

Science

FINDINGS

INSIDE

Study Site: The Duwamish Valley	2
The Community Gets Involved	3
Clues in the Moss	4
Practical Results	5

"Science affects the way we think together."
Lewis Thomas

The More the Mossier: Using Community Science to Map Air Quality in Environmental Justice Investigations



Orthotrichum lyellii. Moss such as this pulls moisture and nutrients from the air—along with heavy metals and other pollutants—making it a useful bioindicator for air pollution. USDA Forest Service photo by Sarah Jovan.

"If you reveal your secrets to the wind, you should not blame the wind for revealing them to the trees."

—Khalil Gibran

In 2015, a team of researchers with the USDA Forest Service Pacific Northwest (PNW) Research Station conducted a study in Portland, Oregon, that would come to be known as the Portland Moss Study.

Using moss from street trees, the team found that the moss samples contained measurable levels of toxic heavy metals, including cadmium, which can cause cancer and kidney malfunction. The team's findings shook the local area, prompting urgent outcries from

residents and immediate investigations by state and local health agencies. The likely sources were a couple of stained glass manufacturing plants that used cadmium to color their glass. The companies subsequently halted their use of the chemical.

Sarah Jovan, a research ecologist with the PNW Research Station, was a key member of that team. The study made national news and prompted researchers and concerned citizens from across the United States to contact Jovan for guidance in conducting similar research.

Fast forward 4 years: Community leaders concerned about air pollution in south-central Seattle neighborhoods along the Duwamish River were familiar with the groundbreaking moss research in Portland and interested in

IN SUMMARY

Concerned about air quality in south-central Seattle's Duwamish Valley, community leaders collaborated with USDA Forest Service Pacific Northwest (PNW) Research Station to implement a study similar to one in Portland, Oregon, in 2015 that found that urban tree moss indicated the presence of airborne toxic metals.

Together, PNW Research Station scientists and community leaders designed a study that not only collected moss samples from this heavily polluted area but also engaged 55 community members, including 25 members of the Duwamish Valley Youth Corps, to do so. The youth corps members collected moss from about 60 locations, mostly in Seattle's South Park and Georgetown neighborhoods, and prepared them for analysis.

The study found concentrations of toxic metals, such as arsenic, cadmium, chromium, cobalt, nickel, and lead, that were significantly higher than in moss collected from other parts of Seattle. Moreover, these concentrations were in an area predominantly inhabited by people of color who are poorer than Seattle's population as a whole.

The results led to an air quality study by the Puget Sound Clean Air Authority and a commitment by the City of Seattle to mitigate pollution in the area. The study also spotlighted the important role that community scientists can play in addressing urban environmental challenges.

using similar methods in their community. The PNW Research Station had the needed expertise. Station scientists, working with the Urban Waters Federal Partnership, helped organize a group of community nonprofits, university scientists, and local government officials to spearhead the first collaborative application of the moss protocol in urban, industrial-adjacent neighborhoods.

The study shed new light on urban pollution and the value of moss as an indicator. It also served as a model for how scientists and local communities can work together, and how their work can support environmental justice—mitigating disproportionate harm from pollution to communities of color and low-income populations. The momentum for the ongoing collaboration has been sustained through several follow-up studies and mitigation efforts led by project partners at universities and local government agencies.

Study Site: The Duwamish Valley

The Duwamish River is the name given to the lower 12 miles of Washington's Green River as it cuts through the southern end of Seattle before emptying into Elliot Bay. It has been Seattle's main industrial corridor since the early 20th century.

The U.S. Environmental Protection Agency (EPA) declared the last 5 miles of the waterway a Superfund site in 2001 because polychlorinated biphenyls (PCBs), arsenic, mercury, and other industrial pollutants

PNW Science Findings

Providing scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
1220 SW 3rd Ave., Suite 1400
Portland, OR 97204

Send new subscription and change of address information to:

