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Citizen Sense

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# INTRO-DUCTION

# PHYTO-SENSOR TOOLKIT

Air pollution is a major issue in many cities throughout the world. While reducing emissions at the source is the best way to address air pollution, plants can play an important role in mitigating air pollution. This Phyto-sensor toolkit provides resources for learning how to make your own air quality garden. The Phyto-sensor toolkit was tested and refined through a workshop and walk held in the City of London in March 2018 to investigate the ways in which vegetation can improve air quality.

The Phyto-sensor toolkit is developed by the Citizen Sense research group, led by Jennifer Gabrys. Citizen Sense is funded through the European Research Council, and is based at Goldsmiths, University of London.

The Phyto-sensor project and events have received additional support through the Low Emission Neighbourhood (LEN) fund, an initiative from the Mayor of London to help local councils improve air quality. There are a number of clean air gardens installed in the City of London, which have also been supported through the LEN initiative, and are partially documented on the map in this toolkit.

# PHYTO-SENSOR

Plants are organisms that are continually sensing and changing our environments. Some plants are especially effective at taking up pollutants, whether by absorbing gaseous pollutants through their stomata, drawing in heavy metals through their roots, or channelling and depositing particulates in their leaves.

The Citizen Sense research group has developed the term ‘Phyto-sensor’ to describe these vegetal processes whereby plants sense and respond to their environments. Of particular focus here is the way in which phyto-sensing can improve air quality, especially in urban settings.

Plants are participants in our urban ecologies, and they

contribute to our urban environmental communities. This exploration of plant sensing is connected to a wider Citizen Sense project area, 'Wild Sensing', which investigates how organisms sense their environments, and how this might inform new types of environmental practices.

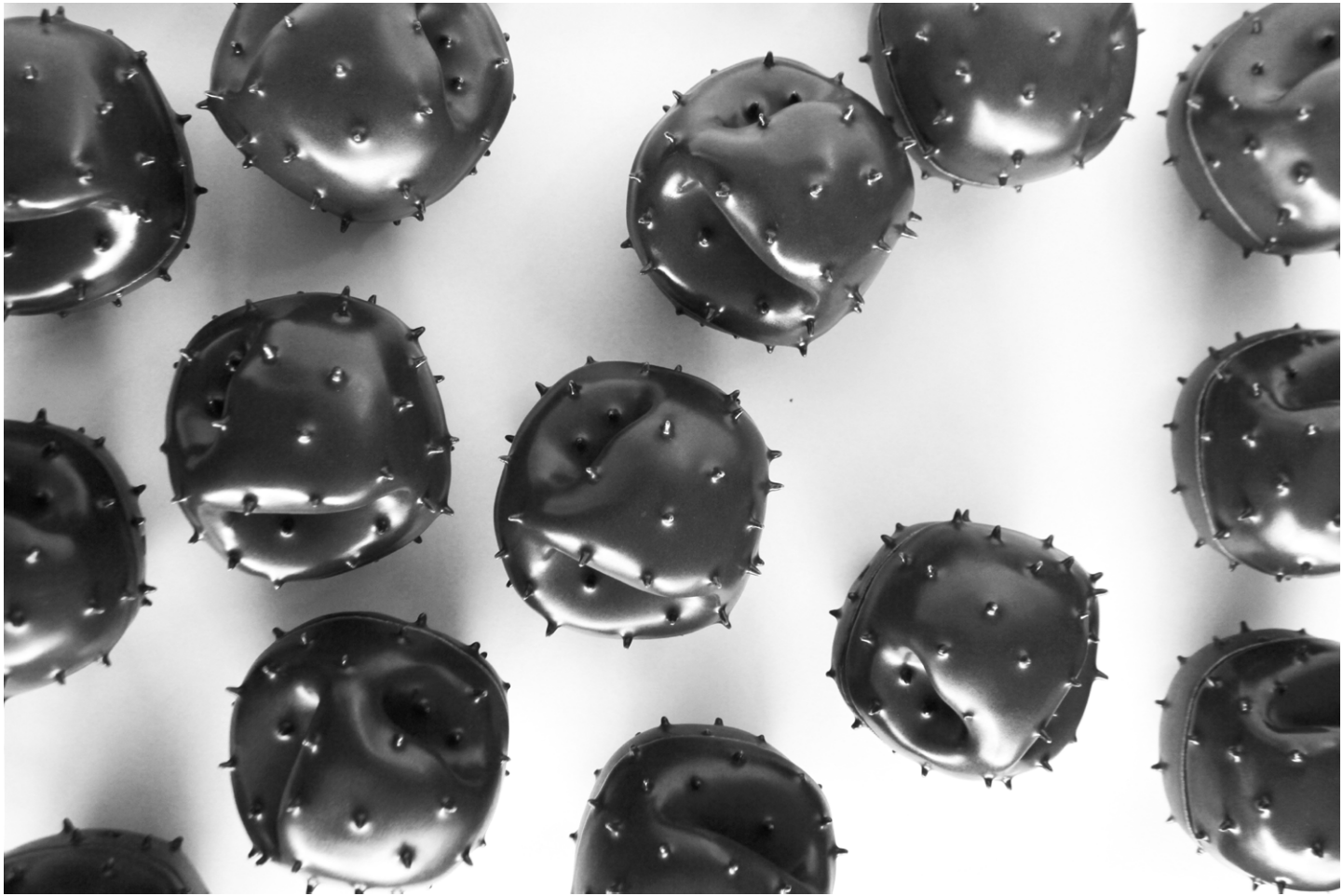
Numerous studies have now established that vegetation can play an important role in mitigating air pollution. Trees and plants can capture particulate matter, absorb gaseous pollutants, and also phyto-remediate soils. In addition, vegegation can enhance biodiversity, capture stormwater and reduce flooding, and lessen the urban heat island effect.

One study undertaken by the Nature Conservancy, "Planting Healthy Air" (McDonald 2016) found that urban trees could make a significant local improvement in air quality by reducing particulate matter levels between 7 to 24 percent. These effects were most notable within 100 meters of a planting.

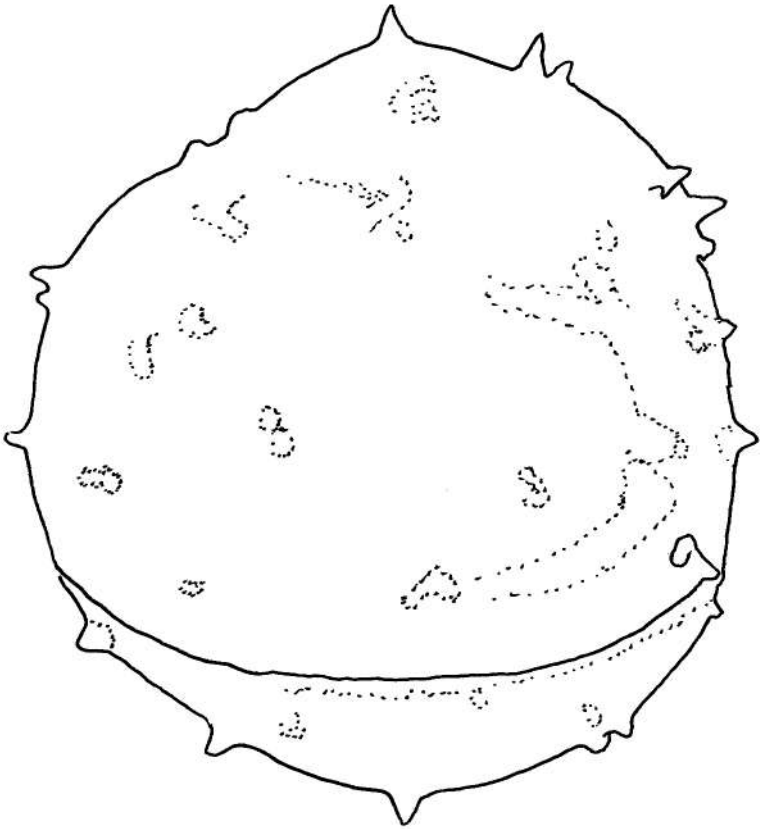
Additional studies from Imperial College (Shackleton et al. 2012) have shown that vegetation, such as shrubs and perennials, planted near or as barriers to emissions sources can also make a positive contribution to lowering particulate matter levels and absorbing some gases such as nitrogen dioxide.

A King's College London report (Tremper et al. 2015) further documents how an ivy screen contributed to the reduction of pollution levels near a playground, with nitrogen dioxide lowered between 24 to 36 percent, and particulate matter 10 levels lowered by between 38 to 41 percent in the immediate proximity of the screen.

Strategies for reducing pollution at source by removing polluting vehicles and cleaning up fuel for heating are the most important place to start when working to improve air quality. However, urban planting can make a clear contribution to improving air quality and urban ecologies more generally.



# CITIZEN SENSING



# DUSTBOX SENSOR

In addition to sensing environments and pollution with plants, it is also possible to sense pollution with different types of digital and analogue sensors. The Citizen Sense research project investigates these different environmental monitoring practices. Citizen Sense has studied as well as built air quality sensors, including the Dustbox (pictured here), which monitors particulate matter 2.5 (PM2.5). The Dustbox is based on the shape of particulates when viewed under an electronic microscope, with cases in the form of pollen and contaminated soil particles.

There are many different technologies available for monitoring the air. Diffusion tubes are one of the most commonly used low-cost technologies for monitoring nitrogen dioxide ($NO_2$). These are commonly placed approximately 2 meters above the ground on a lamppost or similar structure in the area to be monitored. The monitoring period tends to be for 4 weeks, and the tubes are sent to a lab for analysis (for example, see http://www.gradko.com/environmental/products/no2-and-diffusion-tubes.shtml). You can find out more about how to use these technologies on UK DEFRA's website: https://laqm.defra.gov.uk/diffusion-tubes/practical-guidance.html.

The Dustbox technology developed by Citizen Sense is a digital real-time air-quality monitoring device. You can view the logbook for the Dustbox 1.0 used to monitor air quality in South East London at: http://dustbox-logbook.citizensense.net. The logbook includes instructions for monitoring, as well as resources for undertaking citizen air quality monitoring. Citizen Sense is currently developing a Dustbox 2.0 version. For more information, see: http://citizensense.net/kits.

For an overview of digital air quality sensors and toolkit, the US EPA has a comprehensive guide available at: https://www.epa.gov/air-sensor-toolbox/how-use-air-sensors-air-sensor-guidebook.

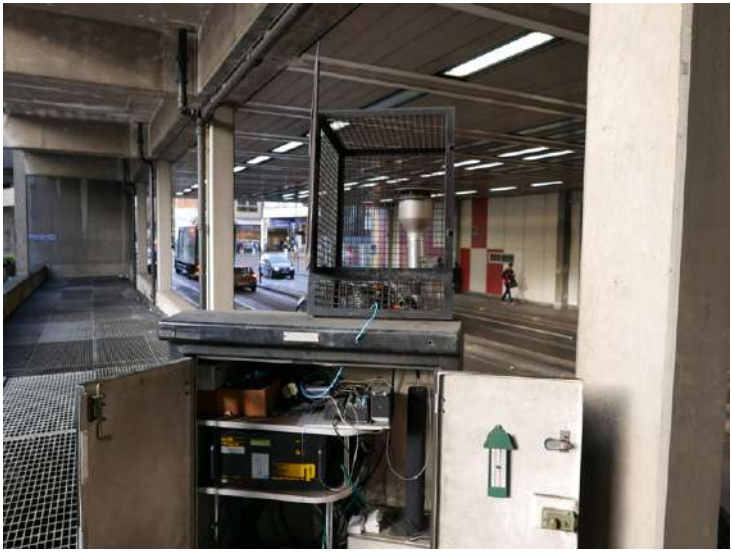
# MONITORING NETWORK

Citizen Sense has previously used the Dustbox to set up a community-monitoring network in South East London. From late October 2016 to September 2017, residents, workers and volunteers hosted Dustbox devices and collected air quality data. With this data, we assembled data stories to communicate the findings from the citizen data. We found that traffic intersections can have significantly elevated levels of particulates, that construction activity can exacerbate these levels, and that the River Thames is also a pollution source. The citizen data also showed that well-planted areas can contribute to lower particulate levels.

For an example of how citizen data can help to identify where urban design projects such as air quality gardens could be most effective, see the Citizen Sense Deptford Data Stories at: http://citizensense.net/data-stories-deptford.

# DUSTBOXES IN THE CITY

While developing the Phyto-sensor toolkit, Citizen Sense located 3 Dustboxes to gather PM2.5 data in the City of London, including at the Museum of London entrance and Beech Street Tunnel. Citizen Sense has developed a DIY data analysis toolkit, Airsift, to analyze data and to document the direction from which pollution is traveling. Airsift is available to view at: https://citizensense.net/kits/airsift-dustbox. Dustbox and LAQN monitoring station data from these locations indicated higher levels of pollution near the Beech Street Tunnel. Traffic intersections were sources of both NO2 and PM2.5 pollution. The map included with this toolkit indicates the monitoring locations installed during this research, as well as prevailing direction of local and regional pollution sources. When planning an air quality garden, it is useful to document where the primary sources of local pollution are located, so that vegetation can be planted as a screen or buffer from these sources.




Dustbox

# AIR POLLU-TION

# AIR POLLUTANTS



There are several key air pollutants that this toolkit addresses. These pollutants have significant negative effects on health and environments. Many pollutants such as particulate matter 2.5 and nitrogen dioxide can impact cardiovascular and pulmonary health, causing asthma, strokes, heart attacks and other cardiovascular diseases. The Royal College of Physicians has estimated that approximately 40,000 air pollution related deaths occur in the UK every year. Air pollution is now considered to be a leading cause of death worldwide, with the World Health Organisation (WHO) estimating that 7 million deaths per year are attributable to air pollution.

Air pollution is an environmental public health problem. Pollutants have negative consequences for human health, and pollutants can also damage plants and ecosystems. Some plants can play a role in mitigating and phyto-remediating pollutants, and well planted gardens on tree-lined pedestrian streets can have significantly lower levels of pollution than busy traffic intersections. However, it is always best to reduce or eliminate pollution at the source, and to develop air quality gardens as a complementary strategy for improving urban environments.

**For information on air quality, see:**
European Commission, "Air Quality Standards", ec.europa.eu/environment/air/quality/standards.htm.

Royal College of Physicians, "Every breath we take: the lifelong impact of air pollution" (23 February 2016), https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution.

World Health Organisation (WHO), "7 million premature deaths annually linked to air pollution" (25 March 2014), http://www.who.int/mediacentre/news/releases/2014/air-pollution/en.

## PARTICULATE MATTER


Particulate matter 2.5 and 10 (PM2.5 and PM10) are criteria air pollutants that are a mixture of dust, sand, soot, and smoke. PM10 is 10 micrometers or smaller, and PM2.5 is 2.5 micrometers or smaller. PM2.5 is particularly hazardous to human health, as it can enter the lungs and bloodstream.

## HEAVY METALS


There are a number of heavy metal pollutants in the air and soil, including lead, cadmium, arsenic and nickel. Plants at times take up heavy metals in a process of phyto-remediation. At other times, plants can be damaged and their growth slowed by heavy metal pollution.

