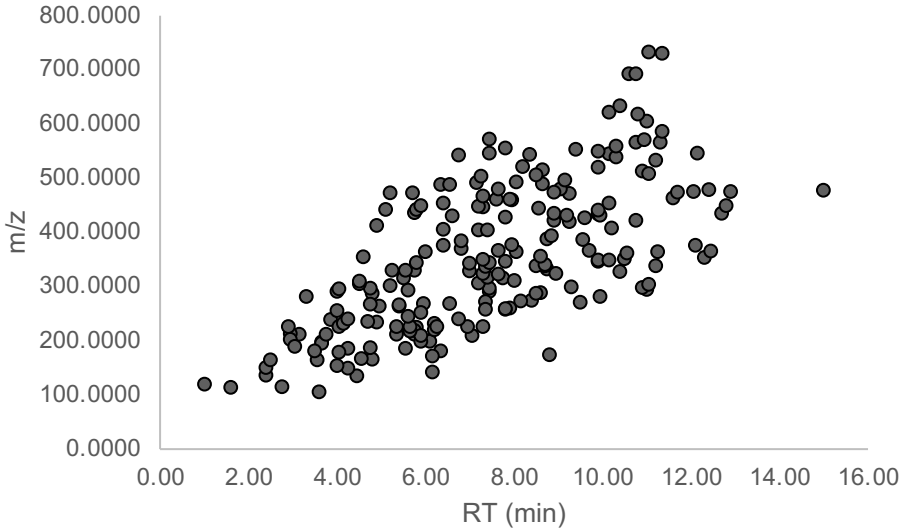
Beyond 6PPD-Q



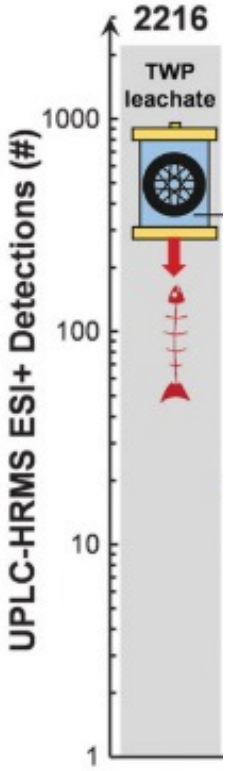
Seiwert et al. 2022. Water Research



https://www.ustires.org/tires-101



Müller et al. 2022. Sci. Total Environ.



Tian et al. 2021. Science

Many other effects – not linked to 6PPDQ

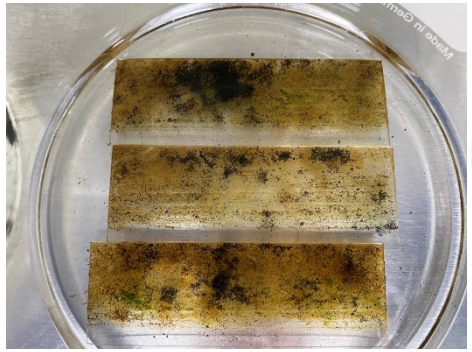
	in vitro biological endpoints:		
Tire associated compound	Estrogenicity	Genotoxicity (-S9)	Bacterial Toxicity
6PPD	**Yes***	No	**Yes**
6PPD-Q	No	No	No
2-Mercaptobenzothiazole	No	No	**Yes**
2-(Methylthio)benzothiazole	No	No	**Yes**
2-2'-Dithiobisbenzothiazole	**Yes***	No	**Yes**
Benzothiazole	No	No	**Yes**
2-Aminobenzothiazole	No	No	**Yes**
2-Hydroxybenzothiazole	No	No	**Yes**
Aniline	No	No	Equivocal†
1,3-Diphenylguanidine	No	**Yes**	No
Cyclohexylamine	No	**Yes**	No

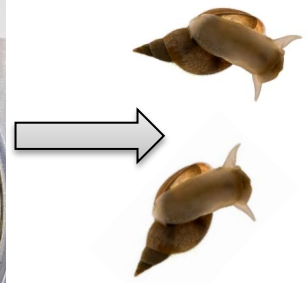
Bergmann et al. 2024. Environ. Toxicol. Chem.

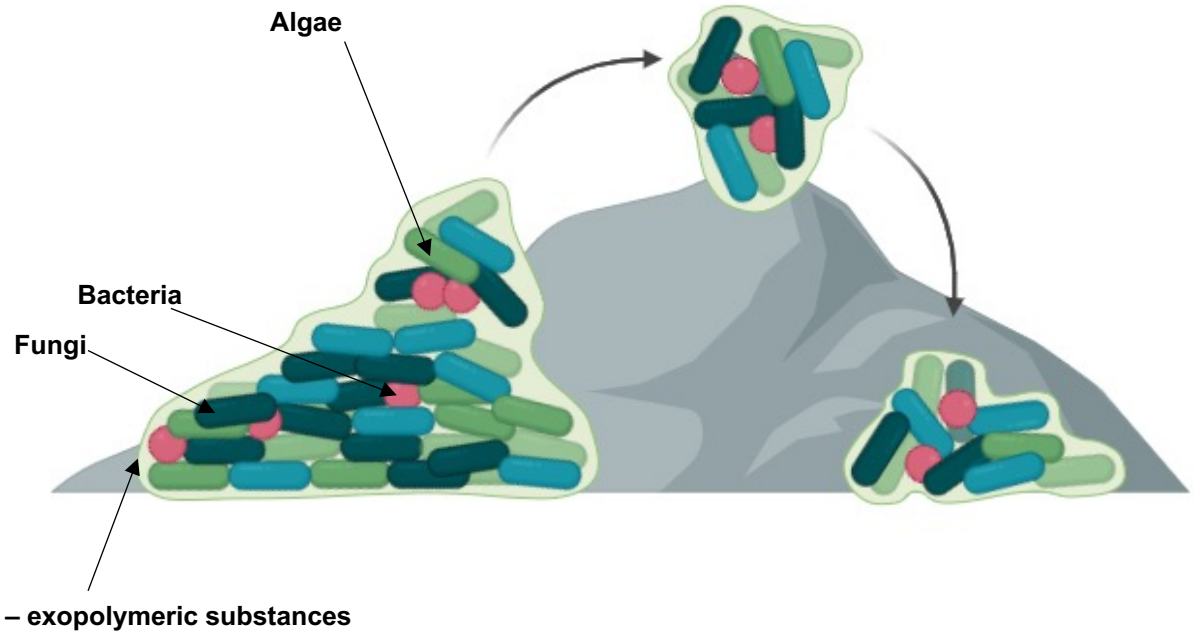
Biofilm is a sink for tire particles

Sara Gonçalves

Interaction with particles:
- Biofilm and EPS help particles to settle out of water column
- Accumulate particles and chemicals





