UNITED STATES DEPARTMENT OF COMMERCE
The Under Secretary of Commerce
for Oceans and Atmosphere
Washington, D.C. 20230

October 15, 2021

The Honorable Marilyn Strickland
Ranking Member
Subcommittee on Railroads, Pipelines,
and Hazardous Materials
Committee on Transportation and Infrastructure
U.S. House of Representatives
Washington, DC 20515

Dear Representative Strickland:

Thank you for your letter regarding the effects of 6PPD-quinone on coho salmon and other salmonids, aquatic species, and watersheds across the country.

As mentioned in your letter, the National Oceanic and Atmospheric Administration (NOAA), along with partners, recently discovered that a chemical contained in car tires (6PPD-quinone) is harmful to fish, especially endangered salmonids. This discovery was the result of 20 years of scientific collaboration.

NOAA has identified several research priorities across a range of disciplines to address the broader conservation challenge of urban stormwater and its effects on aquatic life. To better account for these issues, NOAA needs long-term funding to support a robust environmental health research program and to support management actions that consider water quality as a critical part of species habitats. NOAA's response to the seven specific questions presented in your letter can be found in the attachment.

NOAA remains committed to the conservation and recovery of protected species, relying on the best available science to inform management decisions. If you have further questions, please contact Tanya Dobrzynski, Acting Director of NOAA's Office of Legislative and Intergovernmental Affairs, at (202) 482-4981 or by email at tanya.dobrzynski@noaa.gov.

Sincerely,

Dr. Richard W. Spinrad
Under Secretary of Commerce
for Oceans and Atmosphere
and NOAA Administrator

Enclosure

Northwest Fisheries Science Center Response to Letter from Representative Huffman, et al.

1. What are NOAA and FWS doing to evaluate the impacts of 6PPD-quinone on salmonids and other species?

Our current understanding of toxic stormwater threats to salmonids, including tire-derived 6PPD-quinone, is built on a continuous line of Federal research dating back to the fall of 2001. Following anecdotal reports of adult coho salmon dying prematurely in urban spawning habitats in the late 1990s, the National Oceanic and Atmospheric Administration (NOAA) and U.S. Fish and Wildlife Service (FWS or USFWS) initiated a long-term, intensive field study to identify the underlying causes and conservation consequences of the distinctive pre-spawn mortality syndrome.

NOAA scientists have led or contributed significantly to the foundational literature describing the urban mortality syndrome. (Please see the bibliography of peer-reviewed publications below.) The first decade largely consisted of intensive field surveys and forensic analyses, with major Federal funding from the NOAA Coastal Storms Program (since discontinued) and the USFWS National Contaminants Program (also discontinued). Over the past decade, the joint NOAA-FWS effort has been extensively supported by the Environmental Protection Agency (EPA) as part of the National Estuary Program to recover Puget Sound.

NOAA and FWS lead investigators have assembled teams of collaborators and stakeholders to tackle several key questions deemed vital for the joint habitat and protected species missions of the two agencies, in alignment with the clean water goals of EPA. This work is ongoing, with multiple additional unpublished studies forthcoming. To date, the research has focused on the following core objectives:

1. **An extensive forensic analysis** of adult coho spawners confirmed to have died prematurely from the mortality syndrome in urban habitats (Scholz et al., 2011);
2. **Population modeling** to predict likely future consequences of the mortality syndrome for wild coho currently at risk from lowland coastal development (Spromberg and Scholz, 2011).
3. **Landscape modeling** to predict vulnerability risks to coho in relation to watershed- and catchment-scale land cover (e.g., roads and highways) and land use (e.g., motor vehicle traffic) (Feist et al., 2011; Feist et al., 2017; Ettinger et al., 2021).
4. **Cross-species vulnerability assessments** to evaluate risks to other salmonids, including chum, Chinook, steelhead, and sockeye (Scholz et al., 2011; McIntyre et al., 2018; McIntyre et al, 2021).
5. **Life cycle analyses** to assess the impacts of stormwater on other salmonid life stages, including juvenile coho. The demonstration that juvenile coho were similarly susceptible to runoff toxicity (McIntyre et al., 2015; Chow et al., 2018) was fundamental to the subsequent discovery of 6PPD-quinone (Tian et al., 2021).

