Investigations in Urban Soils

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Overview of Module

Lift up a rock and introduce your students to a new world – the living, breathing soil and its living, breathing inhabitants….

Does this invitation sound like fantasy, suitable only for those lucky teachers in suburban and rural schools situated near untouched woodlands? It doesn't have to be. The soil lives and breathes here in urban Baltimore too, and even scientists are amazed at how much life it contains.

Get your classroom involved in cutting-edge research with the Investigations in Urban Soils instructional module. Each investigation is designed to truly engage students in hands-on soil field research. Your students will be encouraged to ask the same questions that drive current urban soil research in Baltimore, and will learn from the very latest scientific data. How does urbanization affect soils? Is there a typical urban soil? What are the benefits of soil to society and how does urbanization effect these benefits? Where are the greatest concentrations of heavy metals in our city's soil – and when and how did it get there? How does land use affect populations of soil organisms? What is the significance of exotic earthworm species in urban soils? How important is soil biodiversity to nutrient cycling and decomposition? This module gets you and your students involved in answering these questions and many more.

All investigations teach key science concepts, skills, and habits of mind, while aligning with Maryland State and national standards for 6th grade. Use the investigations in sequence or select only those that fit your curriculum best. Use one activity or many; or just access the BES data for a real-world extension activity. The Investigations in Urban Soils module is a resource to help you bring cutting-edge science into your classroom.

Outline of Module

- <u>Background</u>
  - What is soil and why is it important? How does urbanization affect soils? Is there a typical urban soil?
  - Urban Soils
  - Urban Soils and the Baltimore Ecosystem Study
  - Glossary
- <u>Investigations</u>
  - Reconnaissance of urban patches – *under development*
  - Spatial variation in soil properties – *under development*
  - Soil invertebrates – *under development*
  - Earthworms
  - Decomposition and other soil processes – *under development*
  - From the Field – Reflections and examples from teachers – *under development*
  - Resources and links – *under development*

Background: What is Soil and Why is it Important?

Definition

What is soil? Technical definitions abound (see references) but simply stated, soil is the natural mixture of living and nonliving things at the earth's surface. Soil contains air, water, minerals, organic material (matter that was once living), and living organisms in a combination that supports the growth of plants. Dirt, by comparison, is what you find underneath your fingernails: it contains little living material and does not support plant growth. Soil is not dirt!

Please note that terms below are used in the context of soil science, and may be used differently in other disciplines.

Soil Formation

There are five widely recognized factors that affect the formation of soil. We also consider a sixth factor, human activity. Putting them all together, we can say that soil is formed by the combined effects of (1) climate, (2) organisms, and (3) humans, modified by (4) slope, acting on (5) parent material over (6) time. To explain:

1) Precipitation and temperature influence soil formation.
2) Organisms add organic matter to the soil surface and other organisms decompose and mix organic matter into the soil.
3) Humans move and manage soil in many ways, with various consequences.
4) The slope, or topography, determines such things as the amount of rain infiltration and soil thickness.
5) The parent material may be the original bedrock that has been eroded by many years of weathering, or may have been sediment deposited on the bedrock by movements of wind, water, or ice (Figure 1). As a result of weathering processes and the input of organic matter at the soil surface, horizons will form over many years (Figure 1).
6) Soil formation in nature takes a lot of time because the physical and chemical processes that are involved are very slow. It takes thousands of years of to develop the ideal soil for a specific kind of plant. The slow work of natural processes can be undone by humans in a matter of weeks.

Because different places on the Earth have a different set of soil forming factors, soils vary a lot in fertility and their suitability for growing different kinds of plants. Many plants can adapt and thrive in even very poor soils.

Soil Structure

Soil *structure* is defined as: soil particles arranged in the profile in such a manner as to give a distinctive, characteristic pattern. Soil has two solid components: *mineral particles* and *organic material*. Soil mineral particles are *sand*, *silt*, and *clay*. Sand is the largest of the three particles and clay the smallest. Soil *texture* refers to the particle size and the relative proportions of sand, silt, and clay in a soil. Soils may be described as sandy or loamy, for example – the texture is different for every soil (Figure 2). Organic material in soil is living and non-living. Soil is teeming with microorganisms (bacteria, fungi, algae), and invertebrates (protozoa, worms, insects). The dark color we associate with healthy topsoil comes from decaying organic material, often called *humus*.

There is space between the mineral and organic particles. Scientists call these spaces *pores*, and they are filled with varying amounts of air and water (Figure 3), in which nutrients are dissolved. The ideal soil for optimal plant growth is composed of 45% mineral, 5% organic matter, 25% air and 25% water. In compacted soil, such as urban soil, the pore space is greatly reduced (Figure 4).

Soil Functions

Soil is incredible. The trees and other plants we study and cherish could not survive without soil. Without trees and other plants we would not have shade, food, timber, energy, paper, rubber, and many other commodities, and many animals would not have a natural habitat. Soil supports our buildings and roads, filters and stores water, and absorbs our many pollutants including exhaust and fertilizers. Soils even help absorb noise!

The humble soil is home to more species of living things than the famous rain forests – and these nearly invisible creatures recycle organic waste so that plants and other organisms can survive. Without soil organisms, we would be up to our ears in dead plants, animals and microbes.

With “help” from humans, soil can also become contaminated with pollutants, compacted, and eroded (Figure 5). Then, soil will be less able to support soil organisms and plant life and may endanger human health. Soil itself becomes a pollutant when it gets blown or washed away into streams and estuaries (erosion).

Linking Structure and Function in Soil

Proper functioning of the soil depends on its healthy structure. Soil texture (mixture of sand/silt/clay) affects the amount of water soil can hold, the movement of air and nutrients through the soil, and resistance to erosion. Humans can take precautions to avoid compacting soil, which destroys the pore space and limits the oxygen supply to roots and soil organisms. Frequent soil disturbance also affects the distribution of plants. While many native plants and animals may not be used to recovering from these changes, exotic species that are more adapted to urban environments often flourish in human altered soils, soon out competing natives.

Soil as a Habitat

The soil is a great place to live! The temperature and moisture under the soil does not fluctuate as much as it does above-ground over the course of a day or a year. The vast number of pore spaces in soil provides great places for tiny organisms to live and find food (Figure 6). The “community” of organisms that flourishes there is connected to each other in various ways. Microscopic bacteria, fungi, and protozoa digest leaf litter, softening it for other decomposers. Earthworms, mites, millipedes, and ants are a few of the larger decomposers that shred and mix the organic material. They are, in turn, eaten by predacious insects (spiders, centipedes, beetles), which are food for shrews, moles, birds and others.