## NITROGEN DIOXIDE

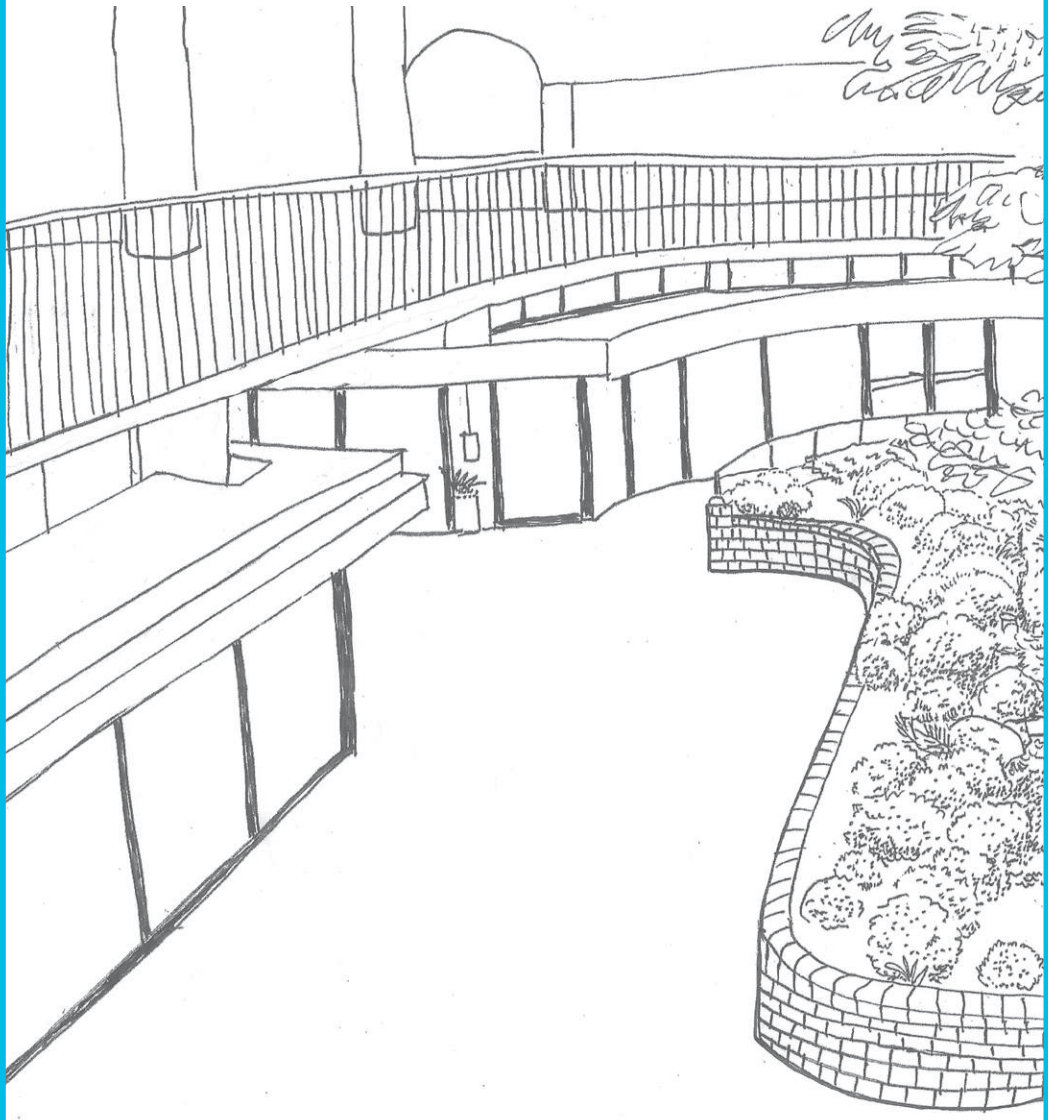

Nitrogen dioxide ($NO_2$) is a reactive gas that forms through the burning of fuel, whether from transport or heating. $NO_2$ can cause respiratory damage and aggravate existing conditions such as asthma. $NO_2$ can also contribute to acid rain, hazy air and nutrient pollution in water.

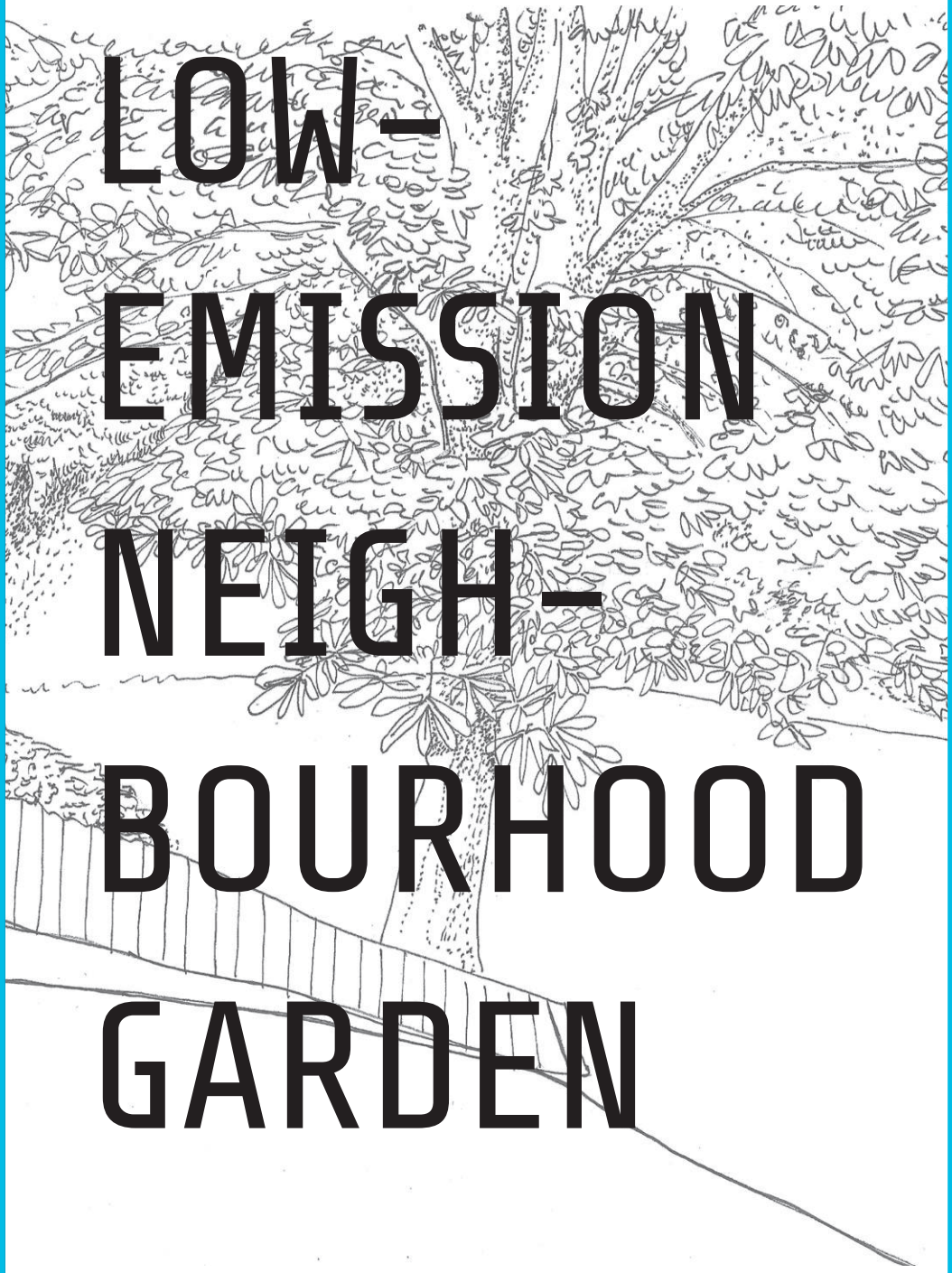
## SULPHUR DIOXIDE


Sulphur dioxide ($SO_2$) most often forms through the burning of coal, as well as other industrial processes. $SO_2$ levels have declined from the time of 'pea soup' fogs in post-war London, but pollutants such as $NO_2$ and PM2.5 have risen. $SO_2$ can contribute to respiratory problems, as well as acid rain and vegetation damage.

# OZONE

Ground-level ozone (O3) is formed through the interaction of nitrogen oxides (NOx) and volatile organic compounds (VOCs). Ozone can contribute to respiratory problems, and it also can damage vegetation and ecosystems that are sensitive to this pollutant.





# LOW-EMISSION NEIGH-BOURHOOD GARDEN

# BACKGROUND

The Phyto-sensor toolkit is created along with two demonstrator garden planters near the entrance to the Museum of London. The Low Emission Neighbourhood (LEN) Urban Garden includes plants that are responsive to air pollution, whether through depositing particulates in leafy structures, taking up nitrogen dioxide through stomata, or displaying sensitivity to ozone.

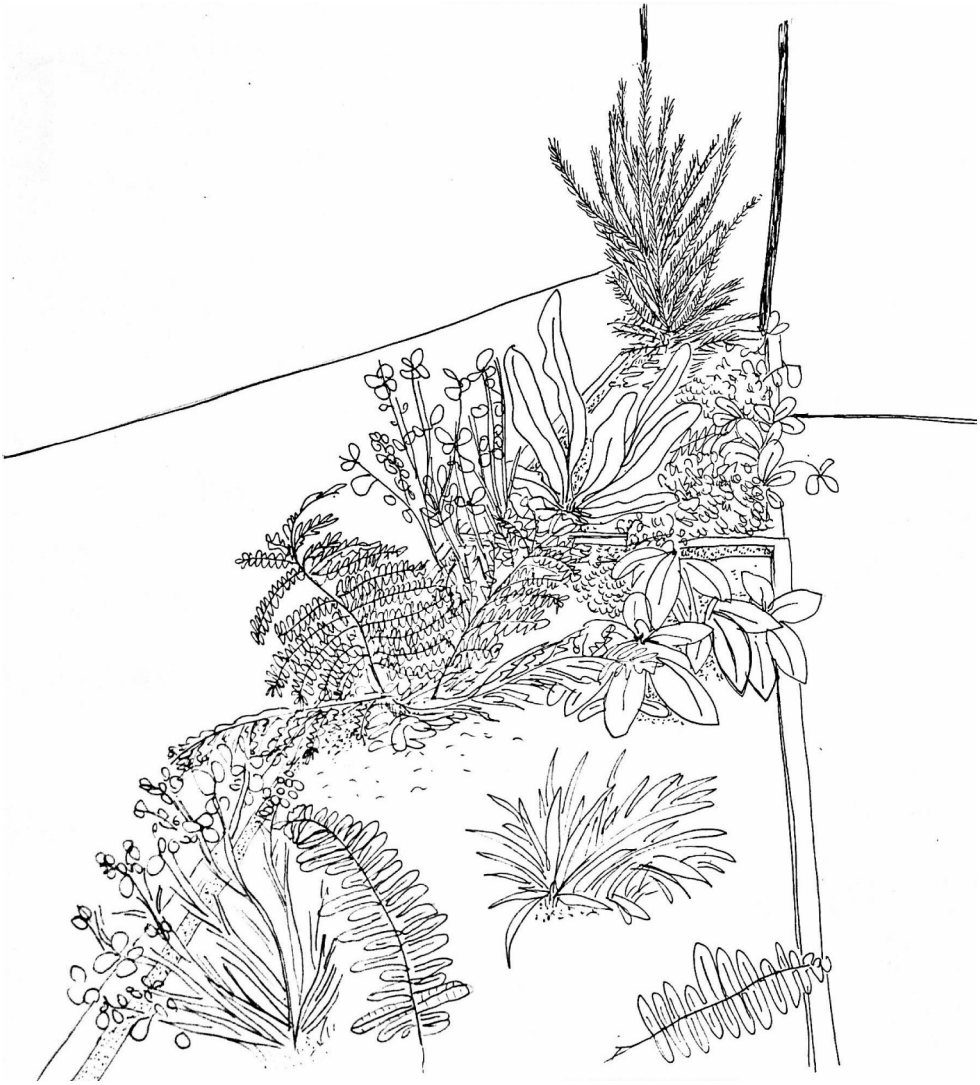
The gardens are installed from September 2017 to summer 2018. Jennifer Gabrys of Citizen Sense advised on the plants to be included in these planters based on their response to different pollutants. Paul McGann of Grow Elephant developed and installed the planters in the autumn of 2017.

# PLANTS

Many of the plants in the LEN Urban Garden are also included in this toolkit with brief descriptions. Some of these plants include: *Taxus baccata* (Yew), *Sorbaria sorbifolia* (False Spirea), *Hedera helix* (Ivy), *Achillea millefolium* (Yarrow), *Aster spp.* (Aster), *Sambucus racemosa* (Red Elder), *Symphoricarpos albus* (Snowberry), *Osmanthus delavayi* (Delavay Osmanthus), *Salvia nemerosa* (Sage), *Lavendula 'Platinum Blond'* (Lavender), *Heuchera spp.* (Coral Bells), and *Euphorbia characias* (Mediterranean Spurge).

# LOCATION

Museum of London entrance / high walk
Closest station: St Paul's
More info: www.museumoflondon.org.uk

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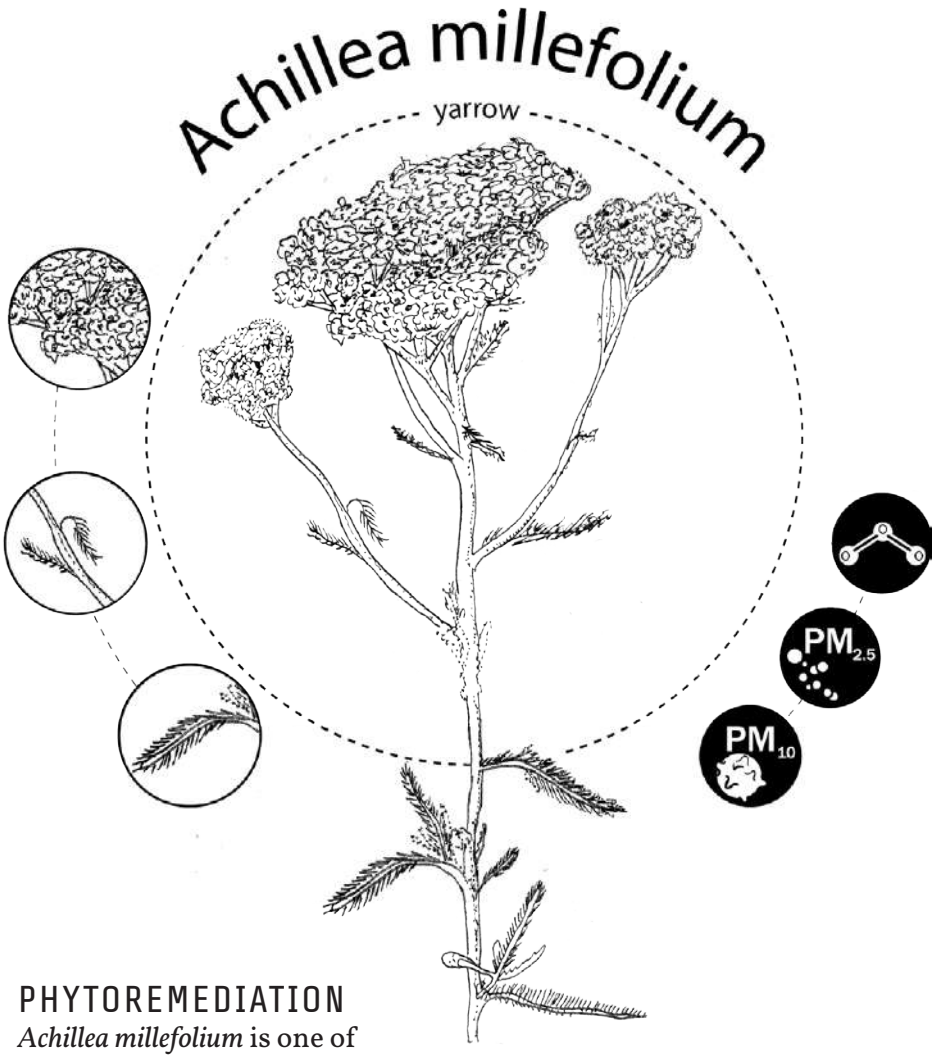
# AIR QUALITY PLANTS




## PHYTOREMEDIATION

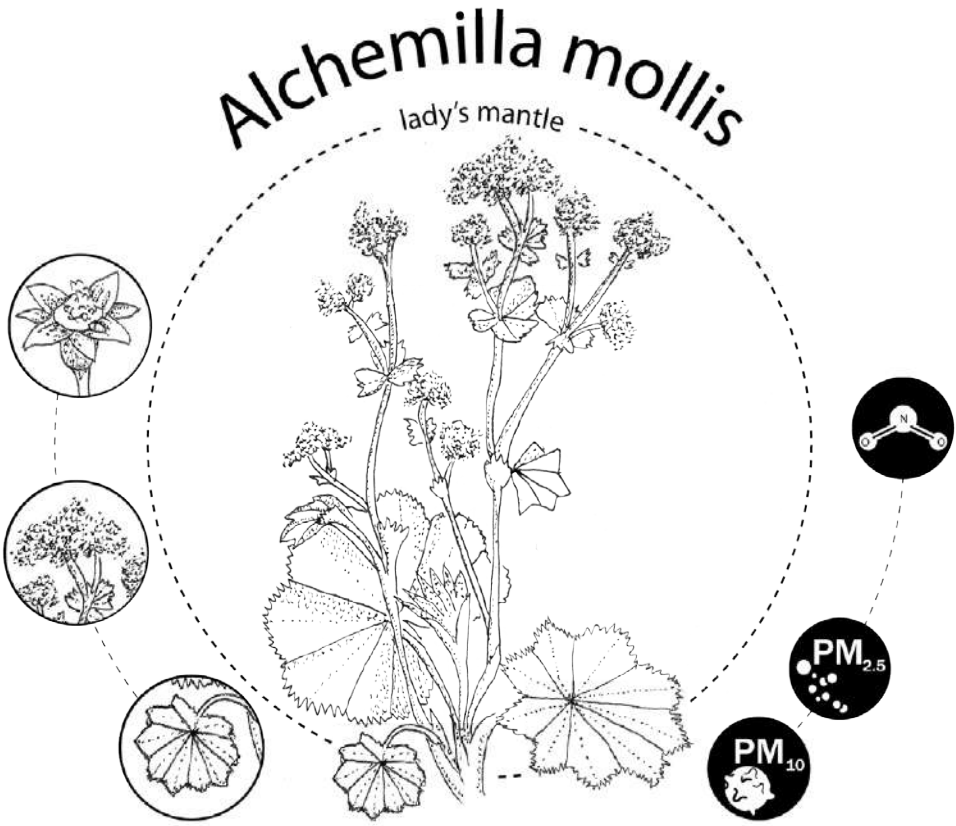
*Achillea millefolium* is one of several species that can colonize soil in urban areas and provide a surface for particle deposition.