6. **Green stormwater effectiveness** studies to identify reliable and inexpensive management options for filtering toxic pollutants, including 6PPD-quinone but also hundreds of other unknown chemicals, thereby protecting aquatic life (McIntyre et al., 2014, 2015, 2016a&b; Spromberg et al., 2016).
7. **Identification of the "smoking gun,"** over the course of multiple studies to fractionate complex chemical mixtures in stormwater and identify the causal agents in the urban mortality syndrome (Du et al., 2017; Peter et al., 2018; Tian et al., 2020).
8. **Threats to other aquatic life**, particularly keystone species such as shore-spawning (i.e., near stormwater outfalls) marine forage fish that support Southern Resident Killer whales, marine birds, and many other priority species for the Services (Harding et al., 2020).

2. What impact is 6PPD-quinone-linked, pre-spawn mortality having on your agencies' coho salmon recovery efforts? How are your agencies incorporating the impacts of this chemical on endangered salmon recovery efforts?

Salmon will need cool, clean water in sufficient quantities to survive both a warming climate and the rapid, ongoing urbanization of major watersheds throughout California and the Pacific Northwest. The term "urbanization" broadly describes the conversion of native forests and grasslands to rooftops, parking lots, roads, and other impervious surfaces that increase stormwater runoff. Climate and land use changes are both major drivers of non-point source pollution, an expanding toxic threat to the many protected species, habitats, and fisheries resources managed by NOAA. Urban stormwater presents an enormously complicated challenge, in part because there are so many potentially toxic chemicals that occur in dynamic mixtures that vary in space and time. Accordingly, research to better understand and reduce stormwater threats to salmon has been a central focus of NOAA's Northwest Fisheries Science Center (NWFSC) Ecotoxicology Program science enterprise for the past two decades. Over the years, this work has led to major advances in our understanding of threats posed by priority contaminants in urban runoff, including metals, petroleum hydrocarbons, pesticides and, more recently, 6PPD-quinone. NOAA research on copper toxicity to the salmon olfactory system, for example, provided a technical foundation for a national phase-out of metals from motor vehicle brake pads (e.g., https://suscon.org/project/brake-pad-partnership/).

If unaddressed, the urban mortality syndrome has the potential to critically undermine ongoing conservation and recovery efforts for west coast salmon populations near urban areas and highly populated coastal communities, now, and in the coming decades. Wild coho stocks are unlikely to withstand the high rates of spawner mortality that have been consistently observed in urban watersheds, many of which have undergone extensive physical habitat restoration (e.g., culvert removal to improve access). Moreover, the impacts of 6PPD-quinone likely extend to other salmonids; NOAA is currently studying sublethal toxicity to steelhead). Further, the aggregate threats posed by toxics in stormwater will extend far beyond 6PPD. This reality continues to influence the science planning for NOAA. For example, the team began working on green infrastructure mitigation strategies for mass pollutant removal several years before 6PPD-

quinone was positively identified. The toxicity of this particular tire-derived chemical will remain a focus for future studies, but the larger conservation challenge related to urban stormwater is much more extensive and complicated.

In specific reference to 6PPD-quinone, NOAA has proposed the following research priorities for FY22-24:

