JUNE 2021

DISCUSSION DRAFT

Product – Chemical Profile for Motor Vehicle Tires Containing N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)

DTSC
Department of Toxic Substances Control

SAFER CONSUMER PRODUCTS

CalEPA
California Environmental Protection Agency

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Candidate Chemical: A chemical that exhibits a hazard trait and is listed on one or more authoritative lists in the Safer Consumer Product Regulations

Product-Chemical Profile: A report generated by DTSC to explain its determination that a proposed Priority Product meets the Safer Consumer Product regulatory criteria for potential significant or widespread adverse impacts to humans or the environment

Priority Product: A product-chemical combination identified in regulations adopted by DTSC that has the potential to contribute to significant or widespread adverse impacts to humans or the environment

ABOUT THIS PROFILE

The Department of Toxic Substances Control (DTSC) identifies product-chemical combinations for consideration as Priority Products in accordance with the process identified in Article 3 of the Safer Consumer Products (SCP) regulations.[1] DTSC has determined that motor vehicle tires containing N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD) meet the key prioritization criteria[2] for listing a Priority Product:

(1) There must be potential public and/or aquatic, avian, or terrestrial animal or plant organism exposure to the Candidate Chemical(s) in the product; and

(2) There must be the potential for one or more exposures to contribute to or cause significant or widespread adverse impacts.

This Product-Chemical Profile (Profile) demonstrates that the regulatory criteria have been met and serves as the basis for Priority Product rulemaking. The Profile does not provide a comprehensive assessment of all available literature on adverse impacts and exposure for 6PPD or motor vehicle tires. DTSC will finalize this Profile after considering public comments and may then start the rulemaking process. If this Priority Product regulation is adopted, the responsible entities must follow the reporting requirements pursuant to the SCP Regulations.[3]

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[1] California Code of Regulations, title 22, Division 4.5, Chapter 55, Article 3, sections 69504-69503.7.

[2] California Code of Regulations. title 22, section 69503.2(a).

[3] California Code of Regulations title 22, section 69503.7 and Article 5 (Alternatives Analysis).

Readers should consider the following:

1. This Profile is not a regulatory document and does not impose any regulatory requirements.
2. This Profile summarizes information compiled by DTSC as of June 2021.
3. DTSC requests that stakeholders provide data on the chemical and product described in this document to assist us in the evaluation process that may lead to our regulatory proposal. Written comments can be submitted using our information management system, CalSAFER,[4] prior to August 6, 2021 at 11:59 p.m. PST.
4. By proposing to list this product-chemical combination as a Priority Product containing a Chemical of Concern, DTSC is not asserting that the product cannot be used safely. The proposal indicates only that there is a potential for exposure of people or the environment to the Chemical of Concern in the Priority Product, that such exposure has the potential to cause or contribute to significant or widespread adverse impacts, and that safer alternatives should be explored.

1. RATIONALE FOR PRODUCT-CHEMICAL SELECTION

DTSC proposes to list motor vehicle tires containing 6PPD as a Priority Product. This product-chemical combination meets the identification and prioritization factors outlined in the SCP Regulations: (1) there is potential for aquatic organism exposure to 6PPD and its reaction products from motor vehicle tires; and (2) the exposure has the potential to contribute to or cause significant or widespread adverse impacts.

Potential for exposure

6PPD has been used as an antidegradant for decades and is found in most if not all motor vehicle tires. 6PPD performs the critical function of protecting rubber from reactions with ozone and oxygen, which can lead to cracks. It is present in tires at 1 to 2% (10,000 to 20,000 micrograms per gram (µg/g)) and slowly migrates over the life of the tire to the tire surface to supply a continual source of 6PPD. As such, the total concentration of 6PPD in the tire decreases over the life of the tire.

6PPD is, by design, highly reactive and transforms into a number of reaction products, both known and unknown, at the surface of the tire or when released into the environment. One of the reaction products of most concern is 6PPD-quinone due to its toxicity to coho salmon.

Tire wear particles (TWP) are generated as tires roll across the road surface, particularly as vehicles brake, accelerate, and turn. TWP, and the 6PPD they contain, can then be released to the aquatic

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[4] https://calsafer.dtsc.ca.gov/cms/commentpackage/?rid=12757.

environment through surface runoff and stormwater. Estimates suggest that in the United States, the per capita generation of TWP is 4.7 kilograms (kg) per year and that over 171 million tires were driven on California's roads in 2020 alone. The large amounts of TWP generated in the state are released to the aquatic environment, especially during rain events, and result in high potential for exposure of aquatic organisms to tire-derived contaminants.

Given the number of tires used in California each year, their end-of-life disposition is a major challenge. At the end of their useful life, tires are landfilled, recycled, or reused—either as is or after processing (e.g., by cutting or shredding). For example, they are used in playground surfaces, erosion control, flood control, stormwater treatment applications, and even incinerated for use as fuel. Many of the end-of-life uses of tires provide direct pathways for chemicals to migrate into the aquatic environment and may represent a source of contaminants like 6PPD. California's extensive efforts to reuse and recycle used tires may contribute to ongoing environmental releases and exposures to 6PPD-quinone.

While it is unclear exactly where and how 6PPD-quinone is formed, detections of 6PPD-quinone in California waterways clearly indicate that it is sufficiently persistent in aquatic systems for aquatic organisms to potentially be exposed. 6PPD-quinone has been measured in California streams at concentrations above those shown to kill at least half of coho salmon (*Oncorhynchus kisutch)* in laboratory experiments.

Potential for significant or widespread adverse impacts

6PPD is toxic toward aquatic organisms at multiple trophic levels, can impair wildlife survival, and is toxic to algae. The chemical compound 6PPD-quinone, a reaction product of 6PPD, is acutely toxic to coho salmon, including juveniles, and kills fish just a few hours after exposure. 6PPD-quinone has been identified as the causal agent in urban runoff mortality syndrome (URMS) observed in the Puget Sound area of Washington state, and it kills coho salmon as they migrate upstream, before they are able to spawn.

The presence of 6PPD in motor vehicle tires and its release to the aquatic environment has the potential to significantly impact two populations of coho salmon in California, one that is listed as endangered and the other that is threatened under the federal Endangered Species Act. The presence of 6PPD-quinone in California runoff and waterways at concentrations above levels that kill at least half of coho salmon in lab studies suggests that exposure to 6PPD-quinone may have contributed to the decline in the coho population over the past 60-70 years. California's Native American tribes and the state together have invested millions of dollars in an effort to retain and replenish coho populations. The presence of 6PPD-quinone in California's waterways continues to threaten the state's remaining coho salmon populations and may jeopardize the recovery of this species, which faces a number of additional challenges including climate change, habitat destruction and loss, and exposure to other contaminants found in urban runoff.

Given the very recent discovery of 6PPD-quinone, little is known about its effects on other aquatic organisms. However, it is potentially toxic to other economically important species that are closely related to coho such as chinook salmon, steelhead, and the California golden trout. The decline of the coho population has adversely impacted important marine food webs. Coho salmon represent a food source for many marine organisms such as seals, sharks, and other fish, and are a source of ocean-derived nutrients to inland ecosystems. In addition to impacts to aquatic organisms, loss of coho salmon in California has significantly impacted California's Native American tribes. The loss of core traditional food sources for tribal communities can be tied to loss of culture, increased physical and mental health issues, and increased poverty.

While there are currently no regulations restricting the use of recycled tires related to the presence of 6PPD or 6PPD-quinone, increased regulatory scrutiny and public concerns for 6PPD and other tire-derived contaminants may limit future end-of-life applications, potentially hindering recycling efforts and interfering with the California Department of Resources Recycling and Recovery's (CalRecycle) legislative mandate to divert tires from landfills. Additionally, the presence of 6PPD-quinone in California waterways at concentrations proven to be lethal to coho salmon indicates that current stormwater treatment efforts are often insufficient for the removal of 6PPD-quinone. If 6PPD or 6PPD-quinone were to be regulated in stormwater, many municipalities would have to adopt expensive special handling measures to meet discharge permits and ensure protection of local waterways.

2. PRODUCT DEFINITION AND SCOPE

This section describes the product that forms the basis for the proposed product-chemical combination.

DTSC defines "tire" as *any product that can be described or observed as a covering for a wheel, usually made of rubber reinforced with cords of nylon, fiberglass, or other material, whether filled with compressed gas (such as air or nitrogen), solid, or non-pneumatic (airless)*. This definition is based on the Global Standards 1 (GS1) Global Product Classification Standard's tire definition (GS1 2020).

This Profile encompasses all parts of new tires (tread, sidewalls, etc.) and tire tread material (circular or linear precured tread and raw rubber for use in mold cure retreading) intended for use on passenger cars (including sport utility vehicles (SUVs) and pickups); motorcycles; motor homes; light-, medium-, and heavy-duty trucks; buses; and trailers (including trailer coaches, park trailers, and semitrailers). This proposal excludes tires intended for use in off-road vehicles including:

- aircraft;
- vehicles intended exclusively for off-road (e.g., dirt, track) use;
- construction and agricultural equipment such as excavators, paving equipment, tractors, combines, bulldozers, and skidders (but not farm labor vehicles); and
- industrial equipment such as forklifts, airport service equipment, and ice-grooming machines.

3. CANDIDATE CHEMICAL DEFINITION AND PROPERTIES

This section introduces the Candidate Chemical (or Chemicals) in the proposed product-chemical combination.

N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine ($C_{18}H_{24}N_2$, 6PPD) is included on DTSC's Candidate Chemicals List (DTSC 2021b). 6PPD is synthesized by reduction of either p-nitro- or p-nitrosodiphenylamine to form 4-aminodiphenylamine (4-ADPA), followed by reaction with methyl isobutyl ketone and hydrogenation over a catalyst (OSPAR Commission 2006; PubChem 2021). 6PPD is a dark brown to violet that is solid at room temperature, and 6PPD or mixtures containing 6PPD are sold as pellets, pastilles, and in liquid form (OSPAR Commission 2006; Eastman 2021; PubChem 2021).

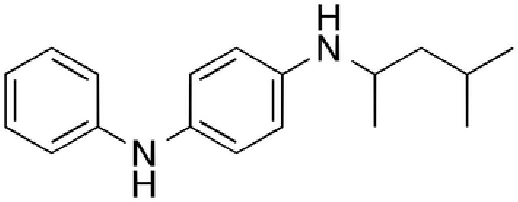

Figure 1. Chemical structure of 6PPD.

Chemical Abstract Service Registry Number (CASRN): 793-24-8

Chemical formula: $C_{18}H_{24}N_2$

IUPAC name: 4-*N*-(4-methylpentan-2-yl)-1-*N*-phenylbenzene-1,4-diamine (PubChem 2021)

Synonyms:

- 4-*N*-(4-methylpentan-2-yl)-1-*N*-phenylbenzene-1,4-diamine (PubChem 2021)
- 1,4-benzenediamine, N-(1,3-dimethylbutyl)-N'-phenyl (PubChem 2021)
- 4-(dimethylbutylamino)diphenylamine (ECHA 2021)
- N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (ECHA 2021)
- N-(4-Methyl-2-pentyl)-N-phenyl-1,4-benzenediamine (ECHA 2021)
- N-(4-Methyl-2-pentyl)-N-phenyl-1,4-diaminobenzene (ECHA 2021)

- N-dimethylbutyl-N’-phenyl-p-phenylenediamine (ECHA 2021)
- 6PPD (PubChem 2021)
- 6-PPD (Wagner et al. 2018)
- HPPD (Lattimer et al. 1983)

Other identifiers (PubChem 2021)

- European Community Number = 212-344-0
- InChI = InChI=1S/C18H24N2/c1-14(2)13-15(3)19-17-9-11-18(12-10-17)20-16-7-5-4-6-8-16/h4-12,14-15,19-20H,13H2,1-3H3
- InChI Key =ZZMVLMVFYMGSMY-UHFFFAOYSA-N
- Distributed Structure-Searchable Toxicity (DSSTox) Substances ID = DTXSID9025114

6PPD is an antidegradant (antioxidant and antiozonant) added to tire rubber to protect the rubber polymer from reaction with oxygen (O_2) and ozone (O_3) (OSPAR Commission 2006; PubChem 2021). Oxidation can cause the rubber comprising the tire to crack, particularly under mechanical stress (Cox 1959; Braden and Gent 1962). It is also used to protect the rubber in transmission belts, hoses, automotive mounts and bushings, and other mechanical products (OSPAR Commission 2006). It is one of several para-phenylenediamine (PPD) additives used to protect rubber materials (Kruger et al. 2005).

Relevant physicochemical properties

Reference: California Code of Regulations, title 22, section 69503.3(a)(1)(D).

Physicochemical properties can be helpful in predicting a chemical’s behavior. A chemical’s behavior in humans, wildlife, ecosystems, and the environment may indicate potential adverse public health and environmental impacts.

The physicochemical properties of 6PPD outlined in Table 1 make it very well suited for use as an antidegradant in tires. Critically, 6PPD is able to diffuse or “bloom” through the rubber to the surface of the tire, where it protects the rubber polymer against oxidation (Cox 1959; Lattimer et al. 1983; Lewis 1986). Importantly, this diffusion must happen quickly enough to offer protection but slow enough to last for the life of the tire (Lewis 1986). After diffusion, ozone preferentially reacts with 6PPD as opposed to the tire rubber, preventing ozone-induced degradation of the rubber (Cox 1959), and forming a protective film along the outside of the tire that further protects the rubber polymer from cracking (Cox 1959; Lattimer et al. 1983).

Table 1. Relevant physicochemical properties of 6PPD. All values were obtained from were obtained from PubChem (2021), unless otherwise noted.

Property	Value
Physical state	Solid, dark violet flakes
Molecular weight	268.4 g/mol
Density	1.02 g/ml
Vapor pressure	Negligible at 25 ^oC
Melting point	45 - 50 ^oC
Boiling point	260 ^oC (500 ^oF) at 760 mm Hg, calculated 354-412 ^oC (U.S. EPA 2021a)
Water solubility	Reported values variable but all < 1 mg/mL (Klöckner et al. 2020; PubChem 2021; ECHA 2021)
Log K_{ow}	Estimated value 4.68 (OSPAR Commission 2006; Klöckner et al. 2020)
Log K_{oc}	4.84

The water solubility of 6PPD reported in the literature is variable. Two citations in PubChem (2021) indicate less than 1 mg/milliliter (mL), while the European Chemical Agency's dossier indicates values around 0.001 mg/mL (ECHA 2021). This variability may be due to 6PPD's high susceptibility to hydrolysis and short half-life in water (see the *Environmental fate* section below). Regardless of the observed variability, 6PPD's water solubility is low.

Environmental fate

Reference: California Code of Regulations, title 22, section 69503.3(a)(1)(E).

Environmental fate describes a chemical's mobility in environmental media, transformation (physical, chemical, or biological), or accumulation in the environment or biota. A chemical's environmental fate in air, water, soil, and living organisms relates to its exposure potential hazard traits, as defined in the California Code of Regulations, Title 22, Chapter 54.

The estimated Henry's Law constant of 6PPD is 7.43 X 10^{-4} at 25^{o}C, which suggests that it has moderate potential to volatilize from surface waters (OSPAR Commission 2006). OSPAR (2006) summarizes research indicating no gaseous emissions of 6PPD from tires; however, it is unclear if that is due to lack of volatility from tires or rapid degradation of 6PPD once released. Detection of 6PPD on atmospheric particles (Wu et al. 2020) indicates that, while its vapor pressure is negligible, 6PPD may be present in air adsorbed to suspended particles or through resuspension of TWP themselves. The high K_{oc} value suggests a tendency for 6PPD to sorb to soils, sediments, and suspended particulates once released to the environment (OSPAR Commission 2006). 6PPD has a high log octanol water partition coefficient (log K_{ow}). Therefore, leaching of 6PPD through soil to groundwater is unlikely (OSPAR Commission

2006). Fugacity modeling suggests that, upon release to the environment, 95% of 6PPD will go to soil, 2% to water, and 2% to sediment (OECD 2012).

6PPD has a calculated bioconcentration factor (BCF) of 801, suggesting that it has a moderate potential for bioaccumulation in aquatic organisms (OSPAR Commission 2006). However, under the California Code of Regulations (CCR), title 22, section 69405.2, only chemicals with BCFs above 1,000 are considered bioaccumulative. Because 6PPD's predicted BCF of 801 is below this value, it would not be considered bioaccumulative for the purposes of the SCP regulatory framework. Primary transformation products of 6PPD, including N-phenyl-p-benzoquinone monoimine, 1,3-dimethylbutylamine, and 4-hydroxydiphenylamine, are also not bioaccumulative (OSPAR Commission 2006; OECD 2012).

Hydrolysis, initiated via reaction with oxygen species, and photodegradation are believed to be the major means of environmental transformation for 6PPD (OSPAR Commission 2006). 6PPD is highly reactive with oxygen and ozone, as further detailed in section 8. Detection of 6PPD in tire eluates but not road runoff suggests that reaction of 6PPD happens on the surface of the tire or road (OSPAR Commission 2006); however, this may also be due to rapid environmental transformation of 6PPD once released from a tire, and associated challenges in analyzing such a reactive compound.

Abiotic degradation

In the atmosphere, 6PPD undergoes indirect photodegradation via rapid reaction with hydroxyl radicals, resulting in a half-life in air on the order of one to two hours (OSPAR Commission 2006; ECHA 2021). 6PPD absorbs UV-B radiation and is also expected to undergo rapid direct photolysis (OSPAR Commission 2006) on a surface, such as that of a tire, in direct sunlight (OECD 2012).

6PPD is highly reactive with oxygen in water, and the reaction rate can be affected by a number of parameters including the presence of metals, pH, temperature, and sunlight (OSPAR Commission 2006). Reported half-lives range from 3.4 to hours to less than a day (OSPAR Commission 2006; ECHA 2021), with shorter half-lives noted in warmer waters and those containing heavy metals (OSPAR Commission 2006); however, long-term stability up to four weeks has been noted in cold conditions at a pH of 2 (OSPAR Commission 2006). While primary transformation products have been relatively well characterized and are produced rapidly, secondary transformation products are less well understood (ECHA 2021) and are not always recovered in degradation experiments (OSPAR Commission 2006). This suggests that primary transformation products, in particular 3-hydroxydiphenyl-amine and benzoquinone-monoimine, are more stable than the parent 6PPD (ECHA 2021).

Biotic degradation

The degradation of 6PPD in many biodegradation studies is almost certainly by a combination of abiotic and biotic processes (OSPAR Commission 2006; ECHA 2021). A comparison of 6PPD's half-life in various aquatic media indicates that degradation was fastest in biologically active river water (half-life of 2.9 hours), and slower, but still quite fast (half-life of 6.8 hours) in sterile deionized water (OSPAR Commission 2006).

6PPD does not meet the Organisation for Economic Co-operation and Development's (OECD) strict definitions of *readily biodegradable*, calculated based on biological oxygen demand over 28 days (OECD 1992; OSPAR Commission 2006). However, 6PPD undergoes rapid loss via hydrolysis, as evidenced by its 92% removal over the same period (OSPAR Commission 2006), suggesting that abiotic processes are dominant. Further, a 6PPD degradation study indicated comparable loss of 6PPD in river water (97%) and sterilized river water (96%) over 22 hours, indicating that biotic degradation was minimal (ECHA 2021).

Degradation in sediment

No information is available on the stability of 6PPD and its metabolites in sediment (OSPAR Commission 2006). However, its strong tendency to adsorb to organic matter suggests that 6PPD may persist in sediments in aquatic ecosystems (OSPAR Commission 2006). 6PPD bound to resuspended sediment in rivers is expected to eventually undergo photodegradation and hydrolysis (OSPAR). Nonetheless, it has been suggested that until further evidence is obtained, 6PPD should be considered persistent in sediments and future monitoring of 6PPD in the marine environment should take the sediment phase into account (OSPAR Commission 2006).

Degradation in soil

No experimental data is available for the degradation of 6PPD in soil, but a half-life of 1,800 hours has been predicted using the U.S. Environmental Protection Agency's (U.S. EPA) Estimation Program Interface (EPI) Suite (ChemSpider 2021). Photodegradation, mentioned above, is almost certainly a predominant mechanism for 6PPD loss in surficial soils (OSPAR Commission 2006).

Removal during wastewater treatment

Little data exist on the ability of wastewater treatment plants to remove 6PPD or 6PPD-quinone. One report summarized by OSPAR (2006) suggests that 6PPD is at least 96% removed during wastewater treatment, but it is unclear if this is attributable to sorption to solids or degradation.

Degradation, reaction, or metabolic products of concern

Reference: California Code of Regulations, title 22, section 69503.3(a)(1)(G).

A Candidate Chemical may degrade, form reaction products, or metabolize into other chemicals that have one or more hazard traits. These metabolites, degradation products, and reaction products (which *may or may not be Candidate Chemicals) may cause different adverse impacts from those of the parent chemical. In some cases, a Candidate Chemical's degradation or reaction products or metabolites may have the same hazard trait, and may be more potent or more environmentally persistent, or both, than the parent chemical. In such cases, adverse impacts may be more severe, or may continue long after, the Candidate Chemical's release to the environment.*

6PPD is used in tires to protect the rubber from degradation by oxygen and ozone. While the chemistry of 6PPD's reactions with oxygen species is not entirely clear (see section 8 below), it is evident that oxygen and ozone react with 6PPD more readily than with rubber polymers.