SM.FS.pnw_pnwpubs@usda.gov

Rhonda Mazza, editor; rhonda.mazza@usda.gov

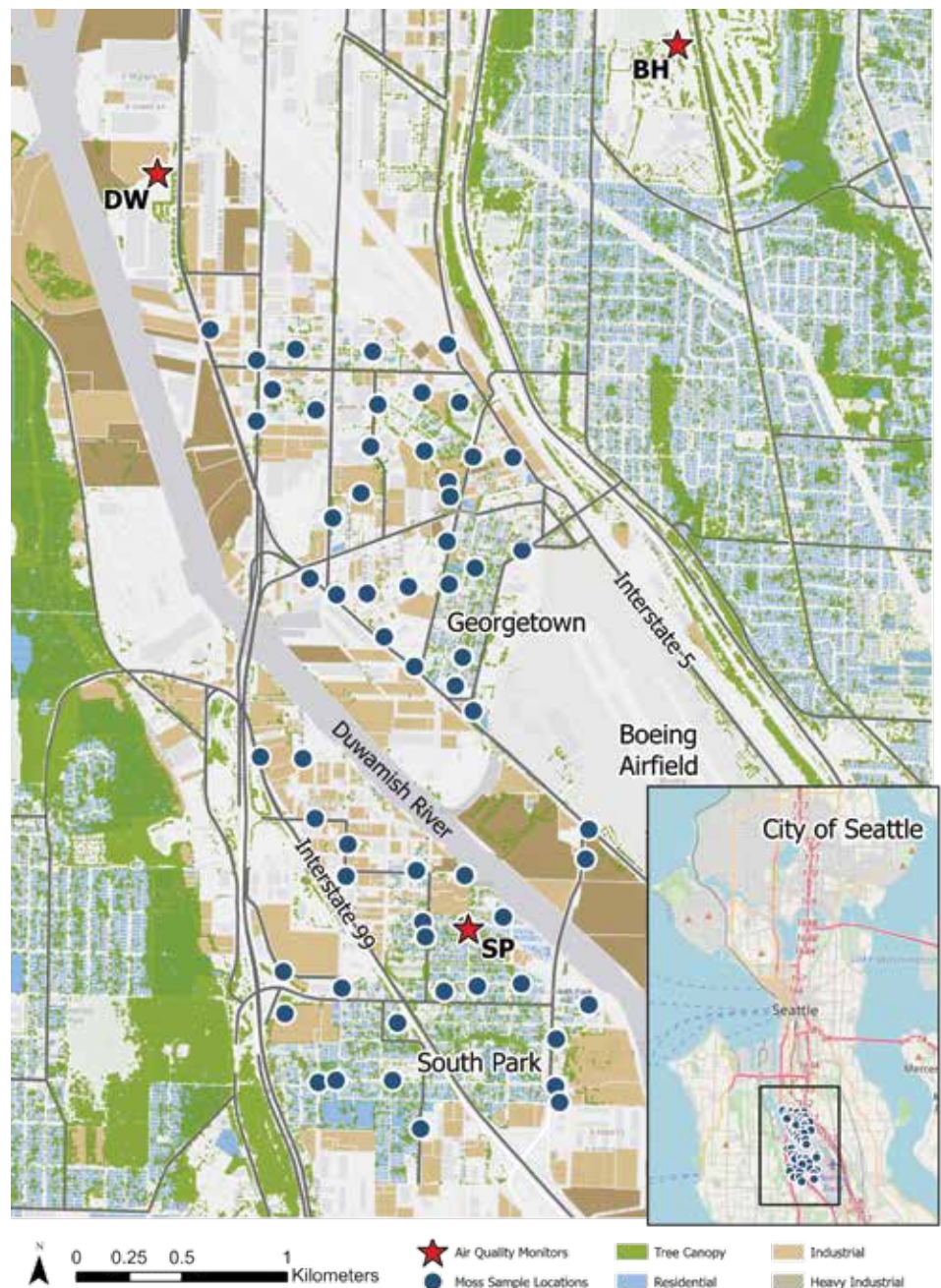
Jason Blake, layout; jason.p.blake@usda.gov

To find Science Findings online, visit
<https://www.fs.usda.gov/pnw/>
and click on **Publications**.

To become a digital subscriber visit:
<https://www.fs.usda.gov/pnw/publications/subscriptions.shtml>



Members of the Duwamish Valley Youth Corps prepare moss samples that they collected for analysis. Further study revealed the presence of arsenic, cadmium, chromium, cobalt, nickel, and lead in the moss. USDA Forest Service photo by Monika Derrien.



Map of the Duwamish Valley in Seattle showing moss sampling locations and air quality monitors relative to major land use types. From Jovan et al. 2022a.

were present. The valley also includes many unpaved roads, railway lines, water traffic, an airport, highways with high levels of commuter and truck traffic, and several types of industrial facilities—some in place for more than a century. Cleanup and restoration efforts are ongoing.