1. **Establish and validate analytical chemistry methods** for measuring 6PPD and 6PPD-quinone in surface waters and fish tissues, for future use in field studies to monitor chemical exposure, environmental persistence and movement through food webs (i.e., bioaccumulation), and similar applications.
2. **Define the mechanism of toxic action** for 6PPD-quinone to determine the precise (i.e., molecular) basis for the mortality syndrome in coho, and why this may or may not extend to other ESA-listed (or candidate) salmonids.
3. **Refine the cumulative risk analytical framework** for the chemical (i.e., water quality) dimension of salmon habitats to include a more extensive consideration of emerging toxics.
4. **Determine thresholds for sublethal toxicity** in coho, and also other focal ESA-listed species.
5. **Evaluate interactions between 6PPD-quinone and other habitat stressors**, including those related to climate change (temperature) and other contaminants (e.g., petroleum compounds that are a parallel priority for NOAA in relation to *Deepwater Horizon* and future oil spills).
6. **Model vulnerability (hotspot mapping) for salmonid mortality** across western watersheds, for example among coho in regions beyond Puget Sound (Lower Columbia River) and steelhead in central and southern California.
7. **Develop novel biological markers for sublethal stress** for future monitoring studies to track the health of wild salmonids – particularly in the context of evaluating the in-situ effectiveness of source control and green infrastructure pollution reduction measures.
8. **Assess water quality risks to salmon habitat restoration projects**, such as those involving culvert replacements, to ensure that 6PPD-quinone and other stormwater-derived chemicals do not undermine the benefits of these projects. At present, the agency is funding the widespread removal of historical migration barriers in ways that may unintentionally create attractive but lethal spawning and rearing habitats (i.e., ecological traps). See, for example: www.thedailyworld.com/news/federal-infrastructure-bill-includes-1-billion-for-culvert-grants/https://www.thedailyworld.com/news/federal-infrastructure-bill-includes-1-billion-for-culvert-grants/

3. *What are sublethal effects of 6PPD-quinone on aquatic species and is there concern about bioaccumulation and biomagnification to higher trophic levels?*

With the recent identification of 6PPD-quinone and the associated development of conventional analytical methods for use by independent laboratories, the extended scientific community is

now actively studying the toxicity of 6PPD-quinone to fish, invertebrates, and other aquatic species. Accordingly, NOAA is anticipating a wellspring of new toxicity information, including sublethal effects. However, in the specific context of stormwater and endangered salmonids, NOAA researchers have a unique combination of experience (20+ years), advanced skills in analytical chemistry and ecotoxicology, and specialized resources (e.g., husbandry facilities for rearing salmon). Thus, the agency is well-positioned to tackle the most critical data gaps for managing ESA-listed species.

Based on the available scientific evidence, 6PPD-quinone is very likely to cause sublethal toxicity to salmonids, at concentrations well below those that are killing adult coho in urban spawning habitats. Studies to explore this in detail are planned for the coming fiscal year, and will build on the success of initial studies using juvenile coho (Chow et al., 2019). In addition to coho, the next phase will focus on steelhead and Chinook. The NOAA team (NWFSC's Ecotoxicology Program) has a long history of studying the sublethal health effects of contaminants, including chemicals such as 6PPD-quinone that likely target the fish respiratory, cardiovascular, and neurobehavioral systems (each of which may underlie the urban runoff mortality syndrome). These particular strengths for the NOAA science platform are incorporated into the FY22-24 research priorities identified above (response to Question #2).

In terms of bioaccumulation and biomagnification, the physicochemical properties of 6PPD-quinone suggest a high potential for bioaccumulation in aquatic species. 6PPD-quinone has a relatively low water solubility and is highly soluble in organic solvents. Chemical characteristics suggest that bioaccumulation could approach levels observed for polychlorinated biphenyls (PCB) and (polybrominated diphenyl ethers (PBDE). However, physiological processes that can modulate bioaccumulation such as biotransformation are unknown at present and require dedicated laboratory experimentation.

4. What are your agencies doing to monitor watersheds where 6PPD-quinone is present and to understand its impacts on aquatic ecosystems?

In a sense, NOAA has been indirectly monitoring 6PPD-quinone as a component of stormwater in salmon-supporting watersheds since 2001. From our first observations of dying spawners in restored urban streams (Scholz et al., 2011), the leading hypothesis for the mortality syndrome has been one or more toxic chemicals in stormwater runoff (McCarthy et al., 2008). The NOAA team, together with our many municipal, tribal, and academic partners, pursued this hypothesis continuously throughout the 2000s and 2010s. This eventually set the stage for the breakthrough discovery of 6-PPD quinone (Tian et al., 2020), an advancement requiring the advent of analytical instrumentation and methods that were unavailable when NOAA began this line of research. Importantly, as the work on 6PPD-quinone has unfolded, NOAA has also maintained a research focus on other contaminants in stormwater (known and unknown). This includes cardiotoxic petroleum compounds that are also ubiquitous in crude oil (Harding et al., 2020) and were central to NOAA's injury assessment and restoration strategies following both the *Exxon Valdez* and *Deepwater Horizon* oil spills.