## LEAF

Plants with hairy and rough leaves can capture a significant amount of particulates. The pinnate hairy leaves of *Achillea* do this work.

## MULTIPLE SPECIES

Depending upon the species it is planted with, *Achillea* can be more or less sensitive to ozone pollution and damage.




## BIODIVERSITY

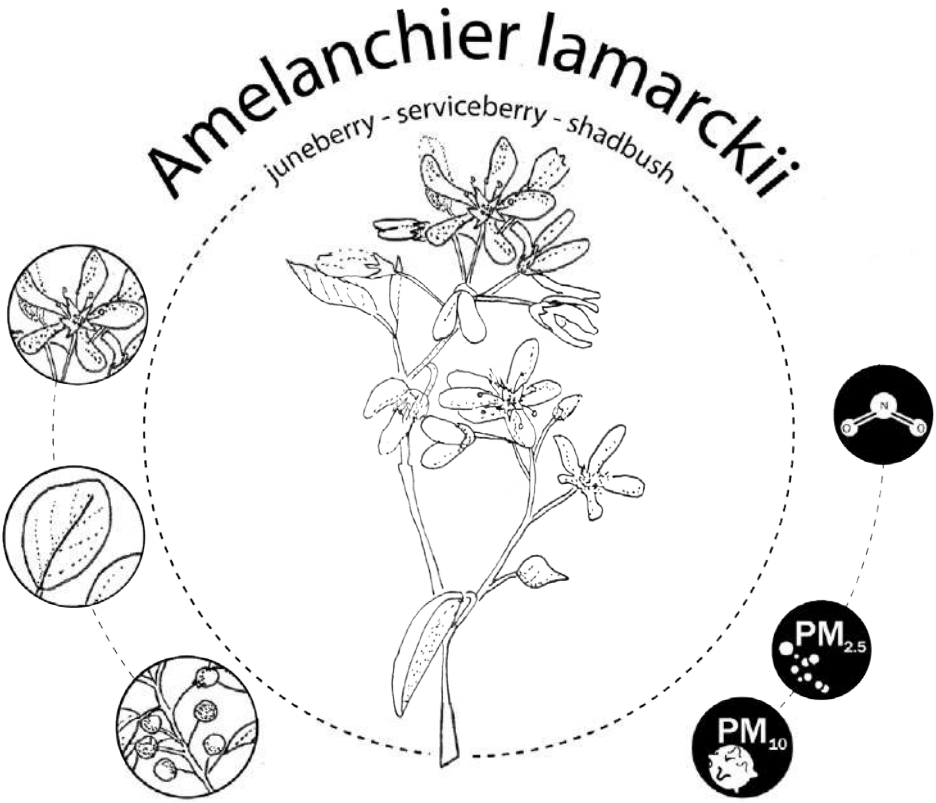
In addition to trapping or responding to air pollution, many plants such as *Alchemilla mollis* provide pollen and nectar for pollinating insects.

## LEAF

Similar to many plants in this toolkit, *Alchemilla* has hairy leaves that trap particulates. These plants can reduce particulates by up to 60 percent, and nitrogen dioxde by up to 40 percent.

## CLEAN AIR GARDENS

*Alchemilla* is a popular plant that can be found in the community clean air gardens in the City of London. One example is at Vestry House on Laurence Pountney Hill.




## POP-UP GARDEN

*Amelanchier* is one of the smaller tree species planted in the Moor Lane Pop-Up Garden, which features air quality plants.

## TREES

Trees such as *Amelanchier lamarckii* can mitigate pollutants such as particulates and nitrogen dioxide, as long as the canopies do not trap pollution at street level.

## WILDLIFE

*Amelanchier* is another species that is particularly good for wildlife, providing berries, pollen and nectar for birds and insects.

# Aster spp.


## HYPERACCUMULATOR

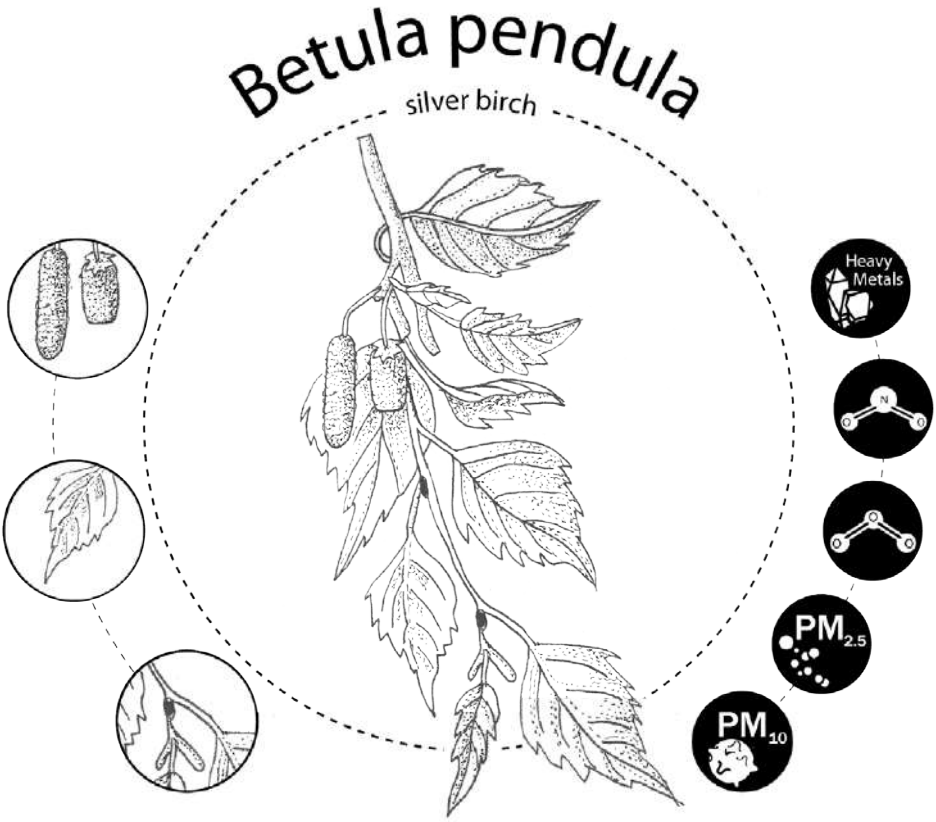
Some plants take up heavy metals from soils. *Aster* is one genus of plants that absorbs metals such as lead, selenium and cadmium, among other soil pollutants.

## BIOINDICATION

*Aster* plants can be particularly sensitive to ozone, and will demonstrate the presence of this pollutant through yellowing of leaves and physiological changes.

## PARTICULATES

*Aster* plants with hairy and many small leaves can also trap particulates and prevent additional dispersion of this pollutant.




## BIOREMEDIATION

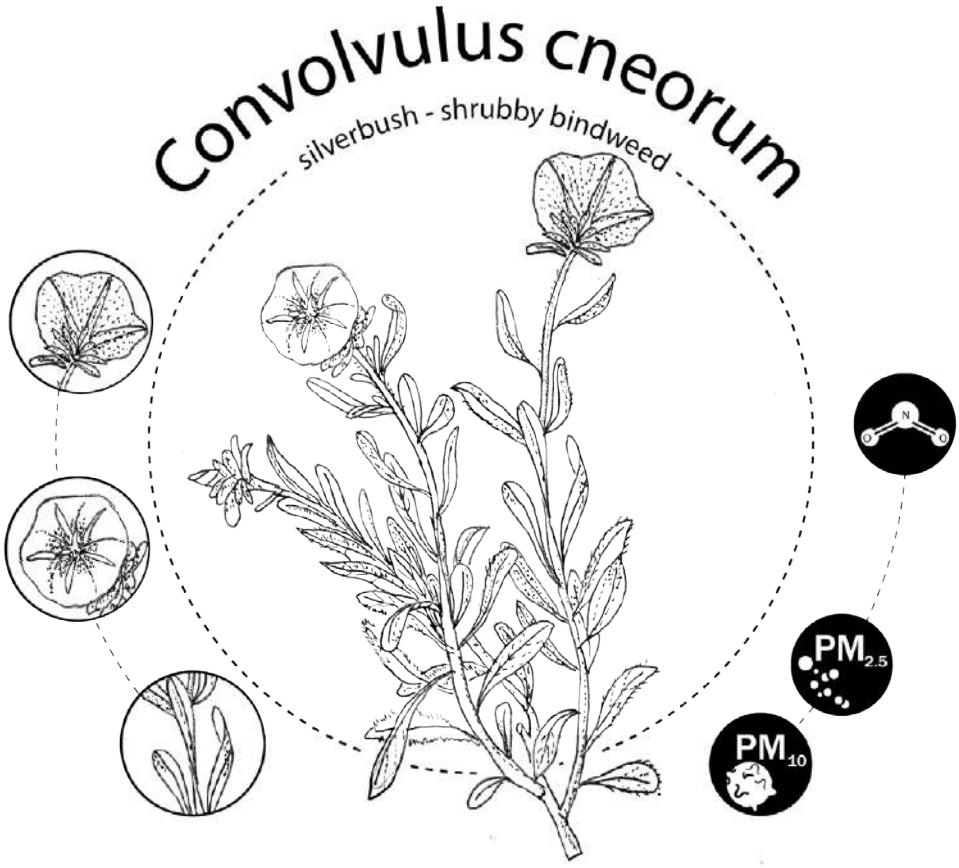
Similar to the *Aster* genus, *Betula pendula* is a potent accumulator of heavy metals. Because *Betula* takes up metals, it also remediates soil and air.

## LEAF SURFACE

The waxy surface of *Betula* can trap particulates, which often wash into the soil after rain. Particulates can also stay in the waxy surface of *Betula* leaves.

## MYCORRHIZA

Certain plants such as *Betula* form mycorrhizal associations with fungi when they are under stress from heavy metals, which aid metal uptake.




## LEAF

*Convolvulus cneorum* has small leaves with a large number of fine hairs, which makes it an ideal plant for capturing particulates.

## CLEAN AIR PLANTER

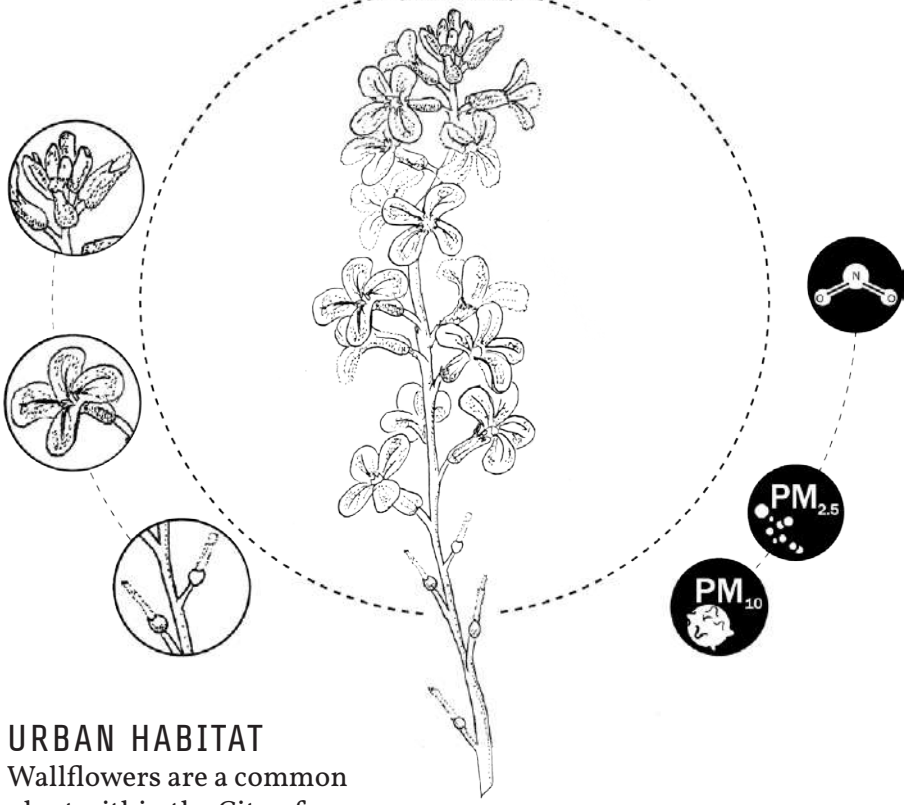
This plant features in a number of community clean air gardens in the City of London, including in the Lauderdale Tower planters near the Beech Street air quality monitor.

## FLOWER

*Convolvulus* is a flowering shrub originally native to southern Europe. It has white flowers in the spring that attract pollinators.

# Erysimum

wallflower




## URBAN HABITAT

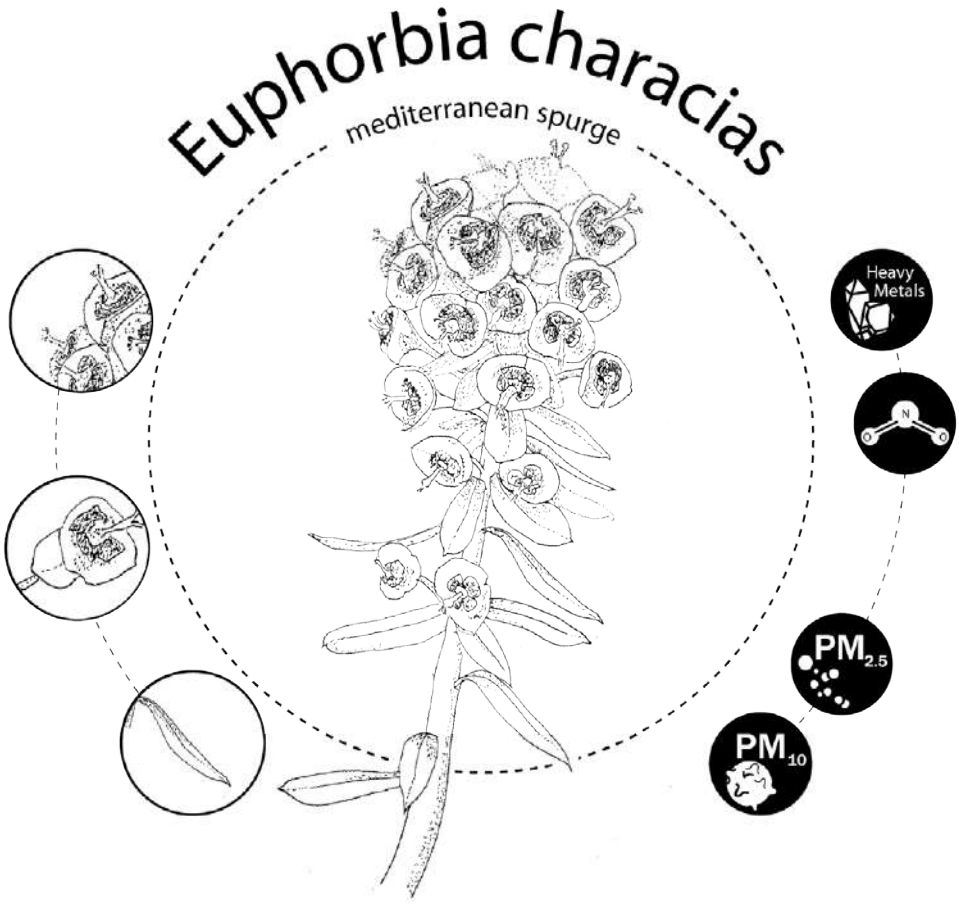
Wallflowers are a common plant within the City of London, and they contribute to the area's biodiversity. Self-seeded wallflowers can be found throughout parks and churchyards.