Once released into the environment, hydrolysis and photodegradation are believed to be the major means of environmental transformation for 6PPD (OSPAR Commission 2006). Some of the known or suspected hydrolytic reaction products, including those generated via reaction with ozone, are listed below. Their toxicological hazard traits and end points, if any, are not known.

- 4-hydroxydiphenylamine (CASRN 122-37-2) (OSPAR Commission 2006)
- N-phenyl-p-benzoquinone monoimine (CASRN 2406-04-4) (OSPAR Commission 2006)
- 1,3-dimethylbutylamine (CASRN 108-09-8) (OECD 2004; OSPAR Commission 2006)
- N-(1,3-dimethylbutyl)-N'-(phenyl)-1,4-benzoquinonediimine (6QDI, CASRN 52870-46-9) (ECHA 2021)
- 4-anilinophenol (CASRN 122-37-2) (OECD 2004)
- p-benzoquinone (CASRN 106-51-4) (OECD 2004)
- 2-anilino-5-[(4-methylpentan-2-yl)amino]cyclohexa-2,5-diene-1,4-dione (6PPD-quinone) (Tian et al. 2021)
- p-hydroquinone (ECHA 2021)
- imino benzoquinone nitrone (OECD 2004)
- benzoquinone dinitrone (OECD 2004)
- 4-nitroso-N-phenyl-aniline (CASRN 156-10-5) (OECD 2004)
- 1,3-dimethylbutanol (OECD 2004)

Tian et al. (2021) recently demonstrated that 6PPD can react with ozone under certain conditions to produce a reaction product implicated in mass die-offs of coho salmon: 6PPD-quinone. However, many questions remain about how and where 6PPD-quinone formation occurs (e.g., section 8). Tian et al. (2021) suggest that the log K_{ow} of $C_{18}H_{22}N_2O_2$, later identified to be 6PPD-quinone, is between 5 and 5.5, while U.S. EPA's EPI Suite prediction software indicates a log K_{ow} of 3.98 (U.S. EPA 2021b). This is confirmed by findings from Spromberg et al. (2016) that stormwater which has passed through soil media used in bioretention treatments is not toxic to coho salmon, suggesting that 6PPD-quinone is particle-reactive to some degree. EPI Suite also suggests a water solubility of 51.34 mg/L, indicating that 6PPD-quinone is more water soluble than 6PPD (U.S. EPA 2021b). There is no environmental fate data available for 6PPD-quinone, but monitoring data of 6PPD-quinone in surface water (see section 4) suggests it persists in aquatic environments longer than 6PPD, and long enough for exposure to aquatic organisms to induce toxic effects. Additionally, the recent detection of 6PPD-quinone in tire and roadwear particles collected from a highway tunnel indicates formation of 6PPD-quinone on road surfaces (Klöckner et al. 2021). However, this finding may not be applicable to all roads, given reduced sunlight and rainfall in road tunnels (Klöckner et al. 2021).

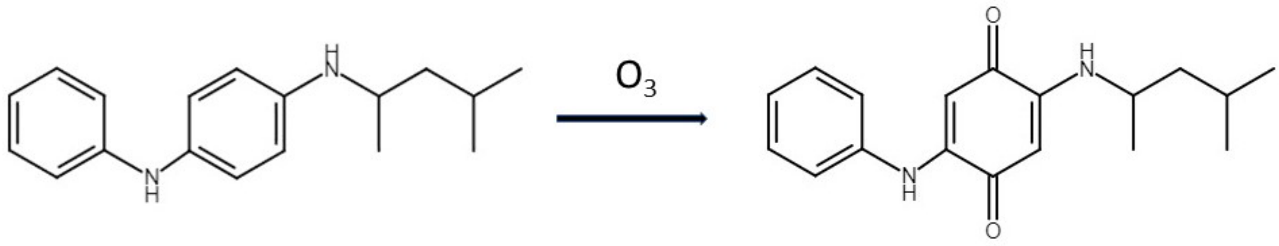

Figure 2: Reaction of 6PPD with ozone (O3) to produce 6PPD-quinone.

Tian et al. (2021) found that leachate from TWP remained toxic after it was heated to 80 °C for 72 hours, suggesting that 6PPD-quinone remains stable under these conditions. Peter et al. (2020) found that elevated concentrations of other tire-derived contaminants, which are often present during URMS events, persisted for at least a day (Peter et al. 2020). Given that 6PPD-quinone has since been determined to be the cause of URMS mortality events (Tian et al. 2021), this data also supports the conclusion that 6PPD-quinone is stable for a day or more in the aquatic environment.

California receives little precipitation for much of year, especially during the summer, when ground-level ozone concentrations are highest (Cataldo 2019). The large and steady flux of 6PPD to roadways and adjacent areas during these long dry periods, combined with high ozone concentrations, may create conditions that allow for significant 6PPD-quinone formation.

Hazard traits and environmental or toxicological endpoints

Reference: California Code of Regulations, title 22, section 69503.3(a)(1)(A).

The hazard traits and environmental or toxicological endpoints summarized in this section are defined in the SCP Regulations sections 69501.1(a)(36) and (33), respectively, both of which refer to the Office of Environmental Health Hazard Assessment's Green Chemistry Hazard Trait Regulations (California Code of Regulations, Title 22, Chapter 54). These include exposure potential, toxicological, and environmental hazard traits.

Although they are both environmentally hazardous and structurally similar, 6PPD and 6PPD-quinone possess distinct hazard traits. We therefore consider the environmental, exposure, and toxicological hazard traits separately for each chemical.

Environmental hazard traits

6PPD

6PPD exhibits phytotoxicity toward algae and impairs wildlife survival at multiple trophic levels (Table 2) (OSPAR Commission 2006). Concentrations for acute lethality in two surrogate fish species have been determined using flow-through exposures. A 96-hour acute fish toxicity experiment using Organisation for Economic Co-operation and Development (OECD) test guideline (TG) 203 determined a median lethal concentration (LC_{50}) of 0.028 mg/L for medaka (*Oryzias latipes*) (OECD 2004; OSPAR Commission 2006). A prolonged exposure study using U.S. EPA Methods for Acute Toxicity Tests with Fish, Macroinvertebrates and Amphibians determined a 28-day LC_{50} of 0.15 mg/L for the fathead minnow (*Pimephales promelas*) (OECD 2004; OSPAR Commission 2006).[5] For a planktonic crustacean (*Daphnia magna*), an experiment using U.S. EPA methods determined a 48-hour LC_{50} of 0.82 mg/L and a no observed effects concentration (NOEC) of 0.56 mg/L at nominal concentrations (OSPAR Commission 2006). Using *D. magna* immobilization or mortality as endpoints, a flow-through exposure using OECD TG 202 methods determined a 48-hour median effective concentration (EC_{50}) of 0.23 mg/L (OSPAR Commission 2006). In a study based on U.S. EPA methodology (Algal Assay Procedure: Bottle Test) using the green alga *Selenastrum capricornutum,* a 96-hour EC_{50} of 0.6 mg/L and NOEC of 0.2 mg/L was determined based on decreased cell count (OSPAR Commission 2006). The effect of 6PPD on micro-organisms was tested in an activated sludge study conducted according to International Organization for Standardization (ISO) 8192 standards; a three-hour (EC_{50}) of 420 mg/L (presumed nominal concentration) was determined based on decreased oxygen consumption (OSPAR Commission 2006). This value indicates that 6PPD is nonhazardous to waste management organisms under aquatic toxicity criteria set forth by the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) based on an EC_{50} less than or equal to 100 mg/L for aquatic species (United Nations 2019). However, based on even the most conservative of the acute toxicity values described for aquatic plants and animals, 6PPD meets the criteria for designation as a Category Acute 1 aquatic toxicant which is the most hazardous GHS classification (United Nations 2019).

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[5] The *P. promelas* aquatic toxicity study was flagged for "significant methodological deficiencies" in the OECD Screening Information Dataset Initial Assessment Report for 6PPD due to elevated ammonia levels, undisclosed concentrations of acetone solvent, and unexplained 6PPD contamination in controls that was observed starting at day 21 (OECD 2004). Despite its shortcomings, this study was nonetheless designated as "critical" by OECD and was similarly cited by OSPAR (OECD 2004; OSPAR Commission 2006).

Table 2. Experimental evidence for environmental hazard traits of 6PPD (OSPAR Commission 2006).

Species	Exposure	Measured Parameter	Result
Medaka (*Oryzias latipes)*	Flow-through	96-hour LC_{50}	0.028 mg/L (effective)
Fathead minnow (*Pimephales promelas*)	Flow-through	28-day LC_{50}	0.15 mg/L (effective)[5]
Water flea (*Daphnia magna*)	Static	24-hour LC_{50}	1.0 mg/L (nominal)
Water flea (*Daphnia magna*)	Static	48-hour LC_{50}	0.82 mg/L (nominal)
Water flea (*Daphnia magna*)	Static	48-hour NOEC	0.56 mg/L (nominal)
Water flea (*Daphnia magna*)	Static	48-hour NOEC Immobilization (6PPD prepared fresh)	0.25 mg/L (nominal)
Water flea (*Daphnia magna*)	Static	48-hour LC_{50} (6PPD prepared fresh)	0.51 mg/L (nominal)
Water flea (*Daphnia magna*)	Static	48-hour NOEC Immobilization (6PPD aged 24 h)	>1.0 mg/L (nominal)
Water flea (*Daphnia magna*)	Flow-through	48-hour EC_{50} Mortality/ immobilization	0.23 mg/L (effective)
Green alga (*Selenastrum capricornutum*)	Static	96-hour NOEC Cell count	~0.2 mg/L (nominal)
		96-hour EC_{50} Cell count	0.6 mg/L (nominal)
Activated sludge (Micro-organisms)	Static	3-hour EC_{50} O_2 consumption	420 mg/L (presumed nominal)

Due to the chemical's instability in water, organisms exposed to 6PPD in aquatic toxicity studies are also exposed to its degradation products (OECD 2004; OSPAR Commission 2006). A degradation toxicity study with *D. magna* examined how the aquatic instability of 6PPD under aerobic conditions affected its toxicity toward aquatic organisms (OECD 2004; OSPAR Commission 2006). *D. magna* were exposed to a freshly prepared 6PPD medium in parallel with an aged 6PPD medium that had been continuously stirred for 24 hours at room temperature (equivalent to approximately two half-lives) (OECD 2004; OSPAR Commission 2006). While the freshly prepared 6PPD medium had a NOEC of 0.25 mg/L, the solution aged under stirring did not produce any effects at the maximum soluble concentration (NOEC > 1.0 mg/L) (OECD 2004; OSPAR Commission 2006). Information on the presence of specific degradation products in the aged medium was not available, although it was presumed that 6PPD was detoxified through oxidation and/or hydrolysis (OECD 2004; OSPAR Commission 2006). Because only *D. magna* was used in this study, it is uncertain whether 6PPD degradation products formed under these conditions would also exhibit decreased toxicity toward other aquatic species.

6PPD-quinone

As described above, the ozonation of 6PPD produces a reaction product, 6PPD-quinone. In aquatic environments, 6PPD-quinone is known to impair wildlife survival and contributes to loss of biodiversity (Table 3). 6PPD-quinone is particularly toxic to coho salmon and persists long enough in the environment to exert adverse effects (Tian et al. 2021). This reaction product is associated with TWP leachate and has been identified in creeks in Washington and California at physiologically relevant levels (Tian et al. 2021). 6PPD-quinone was recently identified as the primary causative agent of URMS in coho populations in the Puget Sound area (Tian et al. 2021). Behavioral symptoms of URMS occur within a few hours of exposure to urban runoff and include "erratic surface swimming, gaping, fin splaying, and loss of orientation and equilibrium" (Scholz et al., 2011). Physiological changes in symptomatic coho were indicative of acute stress and hypoxia, and included increased hematocrit and dysregulation of blood plasma ions (McIntyre et al., 2018). Mortality occurs within a few hours of exposure to urban runoff (Scholz et al. 2011). Symptomatic coho are moribund and do not recover if transferred to clean water (Chow et al. 2019).

Synthetically produced 6PPD-quinone (approximately 98% purity) is acutely toxic toward coho, with an experimentally determined LC_{50} of 0.79 ± 0.16 µg/L in juveniles. (Tian et al. 2021). This closely matches the estimated LC_{50} of 0.82 ± 0.27 µg/L of 6PPD-quinone derived from bulk roadway runoff and TWP leachate exposures (Tian et al. 2021). Further, exposure to synthesized 6PPD-quinone produced behavioral symptoms consistent with observations of URMS in the field (Tian et al. 2021). These data indicate that 6PPD-quinone is the primary runoff constituent responsible for URMS (Tian et al. 2021). The observed toxicity of 6PPD-quinone toward coho demonstrates that it impairs wildlife survival (CCR, title 22, section 69404.9). URMS affects juvenile coho as well as adults returning to spawn in freshwaters (McIntyre et al. 2018; Chow et al. 2019). These adults are often stricken with URMS prior to spawning, with dead or moribund females having retained > 90% of their eggs (Scholz et al. 2011). For a given watershed in the Puget Sound area, URMS is responsible for the annual loss of up to 90% of fall runs of spawner coho returning to freshwaters (Spromberg and Scholz 2011). Modeling indicates that population abundances of coho cannot be maintained at this rate of loss (Spromberg and Scholz 2011). Consequently, 6PPD-quinone contributes to the loss of biodiversity in affected waterways (CCR, title 22, section 69404.4). It is also expected that 6PPD-quinone is not uniquely toxic to coho (Tian et al. 2021).

Table 3. Environmental hazard traits, and associated relevant indicators, for 6PPD-quinone. Defined in CCR title 22, chapter 54.

Environmental Hazard Trait	Relevant Indicators
Wildlife survival impairment (CCR title 22 section 69404.9)	Indicators include but are not limited to death; aquatic or terrestrial toxicity; other organ/system specific toxicities; non-specific toxicities such as narcosis, behavioral impacts, increased susceptibility, or changes in population viability.
Loss of genetic diversity, including biodiversity (CCR title 22 section 69404.4)	Indicators include but are not limited to reduction in the abundance of a species within a community, assemblage, or ecosystem or the genetic make-up of local populations.

The mechanism of action by which 6PPD-quinone causes URMS is not yet established. However, a recent study has identified a key target organ affected by urban runoff. In juvenile coho, exposure to urban runoff caused plasma to leak from the blood vessels around the brain (Blair et al. 2021). This suggested dysfunction of the blood-brain barrier (BBB), a physical barrier that selectively regulates the transport of molecules between circulating blood and the central nervous system (Blair et al. 2021). Plasma leakage into the brain was demonstrated by the presence of an indicator dye that had been injected into the circulatory system and, under normal circumstances, does not leak from blood vessels (Blair et al. 2021). When blood vessels lose their integrity and become permeabilized, plasma leakage can occur (Blair et al. 2021). During previous investigations of URMS, observations of elevated hematocrit were likely indicative of plasma loss (McIntyre et al. 2018; Chow et al. 2019; Blair et al. 2021). Permeabilization of blood vessels at the BBB can cause severe loss of plasma and unregulated entry of chemicals into the central nervous system, either of which can be lethal (Blair et al. 2021). The study concluded that permeabilization of blood vessels was both necessary and sufficient to cause death (Blair et al. 2021). Blair et al. (2021) also report that dye intracardially injected into coho salmon following exposure to urban runoff was observed leaking from the gills. This indicates that gills may be a target organ as well.

It has been proposed that the toxicity of 6PPD-quinone may be partly attributable to oxidative stress (Blair et al. 2021). Quinones often exhibit high redox activity *in vivo* and form reactive oxygen species (ROS), leading to oxidative stress that can damage DNA, proteins, lipids, and other biomolecules (Bolton et al. 2000; Blair et al. 2021). Oxidative stress can also initiate a cascade of molecular events leading to BBB dysfunction, including permeabilization of blood vessel tissue (Bolton et al. 2000; Blair et al. 2021). Higher densities of mitochondria, which naturally produce ROS, may increase the risk for oxidative stress in certain cell types, such as cerebral endothelial cells (Bolton et al. 2000; Blair et al. 2021). Selective transport at the BBB is energy intensive, and endothelial cells at the BBB have a higher density of mitochondria than other parts of the circulatory system to meet these energy needs (Oldendorf and Brown 1975). Thus, these cells may be particularly vulnerable to oxidative stress (Blair et al. 2021). This is generally consistent with the target effect of urban runoff on BBB dysregulation and the symptoms of URMS in coho during laboratory 6PPD-quinone exposure (Blair et al. 2021).

Given that 6PPD-quinone is the putative etiological agent of URMS, the effects of urban stormwater on vasculature are most likely a consequence of oxidative stress from 6PPD-quinone exposure (Blair et al. 2021). As described in the following section, 6PPD-quinone is structurally related to other quinones and may impact the physiology of coho salmon through reactivity with biological systems. It is therefore likely that 6PPD-quinone is a cardiovascular and respiratory toxicant in coho whose effects may be exerted, at least partly, through oxidative stress. It is not fully understood how extraneous factors (e.g., additional stormwater contaminants) may contribute to the toxicity of 6PPD-quinone in coho. For a discussion on possible cumulative effects with other factors, refer to section 5.

Exposure hazard traits

6PPD

Substances with a log K_{OW} greater than or equal to 4 and a BCF greater than or equal to 1000 may be designated with the bioaccumulation hazard trait (CCR, title 22, section 69405.6). Although 6PPD has a calculated log K_{OW} of 4.68, it has a calculated BCF of 801 (Table 1) and is unstable in water as previously described (OECD 2004; OSPAR Commission 2006). 6PPD is therefore not considered bioaccumulative (OSPAR Commission 2006).

6PPD-quinone

As an emerging contaminant, little is understood about the exposure hazard traits of 6PPD-quinone. It has a predicted log K_{OW} ranging between 3.98 and 5.5 (U.S. EPA 2021b; Tian et al. 2021), providing limited evidence for the bioaccumulation hazard trait.

Toxicological hazard traits

This Profile is based on the potential of tire-derived 6PPD and its transformation product, 6PPD-quinone, to contribute to significant or widespread adverse impacts on aquatic organisms. The emphasis on harm toward aquatic organisms is in accordance with reports from authoritative organizations and the available literature (OECD 2004; OSPAR Commission 2006; Tian et al. 2021; Blair et al. 2021). Although this Profile is not based on the impacts of 6PPD or its transformation products on human health, DTSC has nonetheless conducted a brief review of known toxicological hazard traits.

6PPD

In rats, 6PPD is a reproductive toxicant that causes dystocia, commonly referred to as difficult birth (ECHA 2021). It is a skin sensitizer with low potential to cause skin irritation, and exhibits ocular toxicity due to irritation of the eyes (OSPAR Commission 2006). Upon ingestion, 6PPD has the potential for lethality in high doses (median lethal dose [LD_{50}] of 500-1,000 milligrams per kilogram [mg/kg] body weight in rats), causes hepatoxicity at a no observable adverse effect level (NOAEL) of 6 mg/kg body weight/day, and is hematotoxic at a NOAEL of 75 mg/kg body weight/day (OSPAR Commission 2006). A 28-day sub-chronic study using oral gavage exposure determined a NOAEL of 20 mg/kg bodyweight per day in male and female rats (ECHA 2021). It is clastogenic *in vitro* but not *in vivo*, and therefore is not likely to be genotoxic (OSPAR Commission 2006).

6PPD-quinone

Based on its chemical structure, the toxicological hazard traits of 6PPD-quinone include reactivity in biological systems (CCR, title 22, section 69403.15) and respiratory toxicity (CCR, title 22, section 69403.16). See the following section for the rationale.

Structural or mechanistic similarity to chemicals with known adverse impacts

Reference: California Code of Regulations, title 22, section 69503.3(a)(3).

Some chemicals may lack sufficient data to definitively establish presence or absence of harm. In such cases, DTSC may also consider data from other chemicals closely related structurally to the Candidate Chemical to identify potential public health and environmental impacts.

The human exposure potential and toxicological hazards of 6PPD-quinone have not yet been evaluated directly. However, its chemical structure and other properties may provide some indication of its potential hazard traits. According to CCR, title 22, section 69403.15, “the reactivity in biological systems hazard trait is defined as the occurrence of rapid reactions with molecules in the body that lead to alterations in critical molecular function and ultimately adverse health outcomes.” The SCP Regulations state that a chemical substance with “structural or mechanistic similarity to other chemical substances that are reactive in biological systems" may be considered to have this hazard trait. 6PPD-quinone possesses a quinone functional group which imparts structural similarity to other chemical substances (quinones) that are known to be reactive in biological systems (Bolton et al. 2000). Quinones are a ubiquitous and diverse class of compounds that may be found naturally, have an endogenous biochemical role, or may be metabolized from a parent aromatic compound (Bolton et al. 2000). Some quinones are potent redox-active chemicals and may produce ROS including superoxide, hydrogen peroxide, and hydroxyl radicals (Bolton et al. 2000). This causes oxidative stress, a process that damages critical molecules such as DNA, proteins, and lipids, with the potential for other adverse molecular effects (Bolton et al. 2000). Quinones may also cause cellular damage through the alkylation of DNA and proteins (Bolton et al. 2000). The structural relationship between 6PPD-quinone and other quinones suggests that 6PPD-quinone may act through toxicological mechanisms similar to other members of this chemical class (Blair et al. 2021). Because of its quinone functional group, 6PPD-quinone meets the necessary requirements for the reactivity in biological systems hazard trait (CCR, title 22, section 69403.15).