Early on, NOAA scientists realized it could take years (or decades) to identify the causal agent underlying the urban mortality syndrome. Nevertheless, the syndrome represented a direct and highly consequential threat to salmon conservation (Spromberg and Scholz, 2011), and the agency deemed it critical to understand the geographical extent and severity of the phenomenon, while at the same time pursuing the unknown toxicant. This required major investments in monitoring, whereby observations of dying coho served as a proxy indicator of 6PPD-quinone exposure and toxicity. These boots-in-streams surveys of coho spawning habitats were conducted over many years, across gradients of urbanization in Puget Sound, and led by NOAA with the support of hundreds of people from the services and other agencies (Federal, state, local), tribes, non-governmental organizations, and volunteers.

In addition to the direct monitoring of coho spawning habitats, NOAA used the field data to model associations between different land cover attributes (e.g., impervious surfaces) and the severity of recurring coho die-offs across Puget Sound watersheds, first with data from a few highly urban drainages (Feist et al., 2011), and subsequently with a larger dataset from >50 spawning areas with greater suburban and rural representation (Feist et al., 2017). The modeling efforts strongly implicated motor vehicles as the source of as-yet undiscovered 6PPD-quinone, a major line of evidence that subsequently focused the team on potential contaminants from tires. The land cover/land use models were used to generate predictive maps for coho deaths based on the proximity of spawning habitats to the Puget Sound regional traffic grid (Feist et al., 2017). These maps have been used extensively by stakeholders who are actively engaged in stream monitoring. To connect this growing citizen science effort back to NOAA research, the agency partnered with the USFWS and WSU to develop a story map to guide local monitoring activities and provide a portal for monitoring data to feed back into more refined predictive forecast models in the future. The story map can be accessed at: www.arcgis.com/apps/MapSeries/index.html?appid=5dd4a36a2a5148a28376a0b81726a9a4

Looking to the future, monitoring will be a top consideration for NOAA research, as briefly indicated in the responses to Question #2 above. The advent of new methods for directly measuring 6PPD-quinone will allow NOAA to study how the contaminant interacts with salmon biology (uptake, tissue distribution, metabolism, elimination/persistence); how it moves through aquatic food webs, potentially accumulating at higher trophic levels; how tissue levels (e.g., in gill or heart) relate to sublethal toxicity thresholds; and related questions. Reducing these uncertainties will greatly improve NOAA's ability to assess the environmental health of salmon in urban and urbanizing watersheds, including locations where costly habitat restoration actions and/or the expansion of road networks are currently planned in the western United States.

5. How are your agencies working with researchers and stakeholders to understand and address the impacts of 6PPD-quinone?

The NOAA approach to stormwater science has been highly collaborative (see bibliography) and we expect this to continue. As noted above, the progress to date on 6PPD-quinone (as one of a

rapidly-expanding list of novel and uncharacterized chemicals in roadway runoff) would not have been possible without the coordinated efforts of myriad stakeholders and research partners. In the Federal domain, our most important collaborators have been FWS and EPA, the latter as a nexus for project funding through the National Estuary Program (science to support Puget Sound recovery). The NOAA team also works extensively with academic research groups, particularly where strategic collaborations can help fill current gaps in the NWFSC facilities, such as high-end analytical instrumentation, land for building experimental green stormwater treatment installations, etc. However, the NOAA research planning process needs to be responsive to specific Federal management priorities, many of which are litigation-sensitive and require intensive review. Also, NOAA stormwater science has been a relatively long-term investment, to align with adaptive salmon recovery efforts that span decades. We expect the NWFSC will continue leading the Federal research effort as it relates to managing salmon and other NOAA trust resources, with targeted academic collaborations as needed to ensure state-of-the-art science support for the agency and the extended Federal caucus.