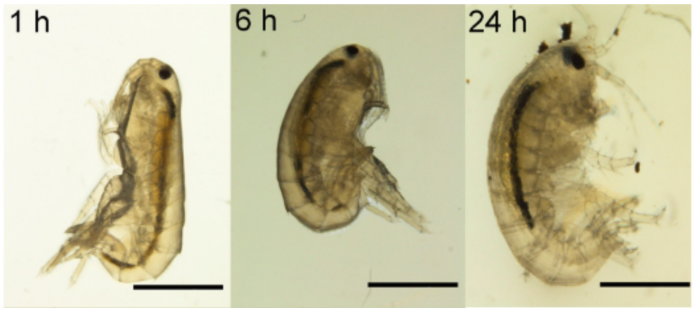


Direct effects:
- Photosynthesis disruption (Liu et al. 2024)
- Alteration in community structure (Ding et al. 2022)

Gonçalves et al. In preparation

Invertebrates can ingest tire particles

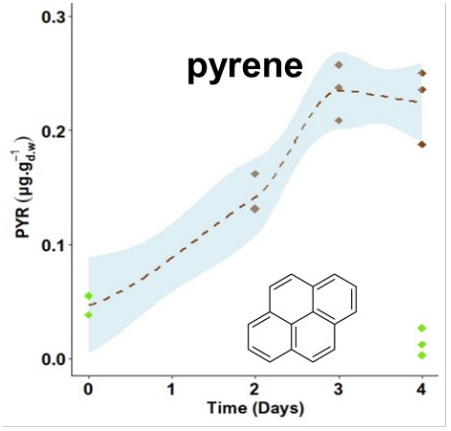
Thibault Masset

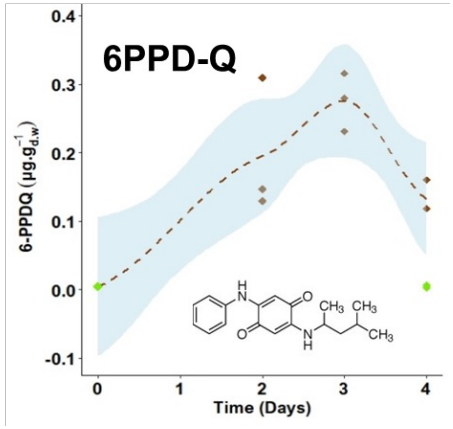


Khan et al. 2019

Direct effects
- Mortality (Roubeau Doumont et al. 2023)
- Impaired reproduction (Cunningham et al. 2024)
- Delayed development (Moreira et al. 2023)

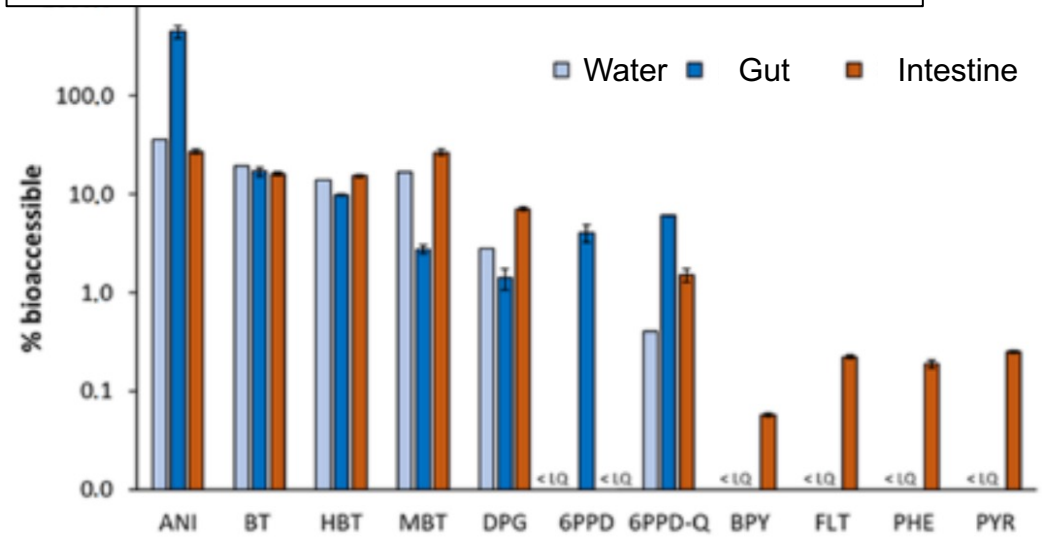
Interaction with particles:
- Ingesting particles and chemicals
- Accumulate tire associated chemicals





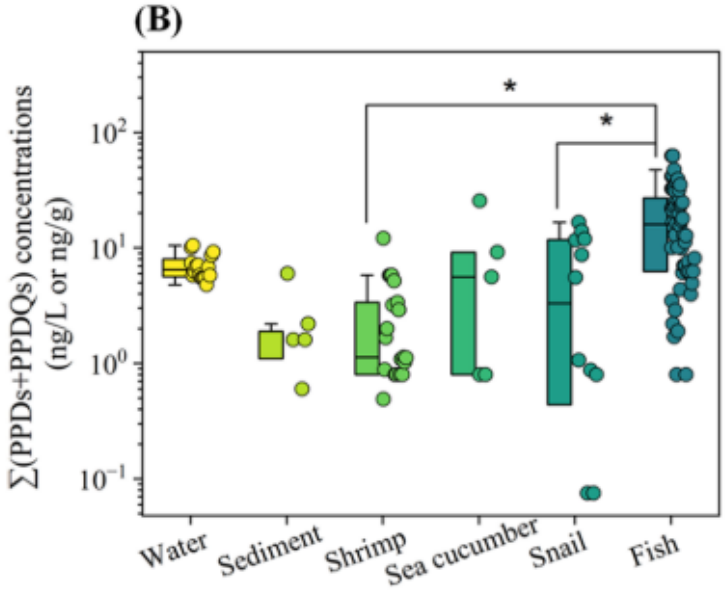
Masset et al. In preparation.