Seattle's South Park and Georgetown neighborhoods are located along the Duwamish waterfront. Nearly 74 percent of residents there are non-white. Area residents are twice as likely to live in poverty and 50 percent less likely to have a college education compared to Seattle's city-wide average. Duwamish Valley residents also have higher rates of asthma and diabetes and lower life expectancies than other Seattle residents.

The Community Gets Involved

Community leaders in the Duwamish Valley worked with colleagues at the PNW Research Station's Seattle lab to figure out how to organize a study similar to the 2015 Portland Moss Study. They were long aware of residents' pollution concerns and health issues and were interested in a collaborative and actionable research design.

"Because of long-standing relationships between scientists at the research station and community leaders, we were able to quickly organize and engage," says Monika Derrien, a research social scientist with the PNW Research Station.

Over the years, the station has invested funds and personnel in urban-focused collaborative projects to pursue scientific questions of mutual interest, Derrien explains.

"Our approach in working in the Duwamish Valley has been: 'we have access to scientific knowledge and tools, so how can we use that to help answer questions that the community prioritizes?'" she says.

The group decided that the type of moss research Jovan conducted in Portland would be a good area of focus and recruited Jovan to take part in the study. Meanwhile, the number of community members who wanted to get involved continued to grow.

"It got so big that we needed more structure, so we formed a steering committee to pull all the pieces together and make sure we were functioning effectively and equitably," Derrien says.

More than 50 people contributed to the research, including members of the Duwamish River Community Coalition and its Duwamish Valley Youth Corps program; the Green-Duwamish designation of the Urban Waters Federal Partnership; the City of Seattle; the University of Washington, Western

Key Findings

- Moss collected from neighborhoods in Seattle's Duwamish Valley showed concentrations of toxic metals (arsenic, cadmium, chromium, cobalt, nickel, and lead) that were significantly higher than moss collected from Seattle city parks and residential areas in Portland, Oregon.
- Members of the Duwamish Valley Youth Corps collected an entire usable dataset of moss samples that were later used for the study's analysis.
- Metals concentrations mainly peaked in the central industrial core where many possible emissions sources converge, including contamination from years past. It's likely that much of the contamination was from dust and dirt, suggesting that larger particles are important carriers of toxic metals.
- The percentage of people of color living in the study neighborhoods was significantly positively associated with lead, chromium, and nickel concentrations. Greater tree cover within about 220 yards of sample sites was associated with lower metal concentrations—in particular, cadmium.

Washington University; an advocacy group called Just Health Action; and Dirt Corps, an organization that focuses on workforce development and economic equity for adult learners entering the environmental field.

"Using community scientists to conduct the study was really the most unique part of it," Jovan says.

"Everyone wanted to work on this project," says Roseann Barnhill, a plant ecologist and one of the founders of Dirt Corps. "They were very excited, and so we got as many people involved as we could."

Dirt Corps' role was instructing Duwamish Valley Youth Corps members, working in groups of five, in collecting, handling, and recording data on moss samples. In all, about 25 local eighth- to twelfth-graders took part in the project. Dirt Corps personnel and other project partners accompanied the youth on each outing.

Derrien says collecting moss samples is a particularly well-suited task for the young participants. It's easily teachable and can be performed after just a few hours of field-work and lab training. In fact, a key piece of the study was determining if the moss samples that the youth corps collected and cleaned could be reliably used to measure the presence of heavy metals. The youth corps' success in collecting useable moss samples fulfilled another goal of the project: engaging young people in the scientific process as community scientists and teaching them about environmental health, environmental justice, and urban forestry where these concepts affect their lives the most—their own communities.

"Demonstrating the idea that a well-designed sampling project could be carried out by community scientists was huge and validating," Barnhill says. "It also validated what



A Duwamish Valley Youth Corps member consults with Pacific Northwest Research Station emeritus scientist Dale Blahna before selecting a moss sample from a tree. USDA Forest Service photo by Monika Derrien.

people understood about pollution in their community, after being told for so long that there was no concern. That affirmation was incredibly powerful."

Clues in the Moss

Without roots or the kind of protective outer layer that other plants have, moss and lichen absorb water and nutrients directly from the air. They also collect whatever toxic elements are in the atmosphere. As such, they are valuable screening tools in urban areas. They save researchers time and help optimize the use of other tools, such as air monitors. Air monitors are ultimately needed to determine if pollution levels pose human health risks, but analyzing moss is a good first step. Moss-based findings can inform decisions about where to place air monitors.

The 2015 Portland Moss Study was the first to bring the power of moss to the attention of the American public.