Many of these organisms spend their entire lives in the soil; others spend a phase of metamorphosis there before becoming surface-dwelling adults; and others simply create nests or burrows in the soil.

Soil Organisms

Soil organisms provide important services to the ecosystem:

(1) Decomposition of organic matter – 90% is carried out by microbes.
(2) Nutrient cycling – microbes do the job, but larger organisms determine the rate.
(3) Bioturbation – mixing of soil and creation of pores.

Microbes

Microbes are microscopic organisms such as fungi and bacteria that digest organic material outside their bodies and absorb the nutrients. This process softens the material and releases nutrients, such as calcium, nitrogen, and phosphorus, into the soil where plants can access them. Microbe activity is central to recycling nutrients between the air, water, and organisms in an ecosystem.

Fungi are slow decomposers that dominate the leaf litter in rural forests. Active fungal communities can take up to five years to decompose a year's worth of leaf litter. Although many fungi produce visible mushrooms in the late summer and fall, chemical decomposition is carried out by their network of microscopic filaments, called *hyphae*. The by-product of fungal decomposition is *ammonium*, a great source of nitrogen for plants. Fungi proliferate best in thick layers of moist, undisturbed leaf litter. These conditions are becoming rare to non-existent in urban Baltimore.

Nitrogen Cycle in Soils

All living things need nitrogen. It is used to make the basic units of all life: DNA, amino acids and proteins. However, most nitrogen exists as a gas in the atmosphere, which very few living things can use.

There are a small number of bacteria that are able to transform nitrogen gas into **ammonia**, through a process called **nitrogen fixation**. These bacteria use the ammonia for their own growth, or they excrete it into the surrounding soil or water. Once in the soil, ammonia can either be absorbed by plants or it can be used by highly specialized bacteria which transform it to **nitrate**. Plants can absorb nitrate as well as ammonia as their source of nitrogen for growth. Animals obtain their nitrogen by eating plants, or other animals.

Once an organism dies, the nitrogen in its proteins is broken down to ammonia again by *decomposing bacteria*, transformed into nitrate by *nitrifying bacteria*, and absorbed again by other plants. In this way, nitrogen in the soil and water is recycled over and over. At every turn of the cycle, nitrogen fixing bacteria add a little nitrogen, while some nitrogen is released back into the atmosphere by another group of bacteria in a process called **denitrification** (Figure 7).

These different processes occur in different places in the landscape. Nitrogen gas is transformed into ammonia at the surface of soils and near the roots of plants. While ammonia stays bound to soil particles, nitrate in excess of plant demand can be leached out of the soil because it is water-soluble. Once nitrate is leached from the soil it can flow into groundwater and accumulate in lakes, wetlands, rivers and estuaries. There, in the waterlogged soils, denitrifying bacteria transform some of the nitrate back into nitrogen gas and release it into the atmosphere (Figure 8).

The nitrogen cycle of a landscape is self-adjusting. The activity of all of these microorganisms in the soil and water maintains a balance between the amount of ammonia and the amount of nitrate in the system, and between the amount of nitrogen fixed in upland areas, and the amount released back into the atmosphere in wetlands. If there is an excess of one form of nitrogen, there are microorganisms that will quickly transform it into another form, thereby retaining a balance. However, this balance is disturbed if the amount of nitrogen input (say, from fertilizer) overloads the system. This can result in the loss of nitrogen from the overloaded ecosystem and its overabundance in receiving waters.

Bacteria are single-cell organisms that exist in mats, clumps, and filaments called colonies. Their populations range from a few billion to 3 trillion organisms in each kilogram of soil. Bacteria reproduce more rapidly than fungi. This is extremely important in soils, and bacteria proliferate in the feces of larger decomposers. Some bacteria obtain their energy from breaking down organic matter, while others obtain their energy from converting ammonium to nitrate. Nitrate used by some plants, but many plants thrive using ammonium rather than nitrate (Nixon, 1995).

Scientists are exploring the relationship between the decomposer "classes" and nutrient cycling, such as the effect of earthworm populations on bacterial activity and subsequent soil chemistry. Under the right environmental conditions (low oxygen, lots of available organic matter, and the optimal temperature), soil microbes can process rain water, surface runoff, and groundwater by converting nitrate in runoff and humus to nitrogen compounds that are less likely to pollute ground and surface water. This is called *denitrification*, and is crucial for recycling nutrients and for healthy watersheds. Under aerobic conditions, soil microbes can work in reverse, returning nitrate to the soil. See sidebar for more on the nitrogen cycle.

Invertebrates:

Many other organisms participate in soil ecosystem food webs. (Figure 9) These include microscopic protozoa and nematodes, tiny mites, and larger invertebrates. Earthworms, sowbugs and pillbugs, and millipedes shred and eat organic material and burrow into the soil, which opens pores for water absorption and makes more space for roots to grow.

Earthworms in particular are voracious leaf-eaters and can decompose a year's worth of leaf litter in under a year. In that time, their droppings, called *castings*, which are hot spots for nitrate release, enrich the soil with soluble nutrients for roots to absorb (Figure 10). That's great in gardens, but scientists are beginning to believe that a forest can be overrun by exotic earthworms. Earthworms mix all the upper layers of soil together, devour small seeds, expose large seeds to seed-eating organisms, and displace microbes and smaller invertebrates (Figure 11). This can result in a bare forest floor with limited biodiversity. Scientists are researching whether certain levels of soil biodiversity are required for all soil functions. Earthworms are considered by some scientists the keystone species in soils, however, because they can greatly influence the distribution of microorganisms in the soil.

Studies in New York and Baltimore show that urban forests have more earthworms than rural forests in the same metropolitan region (Steinberg, et al 1997, Szlavecz et al. *in press*). Most, if not all, of those earthworms are non-native species. Glaciers in the last Ice Age pushed earthworms to the southern parts of the US and most species have not had time since to migrate back (Figure 12). Scientists speculate that the Asian and European species came to the US in soil of ornamental or botanical plants, and the ballast of ships (Gates,1976) (Figure 13). A worm species from the Mediterranean region was recently found in Baltimore - the first time this species was found in the US - and a species new to science also has been identified. Scientists are hoping to discover what characteristics of urban soil habitats are so favorable for the introduced earthworms, many species of which would not be expected to survive a temperate winter.

Sources:

Brady, N. C., and R. R. Weil. 1996. *The Nature and Properties of Soils*, 11/Ed. Prentice-Hall, New Jersey.

Brussard, L. et al. 1997. Biodiversity and ecosystem functioning. *Ambio* **26**: 563-570.

Gates, G.E. 1976. More on oligochaete distribution in North America. *Megadrilogica* **2**: 1-8.

