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The Relationship Between Concentrations of Polycyclic Aromatic Hydrocarbons in Moss
and Tree Cover in Portland OR

by

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An undergraduate honors thesis submitted in partial fulfillment

of the requirements for the degree of

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Introduction:

What are PAHs and how are they produced?

Polycyclic Aromatic Hydrocarbons (PAH) are common environmental pollutants created by the incomplete combustion of organic materials. Some PAH compounds are among the most powerful known carcinogens (Ravindra *et al.*, 2008). PAH exposure has been directly linked to birth defects in a study that examined the birth length, weight, and head circumference of 160 infants born in Poland (Perera *et al.*, 1998). Although PAHs are produced by non-human sources (such as volcanic activity) they are mostly created in postindustrial society by anthropocentric activity (Perera *et al.*, 1998). High vehicular traffic has shown to be a large source of PAH contamination, as was demonstrated by bioaccumulation in lichen species (Blasco *et al.* 2011), and PAH contamination is also associated with the metal mechanic industry. PAH concentrations were found to be highest in urban-industrial areas and the lowest in forested areas; concentrations in agricultural areas were intermediate of urban and forested levels (Augusto *et al.*, 2009).

How are people at risk?

PAH contamination seems to be a higher risk to humans during dry seasons due to the lack of moisture which keeps contaminated soil weighed down rather than blowing away into the air (Rodriguez *et al.*, 2015). Breathing and ingesting contaminated soil has shown to be one of the greatest risks for PAH exposure in humans (Augusto 2015). Reducing concentrations of particulate air pollutants was shown to significantly reduce rates of heritable mutation rates in mice, indicating that air pollution may cause genetic mutation in humans and wildlife. This study also indicates that reducing concentrations of air pollutants can reduce rates of mutation and birth defects in exposed populations (Somers *et al.*, 2004). Links have also been shown between PAH exposure,

respiratory illness, and cardiovascular disease (Burton 1986).

Diet

Along with these patterns of exposure, diet has been also shown to account for 70% of actual PAH exposure in humans. In non-smokers, diet accounts for 70% of total exposure to PAH. Because of how widespread PAH is in our environment, almost all foods contain levels of PAH. In a comparative study on PAH levels in different foods, oils and fats from cereal, as well as uncooked vegetables, contained the highest levels of PAH. PAHs are found in higher levels in meat products when they are cooked over an open flame (Phillips 1999).

How are PAH monitored?

Species of lichens and mosses have been shown to be bioindicators of air pollutants (including PAH contamination) in many studies (Augusto *et al.*, 2009, Blasco *et al.*, 2011, Burton 1986, Jovan *et al.*, 2015, Adams *et al.*, 1992). Their presence or absence can then be used to determine severity of contamination, as different species exhibit varying tolerances to air pollutants. Lots of research addresses lichens as bioindicators of pollution, but less is known about mosses as bioindicators of pollution. This disparity may be explained by the wide variety of lichen species available for pollutant studies (Adams *et al.*, 1992).

Reasons why moss is a good bio-indicator of PAHs

Mosses accumulate contaminants because they rely on atmospheric sources of water, and because they have a high surface area that efficiently entraps particles. Moss leaves are one cell thick while lacking a cuticle- this results in the adsorption of PAH to the

lipids on the cell walls of the leaves. Using bioindicators to analyze PAH contamination is a very desirable method, because of the lower cost when compared to other methods, the feasibility to create fine-scale maps using them, and the ability to test for long-term pollutant integration (Jovan, personal communication, 2015).

There are a variety of reasons why mosses may be suitable bioindicators of environmental pollution. Another reason for using moss is that mosses are more conspicuous and easier to identify than lichens.

Orthotrichum spp.