4. POTENTIAL FOR EXPOSURES TO THE CANDIDATE CHEMICAL IN THE PRODUCT

Reference: California Code of Regulations, title 22, section 69503.3(b).

The SCP Regulations direct the Department to evaluate the potential for public or aquatic, avian, or terrestrial animal or plant organism exposure to the Candidate Chemical(s) in the product by considering one or more factors for which information is reasonably available.

Presence of the Candidate Chemical in the product

Reference: California Code of Regulations, title 22, section 69503.3(b)(2).

This subsection summarizes available information indicating the Candidate Chemical's presence in and release from the product.

6PPD has been used in motor vehicle tires since the 1950s or 1960s (Personal communication, Eastman Chemical Company, June 7, 2021). It has been reported that, in Europe, new vehicle tires contain up to 1 to 2% (10,000-20,000 µg/g) 6PPD (OSPAR Commission 2006). Limited data indicate that the 6PPD content in tires decreases by 90% or more as the tire ages (OSPAR Commission 2006; Unice et al. 2015). Cox et al. (1959) indicate that higher antiozonant concentrations may be required in situations where the tire may be exposed to higher temperatures or higher ozone concentrations; however, the extent to which 6PPD concentrations in tires vary as a function of these parameters is unknown.

Market presence and trends

Reference: California Code of Regulations, title 22, sections 69503.3(b)(1)(A-C).

Product market presence information may be used as a surrogate to assess potential exposures to the Candidate Chemical in the product. This information may include statewide sales by volume or number of units, the intended use(s) of the product, and characteristics of the targeted customer base.

Vehicle tires are ubiquitous in the United States and California. The United States tire manufacturing landscape, however, has changed dramatically over the last 70 years. Seventy-five percent of this United States industry—from 1982 to 1989 alone—faced takeover bids or ultimately restructured (Rajan et al. 2000). In 1971, United States-owned tire manufacturers produced nearly 60% of the world’s tires (Rajan et al. 2000). Today that percentage has declined dramatically. Once-prominent companies such as Firestone and Uniroyal lost control of their operations to foreign-owned corporations.

Most tires sold in the United States today are produced domestically by foreign-owned global tire manufacturers that operate production plants across the United States. The top five largest global tire companies (based on revenues) with plants in the United States are Bridgestone, Goodyear, Sumitomo, Hankook, and Yokohama (Dun & Bradstreet 2021). Goodyear and Cooper represent the two most prominent tire companies headquartered in the United States. The U.S.-owned tire manufacturing universe of competitors may shrink even further, as Goodyear announced plans in 2021 to acquire Cooper (Butcher 2021).

Two North American Industry Classification System (NAICS) codes—326211 and 441320—comprise Tire Manufacturing (except Retreading) and Tire Dealers, respectively. NAICS defines tire manufacturers as “establishments primarily engaged in manufacturing tires and inner tubes from natural and synthetic rubber.” NAICS defines tire dealers as “ establishments primarily engaged in retailing new and/or used tires and tubes or retailing new tires in combination with automotive repair services” (United States Office of Management & Budget 2017). According to data on these two NAICS codes, both the number of U.S. businesses in these sectors and their sales revenues remained relatively steady from 2012 to 2017 (United States Census Bureau 2012; United States Census Bureau 2017). The number of tire manufacturers rose from 111 to 119, while sales revenues fell from $20.2 billion to $18.3 billion (United States Census Bureau 2012; United States Census Bureau 2017). Over the 2015-2019 period, U.S. tire manufacturing industry revenues decreased at an annualized rate of 2.7% (IBISWorld 2020).

The number of tire dealers nationwide rose slightly from 20,300 in 2012 to 20,376 in 2017, while sales revenues remained stagnant at $33.4 billion (United States Census Bureau 2012; United States Census Bureau 2017). Only six tire manufacturers operated in California in 2017: Sumitomo, Toyo, Giti, McLaren Industries, Skat-Trak, and Carlstar Group (Dun & Bradstreet 2021). The same year, 2,248 tire dealers operated in the state (United States Census Bureau 2017).

The 13 members of the United States Tire Manufacturers Association (USTMA) operate 56 manufacturing plants in 17 states (USTMA 2021). USTMA member companies account for approximately 80% of tires shipped each year (USTMA 2020b). Thousands of non-USTMA tire manufacturers also operate worldwide. Some of the largest non-USTMA producers include Doublestar, Shandong Linglong, MRF, and Apollo (Dun & Bradstreet 2021). The vast majority of manufacturers—both USTMA and non-USTMA—operate on the Asian continent (e.g., China, India) (Dun & Bradstreet 2021). Many large manufacturers operate facilities on more than one continent, including North America.

Based on USTMA data, DTSC estimates that approximately 363,916,000 new tires entered the United States supply stream from both domestic and foreign manufacturers in 2019 (USTMA 2020b).[6] This figure is calculated based on the assumptions that (1) USTMA members account for roughly 80% of domestic tire production, and (2) non-USTMA members export approximately the same percentage of total output. Exports are subtracted from total production, and then imports are added to yield the total number of tires entering the supply stream.

Of the total number of tires entering the United States supply stream, the United States imported 196,807,000 tires. Thailand represents—by far—the most significant exporter of tires to the United States (Manges 2020). Approximately 11.3% of all motor vehicles in the United States are registered in California (FHWA 2020). Assuming Californians replace tires at a similar rate to residents of other states, this figure suggests that over 41 million new tires enter the California supply chain stream each year.

The number and types of registered vehicles in California can be used to estimate the number of tires on California roads in a given year. These types include automobiles, motorcycles, commercial trucks, trailers, and long-haul 18-wheel vehicles. California Department of Motor Vehicles data, in combination with DTSC calculations, suggest that 171,461,974 tires rolled on California roads in 2020 (State of California Department of Motor Vehicles 2020).[7]

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[6] DTSC used the following formula to estimate the number of tires entering the supply stream: USTMA Production + non-USTMA Production (estimated) + U.S. Imports – USTMA Exports – non-USTMA Exports (estimated) = Tires Entering the U.S. Supply Stream.

[7] DTSC examined the approximately 10 different vehicle types (e.g., automobiles, motorcycles, International Registration Plan tractor trailers) registered in California, multiplied vehicles times the number of tires associated with each vehicle type, and then totaled the amount.

Potential exposures to the Candidate Chemical during the product's life cycle

Reference: California Code of Regulations, title 22, sections 69503.3(b)(3); 69503.3(b)(4)(A-H).

Potential exposures to the Candidate Chemical or its degradation products may occur during various product life cycle stages, including manufacturing, use, storage, transportation, waste, and end-of-life management practices. Information on existing regulatory restrictions, product warnings, or other product use precautions designed to reduce potential exposures during the product's life cycle may also be discussed here.

Manufacturing

6PPD is considered a high-production chemical (OSPAR Commission 2006; U.S. EPA 2021c). The global production of 6PPD in 2001 was approximately 130,000 metric tons, with the majority being used in tires (OSPAR Commission 2006; OECD 2012). U.S. EPA reports that between 50 and 100 million pounds (equivalent to between 22,680 and 45,359 metric tons) of 6PPD are produced in the U.S. each year (U.S. EPA 2021c). According to the most recent U.S. EPA Chemical Data Reporting (CDR) Summary, 26 companies located in the U.S. reported manufacturing or importing 6PPD in 2015 (U.S. EPA 2021c). None of these companies are in California. Most of these companies are importers; only two companies reported domestically manufacturing any 6PPD in 2015. Six companies reported that the 6PPD they import or manufacture is used as an antioxidant/antiozonant/stabilizer or that it is used in rubber. The remaining companies either reported other uses or did not report a use (U.S. EPA 2021c).

The manufacturing of 6PPD can result in environmental emissions via wastewater, though one study found that on-site wastewater treatment could remove up to 96% of the 6PPD (OSPAR Commission 2006). 6PPD can also be released to the environment during tire manufacturing, for example during the rubber vulcanization process (OSPAR Commission 2006). Based on formulation recipes, Unice et al. (2015) estimated 2,200 µg/g 6PPD in uncured tread and 1,200 µg/g in cured tread. Thus, 1,000 µg of 6PPD per gram of tire tread is either released or converted into a transformation product during the curing process (see section 3).

The U.S. EPA Enforcement and Compliance History Online tool identifies 37 facilities in California that fall under NAICS code 326211 (Tire Manufacturing (except Retreading) and 17 under NAICS code 326212 (Tire Retreading) (U.S. EPA 2021d), which suggests that workers in the state may be occupationally exposed to 6PPD. The United States Bureau of Labor Statistics defines tire builders as workers who "operate machines to build tires" (United States Bureau of Labor Statistics 2021a). The number of "Tire Builders" (Standard Occupational Code 51-9197) is projected to increase by 0.5% to

21,100 nationally by 2029 (United States Bureau of Labor Statistics 2021a). However, in 2020, only 250 workers were employed as tire builders in California (United States Bureau of Labor Statistics 2021b)

The CDR data indicate that, nationally, tens of thousands of commercial and industrial workers may be exposed to 6PPD during manufacturing or industrial processing and use (U.S. EPA 2021c). While the OECD (2012) considers workers' exposure to 6PPD during the chemical's manufacture to be negligible, information regarding potential impacts of worker exposure to 6PPD during tire manufacturing is lacking. The safety data sheet for 6PPD indicates that workers may be exposed through the eyes, inhalation, or skin contact, and that adequate ventilation or respiratory protection are necessary to reduce exposure (SunBoss Chemicals Corp. 2014).

Use

As detailed above, there are over 171 million tires on the roads in California. 6PPD is used in virtually all tires in the U.S. as an antidegradant, to protect against rubber degradation by ozone and oxygen under dynamic conditions (i.e., while the tires are stretched and compressed by driving and bearing the weight of the vehicle) (Huntink et al. 2004). New tires contain approximately 10,000 to 20,000 µg/g 6PPD, but the amount decreases over time to approximately 1,000 µg/g (OSPAR Commission 2006). This decline appears to continue after tires are taken out of service and recycled; a mixture of used shredded car tires sampled in Germany contained an average of 120 ± 29 µg/g 6PPD (Klöckner et al. 2020).

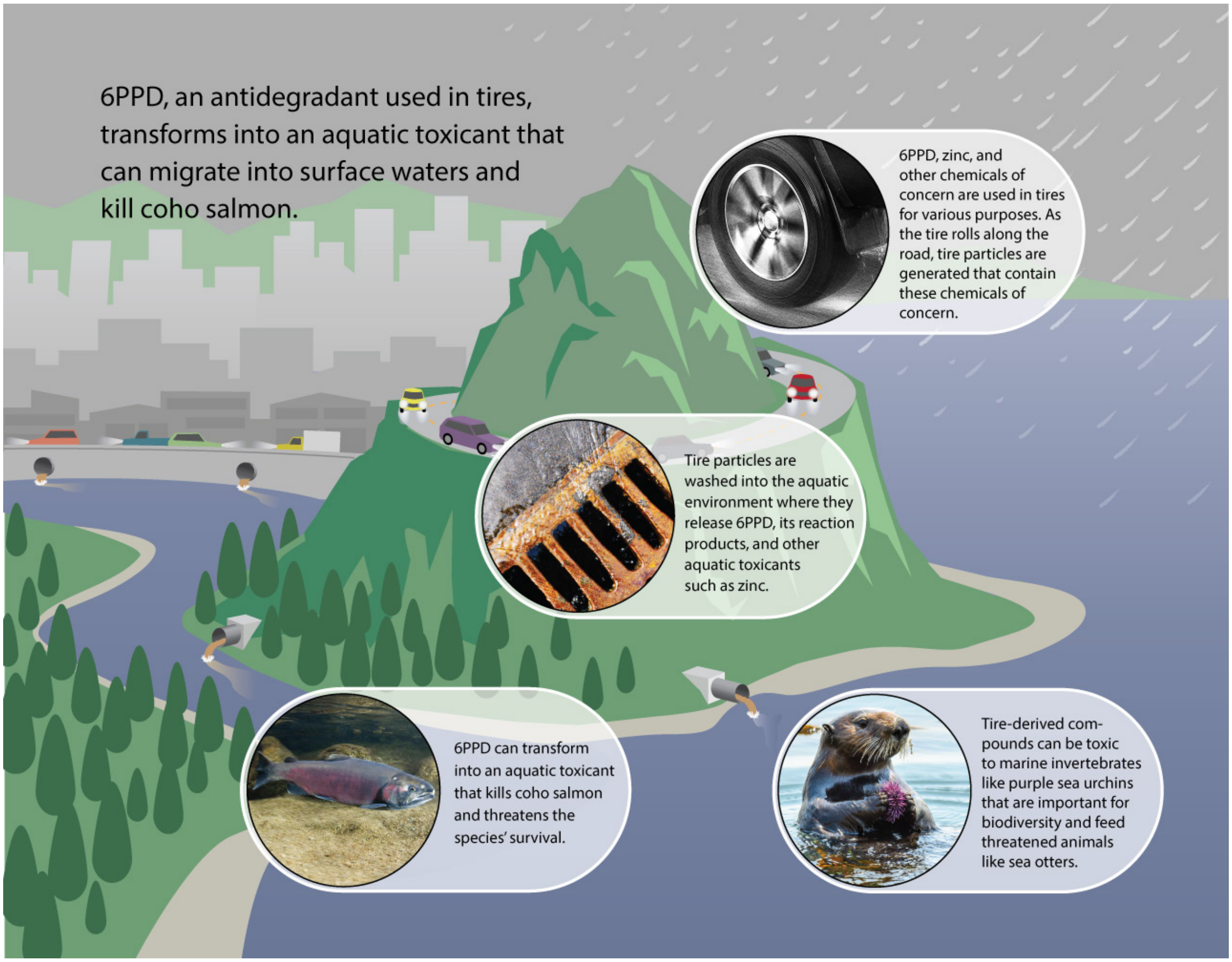
As the 6PPD at the surface of the rubber is depleted by reaction with ozone (see sections 3 and 8), more 6PPD diffuses from the inner parts of the tire toward the surface (Huntink et al. 2004). Fast migration to the surface of the tire and reactivity toward ozone are required characteristics for antiozonants. The diffusion coefficient of 6PPD increases with temperature (Huntink et al. 2004), while its antioxidant protection decreases (Cibulková et al. 2005). Because most of the 6PPD is eventually consumed, ozone protection lasts only for one to five years, depending on service conditions (Huntink et al. 2004).

6PPD and its reaction products can be emitted to the environment from tires in several ways. Some might be leached by rain water or, less likely, evaporate into the atmosphere from the surface of tire products (OSPAR Commission 2006). Leaching losses of PPD antiozonants were shown to increase with decreasing water pH, especially for PPDs of low molecular weight; for 6PPD (molecular weight 268.4 grams per mol), the study found minimal loss (5% or less) at neutral pH and 20% loss at a pH of 4.9 (Latos and Sparks 1969). The main way in which tires release 6PPD and its reaction products into the environment, however, is through mechanical tire abrasion on the roads, which produces microplastics known as TWP (OSPAR Commission 2006; Tian et al. 2021). An estimated 1,120,000 metric tons of TWP are emitted each year in the U.S. (Wagner et al. 2018), as over 10% of a tire's mass is worn away onto road surfaces over its useful life (Blok 2005). Up to 4.7 kg TWP are emitted per year per person, corresponding with an estimated 1,524,740 metric tons per year released in the U.S. on average (Kole et al. 2017). In the San Francisco Bay Area, that adds up to 36.2 million kg of TWP generated each year (Sutton et al. 2019). The amount of TWP generated can vary significantly based on driving behavior (e.g., speed and braking) and the characteristics of the tires (e.g., inflation pressure), vehicle (e.g., type, speed), and road surface (e.g., road roughness) (Blok 2005; ChemRisk, Inc. and DIK Inc 2008). In particular, urban areas that see increased acceleration, braking, and turning are estimated to have twice as much tire wear per kilometer than more rural areas (van der Gon et al. 2008).

According to a recent study, new tire and road wear particles contain an estimated 1,000 µg/g 6PPD, decreasing to 176, 49, 32, and 16 µg/g after 0.1, 0.8, 1.6, and 3.3 years of aging, respectively (Unice et al. 2015). After generation, TWP can remain on the road surface or be suspended in the air, where they can be transported away from the road surface before settling out—although 75% of these particles are expected to fall out within the first six meters (Blok 2005). For instance, 6PPD was found in road dust samples collected in Germany (Klöckner et al. 2020; Klöckner et al. 2021), as well as in atmospheric particles collected in an urban area using a high-volume air sampler in Chicago (Wu et al. 2020). 6PPD was also found at low levels in sediments collected in a technical sedimentation basin and an open settling pond system treating highway runoff in Germany; however, its reaction products such as 6PPD-quinone were not measured in this study (Klöckner et al. 2020). While 6PPD is unlikely to persist in the aquatic environment once released from TWP (Unice et al. 2015), its oxidation reaction products such as 6PPD-quinone might (see section 3). Tian et al. (2021) found 6PPD-quinone in TWP leachate from a mix of used and new tires, while Klöckner et al. (2021) found 6PPD-quinone in tire and road wear particles in highway tunnel road dust. Combining the new information from Tian et al. (2021) and Klöckner et al. (2021) with the decades-old literature on the mechanism of antiozonant action, it appears that 6PPD-quinone forms on the surface of the tire as part of the protective film, and remains present on TWP.

As displayed in Figure 3, stormwater runoff, particularly from urban areas, can serve as a substantial source of tire-derived contaminants to local aquatic environments. An estimated two-thirds of tire wear particles and other debris deposited on the road may run off with rainfall (Blok 2005). During dry periods, TWP and other road debris accumulate on roads, which can result in large pulses of TWP and their associated chemicals into water and sediment, especially after storm events (Unice et al. 2013; Unice et al. 2015; Kole et al. 2017; CASQA 2018; Unice et al. 2019). This is particularly concerning in California climates that can experience dry periods of several months at a time. Klöckner et al. (2021) found that 6PPD and 6PPD-quinone levels increased as the size of the tire and road wear particles decreased. Smaller particles may be more likely to remain suspended in the water column than larger particles, which represents a high potential exposure of coho salmon to these 6PPD and 6PPD-quinone-laden particles.

Peter et al. (2020) conducted a study to better understand how contaminants are released to local waterways during storm events. They evaluated the “pollutograph,” defined as “the pollutant concentration profile across the storm hydrograph” for stormwater-derived organic contaminants. This study analyzed samples from a creek in Washington state during rain events that coincided with observations of coho acute mortality by URMS. While this study predated the discovery of 6PPD-quinone, other tire-derived contaminants were included in the analysis. Typically, concerns for stormwater-induced toxicity have focused on the first flush, or the initial 0.5% to 10% runoff from a storm event, particularly for more traditional stormwater contaminants such as metals (Peter et al. 2020). However, the Peter et al. (2020) study indicated that release of tire-derived contaminants to the aquatic environment persists across the extent of the rain event, beyond the first flush. Even small storms resulted in significant releases of stormwater-derived contaminants and quickly degraded water quality (Peter et al. 2020). The authors suggest that these observations are consistent with an almost infinite supply of some stormwater contaminants during a storm. Such contaminants could potentially include 6PPD-quinone. In these instances, pollutant loading to surrounding waterways is limited only by physical transport, such as rain events generating runoff, and not by the amount of contaminant available to be released. Peter et al. (2020) also found that the total loading of contaminants to the waterway was 3.5 times higher in rain events sampled early in the rain season, which can align with the presence of coho salmon migrating up streams for spawning.



6PPD, an antidegradant used in tires, transforms into an aquatic toxicant that can migrate into surface waters and kill coho salmon.

6PPD, zinc, and other chemicals of concern are used in tires for various purposes. As the tire rolls along the road, tire particles are generated that contain these chemicals of concern.

Tire particles are washed into the aquatic environment where they release 6PPD, its reaction products, and other aquatic toxicants such as zinc.

6PPD can transform into an aquatic toxicant that kills coho salmon and threatens the species' survival.

Tire-derived compounds can be toxic to marine invertebrates like purple sea urchins that are important for biodiversity and feed threatened animals like sea otters.

Figure 3. Environmental release of tire-related chemicals and their impacts on sensitive aquatic ecosystems.