Groffman, P.M. and P.J. Bohlen. 1999. Soil and sediment biodiversity. *BioScience* 49 no 2:139-148.

Jamieson, L. 1995. The nitrogen cycle. *BC Wetlands Network* March. Online at http://www.finnslough.com/Environment%20Pages/nitrogen_cycle.htm

Nixon, W. 1995. As the worm turns. *American Forests* Autumn: 34-36.

Schlesinger, W. and J. Andrews. 2000. Soil respiration and the global carbon cycle. *Biogeochemistry* **48:** 7-20.

Skosey, J. 1999. *Unearthing Soil Secrets – The Underground Adventure Educators' Guide.* The Field Museum, Chicago, IL.

Steinberg, D., R. Pouyat, R. Parmelee, P. Groffman. 1997. Earthworm abundance and nitrogen mineralization rates along an urban-rural land use gradient. *Soil Biology & Biochemistry* **29**, no. 3/4.

Urban Soils

Urban soils by definition occur in human settlements where people live in high densities such as a city, town, or suburban area. Urban soils have formed from natural soils and so for the most part are made up of the same components - mineral particles, organic matter, pore spaces - but due to human alterations, they have characteristics that distinguish them from natural soils. In the Baltimore Ecosystem Study soil scientists are describing and measuring characteristics of urban soils to see how they differ from naturally formed soils and how these differences may affect human health, plants, soil organisms, and services that ecosystems provide to humanity (e.g., purification of water).

Human Influences on Soils in Cities

Humans affect soils in many ways. Perhaps the first large scale human impact on naturally formed soils was when the first farmers in the Middle East planted crops. With the development of agriculture, humans were given the ability to live in settlements and to support larger populations. And since humans began living in villages and eventually larger cities, soils have been modified to form “urban” soils. To build cities (and now suburban areas) humans have had to move the soil around, compact the soil to build structures, import soil from somewhere else, unintentionally (e.g., Pb) or intentionally (e.g., fertilizer) add chemicals to the soil, and drain or irrigate soils. *Can you or your students think of other effects of people on soils?*

Scientists in the Baltimore Ecosystem Study have grouped these human alterations of the soil into **direct** and **indirect effects**. Direct effects are mostly physical in nature and occur very rapidly relative to the time scales that natural soils take to develop (at least 100 years, but it usually takes thousands of years!). Examples of direct effects include digging, filling, compaction, and covering soils with impervious surfaces. Indirect effects constitute changes in the environment that are caused by urbanization, and typically take many years before the effects can be measured in the soil. Examples include the urban “heat island” effect, pollution, and the introduction of exotic species of plants and animals (e.g., Tree of Heaven and Asian earthworms). Intermediate in timeframe are management activities, such as fertilization and irrigation, which will take a few years to have a lasting effect on soil.

The combination of the two effects results in a “mosaic” of soil conditions on the landscape at any point in time (Fig. ?). For example, in just about every city there is a forest patch located in a city park or wildlife preserve (*hint: in Baltimore City, the largest forest patch can be found in Leakin Park*). The soils in these forests have not been physically disturbed or changed by urbanization, but these soils have received large inputs of pollutants since they are located in an urban area. Lawns too, are not all made the same. One homeowner may take very good care of her or his lawn by fertilizing, mowing, irrigating, and controlling pests on a regular basis, while another may just mow the lawn every now-and-then. Therefore, as one walks from place to place in the urban landscape, the soils can be extremely different in their characteristics (Fig. ?).

The soil mosaic in urban areas represents a hodge-podge of soil conditions due to human activity, the emplacement of infrastructure (e.g., sewers), and what remains of the original landscape.

Is There a Typical Urban Soil?

Results of our research in Baltimore and elsewhere (most notably New York City) suggest that characteristics of soils can vary widely in urban landscapes, making it difficult to define or describe a typical “urban soil.” Physical properties and pH in urban soil are more consistent from place to place than are chemical properties. Despite the high amount of variation, consistent differences in soil P, K, bulk density (the weight of soil per unit volume – an indicator of compaction), Ca, and pH related to land use. For example, forest soils in cities were very different from high-density residential soils. In fact, the clearest differences between forests and lawns were in P and K levels. It just so happens that these nutrient elements are a major component of most lawn fertilizers, possibly explaining these differences. Soil pH levels varied among lawn, possibly reflecting differences in how much lime or other amendments people use on their lawns.

Urban Soils in Baltimore

Baltimore lies along the Chesapeake Bay between two **physiographic provinces**: the **Piedmont Plateau** and the **Atlantic Coastal Plain**. The north-northeast trending **Fall Line** separates the two provinces, dividing the city approximately in half (Fig. 1). Most of the city is characterized by nearly level to gently rolling hills, dissected by narrow stream valleys. The Piedmont Plateau in the city is underlain by **amphibolite**, **mafic**, and **ultramafic** rock types, characterized by relatively large concentrations of iron and magnesium which contribute to the rocks’ characteristic dark color (U.S. Geological Survey map of Baltimore’s west quadrangle, 1979). The Coastal Plain in the city is underlain by much younger, poorly consolidated sediments such as gravel and sand. Soils in the Piedmont Plateau of Baltimore are very deep, nearly level to moderately sloping, and well-drained, and are underlain by semi-basic or mixed basic and acidic rocks. Soils in the Coastal Plain of the city are very deep, somewhat excessively drained and well-drained upland soils that are underlain either by sandy or gravelly sediments or by unstable clayey sediment (NRCS, 1998). Highly disturbed soils make up more than 60% of the land area of the city (Pouyat et al., 2001).

Soils in the coastal plain parts of Baltimore, formed over the mafic or ultramafic bedrock, have high levels of some metals (Al, Mg, V, Mn, Fe, Ni) that have important ecological consequence. The fact that natural soil-forming factors, in this case weathering of parent material, has such a clear effect on the current soil despite the large amounts of development and disturbance to these soils is very surprising. Unlike soil properties related to lawn management; heavy metal contents did not differ among land-uses, suggesting that these elements are related to factors such as the history of the site and how close the site is to contaminant sources such as a major road (Fig. ?).

Urban Soils and the Baltimore Ecosystem Study

Key Questions we are Asking about the Urban Soils within BES

1. What are the characteristics of soil in urban ecosystems? Is there a typical urban soil?

By knowing the characteristics of urban soils and how they vary across the landscape, we can use the information to map and interpret soils. Soil maps are used by planners and natural resource managers to delineate soil units in the landscape with each unit having a set of common characteristics. Soil interpretations relate to management and use. In traditional agricultural soil surveys, soil interpretations have been developed for growing specific types of crops. Interpretations need to be developed for urban ecosystems that relate to human health, the use of infrastructure (e.g., underground sewer pipes), growing horticultural plants, and erosion control, among others.