Orthotrichum spp. are found growing in the most polluted sites in Portland, and grow alongside two of the most pollutant resistant lichen genera- *Candelaria* and *Physcia* (Jovan et al. 2015). In areas that demonstrate a comparatively high level of pollution, such as Swan Island, *Orthotrichum spp.*, *Candelaria spp.*, and *Physcia spp.* are the only species found growing on trees. In less polluted sites *Parmelia sulcata* can be found growing on trees, and in even less polluted sites *Evernia prunastri* and the pollution-stunted *Hypogymnia* and *Usnea* are found. It is speculated that *Orthotrichum spp.* may even thrive in areas with PAH contamination (Jovan et al, 2015). *Orthotrichum spp.* is an important resource for bioindication and sample sources in the Portland metro pollutant studies because it is the most common genus of moss in the area, and it is shown to be highly pollutant resistant in comparison to other moss genera (Jovan et al. 2015). However, a different study took data from Linz, Austria and showed that *Orthotrichum spp.* are not particularly tolerant to toxins when compared to other species of lichen and moss, but demonstrate some amount of tolerance. It is important to note that the toxin tolerance of each species was found to be variable in this study, and highly

dependent on the species of the host tree (Zechmeister 2006).

Bullseye Glass

In Portland Oregon there was a public outcry about moss studies indicating unsafe levels of arsenic, chromium, and cadmium being released from SE Portland industrial sites. The US Forest Service used moss samples to find evidence of elevated arsenic, cadmium, and hexavalent chromium, and nickel in SE Portland. The Oregon Department of Environmental Quality was also a part of the investigation-

air quality sensors were set up around SE Portland neighborhoods in 2015, and in 2016 industrial emissions produced by Precision Castparts Corp and Bullseye Glass Company were successfully linked to these elevated levels of heavy metals. Although the levels were higher than the Oregon Health Associations human health based targets, the company was compliant with permits, indicating the federal and state regulations were not effective in creating safe air pollution levels

(portlandmercury.com)(oregonlive.com)(portlandonline.com). Arsenic and cadmium exposure are known to raise the risk of contracting bladder, skin and lung cancers, and can also impair brain development lung cancer and can damage the kidneys. Community organizations Neighbors for Clean Air and Eastside Portland Air Coalition formed and began organizing communities in order to raise public awareness, put pressure on city officials to apply stricter regulations, and attempts to connect industrial sites to cancer clusters in these SE neighborhoods were put in motion. Bullseye Glass Company was sued by class action law suit due to allegations that the company knowingly created a “negligent, reckless, intentional, and/or abnormally dangerous nuisance”

(portlandmercury.com). The result was a cease in production of products requiring the use of arsenic and cadmium, while products using lead continued. They were also made to

pay for urine and blood testing for residents in the areas showing elevated levels of pollutants.

Precision Castparts Corp was also hit with a class action lawsuit after DEQ investigation revealed that nickel, hexavalent chromium, and arsenic were found in surrounding neighborhoods at levels above the health-protective air quality goals. Precision Castparts Corp was also given a cease and desist order by city officials once this information was made public. Because of the combined effort of the US Forest Service, the DEQ, OHA, and newly formed community-based organizations concerned with air quality, new standards for cleaner air have been imposed by city officials on industrial activity involving the use of heavy metals, and public awareness on these environmental and public health concerns have been raised significantly.

Research Questions:

- 1) What is the spatial distribution of PAH as determined by moss?
- 2) What is the correlation (if any) between PAH concentrations around the Portland area and tree canopy cover? How do PAH concentrations and tree canopy cover relate to the position of industrial activity throughout Portland?

Methodology:

Figure 1: A flowchart showing an overview of the map building and analysis methodology.

I was provided with data from the USFS Pacific Northwest Research Station (Sarah Jovan, PhD) to engage in this research. Sarah Jovan and Geoffrey Donovan took moss samples and coordinate data from 500 sites around Portland in 2013. In 2014 they took samples at all public schools in the city. I used strictly quantitative data, sourced from these samples and observations taken in the field, results of lab analyses of the samples for PAH content. The data and samples collected by the USDA Forest Service were analyzed by Specialty Analytical in Clackamas, Oregon. The data on the Portland tree canopy (2014) was obtained from the Portland Metro Data Resource Center (<http://www.oregonmetro.gov>).