Tires and tire debris are found in many places of work throughout the U.S. and California. Some of these occupations include tire manufacturers, mechanics, highway workers (e.g., California Department of Transportation (Caltrans) road workers), street sweepers, car washers, and parking attendants. Current data gaps prevent researchers from estimating the amount of 6PPD that may impact workers, but summing relevant occupational projections listed in this section suggests that at least 125,000 California workers may experience some levels of 6PPD exposure by 2028. For instance, the number of "Highway Maintenance Workers" (Standard Occupational Code 47-4051) is projected to increase by 5.0% from 2019 levels, to 163,800 nationally by 2029 (United States Bureau of Labor Statistics 2021a) and by 3.1% from 2018 levels to 6,700 in California by 2028 (California Employment Development Department 2021). The number of "Tire Repairers and Changers" (Standard Occupational Code 49-3093) is projected to increase by 2.3% from 2019 levels to 116,000 nationally by 2029 (United States Bureau of Labor Statistics 2021a) and to remain flat at 11,300 in California from 2018 through 2028 (California Employment Development Department 2021). The number of "Automotive Service Technicians and Mechanics" (Standard Occupational Code 49-3023) is projected to decrease by 3.7% from 2019 levels to 728,800 nationally by 2029 (United States Bureau of Labor Statistics 2021a) and to fall by 0.9% from 2018 levels to 79,500 in California by 2028 (California Employment Development Department 2021). The number of "Parking Attendants" (Standard Occupational Code 53-6021) is projected to increase by 7.2% from 2019 levels to 160,600 nationally by 2029 (United States Bureau of Labor Statistics 2021a) and by 2.5% from 2018 levels to 24,400 in California by 2028 (California Employment Development Department 2021). Additional research must be conducted to determine the precise 6PPD exposure levels for people employed in these fields and the potential health impacts to these worker population groups.

End-of-life

At their end-of-life, vehicle tires can be repurposed, recycled, landfilled, or littered. In 2019, the U.S. generated an estimated 263.4 million scrap tires (USTMA 2020a). Vehicle tires are recycled in over 110 ways, ranging from stormwater treatment and erosion and flood control to shoe products for developing countries. They can also be reused, for instance as swings, planters, playgrounds, or for earthquake-proofing of buildings (Utires 2017). Waste tires have even been used as artificial reefs (Paylado 2016). California legislation (Public Contract Code Sections 12200-12217) requires that half of the tires purchased by state agencies be retread tires (tires for emergency vehicles are exempt from this requirement (CalRecycle 2020c)). Additionally, the federal Executive Order 13149 mandates the use of retreads on some federal vehicles (CalRecycle 2020c).

The California Tire-Derived Product Catalog, maintained by CalRecycle (CalRecycle, 2020c), includes the following tire-derived products and materials:

- Accessibility products (e.g., ramp systems, edge reducers, entry level surfacing)

- Animal care products (e.g., horse arena footings, exercise and dressage areas, barn and stable flooring, animal bedding, animal wash areas, dog parks)
- Automotive products (e.g., specialized rubber compounds used in tire manufacture and retreading, coating systems, tire sealants, wheel stops used in parking lots)
- Ballistic products (e.g., ballistic rubber backstops and tiles, rifle, pistol, and ballistic ranges, tactical training facilities, combat training pits)
- Civil engineering (construction and infrastructure)
- Coupling fittings
- Flooring
- Landscape surfaces (e.g., commercial landscapes, parks, golf courses, walkways, paths, schools, and universities)
- Mats, pavers, and tiles (e.g., gardens, landscaped areas, walkways, paths, courtyards, patios, decks, water parks, pool decks, hot tub areas, locker rooms, restrooms, sports arenas, ski resorts, barns, stables, restaurants, weed abatement in roads and landscaped areas)
- Paths, walkways, sidewalks, and bike trails (e.g., parks, landscaped areas, playgrounds, driveways, fairgrounds, high-traffic areas in commercial settings, pool areas)
- Paving materials and products
- Playground surfaces (e.g., parks, schools, daycare centers, aquatic parks)
- Retreads
- Roofing
- Sport surfaces (e.g., soccer, football, and rugby fields, golf courses, field hockey, tennis courts, indoor basketball courts)
- Tire-derived material feedstock (e.g., fine mesh crumb rubber used for molded or extruded products, crumb rubber, ground rubber used to produce rubber mulch or playground surfacing, tire-derived aggregate used in civil engineering applications, tire shreds used as tire-derived fuel)
- Traffic-related products (e.g., sign systems, parking lots, seismic transition joints, parking or dock bumpers)

According to CalRecycle, more than 51 million reusable and waste tires are generated in California each year (CalRecycle 2020d). California has 23,000 registered waste tire generators—such as tire dealers and auto shops—and 1,300 registered waste tire haulers (CalRecycle 2020b). In 2019, over 85% of California's waste tires were processed at one of 21 facilities; the rest were either landfilled or used as tire-derived fuel in cement kilns (CalRecycle 2020b). There are 16 manufacturers of tire-derived products located in California (most of them in the Los Angeles area), 17 tire-derived material feedstock suppliers, nine tire-derived product installers that use California-sourced materials, 20 tire-derived paving materials and product suppliers, and 40 retreaders (CalRecycle 2020c). Thirteen

California facilities are permitted to burn waste tires in combination with other fuels, but only five actually do. These facilities burned a total of 10.8 million tires in 2014 (CARB 2016). They include four cement kilns that also burn coal or coke, and one electrical power generating facility that generally uses biomass as a feedstock (CARB 2016).

In 2019, an estimated 470,242 metric tons (518,353 tons) of waste tires generated in California were landfilled, recycled, or managed for reuse (CalRecycle 2020b). Table 4 shows their end-of-life fates.

Table 4: End-of-life fate of the 470,242 metric tons of waste tires generated in California in 2019. Data from CalRecycle (2020a).

% of waste tires	End-of-life fate
22.1	exported for tire-derived fuels
18.0	disposed in landfills
15.8	converted to crumb rubber or ground rubber used for paving, synthetic turf infill, playgrounds, and other landscape and building construction products
13.7	used for tire-derived fuel in California cement kilns
9.2	retreaded
8.6	sold as used tires
6.0	exported as baled tire and tread
3.2	used as alternative daily cover at three landfills
2.6	used as tire-derived aggregate in civil engineering applications
0.8	otherwise recycled

As noted earlier, 6PPD slowly migrates from the interior of the tread to the surface of a tire over its lifetime, and thus the concentration of 6PPD in tires decreases over time. Nevertheless, analysis of used tires shows that they can still contain 6PPD, and the concentration can be significant. A government study detected 6PPD in samples collected from tire recycling plants (U.S. EPA and CDC/ATSDR 2019), and a study in 14 European countries found an average of 1,478.6 µg/g 6PPD in uncoated end-of-life tire materials collected at tire recycling facilities (Schneider et al. 2020a). 6PPD was also tentatively identified in crumb rubber samples from synthetic football fields, end-of-life tires, and rubber mats collected in Europe in a recent study, but could not be confirmed or quantified due to a lack of analytical standard (Skoczyńska et al. 2021). Assuming a concentration of approximately 1,000 µg/g 6PPD in older tires (OSPAR Commission 2006), these 470,242 metric tons of waste tires managed in California in 2019 (CalRecycle 2020b) contained approximately 470 metric tons of 6PPD that can be converted to 6PPD-quinone and enter the aquatic environment.

6PPD's presence in waste tires may result in exposure to workers in occupations that come in contact with products made from those tires. For instance, the number of "Highway Maintenance Workers" (Standard Occupational Code 47-4051) is projected to increase by 5.0% from 2019 levels to 163,800 nationally by 2029 (United States Bureau of Labor Statistics 2021a) and by 3.1% from 2018 levels to 6,700 in 2028 in California (California Employment Development Department 2021). The number of "Paving, Surfacing, and Tamping Equipment Operators" (Standard Occupational Code 47-2071) is projected to increase by 4.7% from 2019 levels to 48,800 nationally by 2029 (United States Bureau of Labor Statistics 2021a). In California, employment in this field is projected to rise by 6.9% from 2018 levels to 3,100 people in 2028 (California Employment Development Department 2021).

Some of these uses of tire-derived products and materials may directly lead to 6PPD-quinone releases in the aquatic environment. For instance, tire-derived aggregate can be used as a medium for stormwater treatment (CalRecycle 2016; CalRecycle 2018) and may lead to inadvertent contamination of treated water with 6PPD. Tire-derived materials are often used in outdoor applications that cover large surface areas. As such, these materials are exposed to storms that can leach 6PPD and 6PPD-quinone. In 2019, an estimated 2,268 to 3,629 metric tons of California-produced ground rubber were sold for playground surfacing, porous walkways, paths and bike trails, horse arena footing, landscaping, and military ballistic applications (CalRecycle 2020b). Approximately half of the California-produced crumb rubber is used for asphalt rubber paving, mainly due to requirements such as those in Assembly Bill (AB) 338 (Levine, Chapter 709, Statutes of 2005), which requires Caltrans to use tire asphalt rubber in at least 35% of its paving projects (CalRecycle 2020b). In addition, in 2019 an estimated 12,701 to 17,237 metric tons of California-produced crumb rubber were used for flooring, roofing, tiles, industrial underground couplings, and traffic safety devices, among other purposes, while an estimated 4,536 to 6,804 metric tons were used as infill in synthetic turf fields (CalRecycle 2020b).

There are between 12,000 and 13,000 synthetic turf fields in the U.S., with approximately 1,200 to 1,500 new installations each year, 95% of which use recycled tire crumb rubber as infill (Benson et al. 2019). In California, there are more than 900 synthetic turf fields with crumb rubber infill (OEHHA 2017). For context, a European football pitch needs an estimated 20,000 to 40,000 tires for crumb rubber infill (Gomes et al. 2021). A study of chemicals in synthetic turf crumb rubber detected (but did not quantify) 6PPD in samples from both indoor and outdoor sports fields (U.S. EPA and CDC/ATSDR 2019). Similarly, a California study detected 6PPD in crumb rubber collected from outdoor synthetic turf fields throughout the state (OEHHA 2019). More recently, a study in 14 European countries found 6PPD at average levels of 571 µg/g in crumb rubber collected from synthetic turf sports fields (Schneider et al. 2020a).

Athletes who use synthetic turf fields may inhale or ingest small crumb rubber particles that may contain 6PPD or 6PPD-quinone. As of this writing, there are no studies on 6PPD-quinone in crumb rubber, but its parent compound, 6PPD, has been found to have high migration rates in artificial sweat, suggesting that it can migrate from rubber into sweat and become available for dermal or ingestion exposure (Schneider et al. 2020b). The National Toxicology Program investigated whether chemicals in crumb rubber are bioaccessible by extracting the crumb rubber with simulated biofluids (sweat, lung fluid, saliva, gastric fluid, and intestinal fluid) to mimic dermal, inhalation, and oral exposure routes. They found 26.3 µg 6PPD in simulated gastric liquid per gram of crumb rubber extracted (NTP 2019), which may indicate a potential for oral exposure to 6PPD.

Aggregate effects

Reference: California Code of Regulations, title 22, section 69503.3(a)(1)(B) and sections 69503.3(b)(3).

Multiple sources of exposure to the Candidate Chemical may increase the potential for significant or widespread adverse impacts.

6PPD is present in numerous consumer products, including many that are common in households and workplaces. Often, the use of these products entails discharging them to the aquatic environment. The rubber industry uses 6PPD as an antidegradant in many products besides tire components, including pressure cooker seals (OSPAR Commission 2006), shoes, and toys (ECHA 2020). According to limited information from the European Chemicals Agency (ECHA), 6PPD has dozens of uses. In addition to rubber products, other outdoor uses from which 6PPD may be released to the environment include metal, wooden, and “plastic constructions”; building materials; treated wood products; textiles and fabrics; brake pads used in trucks and cars; sanding of buildings (bridges, facades) or vehicles (ships); hydraulic liquids used in automotive suspensions; and lubricants used in motor oil and brake fluids (ECHA 2020). Indoor uses of 6PPD that could also lead to environmental releases include flooring, furniture, toys, construction materials, curtains, footwear, leather products, paper and cardboard products, and electronic equipment (ECHA 2020). 6PPD can be released from textiles during washing, or during indoor paint removal (ECHA 2020). 6PPD is also found in other complex articles from which releases are less likely, such as machinery, mechanical appliances, and electrical/electronic products (e.g., computers, cameras, lamps, refrigerators, washing machines), electrical batteries and accumulators, and vehicles (ECHA 2020).

As discussed above, 6PPD can also be found in products made from recycled or reused tires. Many recycled tire products are used in outdoor applications that cover large areas, sometimes in or near waterways (see above). All these products have the potential to release 6PPD and its reaction product, 6PPD-quinone, to the environment and expose coho salmon and other sensitive organisms to these chemicals.

Indicators of potential exposures to the Candidate Chemical

Reference: California Code of Regulations, title 22, section 69503.3(b)(2).

The SCP Regulations consider various data that indicate potential for exposure to the Candidate Chemical or its degradation products, including: monitoring data indicating the Candidate Chemical's presence in the indoor and outdoor environment, biota, humans (e.g., biomonitoring studies), human food, drinking water, and other media; and evidence of persistence, bioaccumulation, lactational and transplacental transfer.

Although 6PPD has been recognized for many years as a high-production volume chemical used in tires, few studies of the environmental presence or fate of anthropogenic chemicals have focused on it. Table 5 presents 2011 Swedish Environmental Research Institute monitoring data from the ECHA dossier on 6PPD.

Table 5: 2011 Swedish Environmental Research Institute monitoring data for 6PPD (ECHA 2020).

Matrix	Median 6PPD concentration	Units	Number of samples
Surface water	0.071	µg/liter (L)	11
WWTP effluent	0.018	µg/L	5
Stormwater	0.110	µg/L	4
Sediment	all values <0.0006	mg/kg	6
Soil	all values <0.0006	mg/kg	6

Klöckner et al. (2020) measured 6PPD in sediments collected from a technical sedimentation basin, an open settling pond system treating highway runoff, and a lake in Germany, but all samples were below the 23 nanogram (ng)/g detection limit. These low levels may reflect the fact that 6PPD is reactive and degrades relatively quickly when exposed to oxygen or ozone or by photodegradation (e.g., on road surfaces) and in water (see section 3). Klöckner et al. (2020) also measured 6PPD in road dust samples collected in Leipzig, Germany. Median concentrations from three distinct regions of the city were 180 ± 66 ng/g, 92 ± 30 ng/g, and <23 ng/g. The authors collected road dust samples from street sweeping cars operated by the communal road cleaning service. They state that water is sprayed on the road surface during sweeping and that the sweepers' dust containers, from which samples were collected, contained water. This is noteworthy because 6PPD hydrolyzes relatively rapidly (see the Environmental Fate section); thus, this sample collection method may have led Klöckner et al. (2020) to underestimate the true concentration of 6PPD in their road dust samples.

More recently, Klöckner et al. (2021) sampled dust in a German highway tunnel and analyzed a range of organic and inorganic constituents, including 6PPD and 6PPD-quinone, in various size and density fractions. The authors found 6PPD in samples collected in two different areas of the tunnel at 1.5 µg/g dry weight and 1.9 µg/g dry weight. While the study did not quantify the concentration of 6PPD-quinone, peak areas across both samples were relatively consistent (220 ± 9.5 peak area/mg dry weight and 270 ± 27 peak area/mg dry weight). Klöckner et al. collected tunnel dust samples using a pressure washer and wet vacuum; thus, as in the study discussed above, some hydrolytic degradation of 6PPD could have occurred between sample collection and analysis. As mentioned previously, the authors also found that the abundance of 6PPD and 6PPD-quinone increased as the size and density of the tire and road wear particles decreased.

As discussed above, 6PPD-quinone was only recently identified as a toxic aquatic contaminant in urban runoff and streams. To date, the clearest indication of the presence of 6PPD-quinone in stormwater runoff and surface waters in California comes from Tian et al. (2021). Following their identification of 6PPD-quinone, Tian et al. retrospectively quantified 6PPD-quinone in archived sample extracts from the Los Angeles and San Francisco regions; see Table 6.

Table 6: Estimated concentrations based upon retrospective analysis of 6PPD-quinone in archived sample extracts (Tian et al. 2021).

Sample Type	Sample Description	Mean 6PPD-quinone concentration (µg/L)
Roadway runoff	Los Angeles Site 1	6.1
Roadway runoff	Los Angeles Site 2	4.1
Receiving water	San Francisco Site 1	2.6
Receiving water	San Francisco Site 2	3.5
Receiving water	San Francisco Site 3	1.0
Receiving water	San Francisco Site 4	1.2

Concentrations of 6PPD in samples from Los Angeles and San Francisco (Table 6) are all above the LC_{50} (0.79 ± 0.16 µg/L) that Tian et al. (2021) reported for juvenile coho salmon. The concentrations observed in Los Angeles roadway runoff are approximately five to eight times higher than the LC_{50}. As noted in DTSC's *Rationale Document for Motor Vehicle Tires Containing Zinc* (DTSC 2021a), for many California waterways, stormwater runoff may constitute a significant proportion of total flow during and immediately following dry-season and early rainy-season precipitation events. Tian et al. (2021)'s estimates of the 6PPD-quinone concentration in San Francisco creeks that receive urban runoff, though lower than those in Los Angeles roadway runoff, are nevertheless alarming: Two of the four estimates are approximately three to four times higher than the LC_{50}. The 6PPD concentrations measured in samples collected in Los Angeles are likely higher than those from San Francisco because the Los Angeles samples were undiluted road runoff. In contrast, the San Francisco samples were taken from creeks whose flow comprised roadway runoff diluted by creek water from other sources. Thus, the 6PPD-quinone concentrations reported for Los Angeles and San Francisco in Tian et al. (2021) demonstrate that 6PPD-quinone is present at ecologically relevant levels in California streams.

Per the SCP Regulations, the expenditure of public funds to mitigate adverse impacts from stormwater is an indicator of potential exposure. While Tian et al. (2021)'s data set is limited, the presence of 6PPD-quinone at these concentrations in California waterways strongly suggests that existing stormwater treatment infrastructure in at least some portions of the state does not remove 6PPD-quinone. Stormwater contaminated with aquatic toxicants such as 6PPD and 6PPD-quinone requires special handling to mitigate adverse impacts to aquatic organisms (see section 5). Spromberg et al. (2016) found that lethal and sublethal effects of acutely toxic highway runoff on adult coho salmon could be prevented by treatment using bioinfiltration through soil columns—a conventional green stormwater infrastructure. If 6PPD or 6PPD-quinone were to be regulated in stormwater, California municipalities may be required to install and maintain treatment infrastructure, at considerable expense, to meet the effluent criteria specified in their stormwater permits and ensure protection of local waterways. While not directly applicable, given that the treatment technologies for metals like zinc and organics like 6PPD and 6PPD-quinone may differ, cost estimates for zinc presented in DTSC's *Rationale Document for Motor Vehicle Tires Containing Zinc* are suggestive: The estimated total capital cost of projects required to meet applicable zinc limits for the Ballona Creek and Upper Los Angeles River watersheds exceeds $5.8 billion, and the estimated total operations and maintenance cost exceeds $249 million per year (DTSC 2021a).

Given the paucity of information on environmental 6PPD or 6PPD-quinone concentrations, other tire-derived chemicals may function as surrogates for 6PPD and 6PPD-quinone. Peter et al. (2020) estimated TWP concentrations in Miller Creek (a small, urban stream that flows into Puget Sound) using measurements of three chemicals:

- 1,3-diphenylguanidine (DPG, a vulcanization accelerator in tire rubber),
- hexa(methoxymethyl)melamine (HMMM, a cross-linking agent in tire rubber), and
- dicyclohexylurea (DCU, a reaction byproduct in tire rubber).

Peter et al.'s detection of DPG, HMMM, and DCU in the water of Miller Creek revealed more than the presence of tire-derived contaminants; the October and November storm events also corresponded with observed coho mortality (i.e., URMS). Peter et al. (2020) could not identify the URMS toxicant(s); however, in hindsight, thanks to Tian et al. (2021), it appears extremely likely that the 6PPD-quinone was responsible. As indicated above, motor vehicle tires are the major source of 6PPD (and, indirectly, 6PPD-quinone) in the environment, and the correlated presence of three other tire-derived chemicals in Miller Creek during URMS events provides additional evidence that 6PPD-quinone was present in Miller Creek at toxicologically relevant concentrations.

The presence of TWP can also serve as an indicator of potential exposure to tire-derived chemicals such as 6PPD and 6PPD-quinone. The San Francisco Estuary Institute (SFEI) assessed microplastics in stormwater, surface water, and sediment throughout the larger San Francisco Bay area. Both stormwater and sediment samples included black fragments with a rubbery texture. SFEI hypothesized that these fragments were synthetic or natural rubber, possibly derived from tires. The black fragments constituted almost half of the particles in the stormwater. Kole et al. (2017) estimated emissions of TWP to be 4.7 kg/year per capita in the U.S. based on World Health Organization data on the number of registered vehicles for the year 2011, U.S. Department of Energy data on annual mileage for the year 2013, and an estimate of TWP emissions per vehicle per kilometer from two sources (Kole et al. 2017). This translates to 36.2 million kg/year of tire-derived microplastics in the San Francisco Bay Area, an estimated 70% of which has the potential to be released into nearby waterbodies (Blok 2005; Sutton et al. 2019). This finding of substantial loading of TWP to the San Francisco Bay Area, which is the southern population range of coho salmon, suggests high potential for 6PPD and 6PPD-quinone exposure to aquatic organisms.