2. How do urban soils differ from natural soils in characteristics and in biological processes (e.g., N mineralization)?

Scientists have studied natural soils for several decades and much has been learned about their development and how they function. Scientists use this information to generate mathematical models to predict the results of a natural disturbance or the effects of pollutants. Unfortunately, we know very little about soils in urban ecosystems and are unable to predict the outcome of lawn management care, heavy metal contamination, and human disturbance.

3. What soil organisms and communities flourish in urban and suburban soils and why? How do physical, biological and social forces shape the living things in soils?

4. How can we manage urban soils so that we can maximize their value to society?

As mentioned previously, soils are important components of any ecosystem and perhaps more so in urban areas. Soils can serve as a sink for pollutants, provides a medium for plant growth and habitat for soil organisms, serves as a foundation for built structures, acts as a water filtration system, and even can reduce noise emanating from highways. To maximize these benefits, and because soils have been greatly modified in urban areas, scientists and managers need to understand how changes in the environment, disturbance regime, and management in urban areas directly and indirectly effects soil functioning.

Preliminary Finding from BES Research in Baltimore and Other Cities

1. Humans affect soils directly and indirectly, and there are feedbacks to these effects. Lead (Pb) contamination of soil exemplifies indirect effects. Human activities (using Pb based products) in urban areas increase the amount of Pb deposited on soil surfaces where it can accumulate over time. High concentrations of Pb in human blood occur partly because of exposure to contaminated soils, especially in older cities. Public outcry over Pb contamination, especially in children, has led to numerous public health

programs aimed at reducing Pb poisoning, representing a feedback loop that reduces environmental lead levels.

2. Spatial arrangement matters.

Pollutants may occur in “hot spots” of high concentrations in urban landscapes. If people traverse or use these areas they may be increasing their exposure to contaminants. Moreover, when a contaminant accumulates in the soil it can be washed off with soil particles in the process of erosion. When these particles get washed into a nearby stream they may accumulate in the sediment and eventually end up in the creatures that live there. Some of these organisms may be captured by people (e.g., through fishing) or by predators, thereby exposing them to those contaminants.

3. Time matters.

How long a soil is exposed to inputs of contaminants is important. In older cities such as Baltimore, the amount of contamination by Pb will be much higher than in newer cities such as Phoenix AZ. Not only do soils in Baltimore City have a longer history of pollutant inputs, but also Baltimore was at its peak population in the 1950’s and 1960’s when Pb was used as an additive to gasoline. With all those people driving cars the amount of Pb emitted into the air was very high compared to the much smaller city of Pheonix during that era. Phoenix, on the other hand, has seen most of its growth occur after Pb was removed from gasoline use.

4. Scale matters.

How soils are affected by lawn management is dependent on the scale (size of the area) of the observation. People of similar economic and cultural backgrounds tend to live near to each other. One can imagine a middle-class neighborhood of small detached houses in western Baltimore compared to larger, more expensive houses in a subdivision in Baltimore County. How each homeowner manages their lawns will also be reflected by the neighborhood they live in. Therefore, differences in soil characteristics that emerge from lawn fertilization (remember that P and K differed among turfgrass covered areas in study discussed above?) will also occur at the same scale that social and economic factors vary in urban and suburban areas. That is, soil characteristics that are affected by management should vary more between neighborhoods than within neighborhoods.

Glossary of Soil Terms

ammonia - NH3+; a cation (a positively charged ion) that contains one nitrogen atom and three hydrogen atoms.

bacteria – single-cell organisms having round, rod-like or spiral shaped bodies. They can be seen only with a microscope. They live in soil, air, water or bodies of plants and animals. Involved in cycling nutrients in the environment.

castings – fecal material (droppings) excreted by earthworms at the soil surface; contain material for microbial activity

clay – very fine soil particles; plastic when moist; sticky when wet; hard when dry; used for brick, tile, etc. Also applies to any Soil material that contains 40% or more clay, <45% sand, and <40% silt.

decomposer – organism that physically or chemically breaks down organic matter into smaller parts and/or chemical components

decomposition – chemical conversion of organic matter into soluble chemicals and minerals, such as nitrogen, calcium, and sulfur

denitrification – the biochemical reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen.

fungus – organisms, including mushrooms and yeast, that absorb nutrients from their surroundings. Made up of many slender threads, called hyphae, each of which can absorb nutrients. Fungi decompose tough lignin in logs and fallen branches.

heat island effect – in urban areas, increased temperatures (6 to 10 degrees F higher than rural areas) caused by radiation of absorbed solar energy from rooftops, dark colored pavements and surfaces. The “urban heat island effect” contributes to pollution by creating ground level ozone.

humus - Total of the organic compounds in soil exclusive of undecayed plant and animal tissues, their "partial decomposition" products, and the soil biomass. The term is often used synonymously with soil organic matter.

litter - The surface layer of the forest floor which is not in an advanced stage of decomposition, usually consisting of freshly fallen leaves, needles, twigs, stems, bark, and fruits.

loam – soil mixture comprised of similar amounts of sand, clay, and silt

microbes - microscopic organisms such as fungi and bacteria that digest organic material outside their bodies and absorb the nutrients mor - a type of forest humus characterized by an accumulation of organic matter on the soil surface in matted Oe horizons, reflecting the dominant mycogenous (fungal) decomposers. The boundary between the organic horizon and the underlying mineral soil is abrupt.

mull - a forest humus type characterized by intimate incorporation of organic matter into the upper mineral soil (i.e. a well developed A horizon) in contrast to accumulation on the surface.

Nitrate - NO3- ; an anion (a negatively charged ion) that contains one nitrogen atom and three oxygen atoms.

nitrogen - an element that is an integral component of many compounds, including chlorophyll and enzymes, essential for plant growth processes. (Brady, 1990)

nitrogen cycle - the sequence of biochemical changes undergone by nitrogen wherein it is used by a living organism, transformed upon the death and decomposition of the organism, and converted ultimately to its original oxidation state.

organic matter – fresh or partially decomposed plant and animal materials

parent material - the unconsolidated and more or less chemically weathered mineral or organic matter from which the column of soils is developed; the rock from which soils are derived.

profile – a vertical section of a soil exposing its various subsurface layers (such as a high bank along the highway, or a soil core)

sand - also refers to soil material that contains 85% or more of sand.

silt – also refers to soil material that contains 80% or more silt and <12% clay.

soil – the collection of natural bodies in earth's surface, in places modified or even made by man of earth's materials, containing living matter and supporting, or capable of supporting, plants out-of-doors. (Soil Survey Staff, 1993) Also: Surface of the earth that supports life – the upper layer of earth that may be dug or plowed

soil structure – the arrangement of individual sand, silt, and clay particles into clusters, chunks, peds, aggregates or compound particles

soil texture - the relative proportions of the various soil separates in a soil as described by the classes of soil texture shown. The textural classes may be modified by the addition of suitable adjectives when rock fragments are present in substantial amounts; for example, "stony silt loam." The sand, loamy sand, and sandy loam are further subdivided on the basis of the proportions of the various sand separates present.