“The Europeans have been using moss to look at heavy metals for several decades, so we had literature and prior research to build on,” Jovan says. “We were the first to use moss like that

in a U.S. urban area and, importantly, develop metals maps at an unprecedentedly fine scale.”

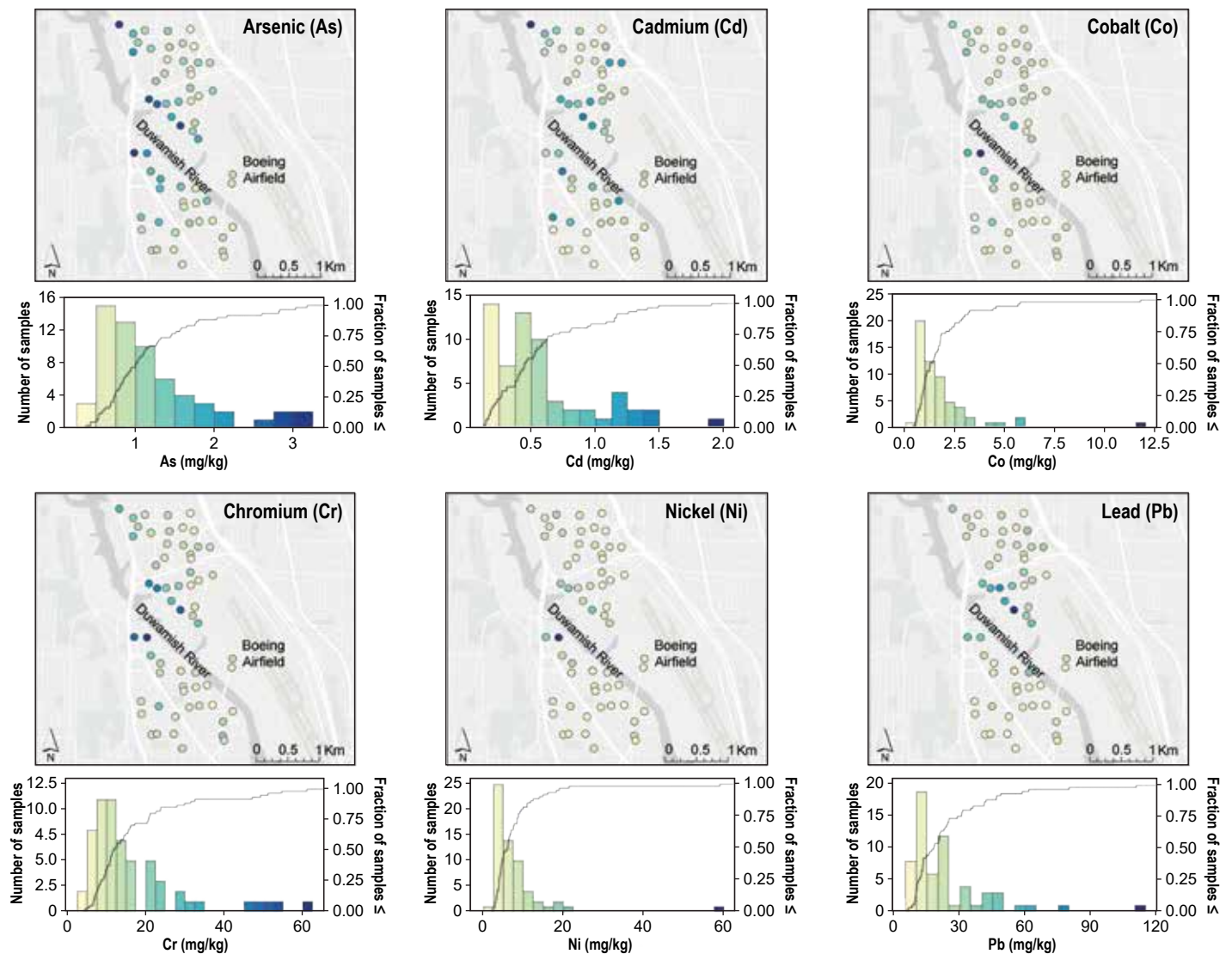
Not only did the 2015 study change the manufacturing practices of two glass companies in Portland, but it was the basis for the largest environmental class action settlement in Oregon history. In 2016, residents near a Precision Castparts plant in southeast Portland cited Jovan’s work when they sued the company over elevated levels of nickel in the area. The settlement, reached in 2022, granted \$12.5 million to local residents, in addition to millions of dollars Precision Castparts already spent to improve emissions controls at its Portland plant.