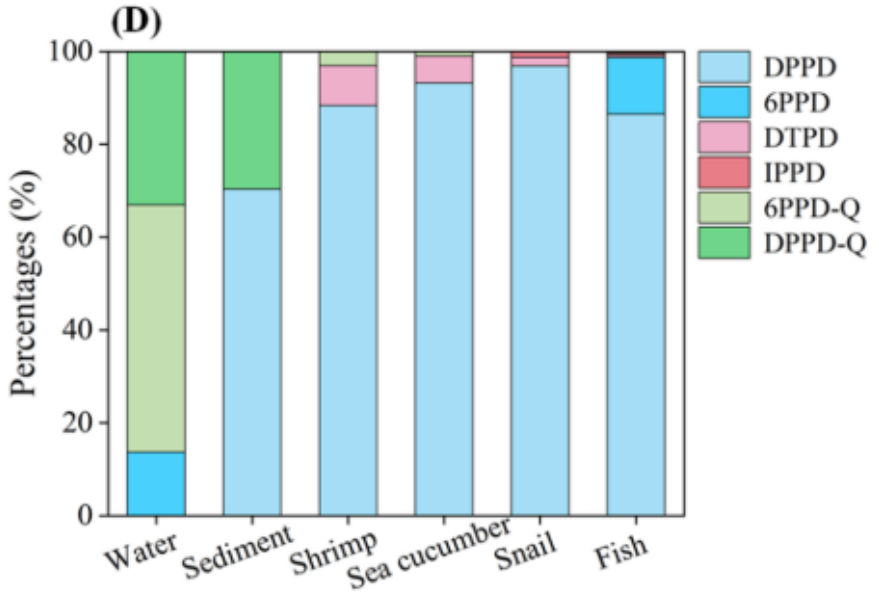
Chemicals can become bioaccessible in simulated fish digestion



Masset et al. 2022. Environ. Sci. Technol.

Trophic transfer

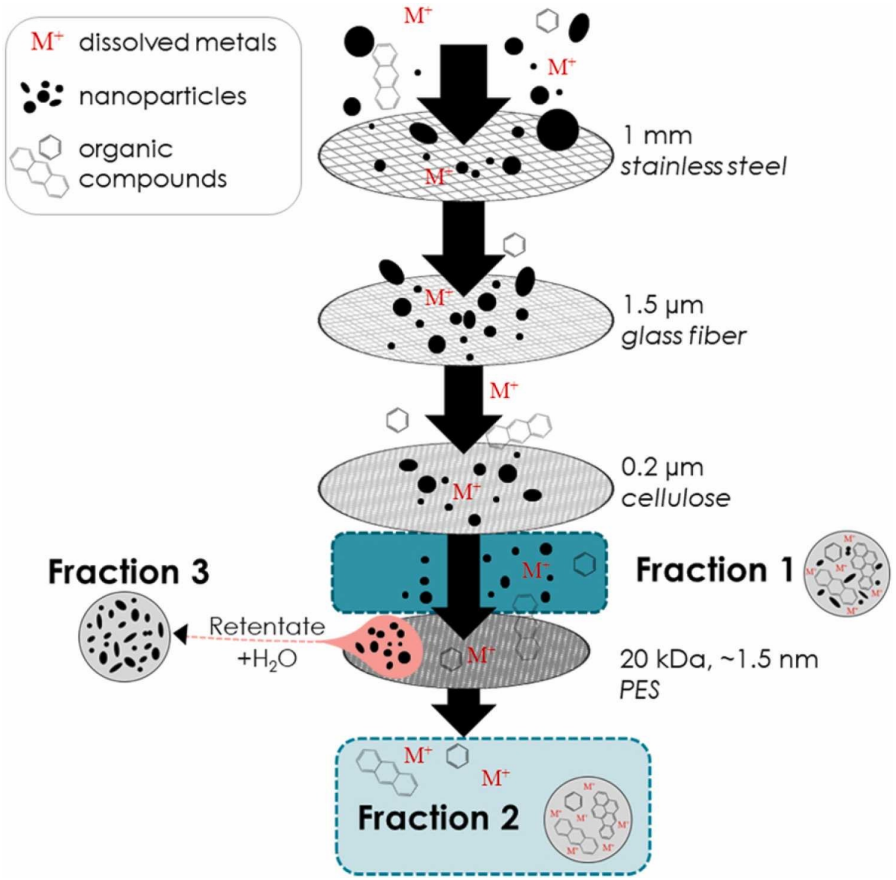


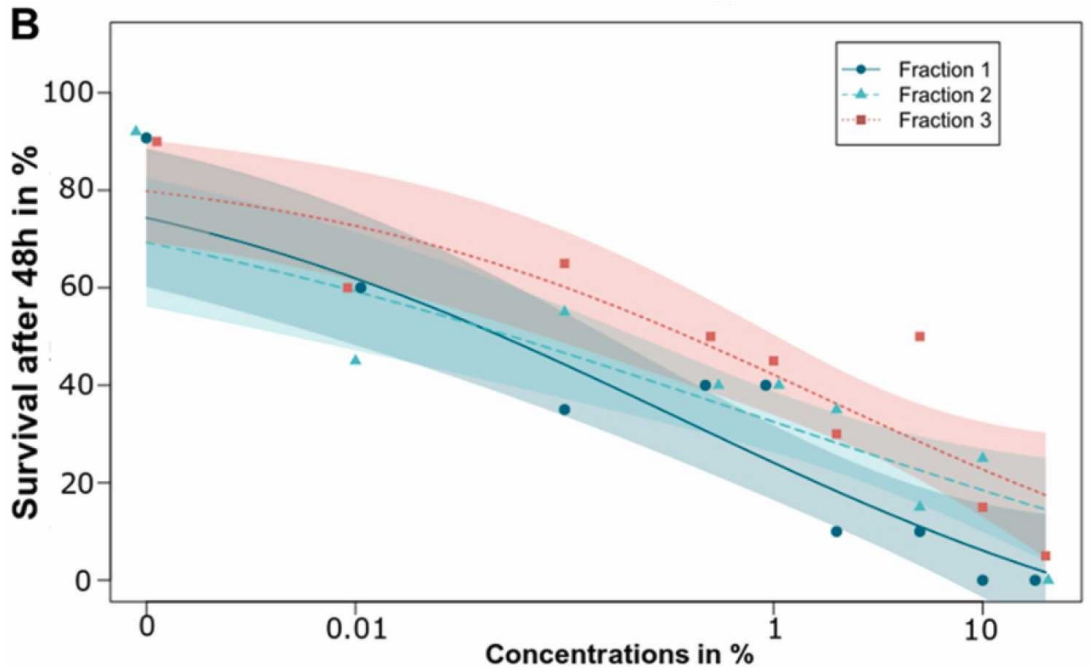


Wei et al. 2024. Environ. Sci. Technol.