We anticipate an expanding relationship with our tribal partners, who have contributed hatchery and laboratory facilities (e.g., Suquamish), monitoring data (e.g., Stillaguamish), and other support. We routinely share research updates with the Northwest Indian Fisheries Commission and incorporate their priorities in our science planning. These converge on science to guide salmon conservation and recovery, and also concerns over safe seafood (novel and potentially toxic stormwater-derived contaminants in shellfish and finfish) and the possibility that degraded water quality may undercut the recovery objectives of ongoing culvert removal projects by unintentionally creating ecological traps. Notably, the first consistent observations of the coho urban mortality syndrome were observed in West Seattle's Longfellow Creek, following a multi-million dollar culvert removal and stream habitat restoration effort (Scholz et al. 2011).

On the academic side, the NOAA team has worked for years with Washington State University (WSU)-Puyallup. Dr. Jenifer McIntyre, the lead WSU author on several joint research papers (see bibliography) was trained in part by the Ecotoxicology Program (dissertation and postdoctoral research). When she was subsequently hired to a faculty position at the Stormwater Center in Puyallup, NOAA and WSU established a 5-year cooperative agreement (CRADA) to further cooperative research. NOAA scientists and technicians assisted with setting up a salmon research facility at the Stormwater Center; to date, the work has yielded major new insights on the effectiveness of green stormwater treatment methods.

The other major academic partner for NOAA is the University of Washington's Center for Urban Waters (Ed Kolodziej laboratory). This group of civil engineering researchers provided the analytical expertise (time-of-flight mass spectrometry and big data analytics) necessary to fractionate complex chemical mixtures into constituent parts, for subsequent toxicity screening in juvenile coho (the basis for the Tian et al. 2020 study). On the NOAA side, our objectives with the UW collaboration have been to: 1) characterize the full chemical complexity of urban stormwater across gradients of urbanization (i.e., how many uncharacterized and potentially

toxic chemicals are out there, as potential obstacles to salmon recovery?); and 2) discover the specific causal agent for the coho urban runoff mortality syndrome.

As of the close of FY21, we have accomplished most of the objectives we set for the WSU collaborations in the mid-2010s. For example, we've now published several studies with WSU showing that inexpensive soil infiltration methods can effectively remove pollutants (including, presumably, 6PPD-quinone) and protect the health of salmon and other aquatic species. With the UW team, we have identified 6PPD-quinone as a key chemical in the coho mortality phenomenon, as anticipated from years of prior work on forensics and other converging lines of evidence. We also have a much more sophisticated and extensive understanding of the full complexity of urban stormwater quality as a roadmap for prioritizing NOAA's ecotoxicology research in the years ahead.

Looking to FY22-24, we expect the WSU team to continue leading the regional scientific effort on green infrastructure science, including the use of conventional model species (e.g., rainbow trout, zebrafish) for rapid toxicity screening. The green infrastructure "tool box" continues to grow, with myriad variations on soil columns, vegetated highway strips, the use of different plants and fungi, etc. These types of projects are particularly suitable for graduate students. Similarly, the UW team will continue to make important contributions in exploratory analytical chemistry. However, many of these questions involve the abiotic transformation and fate of 6PPD-quinone in the environment, the characterization of other novel compounds in tires and other vehicle-related sources, so-called green chemistry alternatives, etc.

We intend to support ongoing collaborations on green infrastructure and stormwater chemistry with the WSU and UW teams, respectively, including the completion of peer-reviewed research papers that are presently in the data analysis and writing phases. However, the NOAA science platform has been greatly diminished since this work on stormwater and salmon began in 2001; staffing is down 50 percent across the Ecotoxicology and Environmental Chemistry Programs. At the same time, the salmon recovery mission of the agency is confronting critical data gaps that our scientists are in the best position to address (e.g., the priorities outlined in response to Question #2, above).