Air monitoring results will bring the picture of air pollution in the Duwamish Valley into finer focus. But so far, the most egregious sources of pollution have yet to be determined. Unlike the Portland study, which could clearly identify individual pollution sources, Jovan explains that the situation in the Duwamish Valley is more widespread.

“There’s such a density of pollution sources emitting heavy metals, it’s difficult to determine exactly who the important sources are,” Jovan says.

Moss collected and analyzed as part of the Duwamish Valley project showed significantly higher concentrations of arsenic, cadmium, chromium, cobalt, nickel, and lead compared to what was found in the Portland study and in moss collected from other parts of Seattle. The metals concentrations were highest in the central industrial core where there were many possible sources—not only emissions from current industries but contamination from the past. These elements and heavy metals can linger in soil and water and continue to affect people and wildlife long after being emitted. Wind can blow contaminated dust, which can be deposited over a wide area and infiltrate people’s lungs.

That’s what was happening to the residents of the Georgetown and South Park neighborhoods. Furthermore, comparing the moss samples with



Dot maps and histograms showing concentrations of metals in Duwamish Valley moss. Adapted from Jovan et al. 2022a.

U.S. Census data showed that the highest concentrations of lead, nickel, and chromium were in areas where a higher percentage of people of color resided.

The researchers created maps of the study area, plotting the different levels of metals concentrations in more than 60 locations. In their article for the scientific journal “Ecosphere,” Jovan and Derrien say that the moss sampling produced a level of detail that the area’s only air monitoring site—or even a few hypothetical monitoring sites—could not match.

Practical Results

The Puget Sound Clean Air Agency (PSCAA) was an advisor for the Duwamish Valley moss study. The agency has been monitoring outdoor air for four counties in Puget Sound since the late 1960s and makes sure businesses comply with air quality regulations.

“We were working with the Forest Service as a technical advisor. As such, we helped them understand the work we’ve done in that area,” says Graeme Carvlin, an air quality specialist for the agency. “It was really informative to see the data they collected. It helped us apply for a \$772,000 EPA grant to do an air toxics study.”

As a part of the air toxics study, PSCAA sampled the air for metals at five locations chosen in partnership with community members. It will calculate the health risks at those locations and compare what they find to the moss results.

One of the study’s focus areas is South Seattle College’s Georgetown campus, a hotspot identified by the moss analysis. The agency installed air samplers, which are essentially vacuums that suck in air at a constant rate and trap metals from the air on a filter. The filters will then be sent to a lab for analysis. The goal is to translate the results of the moss study to measurable health risks.

“The results will answer critical questions that will shape all subsequent steps in this investigation,” Jovan says.

This is the kind of hard data needed if serious mitigation efforts are to be made in the future, Jovan explains.

“Knowledge gaps about local-scale pollution have long hindered mitigation and management efforts in our study neighborhoods despite wide consensus about them being disproportionately burdened with poor health outcomes, poor air quality, and racial inequities relative to other Seattle neighborhoods,” Jovan says.

While the PSCAA was conducting its work, the Duwamish River Community Coalition went on to share the results of the moss study

LAND MANAGEMENT IMPLICATIONS

- Low-cost moss assays are an effective screening tool for hotspot detection of air toxins and for guiding efficient placement of air monitoring instruments.
- The findings, which showed the widespread presence of heavy metals in the Duwamish Valley, are informing mitigation efforts. The findings filled knowledge gaps that previously hindered mitigation efforts despite wide consensus about poor health outcomes, poor air quality, and racial inequities relative to other Seattle neighborhoods.
- Local-scale metals maps of the Duwamish Valley suggest that metals in soil and dust are being resuspended in the air. Spatial analysis links metals concentrations to a variety of environmental and social predictors.

with Seattle officials. As part of its response, the city allocated \$300,000 for urban greening projects in industrial lands in the Duwamish Valley.

The projects, which began in 2022, included tree planting and maintenance and construction of bioswales. Trees remove air pollution by intercepting particulate matter and absorb gaseous pollutants through their leaves. Bioswales remove pollutants by filtering storm runoff.

The fact that the Duwamish Valley moss study was a catalyst for greater monitoring in a heavily polluted part of Seattle was a huge practical outcome. On par with the scientific results, however, is how this collaboration highlights the value of early and ongoing engagement with a wide swath of local communities to make such scientific studies happen.