Sources:

Brady, 1990

Collier, L. Ed. *Exploring the World of Plants & Soils: Soils*. Intermediate Units in the 4-H Plant and Soil Science Project. National 4-H Council, Chevy Chase, MD.

Johnson, E. and K. Catley. 2002. *Life in the Leaf Litter*. American Museum of Natural History, Center for Biodiversity and Conservation.

http://www.cityofchicago.org/Environment/AirToxPollution/UrbanHeatIsland/

Soil Science Society of America, www.soils.org.

Investigations in Urban Soils:

1. Reconnaissance of urban patches
2. Spatial variation in soil properties
3. Soil invertebrates
4. Earthworm Populations
5. Decomposition and other soil processes

Investigations in Urban Soils: Earthworm Populations

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Overview of Unit

Students learn to sample for earthworms in various sites around their school, determining relative population size and habitat characteristics. Students compare their results to BES data and predict earthworm distribution in other urban habitats. Advanced students may also determine species composition and examine long-term trends.

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Investigations in Urban Soils: Earthworm Populations

Sequence of Activities, Concepts, and Skills

Activities	Concepts*	Skills
BACKGROUND *Day 1: Introduction to Investigation* Students read and discuss a scientist's invitation to study earthworm populations in different habitats. They discuss the importance of soil and choose a study site in their community. *Days 2 – 3: Getting to Know Earthworms* Students become familiar with earthworms by observing them in the classroom and learning their relationship with the soil and other organisms	a. Soil b. Earthworms c. Decomposer organisms d. Nutrient cycle	e. Make objective observations a. … background research
STUDENT INVESTIGATION *Day 4: Preparation* Students form research teams, view a map of the site and select habitats to investigate. They watch a demonstration of worm sampling and discuss the importance of sampling consistency. *Days 5 – 7: Earthworm Investigation* Students sample earthworms from their test plot, and record observations about the plot. The next day, they process their results.	c. Populations and habitat preference e. Scientific inquiry f. Data gathering	a. Make predictions b. Design investigation d. Use tools e. Make accurate observations f. Transform data
USING BES DATA & FOLLOW-UP *Days 8 - 9: BES Data Comparison* Students compare their findings to BES data on earthworm populations. They note other measurements BES scientists made and choose 2 – 3 that they can make to enhance their data. *Days 10 - 11: Return to Investigation* Students return to their sites and make the specific measurements they decided on. The next day they process their results. The class discusses possible explanations for results.	d. Change in earthworm populations over time and space l. Negative results (e – f, exotic species)	c. Explain how investigation answers question h. Use data to support predictions b. Design investigation e. Make accurate observations f. Transform data
ASSESSMENT *Days 12 – 16: Report to Scientist* Students prepare reports for scientist on earthworm distribution and habitat characteristics in urban ecosystems. They also predict the outcome of future investigations based on their findings.	k. Evidence for conclusions m. Communication	g. Communicate data h. Use data to draw conclusions

*Only key words from each concept have been included here - click **Concepts** above to see full concepts aligned with state and national standards.

Investigations in Urban Soils: Earthworm Populations

Learning Objectives Correlated with the Maryland VSC and AAAS

Key Concepts - Clustered by Topic	Maryland Voluntary State Curriculum Grade 6	AAAS Project 2061 Benchmark
a. The soil is made up of living and non-living things that interact and perform functions important for all living things. b. Earthworms are soil-dwelling invertebrates that feed on dead organic matter. There are many species of earthworms. c. The ability of a species to populate an area depends largely on the suitability of the habitat, such as availability and quality of food, moisture, temperature, toxins, and the amount human disturbance. Different species prefer different levels of these factors. d. The number and species of earthworms changes from place to place and over time. Scientists have found more earthworms in urban Baltimore than in rural Baltimore, and more of these have been exotic.	*Life Science:* Ecology: Identify and describe that within ecosystems, organisms have different roles and functions. Identify and describe factors that influence the size and stability of populations and ecosystems. *Environmental Science:* Interdependence of Organisms: Recognize and describe how biotic and abiotic factors influence an environment.	5D3-5#2 Insects and various other organisms depend on dead plant and animal material for food. 5A6-8#3 Similarities among organisms are found in anatomical features, which can be used to infer the degree of relatedness among organisms. 5D6-8#1…In any particular environment, the growth and survival of organisms depend on the physical conditions.
e. Exotic species thrive largely due to humans introducing new species and altering the landscape by land management (tilling, fertilizing, and watering). f. Species from another part of the world can compete for food and space with native species: by getting to food faster, eating more of it, or changing the habitat in ways that make it less suitable for the native species.	*Environmental Science:* Interdependence of Organisms: Recognize and describe how biotic and abiotic factors influence an environment.	5D9-12#3 Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems. 5D3-5#4 Changes in an organism's habitat are sometimes beneficial to it and sometimes harmful. 5D9-12#2 …In the long run, ecosystems change when climate changes or when one or more new species appear as a result of migration or local evolution.
g. Dead things decompose because decomposer organisms use them for food.	*Environmental Science:* Recognize and explain how matter is transformed between	5A6-8#5 All organisms, including the human species, are part of and depend on two main interconnected global food webs.