Particle vs leaching chemicals

Liu et al. 2023





Even “depleted” particles were toxic to daphnia magna

Roubeau Doumont et al. 2023. J. Hazardous Materials.

Take home messages

- 6PPDQ is a clear example of risk from tire-associated chemicals to aquatic environment
- Many potential hazards beyond 6PPDQ
- Organisms interact with TWP
  - Some associated chemicals can be transferred between trophic levels
- Hazards from tire particles mostly attributed to leachable chemicals
  - Particle effects should not be discounted

Thanks for your attention

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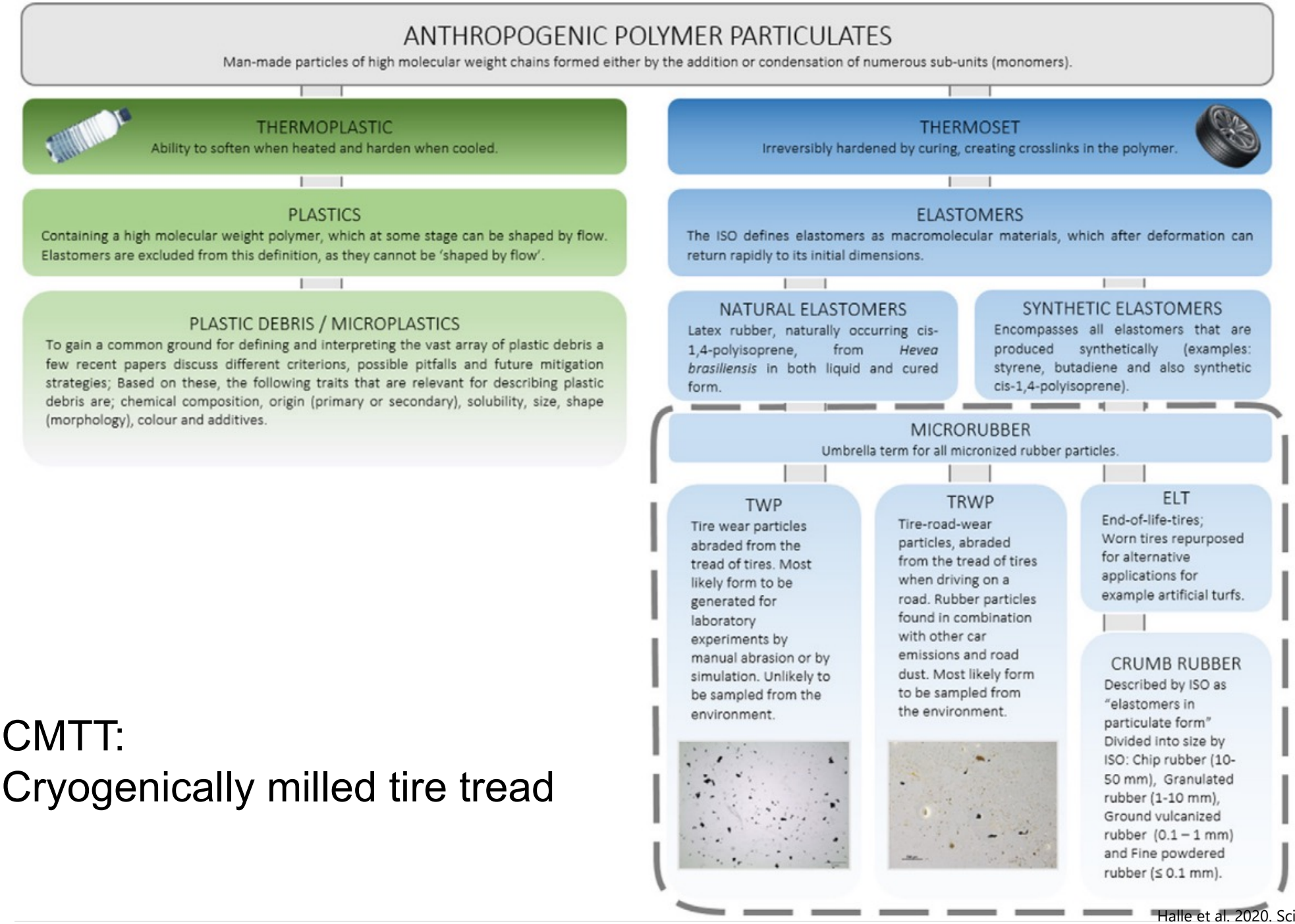
Solutions! Not just problems…

McIntyre et al. 2015. Chemosphere

	Mortality Adult coho		
Exposure (h)	Unexposed	Unfiltered	Filtered
4	0% (0/4)	100% (4/4)	0% (0/4)
24	0% (0/4)	100% (4/4)	0% (0/4)
24	0% (0/4)	100% (4/4)	0% (0/4)
24	0% (0/4)	100% (4/4)	0% (0/4)
24	0% (0/4)	100% (4/4)	0% (0/4)

Spromberg et al. 2016. J. Applied Ecology

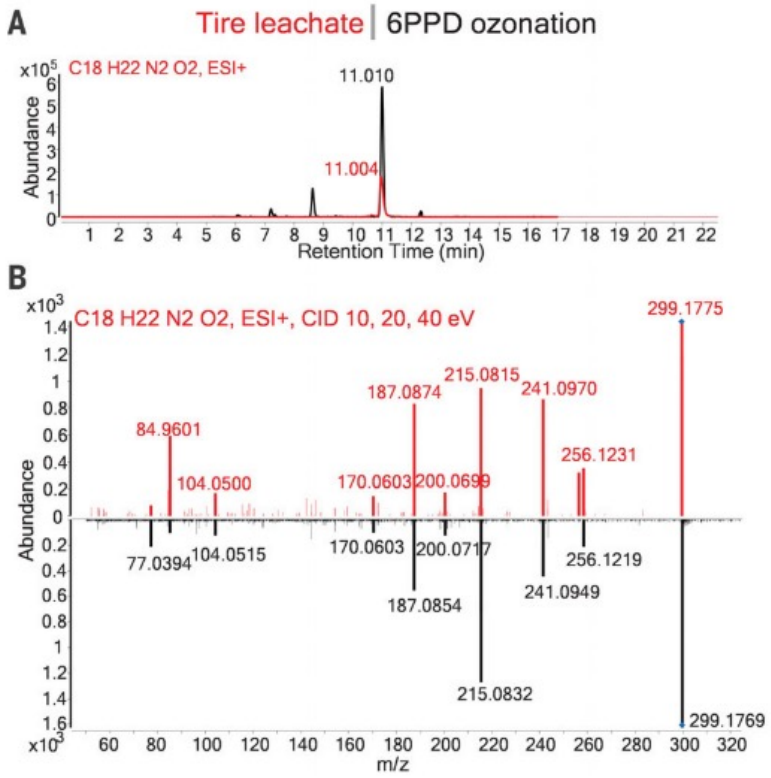
Bioretention treatment (soil/sediment filtration) is successful in preventing coho mortality