The youth corps members provided an invaluable service by collecting the moss and in return got some potentially life-changing experiences by involving themselves with natural science in their own neighborhoods.

“They have engaged in additional rounds of sampling in subsequent years, expanding their radius and continuing to build a culture around community science,” Derrien says.

“Environmental education in cities can help dispel the notion that the ‘nature’ that matters exists elsewhere,” she adds. “It can help people to meaningfully examine social-ecological systems by asking questions such as ‘Who determines what happens here? At what cost? To whose benefit? Why not somewhere else?’”

“Until the great mass of the people shall be filled with the sense of responsibility for each other’s welfare, social justice can never be attained.”

—Helen Keller

For Further Reading

Derrien, M.M.; Zuidema, C.; Jovan, S.; et al. 2020. Toward environmental justice in civic science: youth performance and experience measuring air pollution using moss as a bio-indicator in industrial-adjacent neighborhoods. *International Journal of Environmental Research and Public Health*. 17(19): 7278. <https://doi.org/10.3390/ijerph17197278>.

Donovan, G.H.; Jovan, S.E.; Gatzliolis, D.; et al. 2016. Using an epiphytic moss to identify previously unknown sources of atmospheric cadmium pollution. *Science of the Total Environment*. 559: 84–93. <https://www.fs.usda.gov/research/treesearch/50919>.

Jovan, S.E.; Zuidema, C.; Derrien, M.; et al. 2022a. Heavy metals in moss guide environmental justice investigation: a case study using community science in Seattle, WA, USA. *Ecosphere*. 13(6): e4109. <https://doi.org/10.1002/ecs2.4109>.

Jovan, S.E.; Zuidema, C.; Derrien, M.; et al. 2022b. Measurements of heavy metals in the moss *Orthotrichum lyellii* collected using community science in the Duwamish Valley, Seattle, Washington, USA Dataset. Dryad. <https://doi.org/10.5061/dryad.tqjq2bw1p>.

Kondo, M.C.; Zuidema, C.; Moran, H.; et al. 2022. Spatial predictors of heavy metal concentrations in epiphytic moss samples in Seattle, WA. *Science of the Total Environment*. 825: 153801. <https://www.fs.usda.gov/research/treesearch/63912>.

Writer’s Profile

John Kirkland has been writing about science, higher education, and business for more than 20 years. He lives in Portland, Oregon.



Pacific Northwest Research Station
USDA Forest Service
1220 SW 3rd Avenue, Suite 1400
Portland, OR 97204

Official Business
Penalty for Private Use, \$300

Scientist Profiles



SARAH JOVAN is a research ecologist with the Pacific Northwest Research Station. She serves as national lichen advisor to the Forest Service's Forest Inventory and Analysis Program, which

uses epiphytic lichen communities as sentinels of air quality in forest ecosystems. She also measures pollutants trapped in moss tissue to serve as a screening tool to guide air quality monitoring and mitigation efforts. Jovan earned a B.A. in biology from Oberlin College and a Ph.D. in ecology from Oregon State University.

Jovan can be reached at:

USDA Forest Service
Pacific Northwest Research Station
1220 SW 3rd Avenue, Suite 1400
Portland OR, 97214

Phone: (971) 413-2777

E-mail: sarah.jovan@usda.gov



MONIKA DERRIEN is a research social scientist with the Pacific Northwest Research Station. She studies the human dimensions of natural resource management, especially related to social, cultural,

and health aspects of public lands management. Her research explores how diverse public values can be represented in planning and management activities to support the many ways society relates to and engages with nature. Derrien earned a B.A. in history from Cornell University and an M.S. and a Ph.D. in natural resources from the University of Vermont.

Derrien can be reached at:

USDA Forest Service
Pacific Northwest Research Station
400 N 34th Street, Suite 201
Seattle, WA 98103

Phone: (202) 999-0402

E-mail: monika.derrien@usda.gov

Collaborators

Paulina López, Duwamish River Community Coalition

Christopher Zuidema, University of Washington and USDA Forest Service, Pacific Northwest Research Station

Dale Blahna, USDA Forest Service, Pacific Northwest Research Station

Weston Brinkley, Urban Waters Federal Partnership

Michelle Kondo, USDA Forest Service, Northern Research Station

Troy Abel, Western Washington University

Andrew Schiffer and Roseann Barnhill, Dirt Corps

Amanda Bidwell, Amanda L. Bidwell, LLC

Alberto J. Rodríguez and Sandra Pinto de Bader, City of Seattle

Linn Gould, Just Health Action