Accordingly, as the science underlying stormwater threats to salmon recovery continues to evolve, NOAA will pursue partnerships that most effectively leverage resources in the Federal domain, including funds appropriated directly to NOAA, as well as in-kind (reimbursable) funding from Federal partners, such as EPA Region 10, pursuant to shared goals for clean water and salmon recovery in Puget Sound and other major western metropolitan areas. Much of the "need to know" scientific information is at the intersection of major Federal statutes, including the Clean Water Act and the Endangered Species Act. For example, most of the priorities identified above were formulated in direct anticipation of future ESA section seven consultations between NOAA and other Federal agencies.

6. If salmon mortality from 6PPD-quinone is significant and widespread, as some experts believe, what do your agencies plan to do about it?

The Endangered Species Act (ESA) and the Essential Fish Habitat (EFH) provision of the Magnuson-Stevens Fishery Conservation and Management Act are the principal authorities under which the NOAA National Marine Fisheries Service (NMFS) evaluates the impacts of 6PPD-quinone on salmon outside of NOAA's research work. NMFS' first step in addressing the risks posed by 6PPD-quinone is to ensure our ESA and EFH analyses of actions involving stormwater management adequately assess the known impacts of this contaminant on aquatic life and habitat. NMFS is working closely with our science centers to ensure its analyses reflect the best science available on this issue.

Many actions that cause stormwater effects are currently evaluated under existing programmatic ESA and EFH consultations. Programmatic consultations are in place with multiple Federal agencies including the Federal Highways Administration, Housing and Urban Development, Federal Emergency Management Agency, and the U.S. Army Corps of Engineers. These consultations address hundreds of development projects every year in Oregon, Washington, Idaho, and California. Many of these programmatic consultations were developed prior to a comprehensive understanding of the role of 6PPD-quinone in stormwater.

NMFS has recently begun reviewing these programmatic consultations to ensure they include adequate measures to minimize the amount of 6PPD-quinone reaching waters occupied by salmon. Where necessary, we intend to work with these Federal agencies, as well as state and tribal partners, to revise these programmatic consultations. Identifying stormwater management practices to reduce 6PPD-quinone is an emerging science, one that is likely to require significant coordination between the science researchers, the ESA and EFH consultation staff, and the Federal agencies whose actions affect stormwater sources. Since there are not yet stormwater management practices specific to 6PPD-quinone, we intend to focus on practices known to generally remove contaminants, such as green infrastructure, low impact development, full ground infiltration of stormwater, bioswales, and other techniques. Given the new information about 6PPD-quinone, we will be taking a holistic look at these consultations to ensure Federal agency programs provide an adequate overall level of stormwater treatment. Over time, we will also incorporate new best management practices to address 6PPD-quinone as they become available.

To address the effects of 6PPD-quinone, Federal action agencies will, in some cases, need to acknowledge and incorporate new and additional methods of stormwater management. Such additional measures, for example compensatory mitigation, might be necessary in areas where water quality impacts, caused by stormwater runoff, are threatening salmon recovery. Given the interplay between water quality and climate change, additional conservation may be necessary to ensure the long-term survival and recovery of salmon.

7. What additional resources or authorities do your agencies need to address the impacts of this chemical on the fish, wildlife, and resources that you manage?

Long-term funding is needed to support a robust environmental health research program within NWFSC and management actions that consider water quality as a critical part of habitats to support recovery of protected species and sustainable fisheries. For nearly five decades, NWFSC's Ecotoxicology and Environmental Chemistry Programs have been at the forefront of research on toxic chemical contamination in coastal and marine ecosystems and have supported decision-making needs of NMFS and other NOAA Line Offices. The NWFSC scientific platform for ocean pollution research has diminished because of lack of dedicated funding to support NOAA permanent staff and major laboratory equipment. Since 2010, approximately half of the Federal employees conducting ocean pollution research have been lost due to retirement, and only one for every four positions has been backfilled. If this staffing capability is not maintained and rebuilt to levels needed to address increasing problems with pollution, NMFS and the other NOAA Line Offices will lose the research foundation necessary to effectively address species, habitats, and communities at-risk from toxic chemical pollution, now and in the future. NMFS estimates that an additional $4M would be required annually in the Habitat Management and Restoration budget line for the NWFSC to support a core environmental health research program and critical science advice needed for resource managers. As noted earlier, this research and advice are needed, in part, to help ensure ongoing and intensive investments in culvert removals and other physical habitat improvements are not undercut by 6PPD-quinone and other (as-yet unknown) toxic contaminants in stormwater.