PAH layer

I used Ersi's ArcMap 10.3 to create maps of tree canopy cover and PAH deposition across the Portland Metro area. The PAH data included Client Sample ID (address of sample site), a plethora of PAH types, or compounds, in the moss tissue, and the amount of PAH detected ($\mu\text{g/Kg-dry}$). Google geocoding services were used to turn the addresses of each sample site into coordinates. In order to determine which PAH compounds to include in the analysis, a public health statement by the CDC (CDC, 2015) was referenced. The CDC lists acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[e]pyrene, benzo[b]fluoranthene, benzo[g,h,i]perylene, benzo[j]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-c,d]pyrene, phenanthrene, and pyrene as being PAH compounds of special interest for public health. The reasons for this are:

- (1) more information is available on these than on the others;
- (2) they are suspected

to be more harmful than some of the others, and they exhibit harmful effects that are representative of the PAHs; (3) there is a greater chance that you will be exposed to these PAHs than to the others; and (4) of all the PAHs analyzed, these were the PAHs identified at the highest concentrations at NPL hazardous waste sites. <http://www.atsdr.cdc.gov/phs/phs.asp?id=120&tid=25>

Of these PAH compounds mentioned by the CDC, the sample analysis had data for acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[g,h,i]perylene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-c,d]pyrene, phenanthrene, and pyrene, so these PAH compounds were included in the analysis.

Spatial extrapolation of the PAH layer

Geographic coordinate system “WGS 1984” was selected, so that the values for longitude and latitude would be translated into decimal degrees (meters) and XY data layer could be placed on the map showing each sample location. Inverse Distance Weighting (IDW) was used to create a visual representation of PAH contamination from the XY data. IDW works by weighting the distance between points against the value in question, assuming that the value measured is decreasing as distance from the spatial point increases. The layer of XY data created from the PAH data was selected as the input. For the Z field (the third relevant data besides spatial data), “totalpah” (the sum of all relevant PAH compound concentrations ($\mu\text{g/Kg-dry}$)) was selected.

The data was classified by quantizing the data using Geometric Interval with nine classes for ease of visualization, and to create standard color-coded classes and range of pollution levels for further analysis.

Figure 2: A map of the Portland metro area that includes a raster showing a theoretical spread of PAH across the area as well as the location of the map sample sites.

Verifying accuracy

Figure 3: A raster that serves as an accuracy test of the IDW process, created by removing half of the moss sample sites from the data.

The accuracy test was ran by using Identify to check the value of each sample site as compared to the raster pixel value occupying the same space. Each value in the created raster was within 1.1 $\mu\text{g/Kg-dry}$ of the original dataset that the raster was derived from, indicating a low margin of error. A second accuracy test was ran by creating a new excel spreadsheet of the data with every other sample point excluded.

This accuracy test table was saved as a Comma Delimited (.csv), entered into the map as XY data, and then run through the Inverse Distance Weighting tool with all settings set to the default. The data was classified by quantizing the data with Geometric Interval, and 9 classes. The value of PAH concentration of each XY point was compared to the derived raster value occupying the same point, and it was found that the points were within 1.0 $\mu\text{g/Kg-dry}$ of each other, indicating a low margin of error. With every other coordinate point missing, the raster and the accuracy test raster both resemble each other and show a low margin of error.

Census layers

After this accuracy test was completed, a shapefile of Portland census tracts (2000) was added, as well as a raster dataset of tree canopy cover across Portland that was obtained from Portland Metro (Figure 4., Metro Data Resource Center, 2014). Canopy in this dataset was measured using a normalized difference vegetation index (NDVI) from the imagery and feature heights from LiDAR.

Figure 4: A map of the canopy cover raster clipped to the extent of the clipped census tracts. The census tracts were clipped by the extent of the PAH raster (figure 2).

Combining the layers

The census tracts were clipped to the extent of the PAH raster, and the canopy cover raster was clipped to the extent of this clipped census tract shapefile (Figure 5). Afterwards a zonal analysis was done so that the mean value of both PAH concentration and Tree Canopy Cover could be calculated and shown in two separate tables. These tables were then joined to two copies of the clipped census tract file, and the data was quantized using Natural Breaks with nine classifications to show a spatial representation of mean PAH concentration and mean canopy cover by census block.

After these spatial representations of mean PAH concentration and mean tree canopy volume were generated, the attribute tables for each were exported into Microsoft Excel. Two census blocks that did not contain sufficient data were excluded during this exportation of data. After the two attribute tables were exported into Excel, a scatterplot and regression of the data contained within the tables was generated in order to explore the statistical correlation between mean PAH concentration and mean tree canopy volume.

Figure 5: A map of the mean tree canopy volume across Portland by census block, as well as the location of the moss sample sites.