h. Nutrients are passed along food chains from plants to animals, from animals to animals, and form dead plants and animals to decomposers; decomposers release nutrients back into the environment.	the physical environment and organisms.	… land plants, the animals that feed on them and so forth. The cycles continue indefinitely because organisms decompose after death to return food material to the environment. 5E6-8#2 Over a long time, matter is transferred from one organism to another repeatedly and between organisms and their physical environment.
i. It is important to gather data carefully and systematically, and to keep good records of experiment procedures and results. j. Scientists have to rely on evidence to draw conclusions and support claims. k. Scientists can learn as much from negative results as from results that support their predictions. l. Scientists spend a lot of time communicating with other scientists by writing papers, giving presentations, and having discussions.	*Sills and Processes:* Scientific Inquiry: Collect, organize and accurately display data in ways others can verify using appropriate instruments. Communicate findings from hands-on investigations and text resources. Critical Thinking: Provide supporting evidence when forming conclusions, devising a plan, or solving a practical problem.	1B6-8#1 Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence. 1C6-8#7 Accurate record-keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society. 1B3-5#4 Scientists do not pay much attention to claims… unless the claims are backed up with evidence that can be confirmed and with a logical argument. 12A6-8#2 Know that hypotheses are valuable, even if they turn out not to be true, if they lead to fruitful investigations.
Skills	Maryland Voluntary State Curriculum Grade 6	AAAS Project 2061 Benchmark
a. Make predictions and formulate hypothesis based on observation or background research. b. Design an investigation to test a hypothesis. c. Explain how an investigation will help answer a question. d. Use appropriate tools to make quantified measurements. e. Make objective and accurate observations.	*Skills and Processes:* Formulate and develop hypotheses that can be tested in well-designed investigations. Develop and evaluate a well-designed investigation. Collect, organize, and accurately display data in ways others can verify using appropriate instruments. Analyze data to identify possible explanations for trends.	12D6-8#1 Organize information in simple tables and graphs and identify relationships they reveal.

f. Transform data to appropriate graphs and charts. g. Communicate data to others. h. Use data to draw conclusions and to support claims or predictions.	Communicate findings from hands-on investigations.	

Habits of mind/ways of thinking: Students will more likely:

a. Notice and inquire about things in the immediate environment.
b. Think systematically and with an open mind.
c. Consider multiple possibilities and approaches.
d. Generate accurate and reliable evidence by watching patiently, measuring carefully, and revising or repeating procedures.
e. Show more responsibility or respect for our urban environment.
f. Believe that everybody can do science – no matter who you are or where you live.

Investigations in Urban Soils: Earthworm Populations

Earthworm Background for Teachers

Earthworm Structure

Earthworms are adapted for life under the soil. Two sets of muscles inside each segment extend and contract the body. Each segment also has sets of tiny outer bristles, called setae, that anchor the worm in the soil so it can contract the rest of the body forward. You can see the setae with a hand lens, and can often feel them by running a moist finger gently lengthwise on the earthworm's body. Different species are often differentiated by the number and position of setae on each segment. (For example, Asian worms have setae all the way around each segment.) Earthworms have no eyes but have light-sensitive cells in their skin that makes them sensitive to UV radiation; over-exposure to sunlight can be fatal. Earthworms also have chemical- and touch-sensitive cells along their bodies.

The internal digestive, circulatory, and neural features run down the center of the segments. (See Diagram) Food enters through the mouth, gets physically ground by sand grains in the gizzard, and chemically decomposed and neutralized in the intestine before

being extruded from the anus as castings. Two major blood vessels carry blood; one is along the belly and can be seen well when the digestive tract is empty. Nerve endings connect to each setae and the skin surface, making earthworms sensitive to vibrations. Earthworms absorb oxygen through their moist skin. Earthworms risk their lives by coming to the surface during a rainstorm because rainwater lacks dissolved oxygen.

The clitellum plays a role in reproduction. Earthworms are hermaphroditic and can produce both male and female sex cells. When the worms mate, each deposits sperm in the other's mucous sac around the clitellum. The sac slides down the earthworm past the ovary, which deposits eggs to be fertilized. The fertilized eggs are then deposited in the soil in the mucous egg sac, and two to three weeks later, young earthworms emerge.

The Roles of Earthworms

Earthworms play a number of roles in soil ecosystems, including:

1. Earthworms help decompose organic matter in the soil:
   - They pull plant residue underground where it can decompose.
   - Inside the worms' intestines organic matter is broken down into compounds rich in nitrogen, phosphorus, hydrogen, and sulfur.
   - Worms mix organic and mineral components of the soil.
2. Earthworms interact with soil microorganisms:
   - They move microorganisms from one part of the soil to another.
   - Worm castings promote the growth of soil bacteria.

3. Earthworms alter soil properties:
   - Worm burrows allow water to penetrate the subsoil, reducing runoff and making water more available to plants.
   - Burrows also help oxygenate the soil, supporting aerobic respiration by plant roots and other soil organisms.
   - Burrows reduce compaction and break up hardpans in the soil.
   - As it passes through worm intestines, soil pH is neurtalized, making acidic or basic soil less so.
   - Worm castings improve availability of nutrients and minerals to plants, reducing the need for chemical fertilizers.
4. Earthworms serve as food for other organisms:
   - Worms are eaten by birds, frogs, salamanders
5. Earthworms are important predators:
   - Worms eat harmful nematodes and create soil conditions that discourage their presence.

Earthworm Species

There are at least 3,000 species of earthworms living all over the world. Scientists use sometimes-microscopic external and internal structures to identify species. Only mature earthworms are used in identification because sexual structures, present only in adults, are often unique and thus critical to species classification. Color and behavior are rarely used by scientists to identify species because they can vary even within a species due to age, diet, and stimulation. A few very general tips may be used by students, but sparingly. Very wiggly, dark red worms found near the soil surface are most likely Asian. The mature individuals can be 4 inches or larger. There are wiggly dark red worms, which are much smaller: those are most likely the common compost or manure worms. Common, large, pink worms are usually European; these often dig deep burrows, but any earthworm will retreat in cold or dry weather. Native worms may be paler and smaller; but students in urban Baltimore are not likely to find native worms, unless they dig along stream beds, very moist forest patches, or look under the bark of decaying logs (K Szlavecz, pers comm, 2003).

Exotic species of any kind are sometimes introduced by accident. Some species blend in to the native environment without disrupting it. Others initiate short-term or long-term changes. Whatever the outcome, successful colonization depends on the life history of the organisms (reproductive needs and speeds, dietary selectiveness, life span), and human influence (land use change, further dispersion, creation of favorable habitats).

Current Scientific Research on Earthworms

BES and other scientists studying earthworms in urban and suburban areas have made some interesting discoveries:

- Urban forests support high populations of exotic earthworms, compared to similar rural forests (Steinberg, 1997).
- Exotic earthworms may enhance nitrogen cycling processes even with low-quality leaf litter typical in urban forests (Steinberg, 1997).

- Most exotic species are from the Atlantic region of Europe, accidentally introduced in soil used as ships' ballast, or purposefully introduced by Dutch farmers. The other exotic worms come from Southeast Asia, likely introduced accidentally in ornamental plant stock (Szlavecz and Pouyat).
- Land management practices affect earthworm abundance: high-management areas (e.g., residential garden/lawn) or disturbed areas (urban forest) yield relatively higher worm biomass (Szlavecz).
- Of the eighteen species of earthworm found so far in the Baltimore-Washington metro area, twelve are European, two Asian and four native. (Szlavecz et al, BES).