## LEAF SURFACE

The leaf surface of Wallflower has a high number of short hairs, which contribute to the plant's ability to capture particulates.

## BIODIVERSITY

This plant has flowers attractive to pollinators. Wallflower can grow in ruins in association with many plants that make unique urban ecologies.




## GREEN WALLS

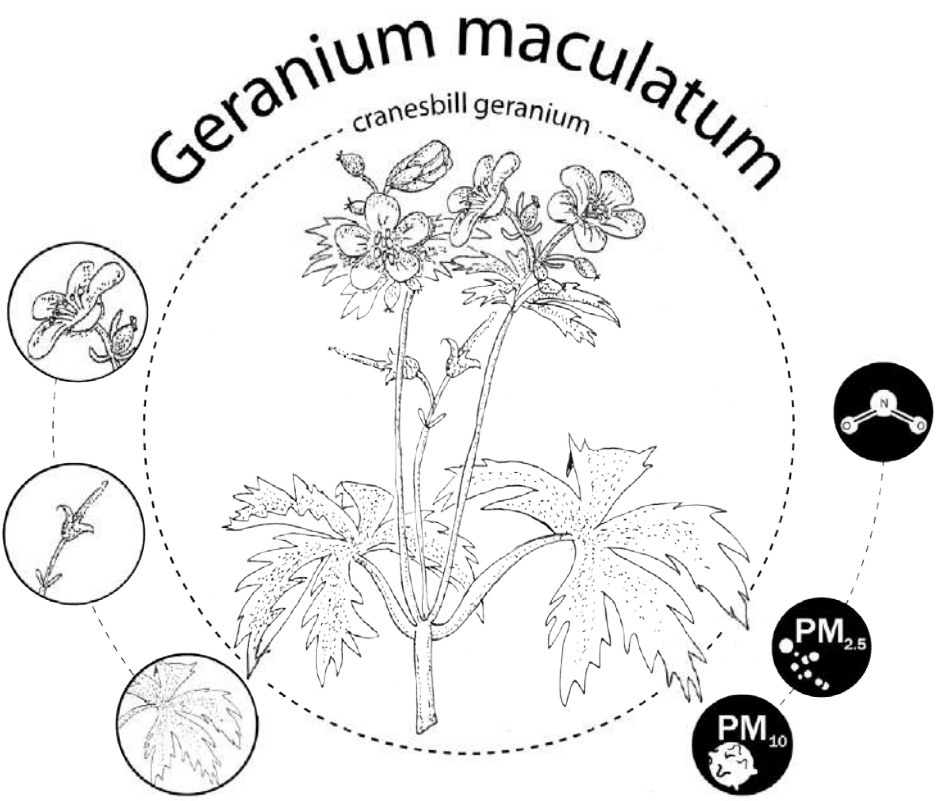
Green walls can introduce high amounts of vegetation in a vertical space for improving air quality. *Euphorbia* species are well suited to green wall planting.

## PHYTOEXTRACTION

*Euphorbia* is another metal hyperaccumulator, taking up lead and arsenic among other contaminants, potentially to ward off herbivores.

## NITROGEN UPTAKE

*Euphorbia* can take up a small amount of nitrogen dioxide. Many (weedy) roadside plant species take up even higher levels of this pollutant.




## LEAF SURFACE

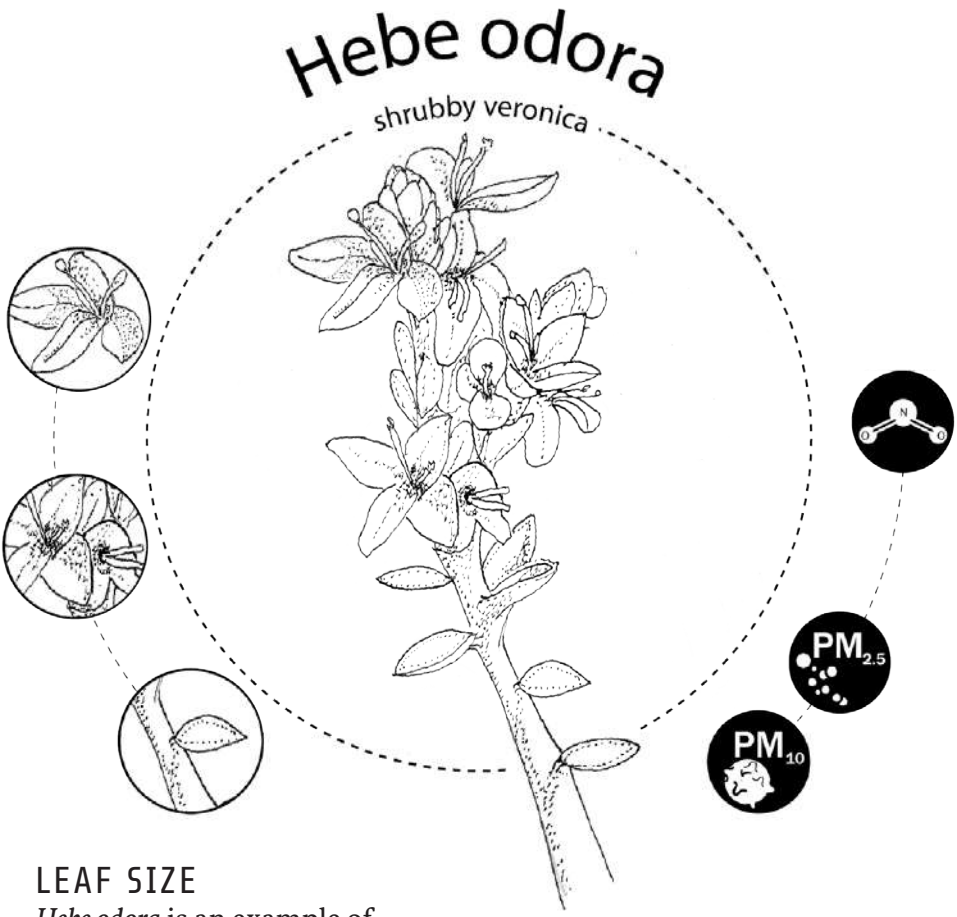
Geranium has a moderate level of leaf hairs, which contribute to an average particulate uptake. More hirsute plants typically capture more particulates.

## CLEAN AIR GARDENS

Geranium is a popular plant in many of the clean air gardens in the City, including at the West Smithfield Cattle Trough and Central Point.

## POLLINATORS

Similar to many plants in the clean air gardens, Geranium has flowers that attract pollinators, thereby contributing to urban biodiversity.




## LEAF SIZE

*Hebe odora* is an example of a plant that has smooth (or glabrous) leaves, but because the leaves are small they contribute to particulate capture.

## CLEAN AIR GARDEN

*Hebe* can be found throughout the City, especially at the Moor Lane Pop-Up Garden and Central Point at the Beech Street monitoring station.

## PLANT SIZE

While plants such as *Hebe* are more efficient in capturing particulates, other larger plants (such as ivy) can capture more particulates overall.

# Hedera helix

common *ivy*


## GREEN WALLS

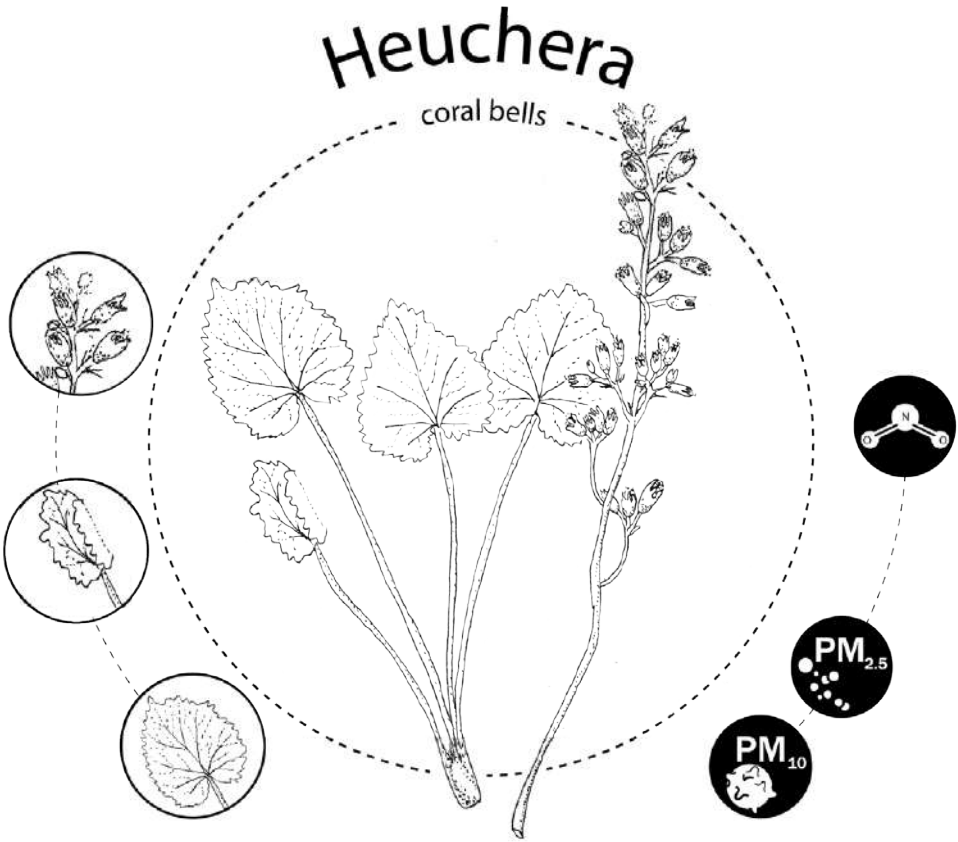
Ivy is a very popular and common plant in green walls. It has a moderate ability to capture particulates, but due to its size it can capture more particulates than smaller plants.

## LEAF SURFACE

While plants with small leaves and needles have greater deposition of particulates, ivy can create extensive green surfaces in urban canyons that greatly reduce pollution

## RESISTANCE

Ivy is one of several species that is relatively resistant to urban pollution and urbanisation, making it an ideal plant for air purification.




## PLATFORM 4

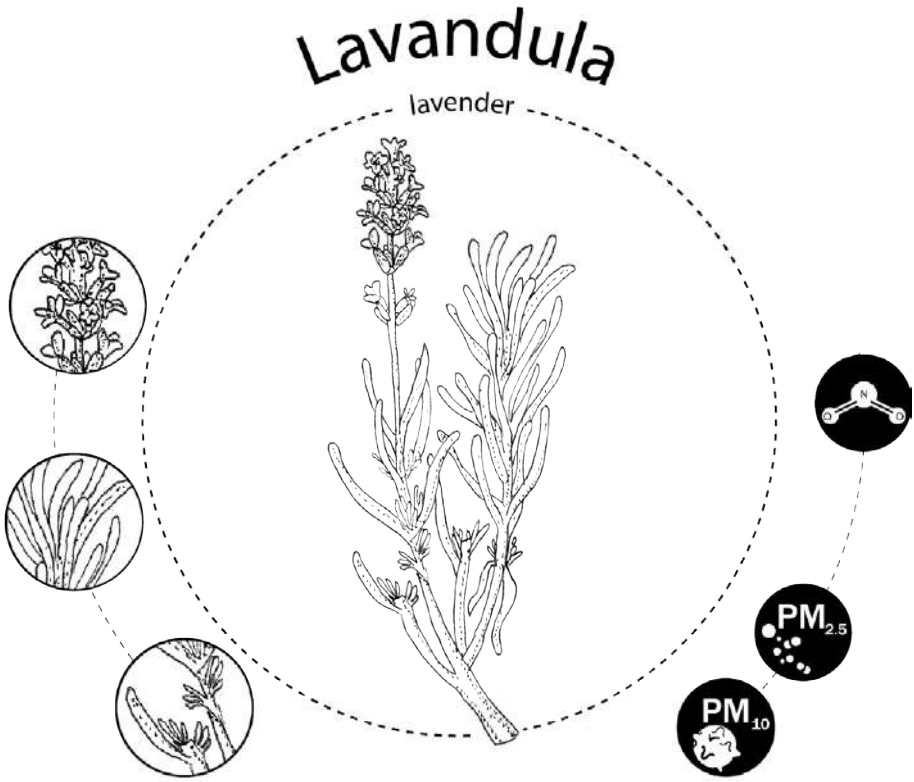
*Heuchera* can be found on the Barbican Station's platform 4, where a community garden of air quality plants has been installed to green the urban canyon of the station.

## LEAF

Unlike many of the plants in this toolkit, *Heuchera* has broad leaves. There are hairs on the underside of the leaf surface, which can capture particulates.

## GOLDEN LANE

The air quality garden at One Golden Lane features *Heuchera*, which has distinctive purple leaves that are easy to identify.




## FUMIFUGIUM

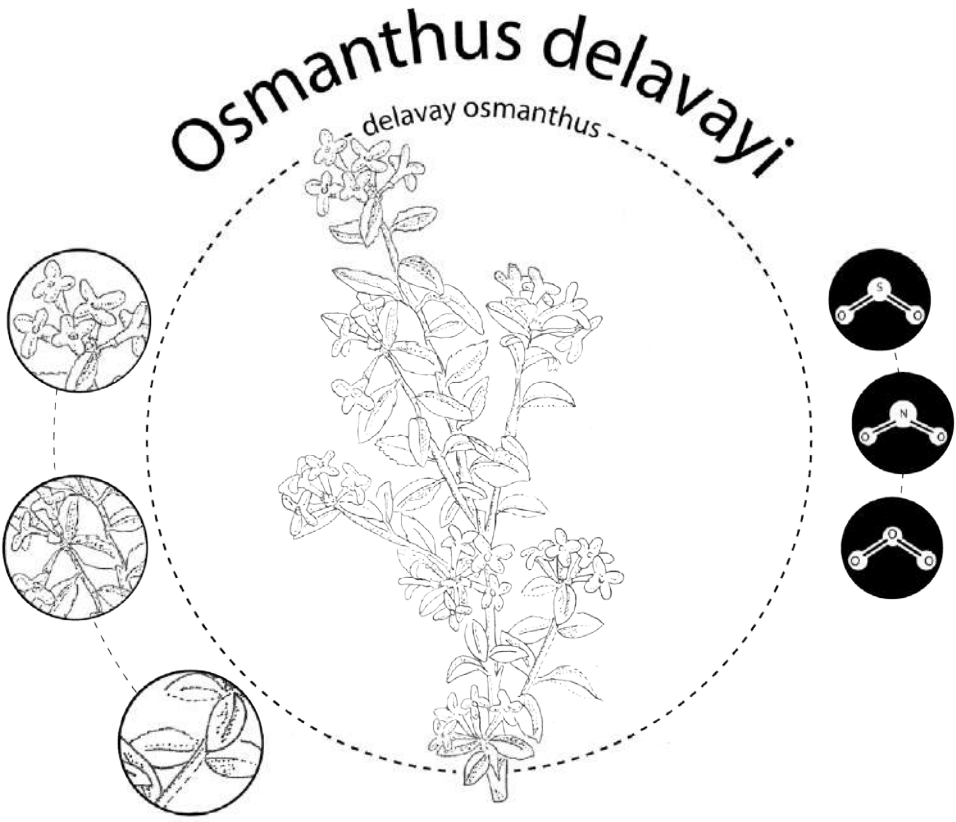
In 1661, John Evelyn wrote one of the first air pollution texts for London, noting that plants with pleasant smells could be effective in addressing air pollution.