Finally, as discussed above in section 4 crumb rubber made from scrap tires is used in a range of applications, including playground surfacing, porous walkways, paths and bike trails, and infill in synthetic turf fields. These and other materials made from recycled scrap tires may represent sources of exposure for the people and animals that use them. For example, people, including children, playing on synthetic turf may be exposed to 6PPD or 6PPD-quinone by inhaling or ingesting small crumb rubber particles or via dermal contact, especially when skin surfaces are wet or sweaty. As described above, 6PPD has been detected in crumb rubber from synthetic turf fields in the U.S., including California (OEHHA 2019; U.S. EPA and CDC/ATSDR 2019). In addition, in urban areas near highways and streets with heavy traffic, people and other terrestrial animals may inhale airborne TWP containing 6PPD or 6PPD-quinone (among other chemicals). Kole et al. (2017)'s literature review concluded that the likely size distribution of TWP is 10 nanometers to several hundred microns (µm) and that most TWP are smaller than 100 µm. Allen et al. (2019) found that plastic fragments smaller than 300 µm can be transported atmospherically up to 95 km, suggesting that airborne transport over shorter distances (e.g., a few km) in urban areas is likely. Wu et al. (2020) collected atmospheric particles in Chicago, Illinois and analyzed them for 47 anthropogenic chemicals. They detected 6PPD in 70% of samples; the median 6PPD concentration was 0.06 picograms per cubic meter (pg/m^3) (range: <method detection limit to 0.41 pg/m^3) (Wu et al. 2020).

5. POTENTIAL FOR SIGNIFICANT OR WIDESPREAD ADVERSE IMPACTS

Reference: California Code of Regulations, title 22, section 69503.2(a).

This section integrates the information provided in the Profile to demonstrate how the key prioritization principles, as identified in the SCP Regulations, are met.

The reaction product of 6PPD, 6PPD-quinone, is acutely toxic to coho salmon, with unknown impacts on other aquatic organisms. The presence of 6PPD in tires and associated release of 6PPD-quinone to the aquatic environment represents a threat to imperiled populations of coho salmon, negatively impacts tribal communities that rely on these fish for cultural and subsistence purposes, may interfere with California's ability to reuse and recycle tires, and may require special handling of stormwater runoff to mitigate adverse impacts. The most efficient method to reduce the concentration of 6PPD and 6PPD-quinone in California aquatic environments is to address it at the source.

Adverse impacts linked to the Candidate Chemical's hazard traits

Reference: California Code of Regulations, title 22, section 69503.3(a).

The SCP Regulations direct the Department to evaluate the potential for the Candidate Chemical to contribute to or cause adverse impacts by considering several adverse impact factors for which information is reasonably available.

Potential for adverse impacts to coho salmon

The populations of coho salmon in California are teetering on the brink of extinction due to decades of habitat destruction and degradation, overexploitation, and climate change (Brown et al. 1994; CalTrout 2017; CDFW 2021a; NOAA 2021d). Additional stressors, including exposure to chemical pollution, may also be involved in the decline of the species (Afonso et al. 2002; Baldwin et al. 2009a). 6PPD-quinone, a 6PPD reaction product that is acutely lethal to coho, is found in California runoff and waterways at concentrations capable of killing the species (Tian et al. 2021). The chemical's presence strongly suggests that 6PPD-quinone may have contributed to the decline in the coho population over the past 60 to 70 years that 6PPD has been used in tires (Personal communication, Eastman Chemical Company, June 7, 2021) in California and poses an ongoing threat to the recovery of the species.

The hazard traits associated with 6PPD-quinone—wildlife survival impairment and loss of genetic diversity and biodiversity—describe the potential for its adverse impacts on coho. These hazard traits are especially concerning because California's coho are listed under the Endangered Species Act (ESA) (CalFish 2018). There are two discrete populations of coho in California, referred to as evolutionary significant units (ESUs) (NOAA 2021d). The Central California Coast (CCC) population has been listed as endangered since 2005 and threatened since 1996 (NOAA 2021b). This ESU extends from south of Punta Gorda in Humboldt County to the tributaries north of Santa Cruz (Brown et al. 1994; NOAA 2021b). The Southern Oregon/Northern California Coast (SONCC) ESU extends from Cape Blanco, Oregon to Punta Gorda, California and has been listed as threatened since 1997 (Garwood 2012; NOAA 2021c) (Figure 3). Its vulnerability ranking and recent counts suggest that the status of the SONCC ESU is likely to be updated to endangered (Crozier et al. 2019).

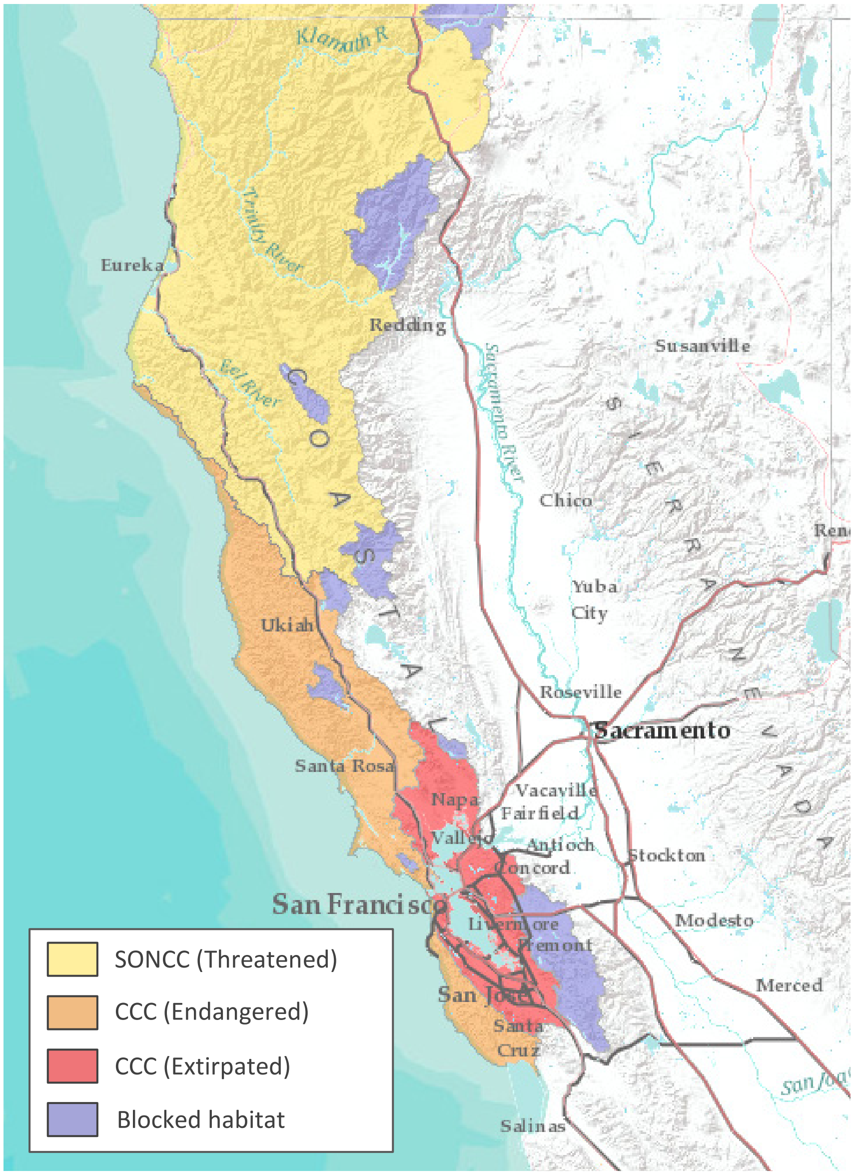


Figure 4: Map of Southern Oregon/Northern California Coast (SONCC) and Central California Coast (CCC) evolutionary significant units (Stone 2013; Stone 2018).

Impacts on the size of the coho population

The historical decline of coho in California has been well documented. A survey of California coho published in 1994 revealed that they have been lost from 46% of their historical streams (Brown et al. 1994). Brown et al., estimated that California's coho population was 6% of its 1940s levels as of the publication date, and that the statewide population had plummeted by 70% since the 1960s. (Brown et al. 1994). This decline may be even more dramatic in the CCC, whose geographic range includes a larger portion of urbanized streams (see Figure 4 & Figure 5) (Brown et al. 1994; Leidy et al. 2005; NMFS 2012). The 30-year period from the 1960s to the 1990s, during which Brown et al. (1994) documented the 70% decline in coho, corresponds with the use of 6PPD in tires (Lattimer et al. 1983; Lewis 1986; Personal communication, Eastman Chemical Company, June 7, 2021). It is also notable that during this period coho were extirpated from the San Francisco Bay Area, which arguably has the highest concentration of vehicle traffic in coho territory within California (see Figure 4). Coho were last documented in the San Francisco Bay estuary in the early to mid-1980s (Leidy et al. 2005). Other factors have undoubtably contributed to the population's decline during this time, such as changes in stream flow and structure due to drought, urbanization, and water diversion for agriculture and flood control (Brown et al. 1994; CDFW 2021a). However, the introduction and use of 6PPD in tires correlates, in part, with the downward population trend.

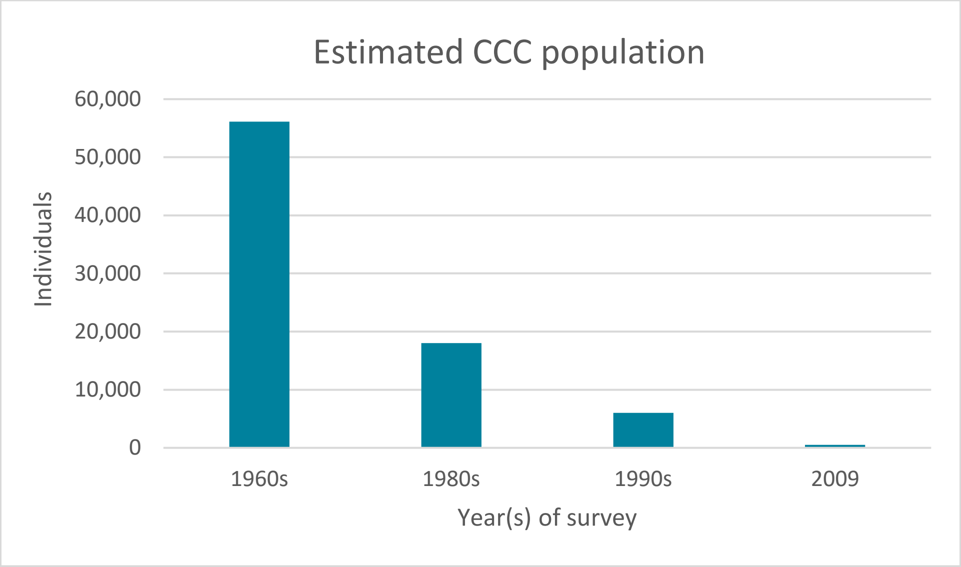


Figure 5: These data reflect the estimated population of the CCC coho from the National Marine Fisheries Recovery Plan (NMFS 2012). There was an estimated 90% decline in the CCC coho from the 1960s to the 1990s.

URMS was first characterized in adult coho that died before spawning, and was initially termed prespawn mortality (Scholz et al. 2011) but has subsequently been observed in all life stages of coho

(Chow et al. 2019). URMS has not been officially documented in California; it is likely difficult to observe and quantify because of the state's small coho population and the fact that they have been extirpated from many of the streams near cities where biologists and citizen scientists have better access. URMS is easier to observe in large adults whose carcasses are obvious compared to earlier life stages when the fish will easily become prey. Data regarding coho prespawn mortality in California are spread across multiple reports based on watersheds and do not have corresponding rainfall information. In addition, some of the surveys to detect prespawn mortality are more focused on chinook because the surveys only include the beginning of the coho spawning season and, for a variety of safety and logistical reasons, the survey locations may not include the small creeks where coho are likely to spawn. (Gough et al. 2021). Nevertheless, cases of prespawn coho mortality have been observed in California (Gough et al. 2021), although the cause of these deaths is unclear and may or may not be related to urban runoff.

After the initial discovery of URMS, Spromberg and Scholz modeled the population decline in the Puget Sound basin based on the failure of adult coho to spawn (2011). In a stream with a 20% prespawn mortality rate, the coho populations were predicted to become extinct within that stream in 115 years (Spromberg and Scholz 2011). In streams where 90% of the coho died before spawning, the coho were anticipated to be extirpated within eight years (Spromberg and Scholz 2011). However, the entire Puget Sound coho population may have some resiliency as long as there are other healthy populations that stray into different natal streams to spawn. Unfortunately, that buffer is projected to diminish when prespawn mortality rises to 25% in most streams, resulting in predictions of population-wide extinction in Puget Sound within 50 years (Spromberg and Scholz 2011) . This modeling was completed before scientists discovered that urban storm runoff, now known to contain 6PPD-quinone, is also toxic to juvenile coho (Chow et al. 2019; Tian et al. 2021). Therefore, the population models likely underestimate the severity of population decline (Spromberg and Scholz 2011). The population of coho in the Puget Sound is much larger compared to the two California populations (NMFS 2012; WDFW 2020; The Nature Conservancy 2021a). Population modeling with 6PPD-quinone-induced prespawn mortality has not been conducted on the California populations, but with smaller initial populations a more precipitous decline might be anticipated.

Impacts of loss of genetic diversity

The diminished population of California coho already show evidence of genetic diversity loss (Bucklin et al. 2007). Smaller populations lead to inbreeding and genetic drift (Bucklin et al. 2007). Scientists from NOAA used genetic markers to demonstrate the lack of genetic diversity within the California populations of coho; many of the fish tested from individual sites were siblings (Garza and Gilbert-Horvath). Further loss of individuals due to 6PPD-quinone toxicity will continue to diminish their remaining genetic diversity. Genetic diversity is important because it provides the biological repertoire that the species can draw on to respond and adapt to new stressors. Interbreeding with hatchery fish is likely to further reduce the genetic diversity and reproductive capacity of the two ESUs (Brown et al. 1994; Chilcote et al. 2011; Moyle 2011), degrading their ability to survive.

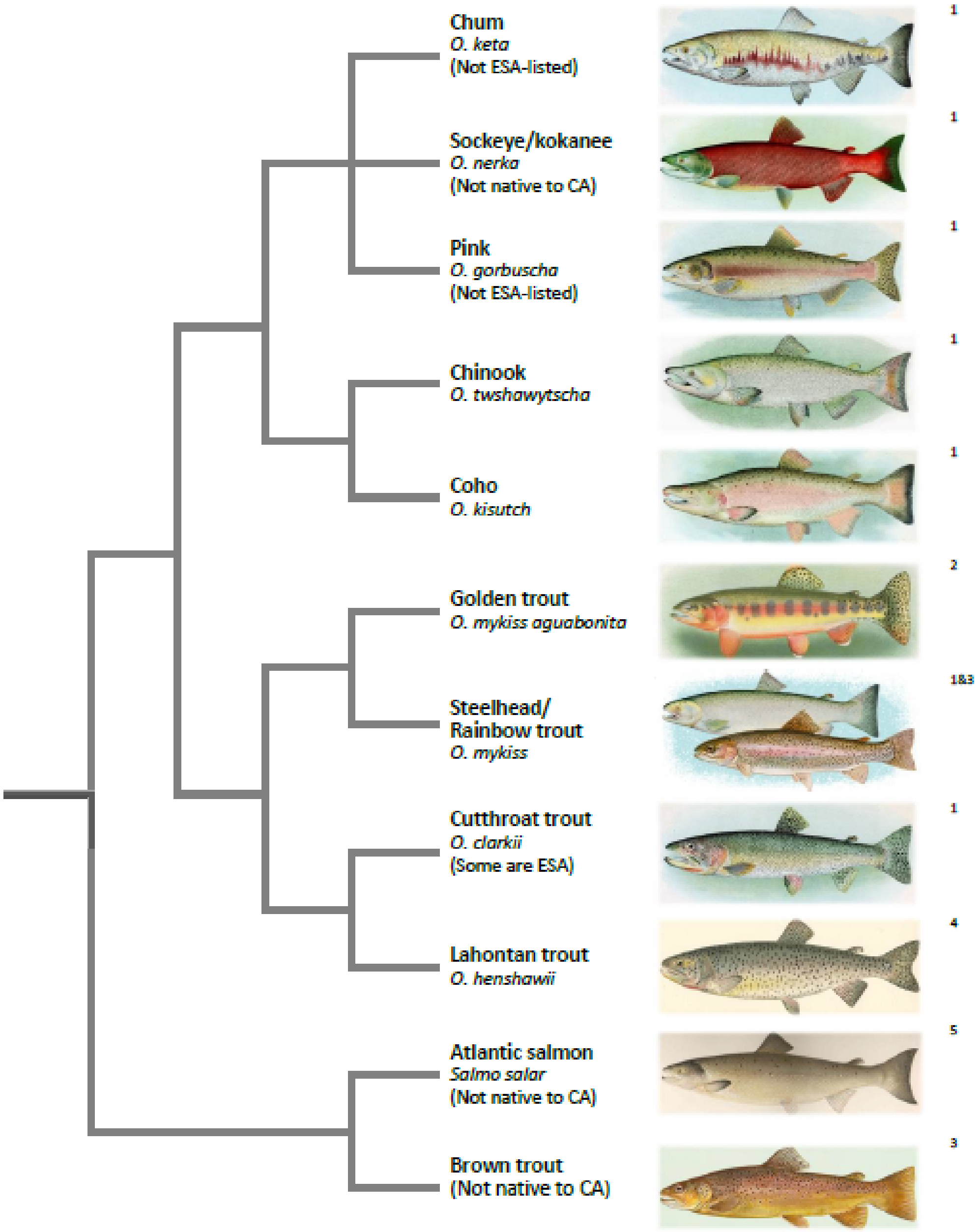
Because the CCC ESU defines the southernmost extent of the coho's range, it likely has important genetic variations that allow its members to survive in warmer temperatures (Brown et al. 1994). The ESU's genetic adaptations may be important to the survival of the entire species, especially the northern coho populations from Oregon through Alaska, in a rapidly warming climate (Brown et al. 1994). Transmission of the CCC's temperature-tolerant genetic variations to these northern population requires emigration to northern areas or intentional breeding programs (Garza and Gilbert-Horvath). Continued loss of the genetic diversity needed to survive in warmer temperatures in the California populations may threaten the survival of the entire species as northern waters experience climate change.

Potential adverse impacts on related species and other aquatic organisms

Little is known about 6PPD-quinone toxicity, specifically its sublethal effects in coho or effects in other fish or trophic levels. However, it is unlikely that a chemical that is so acutely toxic to coho would not be toxic to other organisms (Tian et al. 2021). Coho belong to the *Oncorhynchus* genus; only one other member of *Oncorhynchus*, the chum salmon (*O. keta)*, has been tested for toxicity to urban stormwater runoff (McIntyre et al. 2018). Chum did not exhibit any evidence of toxicity (McIntyre et al. 2018). However, that outcome cannot be generalized to all salmonid species.

Oncorhynchus represents a number of ecologically, economically, and culturally important fishes in California. Given the genetic relatedness of species in the genus, there is potential for 6PPD-quinone to be lethal or cause sublethal toxicities in both anadromous and inland salmonids that are of great importance in California. Figure 6 shows the family tree of the salmonids and indicates that chinook (*O. tshawytscha)* are more closely related to coho than chum, and therefore may be more susceptible to 6PPD-quinone. Chinook have a greater distribution in California, are larger in size than coho, and are generally considered more economically and culturally valuable. Given the chemical's ubiquity in urban runoff, if 6PPD-quinone was determined to be even marginally as toxic to chinook as it is to coho, the decline of chinook would also pose a significant concern in California. However, no data is currently published on the effects of urban runoff or 6PPD-quinone on chinook.

Another closely related species, *O. mykiss,* has two names—steelhead and rainbow trout. Steelhead are anadromous like salmon, meaning they migrate to the ocean and complete part of their life cycle in the ocean before returning to freshwater to spawn, whereas rainbow trout spend their entire life in freshwater. This species also has a much greater distribution across California; and, like the other anadromous salmonids, most populations of steelhead in California are listed as threatened or endangered under the federal ESA (CDFW 2021d). No data is yet available on 6PPD-quinone's toxicity to *O. mykiss*. Similarly, there is no data on the toxicity of 6PPD-quinone to the endemic California golden trout (*Oncorhynchus aguabonita* or *Oncorhynchus mykiss aguabonita*), the state's official freshwater fish. Nor is there information about the toxicity to any of the other trout in California which all belong to the *Oncorhynchus* genus and are closely related to steelhead/rainbow trout: the coastal cutthroat, Eagle Lake rainbow, Goose Lake redband, Kern River rainbow, Little Kern golden, Lahontan cutthroat, McCloud River redband, Paiute cutthroat, or the Warner Lakes redband (CDFW 2021b). Because these species share some common physiology with coho, they may also be sensitive to the toxic effects of 6PPD-quinone. In many cases, these endemic fishes are relatively isolated and have small populations with a minimal capacity to withstand population-level stressors, and thus are listed under the ESA or considered a California sensitive species (Moyle et al. 2015).



Note: All fish species are listed under the Federal Endangered Species Act (ESA) in California unless otherwise noted.