BES scientists are asking a number of questions about earthworms in the Baltimore-Washington area:

- What is the effect of habitat diversity on species diversity?
- To what extent do soil temperature, pH, and moisture and vegetation cover affect earthworm species composition?
- Why are non-native species more prevalent in urban than rural forest stands?
- What is the significance of non-native earthworm species in the Greater Baltimore Metropolitan Area?
- What effects do various species of earthworm have on soil processes?
- What is the effect of earthworms on the movement of water in soil?

BES research is addressing the overall hypothesis:
suburban and urban habitats provide favorable conditions for earthworms compared to rural habitats because of access to a variety of food sources (compost piles), and human-assisted dispersal (anglers). Furthermore, due to suburban and urban land management practices (housing, lawn maintenance), there is usually always a warm, moist place in urban areas, so worms are less subject to seasonal cycles of dryness and cold.

Sources of Background Information on Earthworms

Johnson, E. and K. Catley. 2002. *Life in the Leaf Litter.* American Museum of Natural History, Center for Biodiversity and Conservation.

Nixon, W. 1995. As the worm turns. *American Forests* Autumn: 34-36.

Steinberg, D., R. Pouyat, R. Parmelee, P. Groffman. 1997. Earthworm abundance and nitrogen mineralization rates along an urban-rural land use gradient. *Soil Biology & Biochemistry* **29**, no. 3/4.

Stidworthy, J. 1990. *Simple Animals*. Facts on File, New York.

Squirming in the Soil: Worm Activity Kit (Urban Life Science Module). Acorn Naturalist. 1991.

www.naturewatch.ca/english/wormwatch/ 2003. Worm Watch. Canada.

Investigations in Urban Soils: Earthworm Populations

References and Readings

Earthworm Science
Darwin, C. 1881. *The formation of vegetable mould through the action of worms, with observations on their habits*. Reprint. Vol 028, *The Complete Works of Charles Darwin*. New York University Press, NY. 1990.
Early observations of earthworm behavior and interactions with the environment, written by a famous scientist, can reveal the timelessness of these creatures and their ecological role.

Kelly, J. 2003. Pity the Lowly Earthworm. *The Washington Post*, June 21.
This article disposes of the myth that earthworms emerge during a rainstorm to avoid "drowning".

Minnesota Worm Watch. www.nrri.umn.edu/worms/Default.htm 2004.
This site connects university students with information and research at University of Minnesota on the impacts of invading exotic earthworms. Includes page of Additional Resources.

Nixon, Will. 1995. As the worm turns. *American Forests*. Autumn.
An easy-to-read overview of earthworms' interaction with the ecosystem in urban forests. Includes diagrams.

Steinberg, D., R. Pouyat, R. Parmelee, P. Groffman. 1997. Earthworm abundance and nitrogen mineralization rates along an urban-rural land use gradient. *Soil Biology & Biochemistry* **29**, no. 3/4.
This study examines the surprisingly high numbers of earthworms in urban forests compared to rural forests, and explores possible effects on nutrient cycling.

Worm Watch. Canada. www.naturewatch.ca/english/wormwatch/ 2003.
This website produced by Environment Canada encourages citizens to help scientists monitor and appreciate soil ecology through monitoring earthworms. Includes detailed diagrams and activities in the School Programs pages.

General Earthworm Activities:
Russell, H.R. 2001. Ten-Minute Field Trips: A Teacher's Guide to Using the Schoolgrounds for Environmental Studies, 3rd Ed. NSTA Press, Arlington VA.
Each field trip chapter includes thorough background information for the teacher, related classroom activities, and questions to guide student observation. Earthworms have their own chapter.

Applehof, M., M. F. Fenton, B. L. Harris. *Worms Eat Our Garbage: Classroom Activities for a Better Environment.* Flower Press. 1993.

Hours of investigations for children age 8 – 14 are described. Includes reproducible charts, tables, diagrams, as well as resource lists and a glossary.

Olien, R. 1993. Worm Your Way Into Science. *Science and Children*, Sept 1993: 25 – 27.

Describes and discusses an earthworm observation activity for elementary students. Includes a question sequence to guide observations, and a list of additional text resources.

Earthworms. 1992. Lawrence Hall of Science Great Explorations in Math and Science, Regents of the University of California.

A performance assessment learning activity on earthworms emphasizing animal adaptations and cold-bloodedness.

Berkowitz, A. and P. Bohlen. 1996. *Worm Worlds.* NAAEE-VINE Neighborhood Ecology Network, NY.

Activity directions and illustrated student information cards for sampling earthworms using the mustard slurry method. This and other neighborhood ecology activities are available in the Natural Connections binder for teachers, from the Irvine Nature Science Center, Stevenson, MD.

Squirming in the Soil: Worm Activity Kit (Urban Life Science Module). Acorn Naturalist. 1991.

This earthworm study kit contains brief description of earthworm movement, and comes with materials and reference cards for the activities and projects.

General Soil Information

Johnson, E. and K. Catley. 2002. *Life in the Leaf Litter*. American Museum of Natural History, Center for Biodiversity and Conservation.

This booklet provides an overview of a large number of soil organisms, complete with phylum, class, and order identification, drawings, and an overview of leaf litter conservation.

http://soils.usda.gov/ 2004. Soils. Natural Resources Conservation Service, United States Department of Agriculture.

This site contains information for everyone from professionals to gardeners to students. Includes regional guides, glossary of soil terms, fact sheets, and many more resources designed to foster understanding of soils.

Cycling Back to Nature: Soils Alive from Tiny Rocks to Compost. National 4-H Council.

Hands-on guide for grades 4-12 to explore the development of soil and soil enhancements through composting.

Worm Reference for Students

Stidworthy, John. *Simple Animals*. 1990. Facts on File, New York.

This reference book places earthworms in context with other simple animals and invertebrates. The two-page entry on earthworms is concise and interesting.

Silver, D. M. 1993. *One Small Square: Backyard.* W.H. Freeman and Company, NY.
Richly illustrated, this elementary-middle school book describes the interactions between and among the many organisms that live in the backyard, including the soil. Students will be interested in reading the imbedded captions and identifying organisms in the drawings.

Himmelman, J. 2001. *An Earthworm's Life.* Children's Press.
From the *Nature UpClose* series, this book contains colorful illustrations and stories that follow earthworms through their life cycles and daily lives. For ages 3 – 7.

Meet Wendall's Cousins, on Yucky Kids Discovery Communications Inc, 2000 http://yucky.kids.discovery.com/flash/worm/pg000216.html
This website includes activities kids can do online while they read and learn about earthworms.