## LEAF

Lavender is an odoriferous plant that can perfume the air. It also has small leaves effective for capturing particulates from further dispersal.

## CLEAN AIR GARDENS

Lavender can be found throughout the clean air gardens in the City, including at the Barbican Wildlife Garden.




## BIOINDICATOR

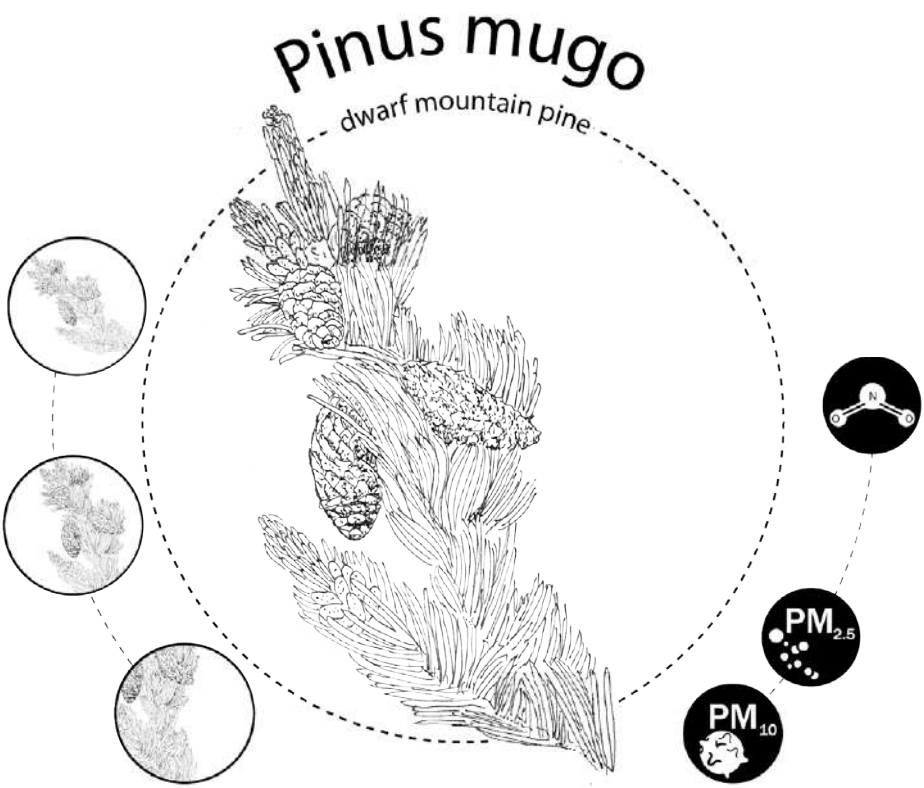
*Osmanthus* is particularly sensitive to pollutants. When exposed to sulphur dioxide, this plant experiences chronic leaf damage, which can be a sign of air pollution.

## STOMATA

Because of the structure of its leaf and action of its stomata openings, *Osmanthus* does not readily absorb gaseous pollutants.

## LOW EMISSION

This plant is in the Low Emission Neighbourhood (LEN) planter at Museum of London entrance. The LEN project supports community projects that address air pollution.




## URBAN PINE

Pine species can play an important role in capturing particulates, which has led some studies to advocate for increasing the role of pine in urban vegetation.

## LEAF STRUCTURE

Coniferous plants such as *Pinus mugo* have many small evergreen needles, which are especially effective at capturing particulates.

## SHRUBS

Because they can be planted by roadsides without creating a canopy that traps pollutants, shrubs such as this one are well suited for air quality planting.

# Salvia nemorosa

woodland sage


## GREENING

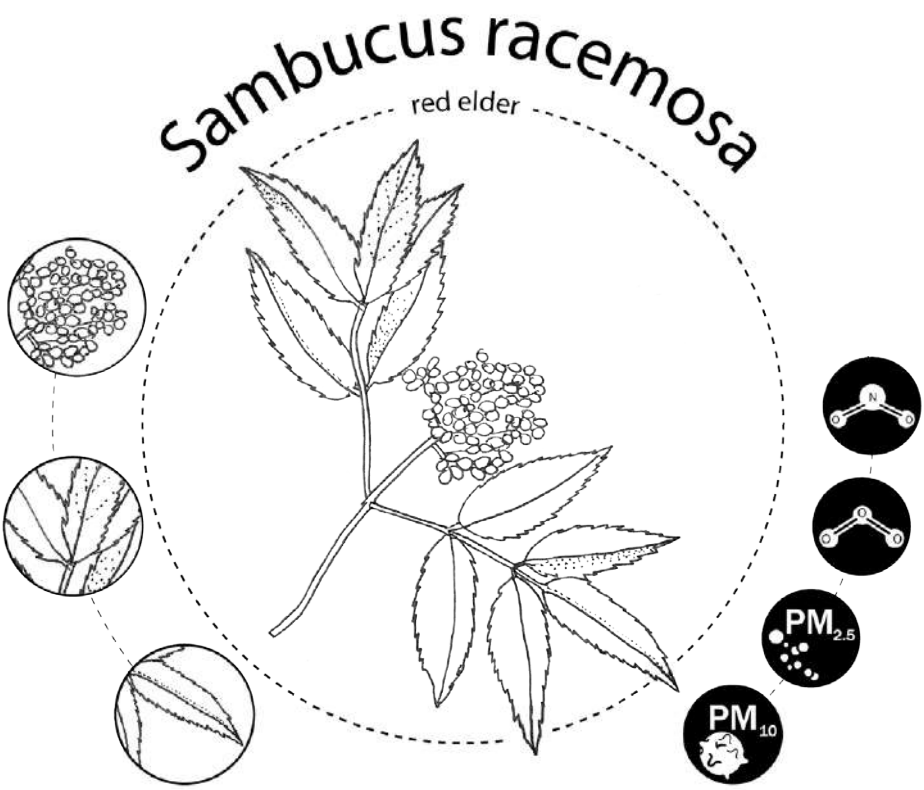
The RHS recommends planting *Salvia*, as a "clean air performer", in planters and green roofs. It has hairy leaves that are effective for capturing particulates.

## BIODIVERSITY

*Salvia* is an example of a plant that is not only good for clean air, but is also beneficial to pollinating organisms, thereby increasing biodiversity.

## BIOACCUMULATION

*Salvia officinalis* has been shown to take up heavy metals such as zinc, although this can cause the wilting of plant leaves.




## OZONE INJURY

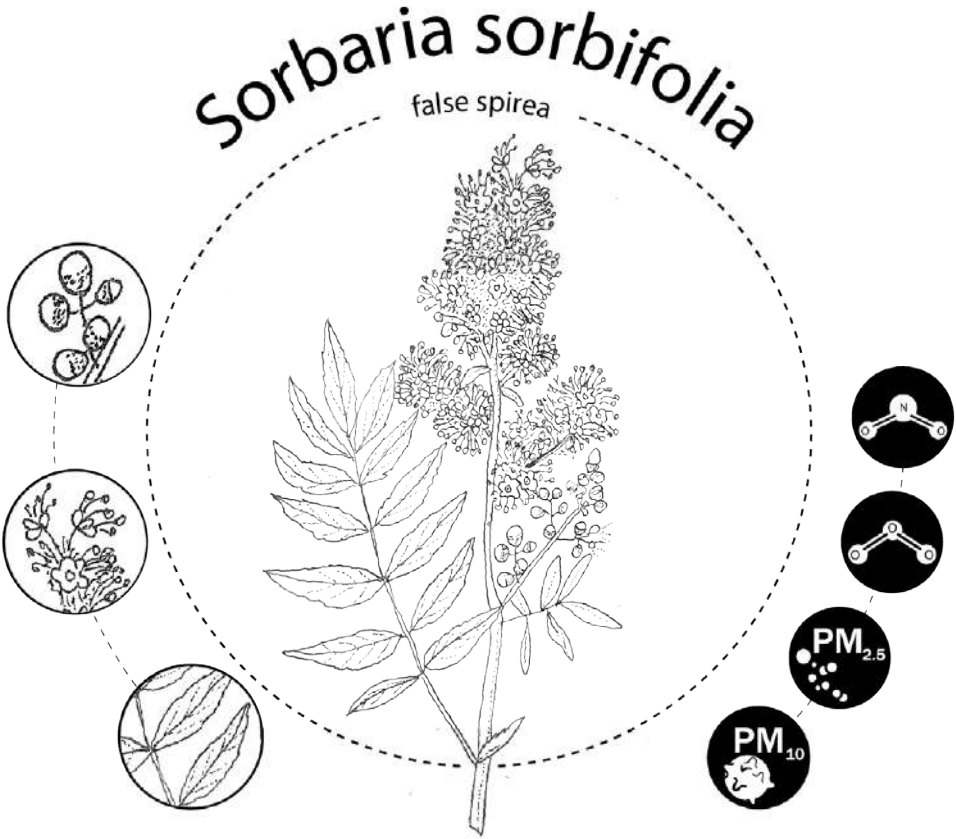
*Sambucus* is an example of a plant that is particularly sensitive to ozone. Damage to leaves and growth can be a sign of the presence of ozone.

## POLLUTION ZONES

In areas with ozone pollution, the change from areas without vegetation to plant communities with *Sambucus* can indicate an improvement in air quality.

## PARTICULATES

*Sambucus* has a moderate ability to capture particulates, although it often grows in plant communities that have a high ability to capture particulates.




## PHYTOREMEDIATION

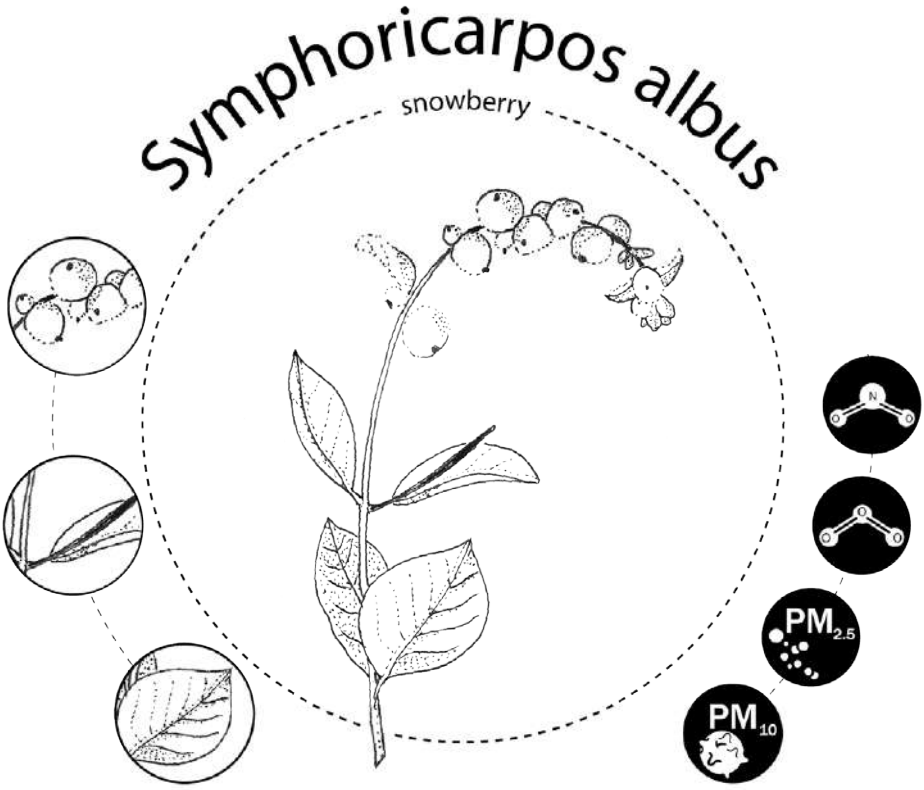
Shrubs such as *Sorbaria* contribute to the capture of particulates, especially near roadsides.

## LOW EMISSION

*Sorbaria* can be found in the Low Emission Neighbourhood (LEN) planter at the Museum of London. This planter demonstrates efffective or sensitive air quality plants.

## OZONE INJURY

*Sorbaria* is sensitive to ozone at relatively low levels, and is an effective species for bioindicating the presence of ozone.




## OZONE INJURY

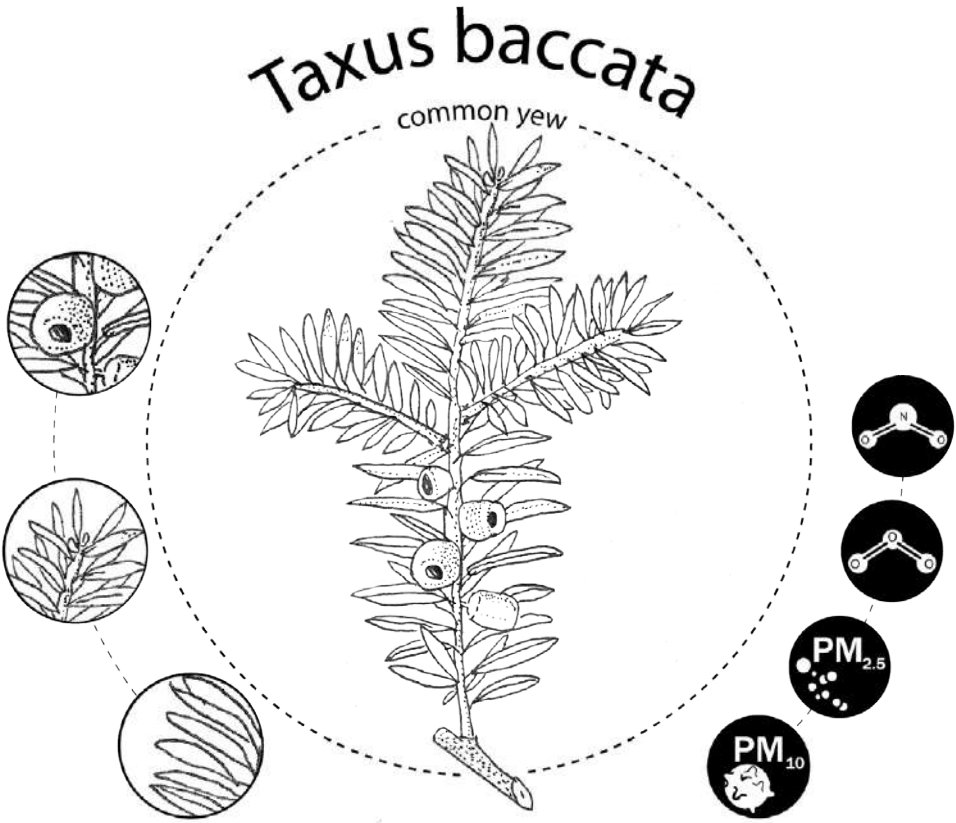
Snowberry is another example of a plant that exhibits leaf injury and impaired growth when exposed to ozone.

## DEMONSTRATOR

The Low Emission Neighbourhood (LEN) planter at the Museum of London entrance includes Snowberry to demonstrate and test the growth patterns of this plant.

## BIOREMEDIATION

Snowberry can also capture heavy metals such as iron and zinc. However, the plant will show signs of impaired growth and foliar injury when exposed to heavy metals.




## GREEN SCREEN

Yew makes an effective hedge and green screen that can capture significant amounts of particulates, especially near roadsides.

## LEAF STRUCTURE

The small needles of the Yew plant are able to capture a high amount of particulates and prevent onward dispersal.

## BVOCS

Yew emits a low level of biogenic voltaile organic compounds, or BVOCs. Some plants emit higher levels, which can contribute to poorer air quality.

# PHYTO-SENSOR WORK-SHOP + WALK

# PHYTO-SENSOR WORKSHOP AND WALK

During the Phyto-sensor workshop and walk we investigated air quality plants and gardens in the locations indicated on the map included with this toolkit. Participants also provided a number of helpful contributions for testing and further developing the toolkit in its final form.

Many of the participants' observations and contributions are included here, along with photo documentation of the event. There are many helpful, detailed, and creative suggestions for air quality gardens and toolkits. Although we have not had space to include all the suggestions in our expanded toolkit, we have incorporated some of these suggestions here. You might find these suggestions helpful when thinking about how to develop air quality gardens in your communities.