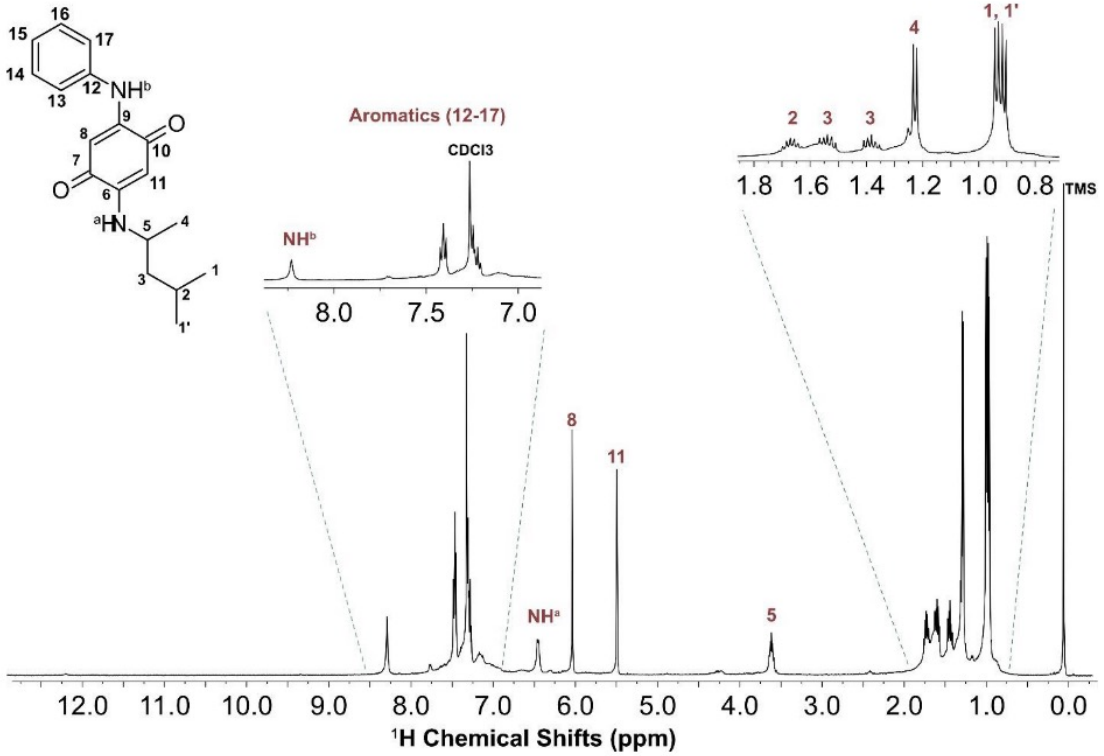
CMTT:
Cryogenically milled tire tread

Halle et al. 2020. Sci. Total Environ.

Confirmation



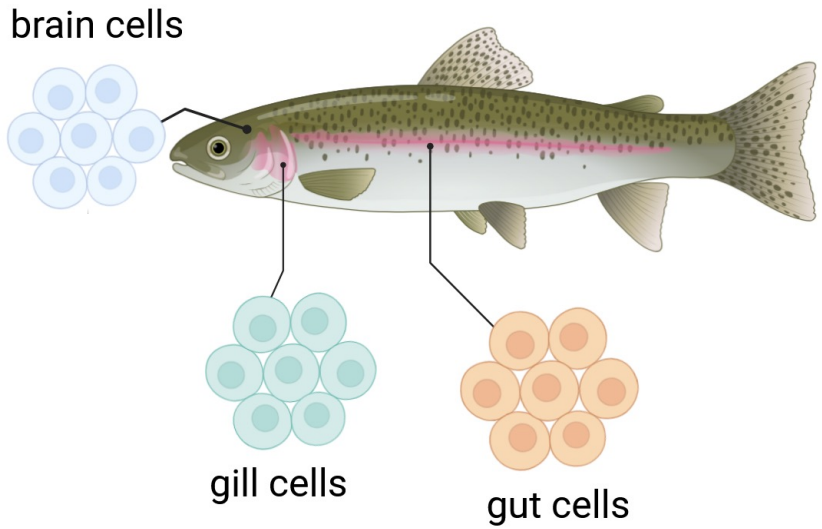
Liquid Chromatography – High Resolution Mass Spectrometry



Nuclear Magnetic Resonance

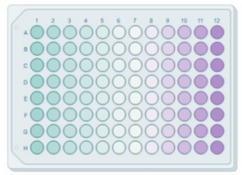
Tian et al. 2021. Science.