Figure 6: A map of Portland showing the mean levels of PAH concentrations (ug/kg) by census block, as well as the moss sample sites.

Results/Discussion:

Figure 7: A scatter plot showing the relationship between PAH concentration (y-axis) and tree canopy (x-axis) by census block. Regression analysis determined this relationship was statistically significant ($R^2=0.034$, $p=0.0039$).

The first regression (Figure 7) shows that there is a significant negative correlation between PAH concentration and tree canopy volume in Portland. However, there is not enough information to come to any concrete conclusions about this relationship, and more in depth studies are needed to better understand how the volume of tree canopy affects PAH concentrations in moss. The linear trend line of the data and the low R^2 value (0.034) shows that there is a lot of variation in the data. There is a large spread of data points on both sides of the line, and the R^2 value for the line is close to zero which demonstrates that the linear equation has very low accuracy for determining a clear correlation between canopy volume and PAH concentration.

Part of the difficulty in establishing a clear relationship may be attributed to the large cluster of data points that display both low canopy volume and low PAH concentration (($30 < x < 60$) ($0 < y < 1000$)). Within this range of low tree canopy cover (30-60) also lays the largest concentrations of PAH. The demonstrated variability of this relationship suggests that a more in depth analysis on land use may uncover more precise conclusions about how PAH and tree canopy affect each other in the urban environment. In order to explore the possibility that the cluster of low value points was giving an inaccurate statistical correlation between tree canopy volume and PAH concentration, a second regression was ran excluding this cluster (($30 < x < 60$) ($0 < y < 1000$)). In this second regression (figure 8), the R^2 value increased to 0.2152, demonstrating less variability in the data and a more statistically relevant correlation between greater tree canopy volume and lower levels of PAH concentrations (ug/kg).

Figure 8: A scatter plot with a line equation, showing how the R^2 value increases to 0.2152 as the cluster of low value points was removed ($30 < x < 60$) ($0 < y < 1000$), demonstrating that a clearer relationship between PAH concentration and tree canopy develops as the cluster is removed.

Figure 9: A map of the Portland area showing industrial sites registered with the EPA Toxic Release Index, as well as the mean PAH concentration (ug/kg) by census block.

Figure 10: A map of the spread of mean PAH value by census block, overlaying a map of Portland Roads and Highways.

Conclusion:

The relationship between tree canopy volume and PAH concentrations across the Portland area has been demonstrated to be complex and variable. The research in this study suggests that land use designation, contamination sources, PAH concentrations, and canopy volume are all factors in determining the relationship between PAH and tree canopy volume. All these variables make determining the effectiveness of tree canopy in lowering PAH concentrations in the air difficult, although a significantly negative correlation was found during the analysis of the data. Having a less variable spread of tree canopy cover across Portland could make finding a more precise correlation between the physiological relationship of tree canopy volume and PAH concentration easier. It is possible that census tracts with less tree canopy cover are disproportionately exposed to more PAH, suggesting that the correlation between tree canopy volume and PAH could have more to do with human land use patterns rather than a physiological function of the tree canopy.

Information on possible industrial sources of PAH deposition is also a barrier to exploring the relationship between PAH and tree canopy. When comparing the spatial analysis of PAH to a layer of industrial sites registered in the US EPA's Toxic Release Index (figure 9), there is no information available on the sources of the two most contaminated areas in Portland. One of these sites measures as an outlier of 12,226.4 (ug/kg). Further analysis of this aspect of land use could be beneficial to a greater understanding of sources of PAH contamination in Portland. As previously mentioned, PAH concentrations are generally lower around forested areas, and these areas also tend to have less vehicular exhaust and industrial activity- two major sources of PAH.