If you would like to contribute further ideas for the Phyto-sensor toolkit, you can send these to Citizen Sense at: phytosensor@citizensense.net.

# PROPOSITIONS FOR AIR QUALITY GARDENS

## PLANNING AND ORGANIZATION

- Ensure that all Councils have a designated air quality officer who can focus on strategies for air quality planting.

- Share best practices and examples of other air quality planting schemes across Europe. Share details of other planting and maintenance systems in place at hot spots such as motorways next to residential areas.

## COMMUNITY INVOLVEMENT

- Tap into gardening communities, and connect with popular gardening programmes on radio and TV to raise the profile of these issues, for example, with Gardener's Question Time on BBC Radio 4.

- Involve communities in monitoring air pollution so they can become more aware of pollution levels and also identify where to locate air quality plantings.

- Set up community groups similar to neighbourhood watch schemes for planting and maintaining new street planting.

- Host community days for local planting and seed swaps of air quality plants.

## PLANTING

- Plant green walls near busy roads, especially where schools and residential blocks are near major traffic intersections.

- Make use of pollution-trapping shrubs and hedges near emissions sources.

- Provide roof gardens and vertical plantings of suitable air quality plants.

- At traffic intersections, locate tall pyramidal planters (with automatic irrigation) planted up with air quality plants that take up particulates and polluting gases. Include signage to explain the purpose of the plantings.

- Plant vegetation that is attractive, so that people who were not aware of the environmental issues could begin by appreciating the aesthetic value of plants, and then learn more about the wider benefits.

- Attend to local water requirements and dynamics by incorporating rainwater-harvesting plants and/or drought-tolerant plants, which also take up pollutants.

## EDUCATION

- Provide information on how to identify air pollution hot spots, including likely sources such as transport sources (tunnels are worse as there is no air movement upwards), at junctions where idling occurs, near busy roads (where green screens could be effective), and by heating outlets where NOx is emitted.

- Provide information on how to identify ecological symptoms, e.g., the presence of certain lichens can indicate clean air. Provide an indicator sheet on how pollution effects plants or how plants take up pollution, e.g., yellow leaves can mean more ozone with some plants, particulates adhere to fine hairs on leaves and stems.

- Provide how-to sheets for undertaking $NO_2$ monitoring with diffusion tubes, so hot spots can be identified.

- Provide a list of trees and shrubs that are most effective for improving air quality, e.g., Birch, Yew.

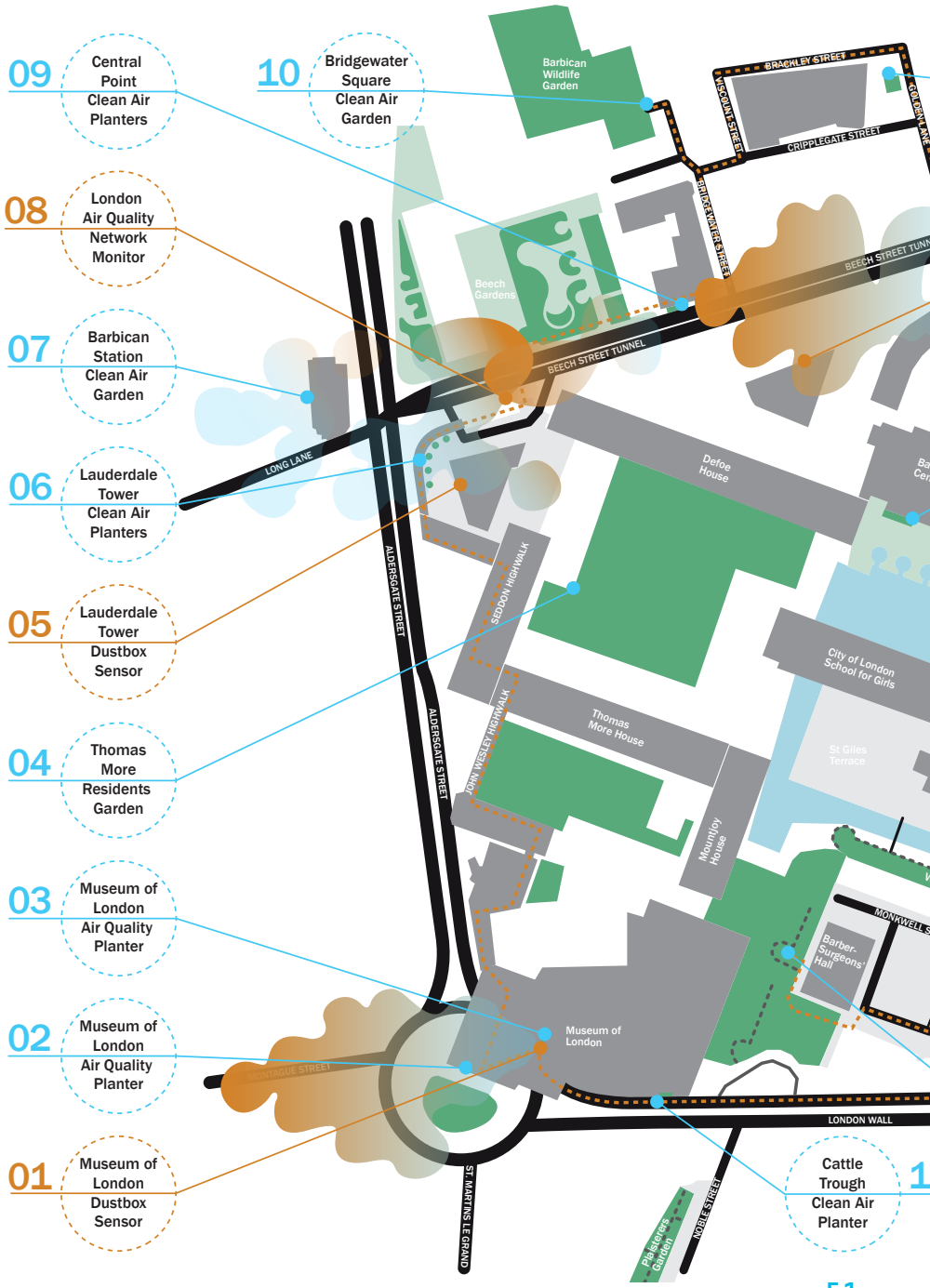
- Provide more resources for people to choose air quality plants that are likely to succeed in the urban environment, including water, light and soil requirements.

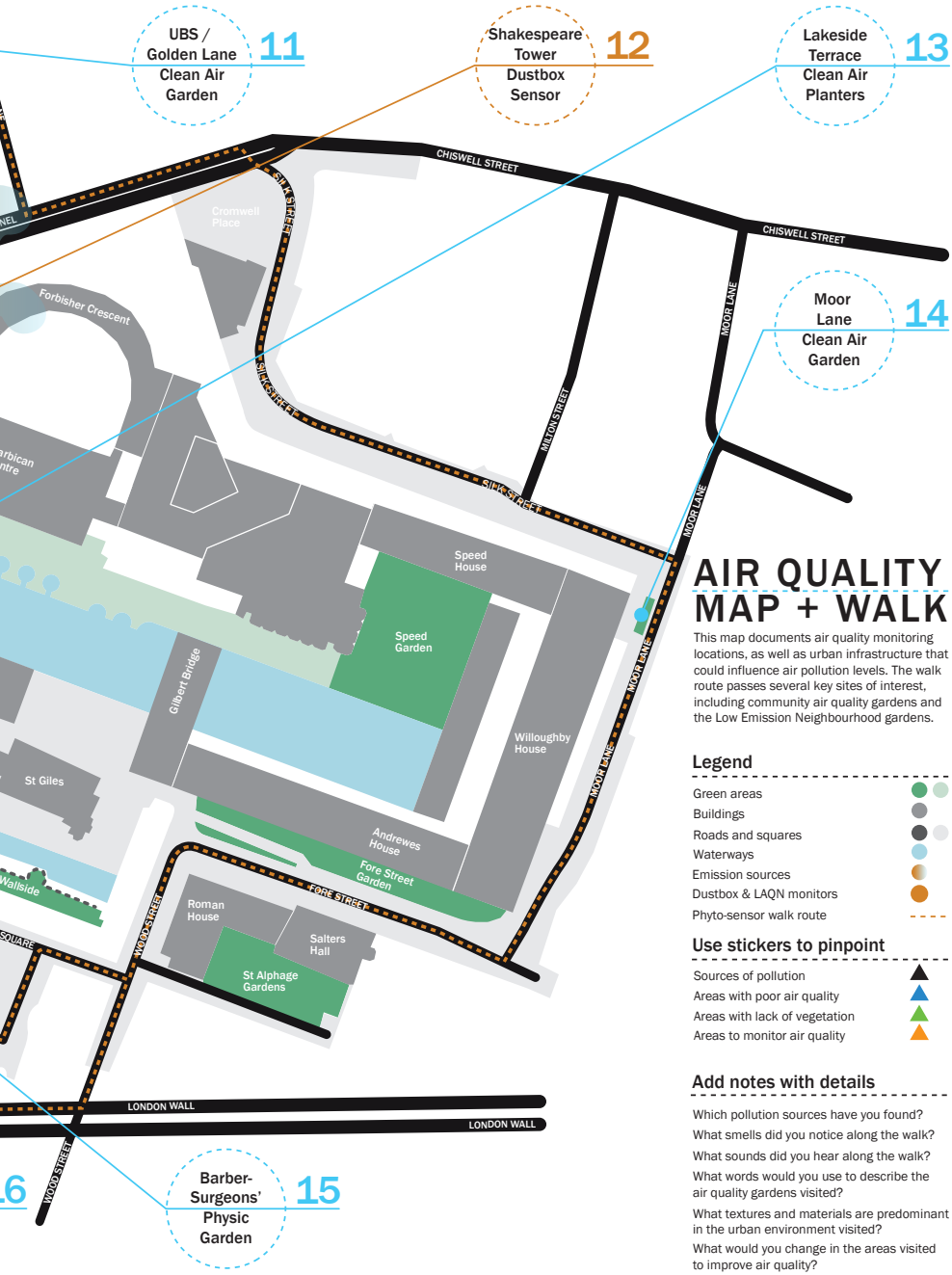
- Provide case studies and layouts of air quality gardens that can give a general idea of the process involved and where to start.

## MAINTENANCE

- Ensure that plants are hardy and able to cope with salinity.
- Plant vegetation that is low-maintenance and drought tolerant.
- Educate councils and people about how to spread salt and grit in the winter to avoid damage to trees and plants.
- Ensure that councils have contracts and policies for tree and plant maintenance that ensure salt, weedkiller and other damaging substances are not sprayed on trees.
- Save seeds from air quality plants to plant in other locations or exchange in seed swaps.
- Wait until flowering and seed setting have taken place before pruning and mowing.
- Compost material from air quality gardens.

# PHYTO-SENSOR WALK






# AIR QUALITY MAP + WALK

This map documents air quality monitoring locations, as well as urban infrastructure that could influence air pollution levels. The walk route passes several key sites of interest, including community air quality gardens and the Low Emission Neighbourhood gardens.

## Legend

- Green areas
- Buildings
- Roads and squares
- Waterways
- Emission sources
- Dustbox & LAQN monitors
- Phyto-sensor walk route

## Use stickers to pinpoint

- Sources of pollution
- Areas with poor air quality
- Areas with lack of vegetation
- Areas to monitor air quality

## Add notes with details

Which pollution sources have you found?

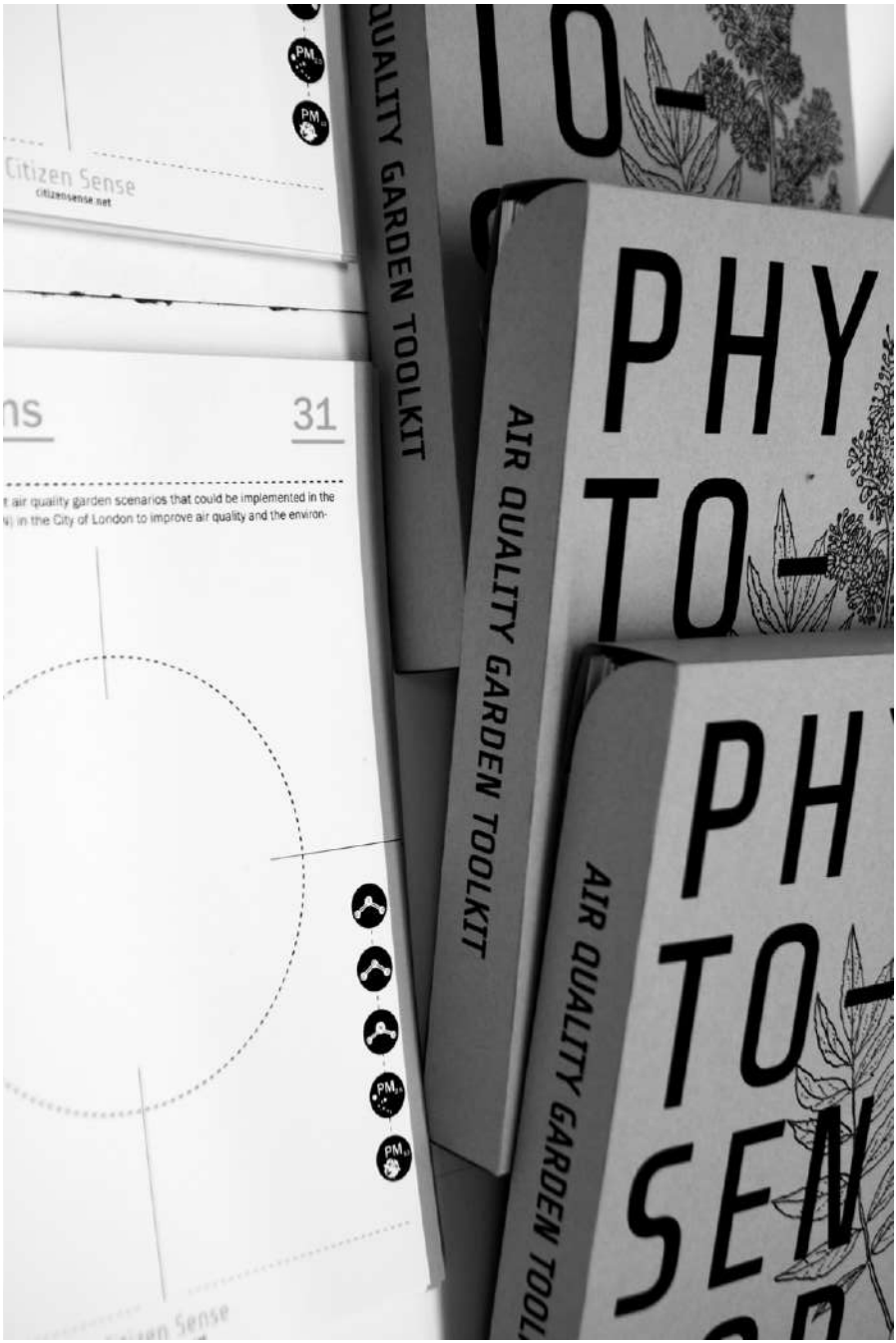
What smells did you notice along the walk?

What sounds did you hear along the walk?

What words would you use to describe the air quality gardens visited?

What textures and materials are predominant in the urban environment visited?