Fish toxicity testing… in vitro



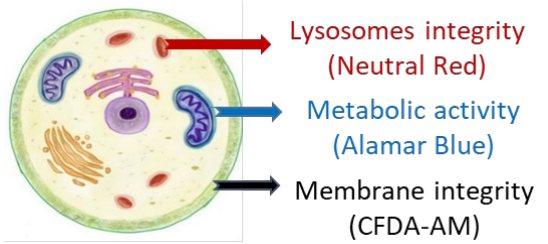
RT: rainbow trout

seeding



exposure

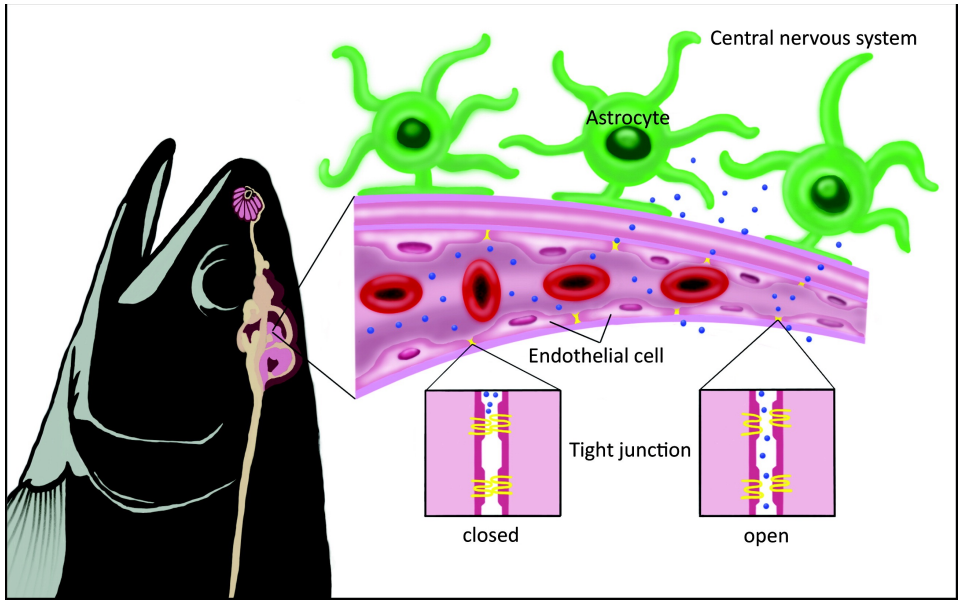
detection



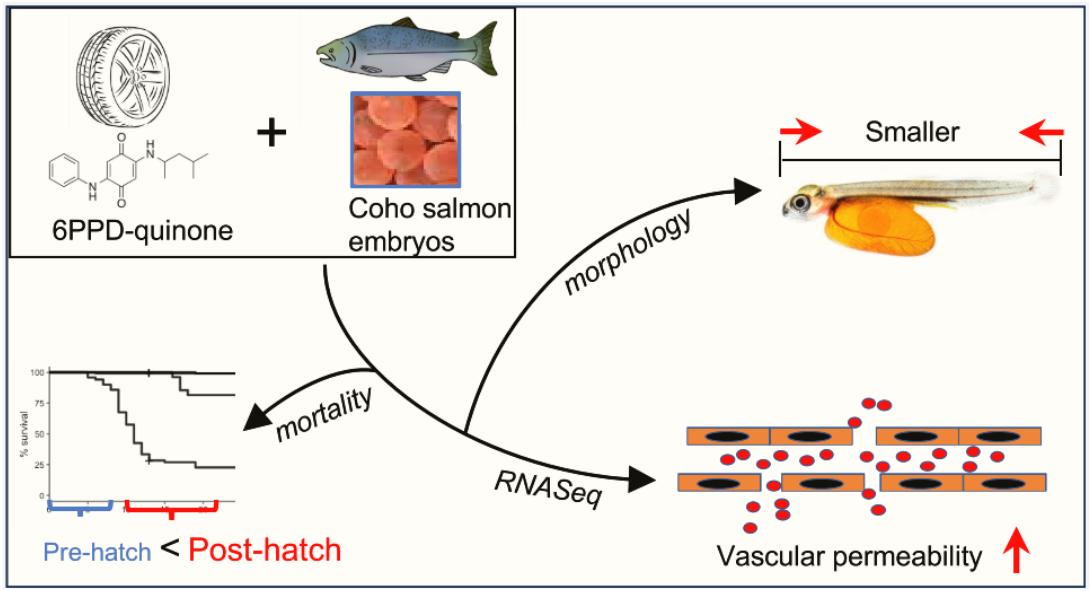
analysis

Neural/ca

Mechanism of toxicity not fully established, but evidence points to nervous system / cardiorespiratory disruption