Furthermore, as described above, a thorough review of the existing science and its applicability to our ESA and EFH authorities, including multiple, widely used programmatic consultations, will require a multi-branch team of highly specialized staff with sufficient time to fully evaluate the science of the effects of 6PPD-quinone on listed species and EFH, as well as the green infrastructure available to avoid or minimize those effects. In addition, this team will need to spend significant time working with our science centers and Federal partners to update our overall approach to evaluating stormwater and any existing programmatic consultations, as necessary and appropriate. At present, our existing staff are already well over capacity with their existing workload, with dozens of consultations in a backlog. Without additional staff with competencies to engage in this important work, efforts to address the impacts of 6PPD-quinone on our resources will either be delayed, or come at the expense of other competing priorities.

As mentioned above, it is possible that salmon recovery may ultimately require Federal agencies seeking consultation to offset stormwater effects that are a consequence of their proposed actions when avoidance is not possible. Such mitigation may require funding not previously anticipated. Absent clear direction or additional funding to help with any such mitigation, Federal agencies may not prioritize making changes to their stormwater management practices.

Bibliography of Relevant Publications (NOAA authors in blue, USFWS in orange)

1. **McCarthy, S.G., Incardona, J.P., and Scholz, N.L.** (2008). Coastal storms, toxic runoff, and the sustainable conservation of fish and fisheries. *American Fisheries Society Symposium*, 64:7-27.

2. **Scholz, N.L., Myers, M.S., McCarthy, S.G., Labenia, J.S., McIntyre, J.K., Ylitalo, G.M., Rhodes, L.D., Laetz, C.A., Stehr, C.M., French, B.L.,** McMillan B., Wilson, D., Reed, L., Lynch, K., **Damm, S., Davis, J.W.,** and **Collier, T.K.** (2011). Recurrent die-offs of adult coho salmon returning to spawn in Puget Sound lowland urban streams. *Public Library of Science ONE*, 6(12): e28013. doi:10.1371/journal.pone.0028013.

3. **Feist, B.E., Buhle, E.R.**, **Arnold, P., Davis, J.W.**, and **Scholz, N.L.** (2011). Landscape ecotoxicology of salmon spawner mortality in urban streams. *Public Library of Science ONE*, 6(8): e23424. doi:10.1371/journal.pone.0023424.

4. **Spromberg, J.A. and Scholz, N.L.** (2011). Estimating the decline of wild coho salmon populations due to premature spawner mortality in urbanizing watersheds of the Pacific Northwest. *Integrated Environmental Assessment and Management*, 4:648-656.

5. McIntyre, J.K., **Davis, J.W.**, **Incardona, J.P., Anulacion, B.F.,** Stark, J.D., and **Scholz, N.L.** (2014). Zebrafish and clean water technology: assessing the protective effects of bioinfiltration as a treatment for toxic urban runoff. *Science of the Total Environment*, 500:173-180.

6. McIntyre, J.K., **Davis, J.,** Hinman, C., **Macneale, K.H., Anulacion, B.F., Scholz, N.L.**, and Stark, J.D. (2015). Soil bioretention protects juvenile salmon and their prey from the toxic effects of urban stormwater runoff. *Chemosphere*, 132:213-219.

7. McIntyre, J.K., **Edmunds, R.C.**, Mudrock, E., Brown, M., **Davis, J.W.**, Stark, J.D., **Incardona, J.P. and Scholz, N.L.** (2016a). Confirmation of stormwater bioretention treatment effectiveness using molecular indicators of cardiovascular toxicity in developing fish. *Environmental Science and Technology*, 50:1561-1569.

8. McIntyre, J.K., **Anulacion, B.F.**, **Davis, J.W.**, **Edmunds, R.C., Incardona, J.P.**, Stark, J.D., and **Scholz, N.L.** (2016b). Severe coal tar sealcoat runoff toxicity to fish is reversed by bioretention filtration. *Environmental Science and Technology,* 50:1570-1578.