Studies of NO₂ pollution in Portland demonstrate the complexity of relating air quality to tree canopy cover. Trees can absorb NO₂ from the environment, and a canopy cover of just 20% can reduce NO₂ pollution by 15% on average depending on the maturity and spacing of the trees (Rao et al, 2014). Rao et al. 2014 predicted that the amount of trees in Portland currently saves 7 million dollars annually, just taking the decreased hospital visits and harmful NO₂ removed from the air into consideration. Another aspect of the findings to take into consideration is that different neighborhoods are being affected disproportionately- one variable that affects the amount of NO₂ pollution present in an area is the amount canopy cover. More research is needed to understand the ecology of NO₂ and urban trees, as some tree species react with NO₂ and release ozone into the environment. When ozone levels near the ground are too high, there are negative impacts on public health such affecting respiratory illness and disease (*epa.gov*). More research must be done in order to determine what tree species will be the most beneficial for controlling air pollution in an urban environment, as the exact variables and biological processes that cause trees to absorb NO₂ are still not completely understood in a way that can be integrated into urban planning and forestry. It was concluded that industrial North Portland would see the least reduction in NO₂ concentration, while Forest Park will see the most reduction of NO₂ concentration (Rao et al, 2014). The negative correlation between tree canopy and NO₂ concentration is encouraging for further research on the physiological relationship between canopy cover and air pollutant mitigation, and the evidence that increased tree canopy improves the respiratory health and economic well-being of citizens is even more encouraging. However, it is concerning that the areas that will see the least amount of reduction in NO₂ tend to be populated by lower income families, and serve as the workplace of working class employees. This is affirmed not only by simple observation of our

city, but also empirical evidence showing canopy cover of a neighborhood and the average annual income its inhabitants have a positive correlation to each other (Zhu et al, 2008).

Caucasian people are the most likely to live in an area with higher canopy cover than all other races, while African Americans are the least likely to live in an area with higher canopy cover, indicating that access to urban canopy is a economic class and race issue (Jesdale et al, 2013).

Another contemporary environmental and public health issue is the Urban Heat Island Effect (UHI). UHI causes urban areas to have a notably higher air temperature than surrounding suburban and rural areas. UHI occurs as a result of the mass of impermeable and artificial surfaces absorbing short-wave radiation that are found in urban areas (Solecki et al, 2005), as well as waste heat generated by energy usage (Zhao et al, 2012). Environmental effects include longer growing seasons in urban centers, greater rainfall downwind of urban areas, warmer water temperature in surrounding areas, and many more impacts on a variety of life and ecosystem functions (Peterson et al, 1999). Environmental effects that most obviously and directly affect humans are a higher air temperature (the leading cause of weather related death in the USA), and an increase in ground-level ozone concentration. People of all ages are affected by elevated levels of ozone, but children and the elderly are the most susceptible. Ground-level ozone pollution harms non-human life and disrupts ecosystem function as well (epa.gov). Studies show that urban areas with more vegetative cover and street trees have the lowest temperature within a UHI. Living roofs, urban forestry, and light-colored surfaces have all been shown to be viable ways to address UHI. When comparing the implementation of living roofs, light- colored surfaces, and urban forestry, planting street trees had the greatest cooling effect per unit area in New York.

Light-colored surfaces, however, had the greatest overall cooling effect when taking

available area for implementation into account (Rosenzweig, 2004). The ties between NO₂, UHI, ozone, and urban vegetation/canopy are apparent from these urban ecological studies. Thus, there is great potential that these studies are highly relevant to PAH/tree canopy studies as well, considering that vehicular exhaust is a main source of both NO₂ and PAH contamination. As shown in figure 10, census blocks lining highways throughout Portland appear to have a higher mean PAH value, suggesting that further study into PAH deposition in relation to distance from a major roads and highways may uncover more valuable information about pollution sourced from vehicular traffic in the urban industrial environment. Trees absorb light energy, filter air pollutants, clean our water, help maintain healthy soil, and absorb storm water that otherwise could end up in rivers (*friendsoftrees.com*). It is plausible that the large surface area generated by tree leaves works as a filter, capturing PAH contaminated particulate matter from the air. These PAHs may work their way to the ground, where the physiological processes of trees that filter water and soil take place. As stated before, the ingestion of contaminated soil is one of the largest sources of human exposure to PAH. Breathing and ingesting contaminated soil is a greater risk during the dry season, when there is less water to hold the surface layer of soil down.