Figure 6: Family tree of salmonids. This indicates the relatedness among the salmonidae family generally found in California. This is not an exhaustive phylogeny, as geographical isolation has led to speciation of some trout in specific watersheds, as indicated in the paragraph above. This is not intended as an accurate phylogenetic tree; horizontal distances are not intended to reflect time since evolutionary divergence. Tree based on Perry et al. (2002). All sources are in the public domain: 1- Hoen and Co. The Fishes of Alaska (1907); 2- Hudson, Charles. Bulletin of the Bureau of Fisheries (1905); 3- Raver, Duane. Commissioned by U.S. Fish and Wildlife Service (1975);. 4- New York Fish and Game Commission (1902); 5- Denton, Sherman. Fishes of North America (1856-1937).

As unfortunate as this story is for the endangered coho, the scientific investment into coho recovery, the characterization of URMS, and the discovery of 6PPD-quinone and its toxicity may ultimately help to protect other aquatic organisms that are not as apparent as silver salmon swimming up a small creek to spawn. Based on limited measurements of 6PPD-quinone (Tian et al. 2021) and the widespread use of tires containing 6PPD (see section 4), there is potential for widespread exposure to other aquatic species in California. 6PPD-quinone is hypothesized to generate ROS in biological systems, which is noteworthy because organisms are generally susceptible to oxidative stress caused by free radicals (Lushchak 2011), suggesting the potential for adverse impacts in other species. Policies to protect other charismatic indicator species, such as the bald eagle from dichloro-diphenyl-trichloroethane (DDT), have helped save many other species and protected human health (U.S. EPA 2014). It will take years of testing to determine 6PPD-quinone's toxicity to other species, but action on 6PPD now may protect other aquatic organisms from potential adverse impacts.

Cumulative effects

Reference: California Code of Regulations, title 22, section 69503.3(a)(1)(C).

Cumulative effects occur from exposures to the Candidate Chemical and other chemicals with the same or similar hazard traits or environmental or toxicological endpoints.

A plethora of stressors has caused the California coho population to plunge since the 1940s and led to their listing under the ESA. Habitat destruction or degradation, climate change, overfishing, introduced disease, and displacement by invasive species have likely all contributed to the species' decline (Brown et al. 1994; Crozier et al. 2019; CDFW 2021a). For the past 60 to 70 years, 6PPD-quinone may have played a role in that decline; it is impossible to attribute the decline exclusively to one factor or another because most of these stressors are additive and impair the survival of the species. In this section we exclusively focus on cumulative impacts of 6PPD-quinone with other chemicals.

Cumulative effects with urban runoff

In addition to 6PPD-quinone, urban runoff exposes aquatic life to many other tire-derived aquatic toxicants that can cause sublethal effects (Young et al. 2018). These toxicants include heavy metals, polycyclic aromatic hydrocarbons (PAHs), and other chemical substances found in TWP, brake pad dust, exhaust particles, and petroleum products (Young et al. 2018). It is unknown whether 6PPD-quinone may interact with other chemicals in urban runoff and whether co-exposure to these chemicals may influence susceptibility of coho to URMS. However, as discussed below, chemicals in urban runoff may exert toxicity at least partly through oxidative stress. Organisms have a limited capacity to buffer against oxidative stress, and imbalance of the redox state may result in cellular damage (Valavanidis et al. 2006; Lushchak 2011). Because 6PPD-quinone is hypothesized to cause oxidative stress (see section 3), 6PPD-quinone may share an underlying mechanism of toxicity with other chemical substances found in urban runoff, and the effects may therefore be cumulative (Blair et al. 2021). Further, while sublethal effects are not acutely lethal, they may still contribute to the impairment of wildlife survival.

As described by Young et al., the zebrafish (*Danio rerio*) is a useful model organism for investigating the biological effects of toxicants in the aquatic environment (Young et al. 2018). In the zebrafish embryo-larval model, urban runoff exposure can impair the lateral line organ, a mechanosensory system composed of hair cell clusters (neuromasts) that sense the movement of water (Young et al. 2018). Normal lateral line function is important for survival, as it facilitates detection of predators, prey, and stream flow, the latter of which is important for orientation of fish relative to the current (Montgomery et al. 1997; Montgomery et al. 2013). Larval zebrafish exposed to urban runoff showed signs of impaired mechanotransduction channel function in lateral line hair cells, demonstrating an acute toxic effect toward this organ (Young et al. 2018). Developmental effects were also observed in zebrafish embryos, as urban runoff exposure reduced the number of neuromasts in the lateral line and resulted in fewer hair cells per neuromast (Young et al. 2018). Coho salmon embryos reared in stormwater also had fewer neuromasts (Young et al. 2018). Because lateral line cells of larval and adult zebrafish respond similarly to various toxicants, the neuromasts of adult fish may also be impaired by short-term stormwater exposure (Young et al. 2018). While bioretention filtration can prevent URMS (presumably due to the filtering of 6PPD-quinone from runoff), it does not ameliorate neuromast defects in coho salmon (Young et al. 2018). Therefore, toxicity toward the neuromasts is likely to be caused by chemicals other than 6PPD-quinone (Young et al. 2018). Because neuromasts are important for proper orientation relative to stream flow, their impairment may complicate the loss of orientation and equilibrium in coho afflicted with URMS due to 6PPD-quinone exposure. In addition to lateral line defects, zebrafish embryos exposed to urban stormwater exhibited growth impairment, deflated swim bladder, and cardiac edema (Young et al. 2018).

While urban runoff contains thousands of chemicals, including those with uncharacterized toxicity, many are relatively well-described toxicants including heavy metals and PAHs (Young et al. 2018). Some heavy metals present in urban runoff, such as copper and cadmium, are known to target the lateral line and may at least partially explain this observed toxicity (Young et al. 2018). These metals can cause oxidative stress, and thus may have cumulative effects with 6PPD-quinone (Mahboob 2013). PAHs, which are known developmental toxicants, may also impair the lateral line and contribute to the other observed malformations in zebrafish following stormwater exposure (Young et al. 2018). The effects of PAHs are generally mediated by the aryl hydrocarbon receptor, which can alter gene expression and cause cardiovascular, craniofacial, and other defects (Incardona 2017; Young et al. 2018). Endogenous metabolism of PAHs can also transform them into toxic intermediates called PAH *o*-quinones, which can cause oxidative stress through the generation of ROS (Bolton et al. 2000).

Cumulative effects with carbon dioxide and climate change

Increasing amounts of carbon dioxide in the atmosphere is the primary cause of anthropogenic climate change (Stocker 2014). Rising temperatures have harmed coho and will continue to do so (NMFS 2012; Crozier et al. 2019). Stream temperatures can impact the growth and survival of coho as young and when they return to spawn in fresh water (NRC 1996; California Fish & Game Commission 2002). Young coho achieve optimal growth in cold water, 12-14 ˚C (NMFS 2012). If water temperatures are typically above 18˚C, young coho are generally absent from the stream (NMFS 2012). Temperatures above 25-26˚C are lethal to juvenile coho (NMFS 2012).

Increased water temperatures are likely to affect an individual coho’s energy balance (NRC 2004) and may cause damage at the cellular level (Nakano et al. 2014). Increased metabolic activity associated with thermal stress may cause increased oxidative stress and the production of ROS, which may be cumulative with effects induced by 6PPD-quinone (Nakano et al. 2014). In addition, as water temperatures increase, fish need to consume more oxygen (Nakano et al. 2014); however, less dissolved oxygen is available in warmer temperatures. This imbalance results in an energy deficit for cells.

Young coho require cold streams for about a year (NMFS 2012). This comparatively long time in freshwater makes them more vulnerable to rising stream temperatures than some other salmonids. Climate change can directly affect water temperatures through ambient warming of the air and precipitation, which will result in increased water temperatures. Further, warming temperatures will convert mountain snow into rain. Slow-melting snow can help provide cold water to mountain creeks in the hottest weather, and reduction in snowfall and subsequent summer snowmelt will likely change the volume and temperature of creeks (Crozier et al. 2019). In addition, the tree canopy provides vital shade that limits warming in streams despite warm ambient temperatures. However, when shade trees are lost due to fires and drought caused by climate change, the surrounding streams may warm to a point that induces thermal stress in the coho (Brown et al. 1994; NRC 2004; Diffenbaugh et al. 2015; The Nature Conservancy 2021b). Thermal stress may render the fish more susceptible to 6PPD-quionone by limiting the metabolism of liver enzymes (Laetz et al. 2014), through a physiological mechanism, such as oxidative stress (Nakano et al. 2014; Blair et al. 2021), or through multiple stressors working on different pathways.

Climate change is expected to modify exposure to, and intensity of, natural physiological stressors. This includes environmental parameters such as temperature, pH, ultraviolet irradiance, and others that influence the fate and ecological consequences of pollutants (Kolomijeca et al. 2020). A study using the fathead minnow demonstrated that the toxicity of tire particle leachate was positively correlated with higher temperatures during the leaching process (Kolomijeca et al. 2020). This indicates that the toxicological impacts of TWP on aquatic environments may change over time as temperatures increase along with increasing atmospheric CO_2 levels (Kolomijeca et al. 2020). Additionally, co-exposure of organisms to natural physiological stressors and chemical stressors usually has a greater-than-additive (synergistic) toxic effect than either stressor alone (Holmstrup et al. 2010). Because of regionalized weather and climate trends, the effects of TWP leachate on aquatic systems is expected to be globally variable, with some geographical regions impacted by TWP differently (Kolomijeca et al. 2020). Notably, the temperatures of streams in California are expected to increase due to climate change (Ficklin et al. 2013). Thus, coho populations in California's warming streams may be more vulnerable to the toxicity of chemicals in TWP, including 6PPD-quinone.

Anthropogenic inputs of CO_2 in the atmosphere cause greater amounts of CO_2 to dissolve into the ocean, forming carbonic acid and lowering the pH of the water (Feely and Doney 2011). This phenomenon is known as ocean acidification (Feely and Doney 2011). The lower pH of the ocean water may interfere with a fish's ability to smell, which is especially important in salmon and allows them to detect predators and return to their natal streams to spawn (Williams et al. 2019; Crozier et al. 2019). Disruption of these behaviors will further impair the species' survival (Williams et al. 2019) and lead to further loss of genetic diversity and biodiversity.

Populations that may be adversely impacted

Reference: California Code of Regulations, title 22, sections 69503.3(a)(1)(F) and 69503.3(a)(2).

This section identifies specific populations of humans and environmental organisms that may be harmed if exposed to the Candidate Chemical in the product. Sensitive subpopulations, environmentally sensitive habitats, endangered and threatened species, and impaired environments in California have special consideration as they may be more vulnerable.

The severe and acute toxicity of 6PPD-quinone to coho is likely to have implications throughout California. Many of California's Native American tribes have historically had an important cultural relationship with coho salmon. This relationship is particularly prominent among the tribes in the northwest quadrant of the state. Loss of coho and other salmonids has had negative consequences on the health of tribal members, on the economies of the impacted tribes, and on their culture. In addition, loss of coho from their California range is likely to have impacts across adjacent ecosystems and for local economies that rely on fishing and fisheries.

For the initial draft of this Profile, we have relied on available literature, which is largely focused on the Yurok and Karuk tribes. The ancestral land of both includes parts of the Klamath Basin of Northern California. While many of the adverse impacts experienced by the Klamath River tribes are likely shared by other tribes who rely on salmon, the accounts of the Yurok and Karuk should not be viewed as representing tribal views throughout California. DTSC's Tribal Affairs Office and SCP are in ongoing consultations with California tribes to expand our understanding of the dietary and cultural significance of coho. These consultations are formal government-to-government dialogs intended to respect the sovereignty of California's tribes and better protect tribal resources (Brown 2011; Gatto 2014). We plan to solicit and incorporate input from all interested tribal governments into future iterations of this document.

Human populations

Coho is a culturally significant taxon throughout its range, and California's Native American tribes have had a relationship with coho and other salmonids since time immemorial. For many tribes along the northern and central California coast, salmon are an essential part of their culture and may have accounted for roughly one-third of the fish in their traditional diet (Schilling et al. 2014). Archeological evidence and personal accounts from members indicate that tribes throughout California traditionally relied on sophisticated trade and travel routes to obtain and use salmon (Gobalet 1990; Schilling et al. 2014). Salmon continue to play an important role in the culture and diet of many of California's tribes. Salmon is their single most-consumed fish, and almost all tribal members interviewed by the California State Water Resources Control Board said they used salmon (Schilling et al. 2014). However, tribal members throughout California say that the traditional use of salmon and other fish has decreased because of diminished populations (Schilling et al. 2014). This is true for coho, whose population is about one-tenth of 1940 levels and is subject to strict catch limits (Brown et al. 1994; NMFS 2012).

Across Indigenous communities, the loss of core traditional food sources can be tied to loss of culture, decreased self-reliance and sovereignty, increased physical and mental health issues, and increased poverty (Norgaard 2005; Schilling et al. 2014; Vinyeta et al. 2016). Samuel Gensaw III, cofounder of the Yurok Ancestral Guard, describes this very plainly: "[o]nce the salmon are gone, it's the end of the world for us and there's no going back" (Rawal 2021). It is difficult to tease out the impacts of the loss of coho from those of the decline in salmonids more broadly because, in many cases, the literature does not address the impacts of the decline of specific salmonid species.

Health impacts

"The salmon run is directly connected to the health of our community," says Samuel Gensaw a member of the Yurok Tribe (Rawal 2021). The human toll of the decline of salmon has been well-documented by the Karuk Tribe in the Klamath Basin in Norgaard's report to the Federal Energy Regulatory Commission (2005). The devastating loss of chinook and coho most closely correlates with the construction of dams on the Klamath River. Traditionally, an individual of the Karuk Tribe ate 450 pounds of fish per year (Norgaard 2005). This was likely a combination of chinook and coho salmon, lamprey, and sturgeon, but the salmonids were the most important food source. Now, the average person is likely to only consume five pounds of salmon each year. This pattern is similar among many tribes in California. Shilling et al. report that traditional tribal diets included about one pound of fish per week, whereas contemporary diets include significantly less (2014). The caloric deficit is most easily made up by replacing lean, protein-rich fish with carbohydrate and fat-laden commodity foods (Norgaard 2005). The decline of the salmon fishery may not be the only factor in the dramatic shift in the diet of the Karuk, but it has had devastating health consequences for the population.

Diabetes, heart disease, hypertension, and stroke, diseases that are strongly influenced by diet, have become more common in the Karuk since the decline of the salmon fishery. The most striking health impact is the increase in Type II diabetes to 21%, which is nearly four times the national average (Norgaard 2005). Prior to the 1970s, Type II diabetes was nearly unknown among the Karuk. The timing of the increase corresponds to the decline of salmonids in the previous decade. As a whole, Native Americans in the U.S. tend to have worse outcomes with diabetes—including blindness, kidney failure, lower-extremity amputations, neuropathy, dental problems, heart disease, disability, decreased quality of life, and premature death (Norgaard 2005)—all of which are directly tied to loss of traditional foods. The effects of dietary changes are exacerbated by changes in how food is obtained. Harvesting fish is vigorous exercise, in stark contrast to buying food from a store. Lack of exercise associated with loss of hunting, fishing, gathering, and traditional cultural practices is a cofactor in the development of Type II diabetes.

Changes in diet may also have generational effects. Pregnant women with diabetes have an increased risk of spontaneous abortion, premature birth, high birth weight (infant macrosomia), and increased infant mortality (Norgaard 2005). The adverse pregnancy outcomes associated with diabetes stand in contrast to the benefits of a diet that is high in fish that contain omega-3 oils, which promote better pregnancy outcomes and healthy brain development (Norgaard 2005). Additionally, the reliance on processed or commodity foods and the reduction in exercise from subsistence fishing have led to increases in childhood obesity, which may lead to poor self-esteem and performance in school for Karuk children (Norgaard 2005).

Some of the effects of the change in Native Americans' diets may affect mental health as well as physical health. Many studies have demonstrated that significant stress arises from the lack of food security (Norgaard 2005; Ling et al. 2019), which is tied with food sovereignty, a concept that attempts to add a social and health equity component to food systems (Declaration of Nyéléni 2007; Weiler et al. 2015). In February of 2007, a group of advocacy organizations convened a "Forum for Food Sovereignty" in Mali, which was attended by 500 delegates from 80 countries. At the close of the meeting, a declaration was issued calling for food sovereignty, which it describes as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems" (Declaration of Nyéléni 2007). Native American advocates assert that access to traditional food sources, such as salmon, helps to promote self-reliance among Indigenous peoples and is fundamentally important to protecting Native community's health, well-being, economic resilience, and cultural heritage (Declaration of Nyéléni 2007; Cramblit 2020; Rawal 2021; Montalvo 2021).

Cultural significance

Yurok Tribal Chairman Thomas P. O'Rourke describes the significance of salmon: "The Klamath salmon is as much a part of our traditional culture as our prayers and our drums. That is what is at stake here, the continuation of our very existence as Yurok people" (Associated Press 2017). Over 90 percent of individuals interviewed from tribes across the state agreed that fishing and eating fish are culturally important to their communities (Schilling et al. 2014). In Native American tribal communities, traditional foods such as salmon are important for physical health, emotional health, cultural practice, family structure and social relations, ceremonial practice, traditional knowledge, and political sovereignty (Norgaard 2005; Vinyeta et al. 2016; Cramblit 2020). Traditional foods are also important for cultural continuity. Some food-gathering activities, such as the salmon harvest, are multigenerational, social events; when a food source disappears, so do the associated cultural activities (Norgaard 2005). As with many cultures, food-related activities serve as social glue that binds Native American communities together. Obtaining, preparing, and sharing food helps to define social roles that instill a sense of identity, and this entire process helps to transmit values (Norgaard 2005). Norgaard writes, "The present ongoing destruction of the resource base leads to further social disruption for Karuk people today. Just as ceremonies surrounding fish … create and maintain community ties and provide identity, so too does their absence and decline lead to further cultural disruption (Norgaard 2005)."

The decline in salmon populations can lead to losses of the skills—and even the language— involved in harvesting and preparing food. These skills, which include the Yurok method for gillnetting (Berkeley Food Institute 2018) and the dipnetting techniques of the Karuk (Norgaard 2005), cannot be taught to younger generations if salmon are absent from their historic streams. Traditional skills involved in processing the meat are also at risk of being lost. Ron Reed, a traditional Karuk fisherman, says this about the importance of food sovereignty and traditional ecological knowledge:

> You can give me all the acorns in the world, you can get me all the fish in the world, you can get me everything for me to be an Indian, but it will not be the same unless I'm going out and processing, going out and harvesting, gathering myself. I think that really needs to be put out in mainstream society that it's not just a matter of what you eat. It's about the intricate values that are involved in harvesting these resources, how we manage them for these resources and when. This knowledge is incorporated under our ceremonies (Norgaard 2005).

This sentiment is echoed by Samuel Gensaw of the Yurok Tribe,

> We’re salmon people. Our whole life revolves around the relationship that we have with these salmon because, we believe that when these salmon disappear, we disappear (Rawal 2021).

Economic Impacts

The decline of the Klamath salmon fishery has coincided with increases in poverty and hunger (Norgaard 2005). The Karuk spend an estimated $1.9 million per year treating and dealing with the consequences of diabetes and related pathologies (Norgaard 2005). As discussed previously, salmon has invaluable cultural significance to many California tribes. While it is difficult to quantify the cultural costs to the Karuk and other tribes from the decline in salmon, the economic impacts are evident (Norgaard 2005). Some tribes have invested resources to acquire replacement food sources and devoted significant capital into the study (e.g., Faukner et al. 2017) and restoration of habitat for fishes (see more in the *Economic importance to California* section below).

There is great diversity among California’s approximately 180 Native American tribes. Each is unique and has its own specific concerns. This discussion has tried to highlight some of the concerns of the Karuk and Yurok Tribes, because the impact of loss of salmon on these communities has been publicly documented and is readily accessible. DTSC recognizes the cultural significance of salmon to California tribes given its prevalence in both traditional and contemporary cultures and diets (Schilling et al. 2014).

Ecological populations

When Pacific salmon migrate upstream and ultimately die, they transfer marine nutrients to the flora, fauna, and fungi of the riparian habitats and adjacent forests (Naiman et al. 2002; Merz and Moyle 2006; Quinn et al. 2018). This redistribution of nutrients from sea to forest is so important to the riparian and adjacent ecosystems that Pacific salmon have been referred to as a keystone species in the Pacific Rim (Quinn et al. 2018). Coho typically spend 18-24 months in the ocean (CDFW 2021a); generally, 95% of a salmon’s body mass is accumulated in the marine environment (Naiman et al. 2002). When the salmon migrate upstream and die, their marine-derived nutrients are readily traceable by their isotopic signatures. These chemical signatures can be traced back to land organisms such as fungi and bacteria, and to trees, and animals, including megafauna such as bears (Naiman et al. 2002; Merz and Moyle 2006). In some cases, enhanced plant and tree growth is associated with more robust salmon runs (Merz and Moyle 2006; Quinn et al. 2018). In a recent decade-long study, nutrients from sockeye salmon were experimentally shown to improve tree growth in an Alaskan forest (Quinn et al. 2018). The nutrients are also important to the river ecosystem (NOAA 2021a), and they support the stream invertebrates that provide food for the young salmon. The continued decline of coho salmon may have unexpected consequences through various ecosystems.