What would you change in the areas visited to improve air quality?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31
air quality garden scenarios that could be implemented in the
in the City of London to improve air quality and the environ-
AIR QUALITY GARDEN TOOLKIT
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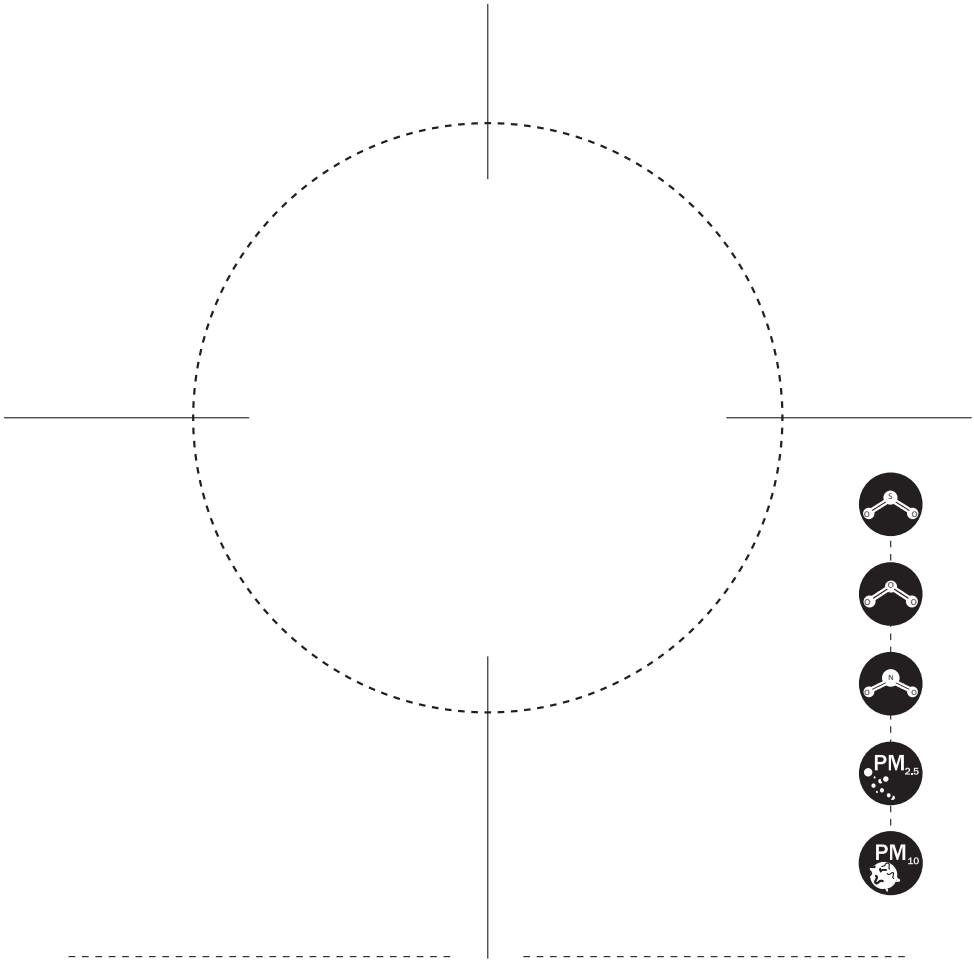
# OBSER-VATIONS

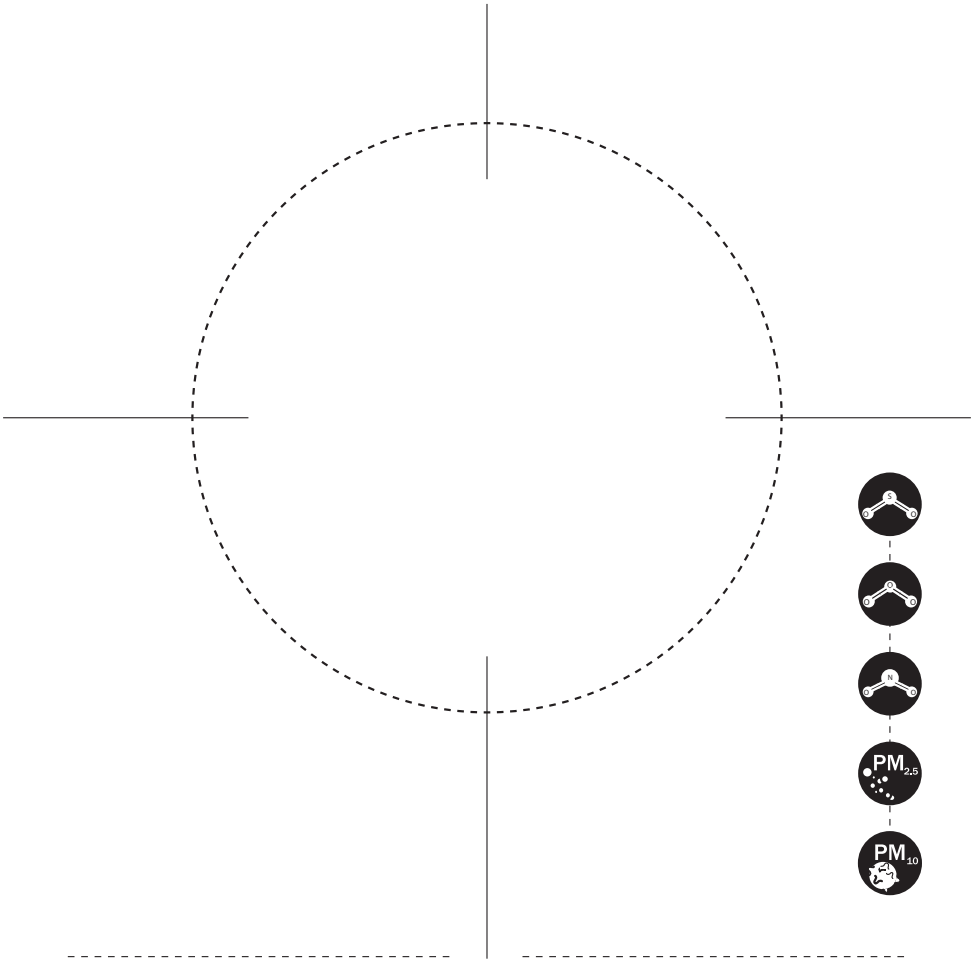
## VEGETATION

Use this space to record your observations about vegetation growing in the area where you plan to develop an air quality garden. Where are plants currently growing? How do they respond to air pollution? Which plants might you add to improve air pollution levels? What planting arrangement would be best suited to the pollution sources in this location?



## POLLUTION

Use this space to document pollution sources in the location where you plan to develop an air quality garden. What are the primary sources of pollution? Where are they located? Can you document air pollution levels and sources with air quality monitors or existing data? Which planting arrangements would be best suited to mitigating the sources of air pollution in this location?



# COMMU-
# NITY
# AIR
# QUALITY
# GARDENS

# MOOR LANE POP-UP GARDEN

## HISTORY

There are a number of community clean air gardens planted in the City of London, many of which were developed in 2017 as part of the City in Bloom challenge. The Phyto-sensor map documents some of these gardens, including the Moor Lane Pop-Up Garden pictured here.

The Moor Lane Pop-Up Garden is an example of a garden that has been developed to raise awareness about the benefits of vegetation for improving air quality. The garden was developed through a considerable volunteer effort, along with contributions from landscape architecture firm xmpl and support from the City of London.

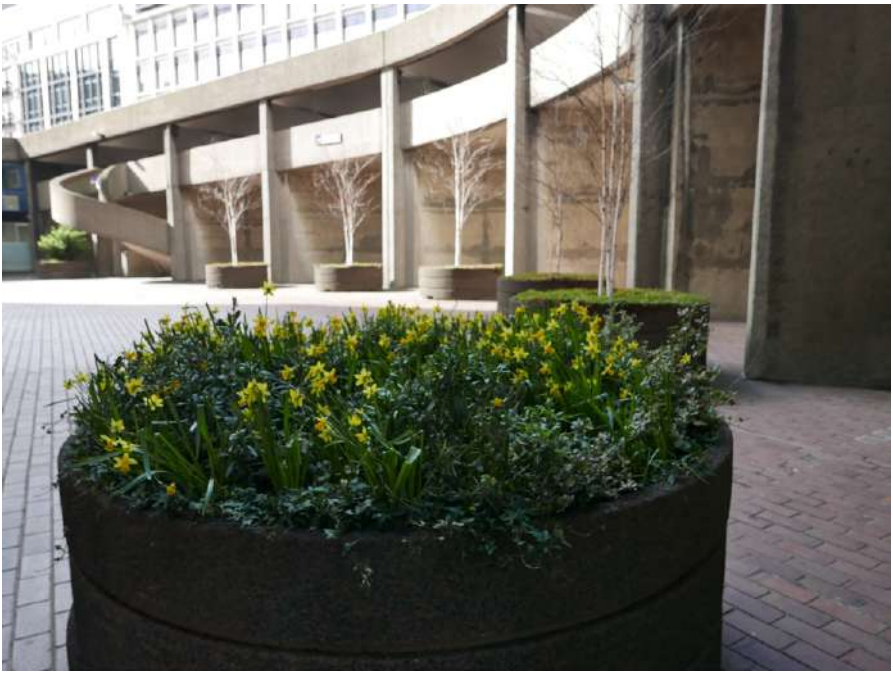
## PLANTS

Many of the plants detailed in this toolkit can be found in the Moor Lane Pop-Up Garden. Some of the clean air plants that you can see installed at this site include *Hedera helix* (Ivy), ferns, and *Convolvulus cneorum* (Silverbush), as well as *Amelanchier* (Juneberry) and Birch trees.

The plants are installed in galvanized steel pipes, which fit well with the hard edge of the parking garage on this side of the Barbican estate.

## LOCATION

Moor Lane (near Silk Street)
Closest station: Moorgate
More info: cleanairgardens.blogspot.co.uk



# BEECH STREET AIR QUALITY GARDEN

## HISTORY

Lauderdale Tower next to the Beech Street Tunnel is the site of elevated air pollution levels. One of the London Air Quality network (LAQN) monitors is located here, and a Dustbox particulate sensor has also been placed inside the Beech Street monitoring station. Both of these monitors show regular episodes of air pollution that exceeds the EU Air Quality Standards for nitrogen dioxide and for particulate matter 2.5.

## PLANTS

Barbican volunteers have planted several concrete planters with air quality plants at the reception area of Lauderdale Tower, in part to create a screen from idling vehicles in the tunnel.

Plants added to the concrete planters include *Hedera helix* (Ivy), *Convolvulus cneorum* (Silver Bush) and *Erysimum bicolor* (Wallflower). These plants are especially effective at depositing particulates and preventing onward dispersal.

There are several additional planters with existing Birch trees (pictured here), which are an effective tree for improving air quality by filtering particulates and absorbing gaseous pollutants.

## LOCATION

Lauderdale Tower at Beech Street
Closest station: Barbican
More info: cleanairgardens.blogspot.co.uk

## COMMUNITY AIR QUALITY PLANTING PROJECTS

There are many creative and compelling community air quality gardens and planting projects in London, the UK, and across the world. Many of the community planting projects listed here are located in London as inspiring examples of projects that have installed vegetation to improve air quality and the urban environment. These projects are in addition to the examples above, as well as those marked on the map in the City of London.

Some of these projects involve planting herbaceous and shrubby plants near roadside emission sources, some consist of tree planting campaigns, others include green walls on busy streets.

## CROSSRAIL FARRINGDON POP-UP GARDEN

Developed by volunteers from the Barbican and Friends of City Gardens, the Crossrail Farringdon Pop-Up Garden is located on the Crossrail site at Farringdon Street and Charterhouse Street. Developed in parallel with the Moor Lane Pop-Up Garden included above, this site was also designed by Studio xmpl, and was planted with air quality plants. For more information, see: http://www.friendsofcitygardens.org.uk/Blog.html.

## BETTER BANKSIDE'S CLEAN AIR MINI NEIGHBOURHOOD PROJECT

The Better Bankside Urban Forest has received funding from the Mayor of London's Air Quality Fund to develop a Clean Air Mini Neighbourhood project from 2017 to 2019. The project includes a number of green interventions to improve air quality, and the initiative is working with

King's College London's Environmental Research Group to monitor the impact of these 'green transformations'. More information is available at: http://www.betterbankside.co.uk/buf/clean-air-mini-neighbourhood.

## EDGWARE ROAD TUBE STATION GREEN WALL

In 2011, Transport for London (TFL) developed a green wall at Edgware Road Tube Station to capture particulates at a busy traffic intersection. The wall holds 14,000 plants of 15 different species. Researchers at Imperial College studied the effectiveness of the green wall, and demonstrated that some plants with hairy leaves were effective at capturing particulates. The green wall was developed as part of a larger green infrastructure initiative. New walls have been installed at Blackfriars and at TFL construction sites. For more information, see: https://tfl.gov.uk/info-for/media/press-releases/2011/november/stunning-green-wall-unveiled-at-edgware-road-tube-station-to-deliver-cleaner-air and https://www.airqualitynews.com/2012/07/09/second-green-wall-installed-in-london-by-tfl.

## GOOSE GREEN SCHOOL

The Friends of Goose Green School (FOGGS) received funding from the Mayor of London's Greener City Fund to install a green screen at the Goose Green Primary School. A group of volunteers from FOGGS installed the green screen during February 2018. The group is also undertaking monitoring of particulate levels using Dustboxes at locations on either side of the green screen. For more information, see: https://www.goosegreenprimaryschool.org/viewer/275 and https://mobilane.co.uk/case-studies/green-screens-cleaner-safer-air-london-school.

## DEPTFORD FOLK: EVELYN 200

Deptford Folk is a parks and amenities group located in South East London. The community group has established the Evelyn 200 project to commemorate the publication of John Evelyn's diaries. Evelyn was a resident in Deptford, and he wrote what is widely considered to be one of the first texts on air pollution, *Fumifugium*, published in 1661. One of the key objectives of Evelyn 200 is to plant 200 trees in 2018 in the Evelyn ward, which has high levels of air pollution and also low levels of tree coverage. For more information, see: www.deptfordfolk.org/evelyn-200.

## ENERGY GARDEN

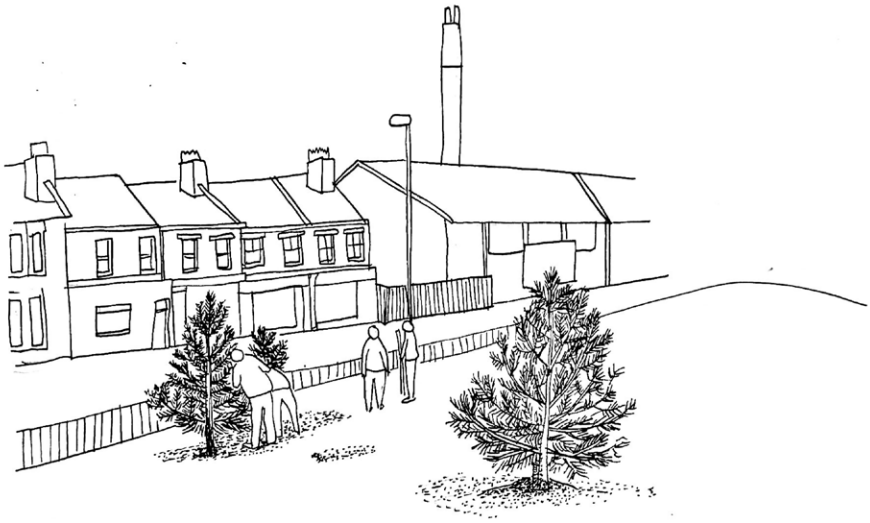
This project introduces air quality plants on the London Overground line. Hedgerows are installed to filter particulates and noise, and living walls are installed on platforms to clean the air. More information is available at: http://energygarden.org.uk/2026-2.


Propositions

# PLANT-ING SCEN-ARIOS

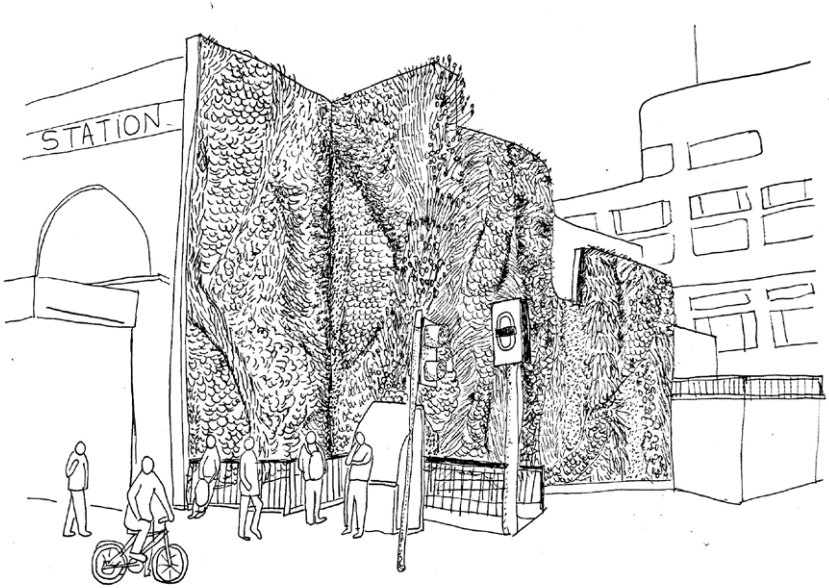
# PLANTING SCENARIO 1: STREET TREES

Trees can help to improve air quality, while also enhancing biodiversity and reducing the urban heat island effect. Trees remove gaseous pollutants, and can capture particulates and phyto-remediate soils. However, trees planted on congested streets and in street canyons can trap gaseous pollutants and particulates at street level, and so planting location and design is important to consider in order to prevent these effects. It is important that clean air from above is able to circulate through to sites. Some trees also release higher levels of biogenic volatile organic compounds (VOCs), which are precursor gases that can form ozone. At certain times of year, some trees can also increase particulate levels through the release of pollen. The image here is based on a photo from Deptford Folk's Evelyn 200 tree-planting project.