The City of Portland has an institutional organization under the Bureau of Parks and Recreation dedicated to Urban Forestry, and the city has been managing the urban canopy since 1972. This part of the city government is called “Portland Parks and Recreation Urban Forestry” (PPRUF). The mission of PPRUF as stated on their website is to “manage and ensure Portland's urban forest infrastructure for current and future generations”. PPRUF asserts that Portland's urban forest “consists of 236,000 street trees, 1.2 million park trees, and innumerable private property trees. (*portlandoregon.gov*). This part of the city government serves a variety of

functions- they give out permits for planting, pruning, and removal of all public and some privately owned trees. They are on-call twenty-four hours a day to respond to tree emergencies (such as a fallen tree). They also accredit specific trees as being “heritage trees”- trees that are protected by city code because of their age, size, and history or horticultural significance.

PPRUF also provides services for dealing with “neighbor tree conflicts”, and responds to reports of violations of city code. They offer resources to find local arborists, and they provide educational information and host public events on tree care, identification, and the benefits of trees. The PPRUF also facilitates the Tree Inventory Project (*portlandoregon.gov/parks*), in which volunteers measure, identify, and map out trees in Portland’s neighborhood. Since the formulation of the Urban Forest Action Plan of 2007, there has been revamped effort by the city to update city tree regulations and manage the urban canopy.

There is also a page on the City of Portland website dedicated exclusively to the trees themselves (*portlandoregon.gov/trees*). The code covers many topics including the urban tree plan, regulation enforcement, tree density standards, tree planting and maintenance specifications, and permit requirements (*portlandonline.com*). A short statement on the City of Portland website explains:

Portland's tree code works to:

- Protect trees during development
- Preserve trees as a community asset.
- Plant new trees when others are removed, ensuring that the urban forest and its benefits continue to grow.

- Educate people about proper tree care and the benefits of trees.
- Increase the resiliency of the urban forest in the face of threats such as climate change and tree pests (*portlandoregon.gov/trees*)

This tree code was updated with the intention of being easier to understand, as well as dynamic and flexible. It also applies stricter penalties on to those who break the regulations of Title 11 Trees (*portlandoregon.gov*).

Another organization heavily involved in Portland's urban forest is Friends of Trees (FOT). Friends of Trees is a 501(c)3 nonprofit whose mission is "to bring people together to plant and care for city trees and green spaces in Pacific Northwest communities" (*friendsoftrees.org*). They are active in Portland, Vancouver, Eugene, and Springfield. Since FOT's founding in 1989, they have planted about half a million trees and native plants. FOT connects with businesses, homeowners, and volunteers to facilitate tree plantings under the guidance of trained crew members. They also offer discounted trees to homeowners. FOT provides resources to learn about tree planting, care, placement, benefits, and advocacy on their website (*friendsoftrees.org*).

Healthier birth weight was linked to being born in areas with more trees by FOT (*friendsoftrees.org*). Given the other research I have cited (Zhu et al, 2008) (Jesdale et al, 2013), it may be that healthier birth weight is attributed to higher socioeconomic class, and subsequently greater access to resources, less exposure to environmental pollutants, and better access to healthcare. For example, programs such as FOT's discounted tree program specifically targets homeowners. 50% of street trees are on private land (*friendsoftrees.org*), and require individuals to take care of them with their own

resources.

PPRUF requires permits to prune a public street tree. FOT hopes to cover 33% of Portland with trees, however it follows logically that lower socioeconomic classes may not fully benefit from these initiatives. Another non-profit organization that plays a role in the urban forest of Portland is the Portland Fruit Tree Project (PFTP). PFTP focuses on trees that bear fruit, in attempt to fight against food insecurity.

Urban forestry in Portland is managed partly by city government, but nonprofits have a high level of involvement as well. Volunteers perform a large amount of labor and tree maintenance in Portland. Academic institutions and governmental departments such as the DEQ primarily execute research on urban forestry.

The relationship between plant life and public health is complex and multifaceted- a full understanding of the related issues goes beyond simply an understanding of the natural sciences and requires an understanding of the sociological and economic influences involved. Trees provide many different environmental services that are highly valuable to the public health of urban populations. More concrete conclusions about the correlation between PAH deposition and canopy cover may be found if greater emphasis is put on placing trees along streets and other areas that demonstrate higher vehicular exhaust and industrial activity. If a more balanced and equitable canopy cover is encouraged across Portland, it may be easier to come to concrete conclusions about the physiological relationship between canopy cover and PAH in Portland.

The relationship between human health and urban tree canopy is complex, and more research may lead to a more complete understanding of how to utilize urban forestry for the greatest public benefit.

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