Blair et al. 2021. Environmental Science & Technology

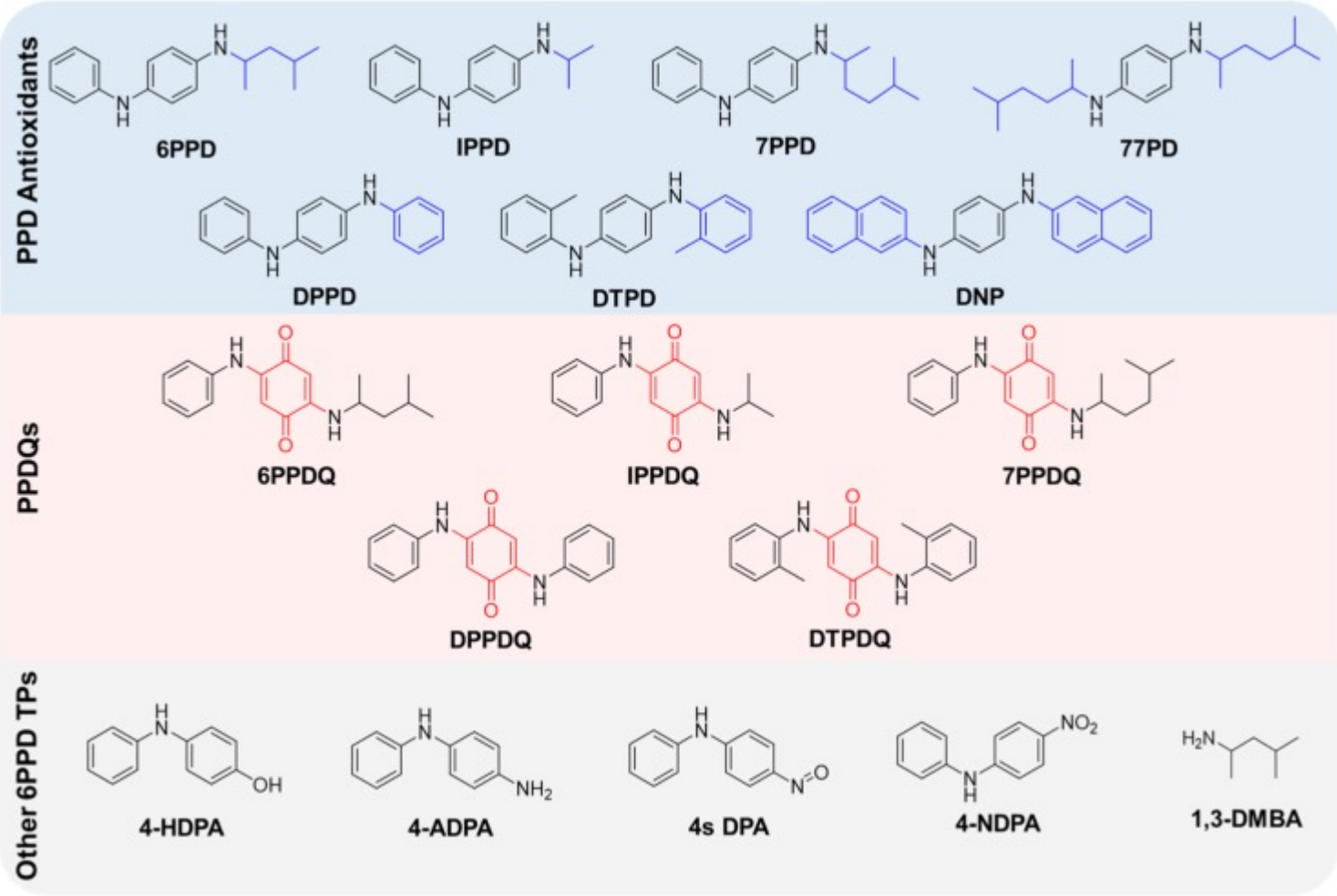


Greer et al. 2023. Environmental Science & Technology

Figure 3. Examples of morphological changes in rainbow trout alevins exposed to 6PPD-Q for 28 days from hatch. (A) Spinal curvature occurring at 1.30 μg/L. (B) Yolk sac edema occurring at 0.44 μg/L. (C) Caudal fin pathology occurring at 0.44 μg/L.

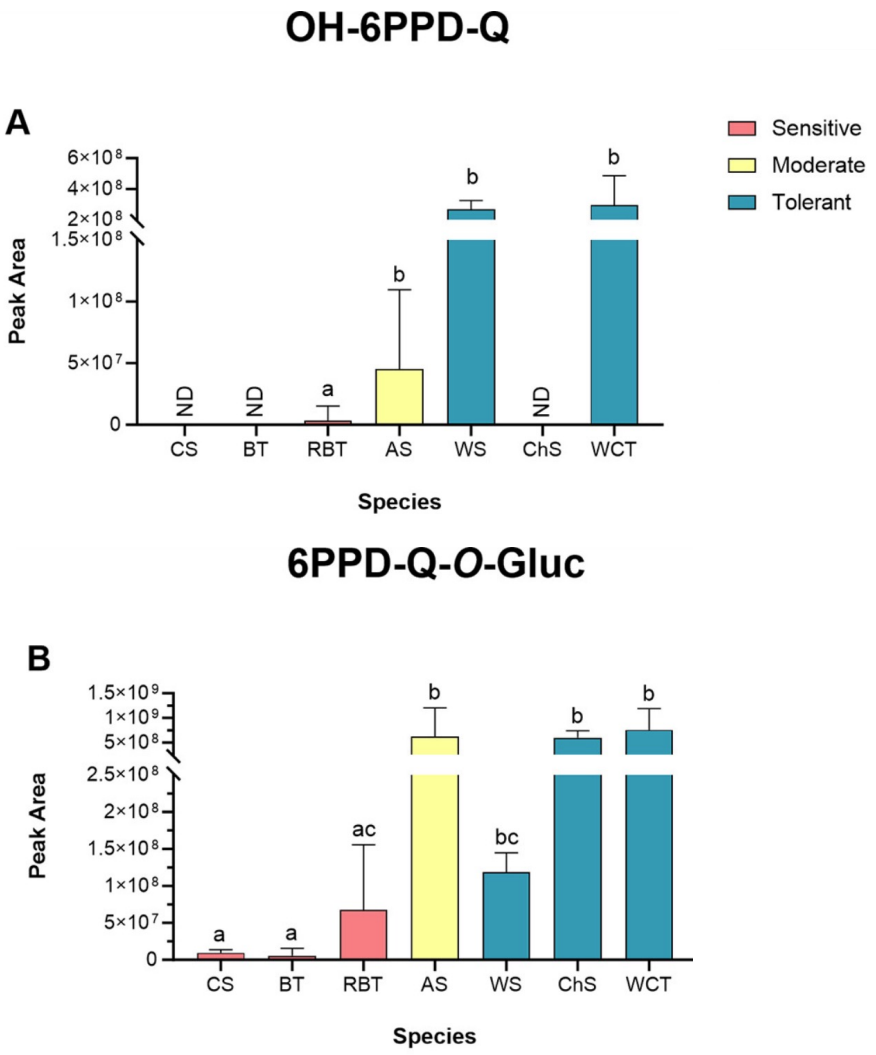
Roberts et al. 2025. Environmental Science & Technology

Family of phenylenediamine antiozonants



Zhao et al. 2023. J. Applied Ecology

Species sensitivity possibly linked to metabolic capacity



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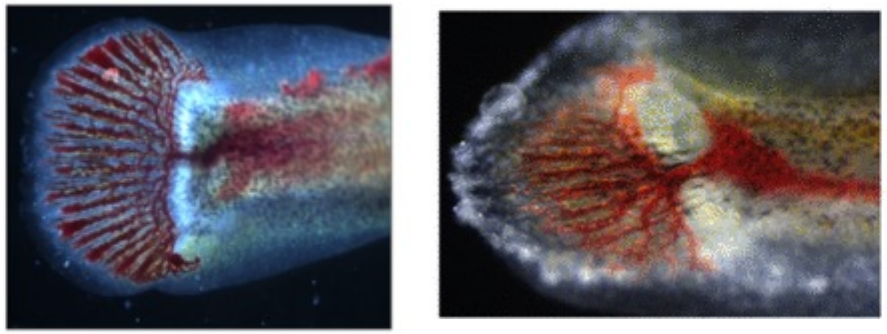

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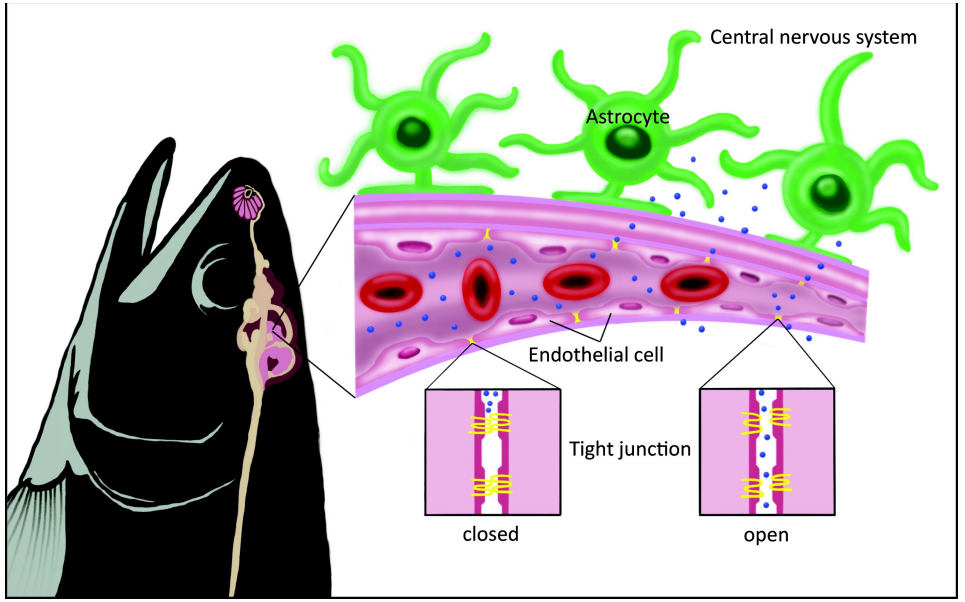