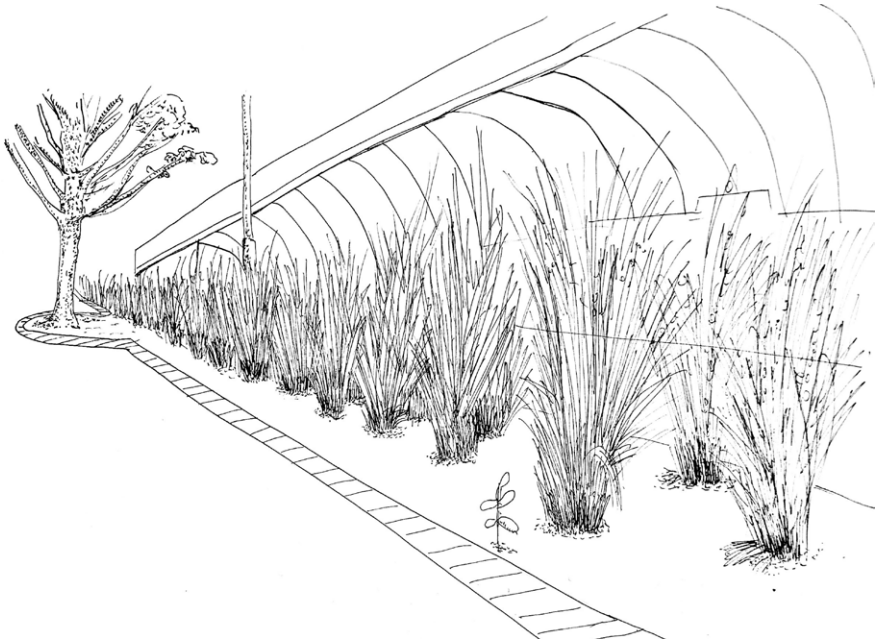
# PLANTING SCENARIO 2: GREEN WALLS AND GREEN SCREENS

Green walls and green screens can be effective installations for trapping particulates. As the community garden examples demonstrate, an ivy screen at the boundary between a busy road and a playground can be one way to mitigate air pollution, with some studies suggesting reductions of up to 40% of particulates in the local area. Green walls can also reduce particulates, although they require more intensive preparation, installation and maintenance for the structure, growing medium and irrigation in order to ensure the plants do not die. The image here is based on a photo from the Edgware Road Tube Station Green Wall.



# PLANTING SCENARIO 3: ROADSIDE PLANTING

Roadside plantings, including shrubs, hedges, herbaceous plants and grasses, can provide barriers to roadside pollution for adjacent land uses. As one example documented in the image here shows, Hammersmith and Fulham Council has developed a Talgarth Road Green Corridor to shield cyclists from pollution generated by an adjacent roadway. Tall grasses have been planted to capture particulates, as well as absorb stormwater. Many of the plants illustrated in this toolkit make effective roadside plantings, some of which also take up and/or phyto-remediate soil contaminants.




AIR QUALITY GARDEN

# RE-SOURCES

# BUILDING AN QUALITY GARDEN

Included in this section are additional resources to help you start your own air quality garden. You might select air quality plants for your own garden, or you might be interested to start a project to green an area in your community. Due to budget cuts, many local governments are not replacing trees or adding to the stock of new vegetation, so community efforts to improve the urban environment are more important than ever.

This section includes plant and tree lists that could be included in an air quality garden, as well as references for researching more about the interactions between vegetation and air quality. To find out more on how to grow particular plants and to see whether they are suitable for your location, the Royal Horticultural Society (RHS) website's plant finder is a useful resource: https://www.rhs.org.uk/plants.

Things to keep in mind when undertaking your air quality garden include:

## 1. IDENTIFY A LOCATION:

By selecting the best location for your air quality garden you can ensure it has the most impact. Because vegetation provides quite local improvement to air quality, knowing where to plant can make the biggest difference in mitigating air pollution. You can use a range of additional techniques, from citizen monitoring to mapping locations of trees in relation to pollution levels, to identify the best locations for planting vegetation.

You might also want to plant near schools, residential areas, hospitals or parks in order to minimize the effects of air pollution on certain populations. According to the Nature Conservancy report, "Planting Healthy Air," those areas with the highest pollution and highest population density can be key areas to target as areas for planting.

## 2. FIND COLLABORATORS

Existing community or gardening groups might exist with whom to collaborate, or other volunteers and neighbours might want to work together to install an air quality garden. By working collaboratively, you can pool skills and resources, expand your network, and contribute to the wider community. Tree Societies, parks groups, allotments and gardening groups could all be worthwhile organisations to research and meet for starting a potential project.

## 3. IDENTIFY RESOURCES

Some resources do exist from the Mayor of London as well as councils to develop green space and green infrastructure. It is worth researching which funding sources might be available in your area. You might also be able to receive in-kind donations or donated supplies. Some garden projects have successfully used crowd-funding to support activities. By emphasizing the importance of your garden to environmental public health as well as improving air quality you might be able to find resources that are health and environment focused.

## 4. DESIGN THE SPACE AND SELECT PLANTS

There are many air quality gardens and planting schemes now built, so it is worthwhile to look at these in person to see how they are developed. A small selection of planting schemes are included in this toolkit (both on the map and in the list above), but first-hand investigation of air quality garden sites can provide many ideas for how to develop your own planting. When designing your installation, consider the site requirements as well as the emission sources and how best to plant in response to the context. When selecting plants, consider whether trees, a green screen, herbaceous plants or shrubs, or all of the above, might be best for the site conditions. This toolkit contains a sample of some effective air quality trees and plants, noting their key characteristics in relation to pollution, which can be a good place to start when selecting vegetation.

## 5. GET IT IN THE GROUND

Once you've developed the design and selected the plants you will need to consider how the planting will be undertaken. Will you build the installation through volunteer effort, or will you hire a contractor? Which supplies and tools will you need to plant the garden? Remember to properly prepare the soil with compost and fertiliser, and to water the installation well. Some design groups can provide pro-bono support to help you work through how best to build a garden, and depending upon its scale, how to phase it over time. Some gardens can be built in a day, others can take longer to complete. You might also want to monitor the space with analogue or digital monitors to test whether air pollution levels change, and whether a pattern is detectable.

## 6. HOST A LAUNCH EVENT

Once the planting is in place, it is time to have a launch event and bring everyone together who contributed to the air quality garden. Consider letting the local press and your Local Council know about the event, and be sure to send out news on social media and post flyers locally so new community members can also learn about the space and get involved.

## 7. MAINTENANCE

Maintenance can be the hardest part of ensuring the planting is successful over time. Have a look at the propositions from the Phyto-sensor workshop and walk, where many useful suggestions by participants are made about how to ensure plants receive the attention they need to become established and thrive over time. You will need to ensure systems are in place for watering, as well as pruning and weeding. Decide whether this will be undertaken as a volunteer effort, or through a contractor, and how this will be coordinated and supported over time.

# EXTENDED LIST OF AIR QUALITY PLANTS

Included here is an extended list of plants that are best suited to reducing and/or bioindicating air pollution in the urban environment. In the following section you will also find resources for learning more about planting tress for improving air quality. While by no means definitive, the below lists should provide a starting point for putting together an air pollution garden that can be studied and engaged with in relation to air quality. To assess the suitability of planting these trees and plants in a particular context, you can search and review plants at the Royal Horticultural Society plant finder at: https://www.rhs.org.uk/plants.

## PARTICULATE MATTER (PM)

Plants that interact with particulate matter primarily have dispersal and deposition effects, where vegetation can influence the flow and movement of particulates, and/or particulates can be trapped on the surface of vegetation. Plants with hairy/hirsute leaves, and vegetation with large or broad leaves, as well as plants with grooves on their leaves tend to be the most effective for capturing particulates.

Example plants and shrubs include:

- *Achillea millefolium* (Yarrow)
- *Alchemilla mollis* (Lady's Mantle)
- *Amelanchier lamarckii* (Juneberry—small tree/shrub)
- *Aster spp.* (Aster)
- *Convolvulus cneorum* (Silverbush)
- *Erysimum* (Wallflower)
- *Euonymus japonicas* (Spindle)
- *Euphorbia characias* (Mediterranean Spurge)
- *Forsythia × intermedia* (Forsythia)
- *Geranium maculatum* (Cranesbill Geranium)
- *Hebe spp.* (Shrubby Veronica)
- *Hedera helix* (Common Ivy)
- *Heuchera* (Coral Bells)

- *Hydrangea arborescens* (Hydrangea)
- *Iris wilsonii* (Iris)
- *Lamium maculatum* (Spotted Deadnettle)
- *Lavandula spp.* (Lavender)
- *Osmanthus delavayi* (Delavay Osmanthus)
- *Parthenocissus quinquefolia* (Virginia Creeper)
- *Parthenocissus tricuspidata* (Boston Ivy)
- *Physocarpus opulifolius* (Ninebark)
- *Pinus mugo* (Creeping Pine)
- *Pyracantha* (Firethorn)
- *Salvia spp.* (Sage)
- *Sorbaria sorbifolia* (False Spirea)
- *Spiraea sp.* (Spiraea)
- *Stachys byzantine* (Lamb's Ear)
- *Stephanandra incisa* (Laceshrub)
- *Syringa meyeri* (Lilac)
- *Taxus baccata* (Yew)
- *Taxus x media* (Yew)
- *Verbena bonariensis* (Verbena)
- *Vitis spp.* (Grape)

## NITROGEN DIOXIDE ($NO_2$)

Most of the research in relation to vegetation and reducing nitrogen oxides levels focuses on trees. Some of the plants included here are woody species that could grow as shrubs or small trees. Green walls are seen to be a beneficial way to reduce $NO_2$, including with Common Ivy. Grass is also a potentially beneficial plant for reducing $NO_2$. Some of the plants listed above in relation to particulates also have some mitigating effect on $NO_2$.

Example trees and plants include:

- *Magnolia kobus* (Magnolia)
- *Nicotiana tabacum* (Cultivated Tobacco)
- *Robinia pseudoacacia* (False Acacia)
- *Prunus cerasoides* (Cherry)
- *Prunus lannesiana* (Cherry)

## OZONE (O3)

Plants that interact with ozone do so typically in a bioindicative way or through demonstrating sensitivity and thereby demonstrating the relative presence or absence of ozone on the basis of the health and appearance of plants. Note that these plants do not absorb ozone, but rather indicate the presence of this pollutant, and so can be damaged when ozone levels are high. NASA has put together an ozone bioindicator garden, including plants and monitoring protocols, for assessing ozone. To see this garden, visit: https://science-edu.larc.nasa.gov/ozonegarden/garden-design.php.

The NASA Ozone Bioindicator Garden plants include:

- *Rudbeckia lacinata* (Cut-Leaf Coneflower)
- *Phaseolus vulgaris* (Snap Bean)
- *Asclepias syriaca* (Milkweed)

Some additional plants sensitive to ozone include:

- *Armeria maritima* (Thrift)
- *Artemisia spp.* (Mugwort)
- *Aster spp.* (Aster)
- *Campanula rotundifolia* (Common Harebell)
- *Festuca rubra* (Red Fescue)
- *Molinia caerulea* (Purple Moor Grass)
- *Oenothera spp.* (Evening Primrose)
- *Physocarpus spp.* (Ninebark)
- *Potentilla erecta* (Cinquefoil)
- *Rhus typhina* (Sumac)
- *Sambucus racemosa* (Red Elder)
- *Solanum tuberosum* (Potato)
- *Sorbaria sorbifolia* (False Spirea)
- *Symphoricarpos albus* (Snowberry)
- *Vaccinium myrtillus* (Bilberry)
- *Vitis spp.* (Grape)

## BENZENE, FORMALDEHYDE AND TRICHLOROETHYLENE (INDOOR POLLUTANTS)

In addition to the above, NASA has undertaken research on indoor plants to demonstrate their effect on reducing levels of VOCs. Some of these plants, such as ferns (Boston fern), could also be suitable for outdoor planting. Indoor air quality is affected by outdoor air quality, and can often be worse due to the number of plastic-based and synthetic items found in the home. However, these air pollutants are not monitored through the LAQN, and are not typically monitored through citizen devices, so parallel data would not be readily available for assessing the possible mitigating effect of the plants.

Example plants for addressing indoor air quality include:

- *Aloe vera* (Aloe)
- *Chamaedorea seifritzii* (Bamboo Palm)
- *Chrysantheium morifolium* (Chrysanthemum)
- *Chlorophytum comosum* (Spider Plant)
- *Dracaena deremensis "Janet Craig"* (Janet Craig)
- *Dracaena deremensis "Warneckei"* (Warneckei)
- *Dracaena marginata* (Marginata)
- *Dracaena massangeana* (Mass Cane)
- *Ficus benjamina* (Weeping Gig)
- *Gerbera jamesonii* (Gerbera Daisy)
- *Hedera helix* (English Ivy)
- *Rhododendron simsii* (Azalea)
- *Sansevieria trifasciata 'Laurentii'* (Snake Plant)
- *Spathiphyllum "Mauna Loa"* (Peace Lily)

# EXTENDED LIST OF AIR QUALITY TREES

Included here is an extended list of trees that are best suited to reducing air pollution in the urban environment. These trees are selected for the UK and zones with similar climatic conditions. In the references section you will also find resources for learning more about planting tress for improving air quality. This list is informed by the Woodland Trust report, "Urban Air Quality" (2012), which ranks trees according to their Urban Air Quality Tree Score (UTAQs) based on the research of Donovan (2005). Trees with high scores are generally better for air quality.

## TREES WITH THE HIGHEST UTAQS:

- *Alnus glutinosa* (Alder)
- *Acer campestre* (Field Maple)
- *Acer platanoides* (Norway Maple)
- *Betula pendula* (Birch)
- *Chamaecyparis lawsoniana* (Lawson Cypress)
- *Crataegus monogyna* (Hawthorn)
- *Larix decidua* (Larch)
- *Pinus nigra cvs.* (Pine)
- *Prunus laurocerasus* (Laurel)

## TREES WITH MEDIUM UTAQS:

- *Acer pseudoplantanus* (Sycamore)
- *Alnus cordata* (Italian Alder)
- *Alnus incana* (Grey Alder)
- *Corylus avellana* (Hazel)
- *Cuprocyparis leylandii* (Leyland Cypress)
- *Fraxinus excelsior* (Ash)
- *Ilex aquifolium* (Holly)
- *Malus spp.* (Apple)
- *Prunus avium* (Cherry)
- *Sambucus nigra* (Elder)
- *Sorbus aucuparia* (Rowan)

- *Syringa vulgaris* (Lilac)
- *Tilia x europaea* (Common Lime)
- *Ulmus procera* (English Elm)

### TREES WITH LOW UTAQS:

- *Quercus petraea* (Sessile Oak)
- *Quercus robur* (English Oak)
- *Quercus rubra* (Red Oak)
- *Populus tremula* (Aspen)
- *Salix alba* (White Willow)
- *Salix caprea* (Goat Willow)
- *Salix fragilis* (Crack Willow)

## REFERENCES

There is a wide array of research on plant responses to air pollution, as well as suggestions for best plants to install to improve air quality. Included here is a selection of resources and references for following up with further research on air quality gardens and plants in the UK and across the world.

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GARDEN TOOLKIT

# CREDITS

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