In the ocean, juvenile California coho may be consumed by a variety of other fish, seals, and California sea otters, which are listed as threatened under the ESA and depleted by the Marine Mammal Protection Act (Naiman et al. 2002; NOAA 2021a; Marine Mammal Commission). Adult coho are a source of food for marine megafauna, including sharks, sea lions, seals, and orcas (NOAA 2021a). Again, despite their small size and relatively low abundance, the further loss of coho may still have significant ecological impacts, especially on megafauna whose survival is increasingly imperiled.

Populations potentially exposed to 6PPD-quinone through fish consumption

The potential impacts of consuming fish contaminated with 6PPD or 6PPD-quinone, if any, are unknown. California tribal members have expressed concern about the potential impacts to their communities and to other animals from consuming such fish. The discovery of 6PPD-quinone is so recent that there is little information about its metabolism in organisms. K_{OW} estimates suggest that it may have the potential to bioaccumulate (see section 3) but structural studies suggest that it is likely to be reactive, and therefore likely to be transformed in an organism's body (see section 3 and Bolton et al. 2000). More research is needed to understand the risks, if any, to people or animals who consume fish that may have been exposed to 6PPD-quinone and its metabolic products.

Economic importance to California

Salmon are economically important in California, beyond their importance to Native American tribes as discussed above. California's recreational and commercial salmon fisheries, combined, were valued at $121 million in 2015 based on sales of fish, income for commercial fishers and guides, licenses and fees, boat maintenance and fuel, bait and tackle, and services used by commercial anglers (FishBio 2017). Recreational salmon fishing in streams was valued at $1,236 per fish, while the value is lower for those caught recreationally or commercially in the ocean (FishBio 2017). These numbers are not specific for coho but provide an approximation of the economic impacts related to declines in their populations.

The state of California, as well as California's Native American tribes, have invested millions of dollars to support projects that improve the habitat for salmonids through the Fisheries Restoration Grant Program (CDFW 2021c). These projects tend to focus on improving the physical habitat by controlling erosion and adding features to urbanized streams such as pools and riffles. In Washington state, ironically, these activities may have lured coho back into urbanized streams where they fell victim to the toxicity of 6PPD-quinone (Scholz et al. 2011; Tian et al. 2021). Reductions in the release of 6PPD-quinone into streams would help to ensure these resource-intensive restoration projects will help the recovery of coho.

Adverse waste and end-of-life effects

Reference: California Code of Regulations, title 22, sections 69503.2(b)(1)(B) and 69501.1 (a)(8).

This section summarizes findings related to the waste materials and byproducts generated during the life cycle of the product and their associated adverse effects, as described in the SCP Regulations. These considerations can form part of the basis for proposing the product-chemical combination.

Effects on solid waste and wastewater disposal, treatment, and recycling

As discussed in section 3, tires represent a significant volume of material that must be disposed of or recycled. To address the large volume of solid waste in California landfills, including tires, AB 341 (Chesbro, Chapter 476, Statutes of 2011) set a policy goal for California to divert 75% of its solid waste from landfills by 2020 and mandated that CalRecycle develop a strategy to achieve this goal (CalRecycle 2020a). While not required by the statute, CalRecycle is also aiming for a 75% recycling rate specifically for waste tires (CalRecycle 2021). To continue achieving and exceeding this goal, new and expanded markets for used tires are needed (CalRecycle 2020b). Some current recycling practices will likely need to be reassessed given the recent discovery of the link between 6PPD-quinone and salmon mortality, and any new tire recycling options will also need to take the potential for release of this chemical into account. As discussed above, 6PPD-quinone is a transformation product of 6PPD that is lethal to coho salmon.

Many end-of-life uses of tires have direct pathways to the aquatic environment and may represent a source of contaminants like 6PPD (section 4). While there are currently no regulations restricting the use of recycled tires due to the presence of 6PPD, increased regulatory scrutiny and public concerns for 6PPD and other tire-derived contaminants may limit future applications (e.g., tires as stormwater filters (Lahontan Regional Board 2018)), potentially hindering recycling efforts and interfering with CalRecycle's legislative mandate.

If California's recycled tire market were limited due to the presence of 6PPD, there would be a significant impact on the business infrastructure developed to support tire recycling efforts. For example, there are 23,000 registered waste tire generators in California (such as tire dealers and auto shops), and 1,300 registered waste tire haulers (CalRecycle 2020b). In 2019, over 85% of California waste tires were processed at 21 facilities (CalRecycle 2020b). A total of 16 landfills received significant quantities of waste tire shreds in 2019, but seven of them accounted for over 90% of the waste (CalRecycle 2020b). Furthermore, reducing tire recycling due to the presence of toxicants such as 6PPD and its degradation products could lead to drastic increases in the number of tires being landfilled, burned, or illegally dumped.

Special handling needed to mitigate adverse impacts

Stormwater contaminated with aquatic toxicants such as 6PPD requires special handling to mitigate adverse impacts to aquatic organisms. While neither 6PPD nor 6PPD-quinone is currently regulated in stormwater, if they were, their removal would likely pose challenges similar to those of zinc, another tire-derived stormwater contaminant that is toxic to aquatic life.

As detailed in the California Stormwater Quality Association's 2018 petition to DTSC (CASQA 2018), as well as in DTSC's *Rationale Document for Motor Vehicle Tires containing Zinc* (DTSC 2021a), removing contaminants of concern such as zinc from stormwater often requires special handling that is often technically and financially infeasible in California. The presence of 6PPD-quinone in California waterways at concentrations that have proven lethal to coho salmon (Tian et al. 2021) indicates that current stormwater treatment efforts in some cases are insufficient for the removal of 6PPD-quinone. If 6PPD or 6PPD-quinone were to be regulated in stormwater, municipalities would potentially be required to adopt expensive special handling measures to meet discharge permits and ensure protection of local waterways.

6. OTHER REGULATORY PROGRAMS

Reference: California Code of Regulations, title 22, section 69503.2(b)(2).

When deciding whether to list a product-chemical combination as a Priority Product, DTSC must consider other California and federal laws that regulate the product or the Candidate Chemical in the product and the extent to which these other regulations provide adequate protections with respect to the same exposures and adverse impacts. If the exposures or impacts are regulated by another entity, DTSC may only list a product-chemical combination as a Priority Product if it determines that doing so would meaningfully enhance protection of public health or the environment.

DTSC has assessed all applicable state and federal laws and regulations, as well as international treaties or agreements with the force of domestic law, related to the proposed Priority Product and the Candidate Chemical in the product. The results of these assessments are summarized below. DTSC has determined that these programs do not overlap or conflict with this proposal to list motor vehicle tires containing 6PPD as a Priority Product, nor with any subsequent regulatory response that may result from such listing.

Regulations addressing the same exposures and impacts

The federal Clean Water Act prohibits the discharge of stormwater containing specific pollutants without a National Pollutant Discharge Elimination System (NPDES) permit. U.S. EPA delegates this federal permitting program to the State of California. California's Municipal Storm Water Program manages NPDES permits for municipalities and the statewide permit for Caltrans. These permits are intended to address the same potential exposures and impacts described in this Profile. Neither 6PPD nor 6PPD-quinone is currently regulated by the California State Water Resources Control Board.

DTSC has determined that listing motor vehicle tires containing 6PPD as a Priority Product could meaningfully enhance protection to the environment by requiring manufacturers to conduct an Alternatives Analysis to determine whether there are alternatives to the use of 6PPD that are safer for the environment and public health and ensure that tires meet existing performance and safety requirements.

Regulations addressing the safety and performance of tires

The National Highway Traffic Safety Administration (NHTSA) regulates the safety of tires. NHTSA has established several Federal Motor Vehicle Safety Standards setting safety and performance requirements for tires (Code of Federal Regulations, title 49, subtitle B, chapter V, part 571, subpart B), including:

- Standard No. 109; New pneumatic and certain specialty tires
- Tire selection and rims and motor home/recreation vehicle trailer load carrying capacity information for motor vehicles with a gross vehicle weight rating (GVWR) of 4,536 kilograms (10,000 pounds) or less
- Standard No. 119; New pneumatic tires for motor vehicles with a GVWR of more than 4,536 kilograms (10,000 pounds) and motorcycles
- Tire selection and rims and motor home/recreation vehicle trailer load carrying capacity information for motor vehicles with a GVWR of more than 4,536 kilograms (10,000 pounds)
- Standard No. 139; New pneumatic radial tires for light vehicles

DTSC has determined that these regulations do not overlap or conflict with the proposal to list motor vehicle tires containing 6PPD, as they do not address the potential exposures or adverse impacts under consideration. If motor vehicle tires containing 6PPD were listed as a Priority Product, they would still be required to meet the same standards for safety and performance. The SCP Regulations do not allow DTSC to require the use of alternatives to a Chemical of Concern that would compromise a Priority Product's compliance with health and safety requirements.

Regulations addressing the recycling, reuse, and disposal of tires

Current laws and regulations require people who store, stockpile, accumulate, or discard waste tires to comply with tire storage and disposal standards and to obtain a waste tire facility permit. CalRecycle is responsible for administering waste tire programs in California and has established technical standards and a permitting program for waste tire facilities (CalRecycle 2021).

DTSC has determined that these regulations do not overlap or conflict with the proposal to list motor vehicle tires containing 6PPD, as they do not address the potential exposures or adverse impacts under consideration. CalRecycle's waste tire and storage and disposal standards primarily address preventing fires and the breeding of mosquitoes, rodents, and other pests. If motor vehicle tires containing 6PPD were listed as a Priority Product, they would still be subject to the same requirements.

7. POTENTIAL ALTERNATIVES

Reference: California Code of Regulations, title 22, section 69503.2(b)(3).

This section summarizes information available to DTSC regarding alternatives that may or may not be safer than the Candidate Chemical. DTSC does not need to ensure that these alternatives are safer and may summarize their associated hazards to illustrate readily available information. The sections below may include information such as how readily available an alternative is, product functions addressed by the alternative, and implications for manufacturers using the alternative (e.g., use limitations, product reformulation, different equipment needs).

As long as rubber tires are used on motor vehicles, they will likely need to be protected from ozone and oxygen. Cataldo (2019) indicates that ground-level ozone concentrations have risen over the past hundred years and are predicted to continue to rise, presumably making antiozonants more important in materials, like tire rubber, that are susceptible to degradation by ozone. Ideally, a safer alternative to 6PPD would exhibit relatively low toxicity itself and in its transformation products.

Perhaps the most obvious chemical alternatives to 6PPD are other 4-aminodiphenylamine (4-ADPA) derivatives such as:

- N-(1,4-dimethylpentyl)-N'-phenyl-p-phenylenediamine (7PPD, CASRN 3081-01-4),
- N-(1-methylethyl)-N'-phenyl-p-phenylenediamine (IPPD, CASRN 101-72-4),
- N-cyclohexyl-N'-phenyl-p-phenylenediamine (CPPD, CASRN 101-87-1),
- N,N'-diphenyl-p-phenylenediamine (DPPD, CASRN 74-31-7)

and dialkyl-substituted PPDs. Although structural similarity to 6PPD is likely to imply similar desirable properties for analogs (e.g., reactivity toward ozone and compatibility with vulcanization packages and other materials used in tires), close structural similarity would also predict analogous transformation products and toxicity. As described below in section 8, research begun in the early 1980s concluded that 6PPD and other PPDs form dinitrones upon reaction with ozone. If Tian et al. (2021) are correct that the dinitrone is, in fact, a quinone, then those other PPDs likely also form quinones.

There may be other chemicals that function as effective antidegradants, are compatible with tire rubber, and are less toxic than 6PPD and its transformation products. Achieving the same level of performance may require tire manufacturers to assemble a package of safer chemicals, given that a single PPD is able to protect rubber from degradation by ozone, oxygen, fatigue, heat, and metal ions (Ignatz-Hoover 2020). However, Ignatz-Hoover (2020) also notes that, in selecting antidegradants, product formulators must generally select for superior antioxidant or antiozonant performance and that it makes little sense to sacrifice PPD antiozonants to oxidative loss when less expensive antioxidants are available. As a result, chemical antioxidants such as (*N*-1,3-dimethyl butyl-*N'*-phenyl quinone diimine (6QDI) and polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ; CASRN 147-47-7) may be added to tires (Cardno ChemRisk 2013; Ignatz-Hoover 2020). Ignatz-Hoover (2020) observes that 6PPD and TMQ are an effective antioxidant combination, but that 6QDI is even more effective. 6QDI and 6PPD are closely related chemical species: 6QDI can be generated by oxidizing 6PPD; conversely, 6PPD can be generated by reducing 6QDI. During vulcanization, 6QDI can both undergo oxidation to generate 6PPD and bond to rubber polymers or the carbon black typically added to tires (Huntink et al. 2004; Ignatz-Hoover 2020). This means that 6QDI in tires represents a potential source of 6PPD and 6PPD-quinone. Structural analogs of 6QDI may similarly generate other PPDs and PPD-quinones.

Huntink et al. (2004) and Ignatz-Hoover (2020) review many possible alternatives to PPD antidegradants, with an emphasis on long-lasting and non-staining or non-discoloring products. They include hindered phenols and bisphenols; hydroquinones; phosphites; organic sulfur compounds; hindered amine and nitroxyl compounds; phenylnaphthylamines; dihydroquinolines; diphenylamine derivatives; amine-based, bound-in or polymer-bound antioxidants; petroleum waxes; nickel dibutyldithiocarbamate; 6-ethoxy-2,2,4-trimethyl-1,2-dihydroquinoline; triazines and triazinethiones; and oligomeric or polymeric antioxidants (e.g., derivatized polysiloxanes). The limitations of these 6PPD alternatives may include high cost, suspected toxicity, and incompatibility with vulcanization. Krüger et al. (2005) discuss PPD derivatives with a sulfoxide or thioether moiety bearing a long hydrophobic chain; this modification increases solubility in nonpolar elastomer matrices and confers the ability to react (i.e., bond) with the rubber polymer. Huntink et al. (2004) and Krüger et al. (2005) focus, in part, on antioxidants used in food contact or medical applications in which extraction resistance is a key attribute of additives, so the applicability to tire rubber is unknown.

Another possible approach could involve a coating or physical barrier to prevent gas-phase ozone from reaching the tire surface. However, while such an approach might be feasible under static conditions (for example, during transportation to the point of sale and storage), it would likely face significant challenges under dynamic conditions—that is, during a tire's intended use on a motor vehicle. Furthermore, this would likely be an infeasible means of protecting the tire tread.

The observation that manganese oxide can catalyze the destruction of ozone (Li and Oyama 1998) suggests that other, as-yet undiscovered additives or coatings that could protect tires from the destructive effects of ozone and oxygen may exist. These possibilities represent potential future research efforts.

Additionally, tires could be made from materials that are less susceptible than conventional tire rubber blends to oxidative degradation. This approach could reduce the need for antidegradants. Huntink et al. (2004) discuss the addition of ozone-resistant polymers (e.g., ethylene propylene rubber, ethylene propylene diene rubber, halobutyl, and polyethylene) to rubber mixtures. Huntink et al. assert that the ideal proportion of ozone-resistant polymers is 20% to 50%; however, they also state that such polymer blends are imperfect in that they do not completely prevent ozone damage under dynamic stress and, when vulcanized, they lack some of the desired performance characteristics of conventional rubber blends (Huntink et al. 2004).

So-called airless or non-pneumatic tires are another example of tires made from unconventional materials. As the name suggests, airless tires do not rely on trapped, compressed air (or other gas) to support the weight of the vehicle. Current prototypes and the few commercially available examples instead rely on structural elements (for example, spokes) made, at least in part, of materials other than rubber. For example, Michelin's Unique Puncture-proof Tire System prototype airless tire, designed for passenger cars, features "a flexible load-bearing structure made from glass fiber reinforced plastic" (Michelin 2021a). Bridgestone's "Air Free Concept (Non-Pneumatic) Tire" features spokes made of a thermoplastic resin that becomes flexible and can be shaped or molded when heated, and that hardens as it cools. The materials used to provide structural support in airless tires may be sufficiently different that PPDs are no longer the best choice of antiozonant, although this may not be the case for the treads. Thus, airless tires may reduce the amount of antiozonant used per tire, thereby reducing the total flux of these chemicals to the environment. Several tire manufacturers (Bridgestone, Goodyear, Hankook, Michelin, Sumitomo, Toyo) have signaled that they are developing airless tires for motor vehicles (Hankook 2015; Goodyear 2017; Bridgestone 2021; Michelin 2021b; Sumitomo 2021; Toyo 2021). Michelin's Tweel is presently available for applications—such as golf carts, riding mowers, all-terrain vehicles, and light construction equipment—not covered by DTSC's proposed definition of motor vehicle for this Priority Product (Michelin 2021c).

Another less immediate possibility is commercialization of so-called spring tires for motor vehicles, such as those developed by the National Aeronautics and Space Administration; these are made of a nickel-titanium shape memory alloy (NASA 2021a) and do not use rubber. A version developed by the

SMART Tire Company for bicycles is reportedly slated for sale in 2021 (NASA 2021b; The SMART Tire Company 2021).

8. ADDITIONAL CONSIDERATIONS

This section summarizes other relevant information not captured under the adverse impact and exposure factors named in section 69503.3 of the Safer Consumer Products Regulations.

6PPD antidegradant mechanism

6PPD, like some other PPDs, is thought to function as an antidegradant by migrating to the surface of the tire (a process known as blooming), where it reacts with atmospheric ozone faster than the rubber can, forming a protective film (Lattimer et al. 1983; Huntink et al. 2004); however, the composition of the protective film may be very complex and remains unclear. For example, PPDs may also react with phenolic antioxidants (if present in tires), producing a variety of reaction products, including some quinones other than 6PPD-quinone (Taimr and Pospiil 1984). There are now competing theories for the mechanism of 6PPD's reaction with ozone. Researchers in the early 1980s (Lattimer et al. 1983) proposed a dinitrone structure for one of the ozonation products of 6PPD ($C_{18}H_{22}N_2O_2$), a conclusion that was supported by subsequent investigations (Huntink et al. 2004). However, a recent study (Tian et al. 2021) using two-dimensional nuclear magnetic resonance (NMR) spectroscopy concluded that $C_{18}H_{22}N_2O_2$ is a quinone, not a dinitrone.

Lattimer et al. (1983) identified 13 structures for ozone-6PPD reaction products, including one with the formula $C_{18}H_{22}N_2O_2$ that they described as a dinitrone, and that Tian et al. (2021) subsequently identified as 6PPD-quinone. Lattimer et al. (1983) considered several possible mechanisms that could produce these structures and concluded that the reaction follows three competing ozonation pathways. According to their findings, the dominant mechanism is the nitroxide radical pathway, which leads to the formation of a nitrone (Figure 7a) and, to a lesser extent, the dinitrone (Figure 7b). The other two relevant pathways are the amine oxide pathway (forming nitrosoaryl and nitroaryl products) and side chain oxidation pathway (forming low molecular weight products, including some amides).

Subsequent studies describe several intermediate reaction products during the oxidation of 6PPD, including 6QDI (Figure 7c) (Hong and Lin 2000; Cataldo 2002; Li and Koenig 2003; Huntink et al. 2004; Cibulková et al. 2005).

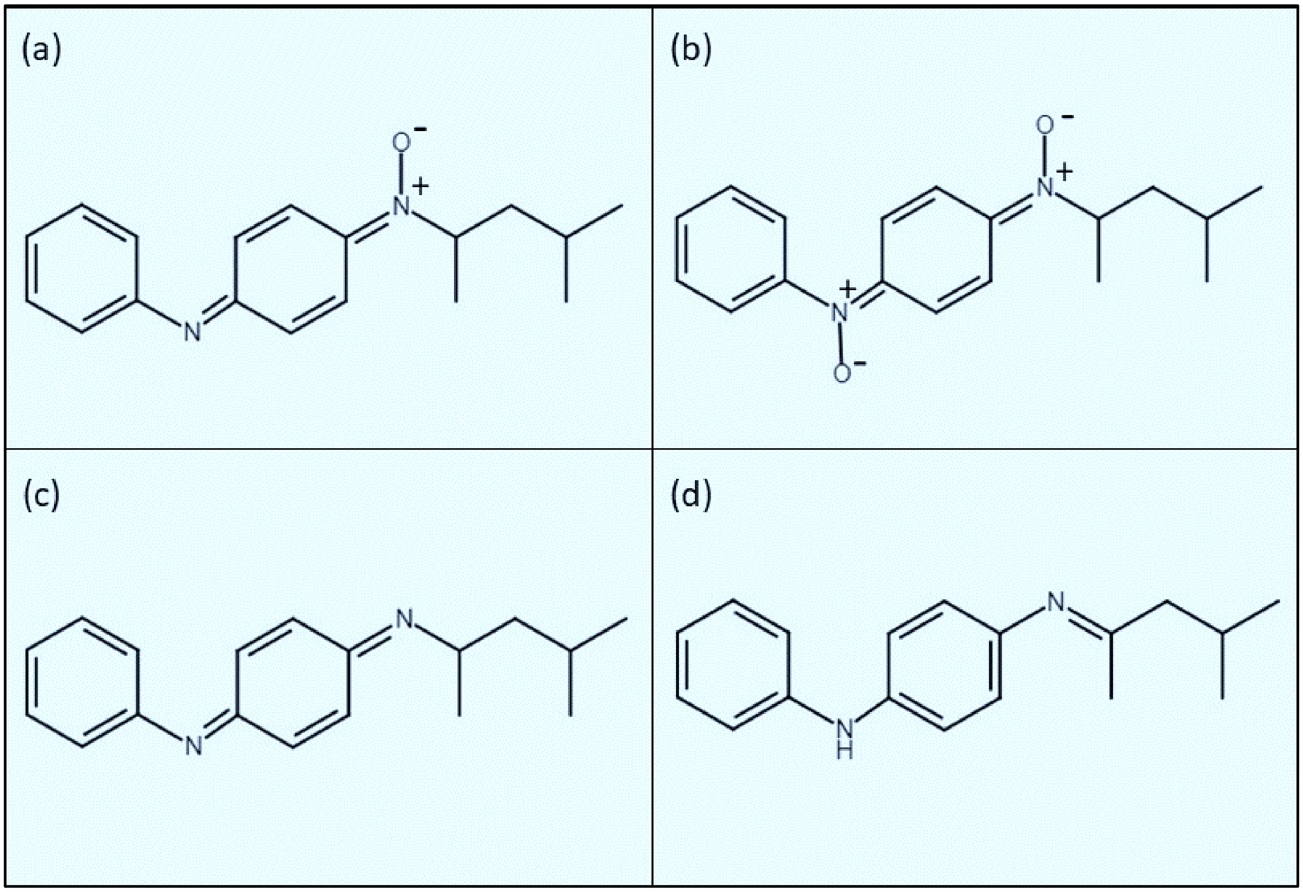


Figure 7: Oxidation products of 6PPD proposed in earlier studies: (a) nitrone; (b) dinitrone; (c) 6QDI; (d) ketimine.