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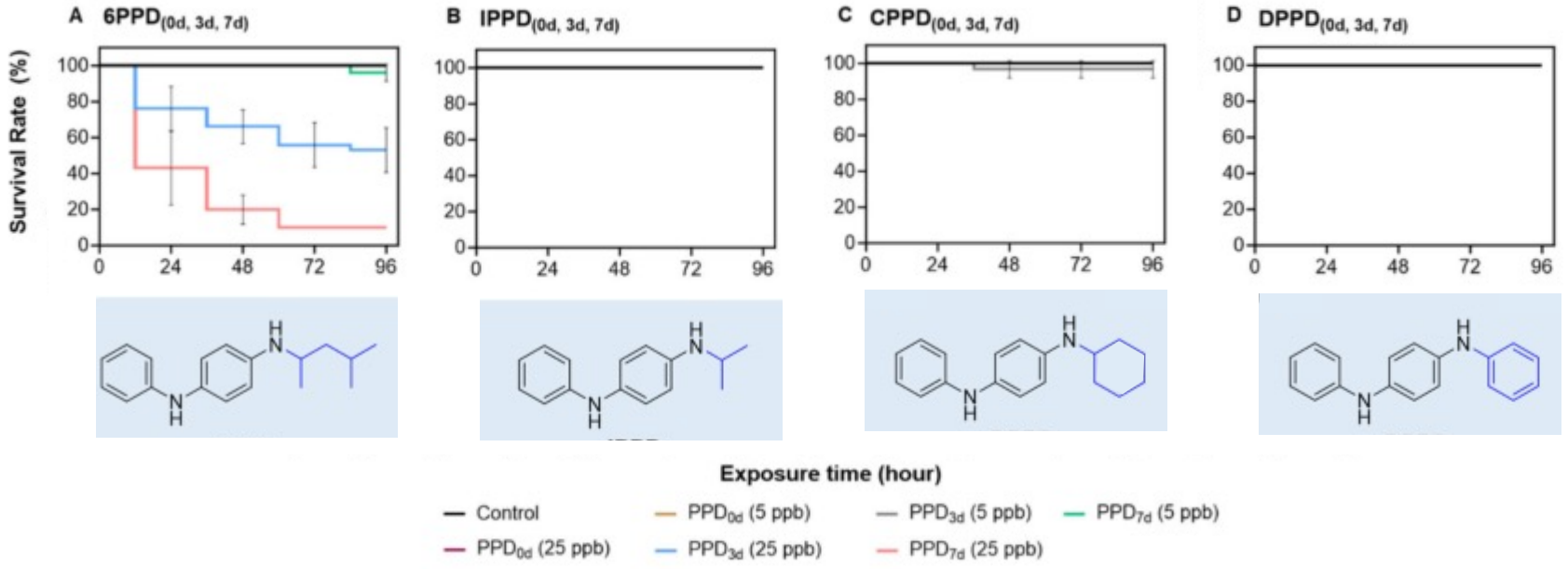
Toxicity is structure specific

96h survival of juvenile rainbow trout exposed to ozonated PPDs



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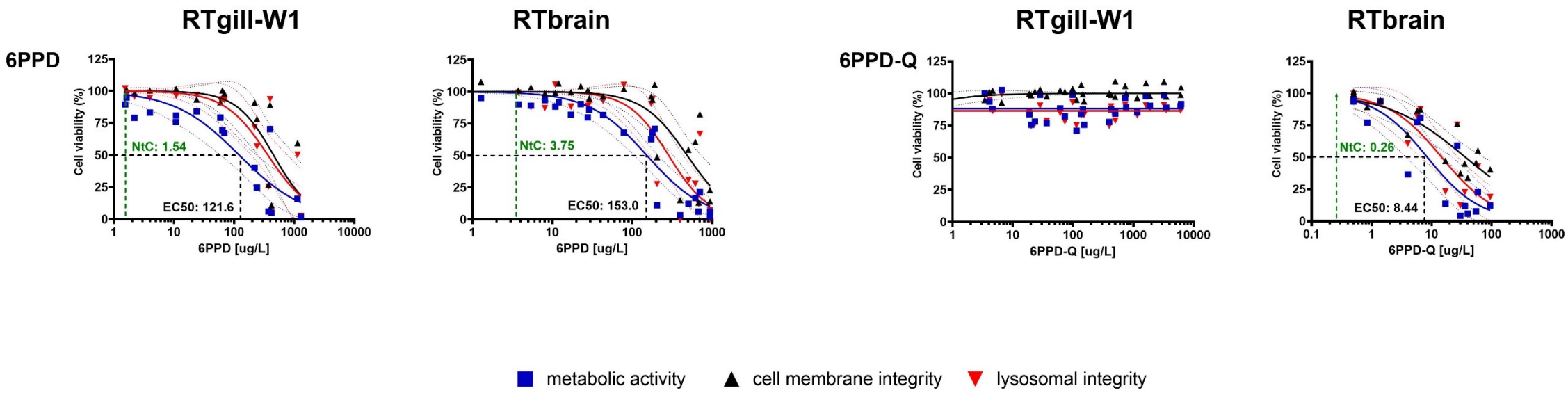

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RTbrain data: Pigneres M, Dudefoi W, Schirmer K et al. Manuscript on preparation.

Knowledge gaps

- 6PPDQ mechanism of action
- 6PPDQ chronic toxicity assessment

- Identity of chemicals responsible for other effects

- Evidence of trophic transfer in controlled setting: Mesocosms

- Attribution of toxic effects: leachates vs particles