9. **Spromberg, J.A., Baldwin, D.H.**, **Damm, S.E.**, McIntyre, J.K., Huff, M., **Davis, J.W.**, and **Scholz, N.L.** (2016). Widespread adult coho salmon spawner mortality in western U.S. urban

watersheds: lethal impacts of stormwater runoff are reversed by soil bioinfiltration. *Journal of Applied Ecology* (Editor's Choice), 53:398-407.

10. Du, B., Lofton, J.M., Peter, K.T., Gipe, A.D., James, C.A., McIntyre, J.K., **Scholz, N.L.**, Baker, J.E., and Kolodziej, E.P. (2017). Suspect and non-target screening of organic contaminants and potential toxicants in highway runoff and fish tissue with high resolution time of flight mass spectrometry. *Environmental Science: Processes and Impacts*, 19:1185-1196.

11. **Feist, B.E., Buhle, E.R., Baldwin, D.H., Spromberg, J.A.**, **Davis, J.W., Damm, S.E.**, and **Scholz, N.L.** (2017). Roads to ruin: conservation threats to a sentinel species across an urban gradient. *Ecological Applications*, 27:2382-2396.

12. McIntyre, J.K., **Lundin, J.I., Cameron, J.R.,** Chow, M.I., **Davis, J.W.**, **Incardona, J.P., and Scholz, N.L.**(2018). Interspecies variation in susceptibility of adult Pacific salmon to toxic urban stormwater runoff. *Environmental Pollution*, 238:196-203.

13. Peter, K.T., Tian, Z., Wu, C., Lin, P., White, S., Du, B., McIntyre, J.K., **Scholz, N.L.**, and Kolodziej, E.P. (2018). Using high-resolution mass spectrometry to identify organic contaminants linked to an urban stormwater mortality syndrome in coho salmon. *Environmental Science and Technology*, 52:10317-10327.

14. Chow, M.I., Young, G., Mitchell, C., **Davis, J.W.**, **Lundin, J.I., Scholz, N.L.**, and McIntyre, J.K. (2019). An urban stormwater runoff mortality syndrome in juvenile coho salmon. *Aquatic Toxicology*, 214:105231.

15. **Harding, L.B., Tagal, M., Ylitalo, G.M., Incardona, J.P., Scholz, N.L.**, and McIntyre, J.K. (2020). Urban stormwater and crude oil injury pathways converge on the developing heart of a shore-spawning marine forage fish. *Aquatic Toxicology,* 229:105654.

16. Tian, Z., Zhao, H., Peter, K.T., Gonzalez, M., Wetzel, J., Wu, C., Hu, X., Prat, J., Mudrock, E., Hettinger, R., Cortina, A.E., Biswas, R.G., Kock, FVC, Soong, R., Jenne, A., Du, B., Hou, F., He, H., Lundeen, R., Gilbreath, A., Sutton, R., **Scholz,, N.L.**, **Davis, J.W.**, Dodd, M.C., Simpson, A., McIntyre, J.K., Kolodziej. 2020. Ubiquitous tire rubber-derived chemical induces acute mortality in coho salmon. *Science*, 10.1126/science.abd6951.

17. **Ettinger, A.K., Buhle, E.R. Feist, B.E.**, Howe, E., **Spromberg, J.A., Scholz, N.L.**, and Levin, P.S. (2021). A framework for prioritizing stormwater-related conservation actions in urbanizing landscapes. *Scientific Reports*, 10.1038/s41598-020-79258-2.

18. McIntyre, J.K., Prat, J., **Cameron, J.,** Wetzel, J., Mudrock, E., Peter, K.T., Tian Z., Mackenzie, C., **Lundin, J.**, Stark, J.D., **King, K., Davis, J.W.**, and **Scholz, N.L.** (2021). Treading water: tire wear particle leachate recreates an urban runoff mortality syndrome in coho but not chum salmon. *Environmental Science and Technology*, In press.