Environmental conditions have not been conserved across a plethora of studies involving the mechanism of PPD oxidation; this has led to debate over competing mechanisms with multiple possible intermediate and final reaction products. Benzoquinone diimines (QDIs) are generally thought to be intermediate reaction products in the oxidation of PPDs that protect the rubber (Cibulková et al. 2005), but they are not included in the 6PPD-quinone formation mechanism suggested by Tian et al. (2021). At neutral or weakly basic pH, alkyl-aryl PPD-derived quinone diimines appear to be relatively stable, but at even slightly acidic pH in the presence of water they hydrolyze to their benzoquinoneimine derivatives (Taimr and Pospisil 1984). Some researchers have argued that the mechanism involves the preferential dehydrogenation of the PPD at the N-bonded tertiary carbon atom, resulting in a ketimine (phenyl-N=C, see Figure 7d) rather than a quinone diimine (phenyl=N-C, see Figure 7c) (Polovková et al. 2006; Gatial et al. 2007). Subsequently, Rapta et al. (2009) described different mechanisms for the antioxidant action of PPDs, depending on the environmental conditions, especially on the matrix, pH, and temperature. They found that benzoquinone diimines are the final oxidation products of PPDs in solution, whereas the ketimine structure forms when the PPD sample is heated in air.

Thus, for the past few decades, the reaction protecting tires against ozone attack was thought to start with ozone extracting an electron from a nitrogen atom of the PPD molecule. It was reported that PPDs donate hydrogen atoms, forming aminyl radicals through a process that involves condensation, hydrolytic, and redox reactions (Klein et al. 2005), but the exact mechanism depends on temperature (Puškárová et al. 2016) and pH (Taimr and Pospisil 1984).

The study by Tian et al. (2021) changed the current understanding of 6PPD ozonation mechanisms. They used two-dimensional NMR spectroscopy and simulations to demonstrate that the compound with formula $C_{18}H_{22}N_2O_2$ first described by Lattimer et al. (1983) as a dinitrone (Figure 7b) is, in fact, a quinone, which they called 6PPD-quinone (Figure 2). They also demonstrated that 6PPD-quinone can form from the reaction of 6PPD and ozone in gas phase in the lab. They hypothesized that the 6PPD-quinone forms through a phenol or semiquinone radical intermediate.

While Tian et al. (2021) make a compelling case for the quinone structure of $C_{18}H_{22}N_2O_2$, several questions remain. Their proposed mechanism does not account for the $C_{18}H_{22}N_2O$ compound described as a nitrone by Lattimer et al. (1983), nor for the $C_{18}H_{22}N_2$ compound described as a quinone diimine (i.e., 6QDI) (Huntink et al. 2004; Cibulková et al. 2005) or a ketimine (Polovková et al. 2006; Gatial et al. 2007; Rapta et al. 2009) in previous studies. It is unclear under what environmental conditions (e.g., temperature, ozone levels, presence or absence of water) the mechanisms proposed by Tian et al. (2021) would be favored compared to mechanisms producing these other compounds identified in earlier 6PPD oxidation studies. It also remains to be seen whether other mechanisms beyond those proposed by Tian et al. (2021) could lead to the formation of 6PPD-quinone and whether 6PPD-quinone can also form from other 6PPD oxidation products such as 6QDI.

Regardless of the exact mechanism or chemical structure, Tian et al. (2021) demonstrated that the $C_{18}H_{22}N_2O$ compound is present in TWP leachate and is lethal to coho salmon. Filling some of the data gaps about the exact reaction mechanism that leads to the formation of 6PPD-quinone and where that reaction takes place can help inform DTSC’s work, but the acute toxicity of 6PPD-quinone has been amply demonstrated and there is sufficient information about potential exposures and adverse impacts for DTSC to propose regulating tires containing 6PPD as a Priority Product.

Stressors that exacerbate the impact of 6PPD-quinone on coho populations

A range of anthropogenic factors can exacerbate 6PPD-quinone’s lethality to coho. While the chemical’s toxicity is newly discovered, it has been used in tires for decades as an antiozonant. 6PPD’s use since roughly the 1950s or 1960s (Personal communication, Eastman Chemical Company, June 7, 2021), has coincided with a dramatic drop in California’s coho populations (Brown et al. 1994). 6PPD’s reaction product, 6PPD-quinone, may have been a previously unrecognized factor—among many other stressors (Brown et al. 1994; CalTrout 2017; CDFW 2021a)—contributing to the coho's decline. The interaction between these stressors, discussed below, can cause adverse impacts at both the individual and the population level. Sublethal effects of 6PPD-quinone and these other stressors have potentially acted in concert to depress the coho population over the past 60 years (Brown et al. 1994; NRC 2004; Baldwin et al. 2009b). The cumulative impacts of sublethal levels of toxicants and other stressors wreak havoc on the individual's physiology and may threaten the animal's survival. At the population level, 6PPD-quinone represents one of many stressors faced by California's already-decimated coho populations that, taken together, threaten the survival of the species.

Changes in stream flow

Dams

Dams block access to rivers and streams that formerly provided habitat for coho (California Fish & Game Commission 2002; NRC 2004). For example, in the Klamath Basin, the Iron Gate Dam blocks the main stem of the Klamath, while the Dwinnell Dam blocks the upper Shasta River, and the Trinity River Diversion Project disrupts that river's flow (see Figure 4 above). Further, there are numerous small dams, used for irrigation, blocking small tributaries that previously provided habitat for spawning and for the young coho to mature (NRC 2004). Dams are generally a stressor at the population level by reducing previously available habitat. In addition, changes in water flow due to dams may alter the temperature of creeks and cause physiologic stress at the individual level.

Drought

Disruption of the precipitation patterns that have allowed coho to thrive along the Pacific Coast for the past 6 million years (Waples et al. 2008) is another factor stressing coho salmon (Barboza et al. 2014; Crozier et al. 2019). The frequency and severity of droughts in California is predicted to increase with climate change (Diffenbaugh et al. 2015). Winter rains are needed to allow adults to pass sand bars and other barriers to migrate upstream to spawn. In the drought of 2014, hundreds of adult coho were seen circling at the mouth of Scott Creek near Santa Cruz, waiting for sufficient winter rains to be able to pass the sand bar that partly blocks the mouth (Barboza et al. 2014). The same year, in Siskiyou County, coho returned in abundance to Scott River but there was so little water in the smaller tributaries that fish could not reach 90% of their natal streams to spawn (Barboza et al. 2014). Failure to spawn may result in a failure of an entire year class. Furthermore, during droughts, some creeks may dry up, trapping young salmon in isolated pools whose water is likely to exceed the temperature lethal to coho. Again, this could kill off an entire year class. It is unlikely that a coho population can survive many successive years of drought.

In addition, the low water flows and high water temperatures associated with dammed rivers may also exacerbate the lethal effects of the salmonid bacterial pathogen, *Ceratonova shasta* (Som et al. 2019).

With normal river temperatures and flows, the *C. shasta* population is kept at a moderate level and does not typically harm healthy fish (Som et al. 2019). Unfortunately, in May 2021, Yurok fish biologists reported that 97 percent of juvenile salmon caught in traps in the Klamath were infected with the bacteria due to low flows caused by the drought (Associated Press 2021; Greenson 2021). The effects of toxicants and pathogens can be additive, where the sublethal effects of one stressors may make the fish more vulnerable to the effects of the other (Austin 1998; Arkoosh et al. 1998; Beiras 2018; Lundin et al. 2019). Thus, 6PPD-quinone may make fish more vulnerable to bacterial infections, and fish weakened by a heat-related high pathogen load may be more susceptible to the chemical's toxicity.

Drought may also indirectly affect coho. The tree canopy provides vital shade that limits warming in streams, despite warm ambient temperatures. When shade trees are lost due to droughts or drought-induced fires (Diffenbaugh et al. 2015), heavily shaded stream sections may no longer be available, and therefore streams can warm to the point that they may cause thermal stress for the coho (Brown et al. 1994; NRC 2004). This heat stress could make individuals more susceptible to the effects of 6PPD-quinone and other toxins (Laetz et al. 2014). At the population level, heat stress is yet another factor contributing to the decline of coho in California.

Changes in stream morphology and sedimentation

Salmon require complex stream morphology, with pools, riffles, and gravel beds for spawning and juvenile development (CDFW 2021a). Salmon lay eggs in gravelly substrate on the stream bed (CDFW 2021a). The gravel helps to hide the hatchlings when they emerge from their eggs (UC ANR 2021). As the fish mature, they tend to prefer deeper pools, especially those created by downed trees or fallen branches that provide refuge from predators and storms (CDFW 2021a; The Nature Conservancy 2021b; UC ANR 2021). When the levels of dissolved oxygen decrease, juvenile salmon often move into riffles or other areas of turbulent water flow, where the oxygen levels are higher (UC ANR 2021). All these physical features in streams are critical for the long-term success of coho. Urbanization often leads to the channelization of streams—straightening their curves and creating a more uniform depth. These changes in the stream may facilitate human management of the water, but they destroy the coho habitat (CDFW 2021a; The Nature Conservancy 2021b).

Besides urbanization, other land-use changes can impact the physical habitat of the stream by changing the pattern of runoff. For example, logging and the associated road-building required to transport machinery and logs increase erosion on steep and often fragile slopes (NRC 2004). The increased deposition of sediment into streams limits the availability of ideal substrate for spawning salmon to build their nests, as well as the availability of habitat for hatchlings to hide (Cederholm and Reid 1987; NRC 2004; KRISWeb 2011; Moyle 2011). Runoff can smother the eggs and reduce hatching success, particularly if it is laden with fine sediment (KRISWeb 2011; CDFW 2021a). Sediment can also fill the pools and crevasses where juveniles seek refuge (Muck 2010). Increased turbidity may reduce the juvenile's ability to effectively forage and hunt (Cederholm and Reid 1987). At the individual level, sediment may accumulate on the gill filaments, interfere with respiration, and harm gill tissue (Cederholm and Reid 1987). Increased sediment loading may have synergistic effects with 6PPD-quinone, since the gills are seemingly a target of the chemical's toxicity (Kendra and Willms 1990; Blair et al. 2021). At high sediment concentrations, juvenile coho show visible signs of distress, such as rapid opercular movements and coughing (Cederholm and Reid 1987). Even moderate levels of sediment may result in sublethal and behavioral effects such as increased activity, stress, , and a decline in prey capture success (Cederholm and Reid 1987). Other salmonids also show reduced growth and resistance to disease; physical abrasion; biochemical changes; avoidance of the area; and interference with orientation in homing and migration at higher turbidity levels (Servizi and Martens 1992; Muck 2010).

Natural life history

Pacific salmonids, including coho salmon, are anadromous species (Crozier et al. 2019). They have complex life cycles that involve multiple growth stages and distant migrations (Crozier et al. 2019). Salmonids have evolved physiological and behavioral capacities that allow them to survive under stressful conditions (Katz et al. 2013). This is particularly true of salmonids native to California, which live at the southern edge of their species' range and have adapted to seasonal extremes and inter-annual variability in stream flow (Katz et al. 2013). These adaptations come at the cost of living near or at their physiological limits, which may make the salmonids particularly vulnerable to the rapid onset of adverse environmental conditions caused by human activities (Katz et al. 2013).

While it is impossible to tease out 6PPD-quinone's role in the decline of coho in California, the chemical's continued presence in California's waterways poses a serious challenge to the recovery of the state's coho populations. Other stressors may have made individuals more susceptible to the chemical's effects. It may also be that the population is so suppressed by these other stressors that losing even a fraction of coho to 6PPD-quinone could push the species past the tipping point for extinction.

Alignment with other efforts

6PPD is on Minnesota's Toxic-Free Kids Act Chemicals of High Concern List (Minnesota Department of Health 2019) and Maine's Chemicals of Concern list (Maine DEP 2017). Like California, both states list 6PPD by reference to Part A of the list of Chemicals for Priority Action adopted by the Oslo and Paris Conventions for the Protection of the Marine Environment of the North-East Atlantic (OSPAR).

Two bills (H.F. 639 and H.F. 1079) in the Minnesota House of Representatives would require the state Clean Water Council to develop and issue a request for proposals for a study of the impacts of 6PPD-quinone on the state's waters and fish populations (Hansen et al. 2021; Leon and Rick 2021).

9. CONCLUSIONS

DTSC has determined that motor vehicle tires containing 6PPD meet the key prioritization criteria for listing a Priority Product (CCR, title 22, section 69503.2(a)):

(1) There are potential public and/or aquatic, avian, or terrestrial animal or plant organism exposures to 6PPD and 6PPD-quinone from motor vehicle tires; and
(2) There is a potential for one or more of these exposures to contribute to or cause significant or widespread adverse impacts.

The use of motor vehicle tires is widespread across California. It has been estimated that over 171 million tires are rolling on California roads in 2021 alone. 6PPD is present in most, if not all, of these tires at concentrations up to 1% to 2% by weight (10,000 to 20,000 µg/g). The chemical slowly migrates from the interior of the tire over the tire's lifetime to ensure a continuous source of 6PPD at the tire surface. 6PPD reacts with ozone at the surface of the tire and forms a number of reaction products, including 6PPD-quinone.

TWP are generated as tires roll across road surfaces and can enter the aquatic environment through surface runoff and stormwater. While an individual tire generates only a small amount of TWP per mile, the aggregate amount released by the tens of millions of tires on California's roads is very large. TWP have a high potential to expose aquatic organisms to 6PPD and 6PPD-quinone. Repurposing, recycling, or landfilling used motor vehicle tires may exacerbate the potential for 6PPD and 6PPD-quinone exposure to coho and other aquatic life.

6PPD-quinone has been detected in California streams at concentrations that are lethal to coho in laboratory experiments. Detections of 6PPD-quinone in California waterways clearly indicate that it is sufficiently persistent in aquatic systems, and exposures to coho salmon and other aquatic organisms can occur.

6PPD is acutely toxic toward aquatic organisms at multiple trophic levels and can impair wildlife survival. 6PPD is also phytotoxic. 6PPD-quinone, a reaction product of 6PPD, is acutely toxic to coho salmon, including juveniles, and kills fish just a few hours after exposure. The compound has been identified as the causal agent for URMS in the Puget Sound area of the Washington coast. 6PPD kills coho salmon as they migrate upstream, before they are able to spawn. Thus, the presence of 6PPD in motor vehicle tires and its release to the aquatic environment has the potential to significantly impact two populations of coho salmon in California, one of which is endangered and the other threatened.

California tribes and the state of California together have invested millions of dollars in an effort to retain and replenish coho populations. The continued presence of 6PPD-quinone may jeopardize the recovery of this species, which faces a number of additional challenges including climate change, habitat destruction and loss, and exposure to other contaminants found in urban runoff.

Given the very recent discovery of 6PPD-quinone, little is known about the effect of this compound on other aquatic organisms besides coho. However, toxicity is particularly likely for economically important species closely related to coho such as chinook salmon, steelhead, and the California golden trout.

Many of the end-of-life uses of tires have direct pathways to the aquatic environment and may represent sources of contaminants like 6PPD. Release of 6PPD from used tires and tire-derived products may exacerbate the environmental releases and exposures during tires' use phase. Since the recent publication of the paper by Tian et al (2021), 6PPD's use in tires has drawn increased regulatory scrutiny and heightened public concern about tire-derived contaminants. This attention could hamper current and future efforts to divert tires from landfills through various types of recycling. If 6PPD or 6PPD-quinone were to be regulated in stormwater, municipalities would be forced to adopt expensive special handling measures to meet discharge permits and ensure protection of local waterways.

Further studies may help inform DTSC's future decision-making. Despite these data gaps, DTSC has sufficient information regarding potential exposures and adverse impacts from motor vehicle tires containing 6PPD to designate this as a Priority Product.

ACRONYMS AND ABBREVIATIONS

6QDI	N-1,3-dimethyl butyl-*N′*-phenyl quinone diimine
6PPD	N-1,3-dimethylbutyl-N’-phenyl-p-phenylenediamine
6PPD-quinone	2-anilino-5-[(4-methylpentan-2-yl)amino]cyclohexa-2,5-diene-1,4-dione
7PPD	N-(1,4-dimethylpentyl)-N’-phenyl-p-phenylenediamine (CASRN 3081-01-4)
BBB	Blood-brain barrier
BCF	Bioconcentration factor
Caltrans	California Department of Transportation
CASRN	Chemical Abstract Service Registry Number
CCC	Central California Coast population of coho
CCR	California Code of Regulations
CDFW	California Department of Fish and Wildlife
CDR	Chemical Data Reporting
CO_2	Carbon dioxide
CPPD	N-cyclohexyl-N'-phenyl-p-phenylenediamine
DCU	Dicyclohexylurea
DDT	Dichloro-diphenyl-trichloroethane
DPG	1,3-Diphenylguanidine
DPPD	N,N'-diphenyl-p-phenylenediamine
DTSC	Department of Toxic Substances Control
EC_{50}	Median effective concentration
ESA	Endangered Species Act
ESU	Evolutionary significant unit
g	gram

GHS:	Globally Harmonized System of Classification and Labelling of Chemicals.
GPC	GS1 Global Product Classification
GVWR	Gross Vehicle Weight Rating
HMMM	Hexa(methoxymethyl)melamine
IPPD	N-(1-methylethyl)-N'-phenyl-p-phenylenediamine
IUPAC	International Union of Pure and Applied Chemistry
kg	Kilogram
K_{ow}	Octanol water partition coefficient
L	Liter
LC_{50}	Median lethal concentration
LD_{50}	Median lethal dose
mg	Milligram
µg	Microgram
µm	Micron
mL	Milliliter
NAICS	North American Industry Classification System
ng	Nanogram
NHTSA	National Highway Traffic Safety Administration
NMR	Nuclear magnetic resonance
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
O.	*Oncorhynchus* genus
O_2	oxygen or dioxygen
O_3	ozone

OECD	Organisation for Economic Co-operation and Development
OSPAR	Oslo and Paris Conventions for the Protection of the Marine Environment of the North-East Atlantic
PAH	Polycyclic aromatic hydrocarbon
pg/m^3	picograms per cubic meter
PPD	para-Phenylenediamine
QDIs	Benzoquinone diimines
ROS	Reactive oxygen species
SCP	Safer Consumer Products
SFEI	San Francisco Estuary Institute
SONCC	Southern Oregon/Northern California Coast population of coho
SUV	Sport Utility Vehicle
TMQ	2,2,4-Trimethyl-1,2-dihydroquinoline
TWP	Tire wear particles
URMS	Urban runoff mortality syndrome
USTMA	United States Tire Manufacturers Association
U.S. EPA	United States Environmental Protection Agency

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APPENDIX A: POTENTIAL RELEVANT FACTORS

Non-exhaustive list of adverse impact factors that may be relevant to this proposed Priority Product

Relevant Factors are used in SCP's Alternatives Analysis (AA) to make a focused and meaningful comparison of adverse impacts during the product's lifecycle between the PP and alternative. This Profile has identified adverse impacts in the following categories:

- Adverse environmental impacts
- Adverse public health impacts
- Adverse waste and end-of-life effects
- Environmental fate
- Physicochemical properties
- Associated exposure pathways and life cycle segments
    - Manufacture
    - Use
    - Waste generation and management
    - Reuse and recycling
    - End-of-life disposal

At a minimum, all AAs submitted for this product-chemical combination must include a discussion of these impacts and how they compare between the Priority Product and whatever alternative(s), including their reaction products, have been identified at the appropriate point in the lifecycle. This list is not intended to be comprehensive. Also, alternatives evaluated in the AA report will likely have additional adverse impacts that don't apply to the Priority Product; these will also need to be assessed in the AA report. Product performance and economics are generally not evaluated in the Profile.

APPENDIX B: REPORT PREPARATION

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