Fiction Books

O'Callahan, Jay. 1996. *Herman and Marguerite, An Earth Story*. Peachtree Publishers, Ltd, Atlanta, GA.
A story about singing earthworms that emphasizes the interdependence of life. Accurate portrayal of earthworms (besides singing), and ideas for backyard explorations at the end.

Larson, G. 1999. *There's a Hair in My Dirt! A Worm's Story.* Harper Perennial,NY.
A young earthworm learns about his important role from his father, who tells this satirical tale about the ignorance of many humans toward ecological balance.

Cronin, D. 2003. *Diary of a Worm*. Harper Collins, NY.
A young earthworm narrates a season in his life, including trouble with homework, surviving fishing season, and his aspirations to be in the CIA. Earthworms are depicted with some anthropomorphic characteristics, but many of their activities are ecologically sound.

Investigations in Urban Soils: Earthworm Populations

Activities

Part 1 - Background

Day 1: Introduction to Investigation

Students read and discuss a scientist's invitation to study earthworm populations in different habitats. They discuss the importance of soil and choose an investigation site in their community.

Materials:

- ☐ invitation letter from scientist (see Handout #1)
- ☐ background reading or story about soil
- ☐ map (see Figure 15) of community within walking distance of school; vegetated areas colored
- ☐ photos and soil samples from sites (optional)

Preparation:

1. Contact the soil scientist in advance to update and sign the letter or write a new one. Schedule a visit if possible.

2. Scout out the nearby vegetated sites – parks, fields, even a safe median will do. Try to choose a site with a variety of habitats. Dig around for earthworms to make sure your students will get something during their investigations. It is very discouraging for students to keep pouring the mustard solution into the soil with nothing coming out. Students will lose enthusiasm quickly.

3. Gain permission from the owner or institution prior to sampling.

4. Take photos of various habitats (shrubs, mulch, grass etc) at each site and gather soil samples if possible. Divide samples into clear plastic baggies and attach to photos. Make one set for each student pair.

5. Find and enlarge a local map or make many small copies. Make sure ideal (vegetated) sites are coded with color or texture so students know what areas they may consider. Give each site a name if it does not have one.

6. To get better data and to cover more area in the community, consider teaming up with another teacher of the same grade. Each class can go to a different site to sample for earthworms. During the project and at the end, the classes can practice communicating their ideas and findings.

Procedure:

1. Ask students if they have ever done a science investigation, met a scientist, or felt like a scientist. This will give you an idea of the students' backgrounds and level of enthusiasm.

2. Provide copies of the scientist's letter and read it together. Have students share or write their first reactions. Then underline or highlight and define any words or phrases that are new or confusing. Have students write down and share their questions and any predictions they might have. The idea is to help all students feel confident and curious about the invitation.

3. Ask students what they need to know to begin understanding earthworms. They may suggest understanding the soil that earthworms live in. Share reading material about soil (see Suggested Readings). Students can complete a graphic organizer on the importance of soil. Ask questions to help students see that soil is important even in the city. This research is important for students to build a background for future interpretation of results.

4. Ask students what should be a first step in the investigation. They may suggest starting by selecting an investigation site. Provide a map (see Figure 15) of the local area. Orient students by pointing out the school and notable landmarks, including students' houses. Describe the sites they may choose from and/or provide photos and soil samples in zipper baggies for passing around. Students should discuss and reflect on the differences between the soil samples and may notice soil organisms they read about.

5. Have students list positives and negatives of each location and then take a vote. One way to make a decision is based on the diversity of habitats at the location. For example, a park that is just open grass might not provide interesting results compared to a garden park with bushes, trees, untended grassland, and a playing field.

6. Curriculum Extension: This could be an appropriate time to present BES data to students, so they could learn what scientists have already done to investigate their questions. If students are not familiar with the scientific process, they could summarize the process used by BES scientists to provide them with a model for research.

Days 2 – 3: Getting to Know Earthworms

Students become familiar with earthworms by observing them in the classroom and learning their relationship with the soil and other organisms (See Related Activities)

Materials:

For each student team:

- ☐ 2 earthworms
- ☐ disposable plastic gloves
- ☐ small clear container of soil and leaves (peanut butter jar)
- ☐ plastic tray or paper plate
- ☐ 1 moist paper towel
- ☐ 1 hand lens
- ☐ notebook or Handout #2: Getting to Know Earthworms
- ☐ 1 plastic Petri dish, top and bottom (optional)
- ☐ Background information on earthworms (Handout #3)

Preparation:

1. Obtain the worms from a garden or pile of leaves. Try to get light-skinned worms because the internal organs are easier to see, although a variety of worms will be a clue to students that not all worms are the same. Also try to get a mix of juvenile and mature (mature have the clitellum). Store worms in a container of loose soil and leaves with a tight lid (worms climb) punched with holes. Students may bring worms from home if they choose.

2. If washing the worms, use aged water – tap water that has sat uncovered for 24 hours – or add dechlorinator drops to chlorinated tap water.

Procedure:

1. Begin by asking students to draw and describe an earthworm from memory. The description should include what the worm looks like, how it moves, what it eats, where it lives, and how it affects other creatures including humans. These descriptions may be full of gaps in information; make a class list of questions about earthworms. (If this part is done a day in advance, the observation worksheet can be made the night before the exploration based on what the class wants to find out about earthworms.)

2. Distribute materials and instruct students to wear gloves when handling soil and to treat the worms gently. Students may empty the soil onto the plate and observe the worms crawling behavior. The paper towel can be used to gently clean the worms for examination with the hand lens. Besides physical observations, encourage students to test the worms' preference for damp or dry paper towels, and to watch long enough to determine what the worm eats and watch for castings. Always have students record their predictions, procedures, and data for at least three trials.

3. Additional observations: (A) Students can place the worm on top of the soil in the jar and record how long it takes to burrow (average of at least three trials). (B) Place a clean worm inside a damp Petri dish with the top inverted to hold the worm in place. Hold the worm to the light or on a white paper to view the blood vessels more easily (keep the worms in damp oatmeal the day before if you want the vessels to show up better). Record pulse rate in various temperatures (see resource list). (C) Test the worm's preference for light or dark, or various foods. (D) Test the pH of soil versus castings.

4. Curriculum Extensions: read about two other earthworm activities that support student learning about these organisms and their role in decomposition in a separate section below.

5. Provide Background readings for students about earthworms (Handout #3), and/or show The Amazing Earthworm PowerPoint presentation. The student guides to the PowerPoint presentation (Handouts #4 and 5) are pages on which students take structured notes. Students can answer any questions they still have from the first discussion or new questions the exploration raised.

Part 2 - Student Investigation

Day 4: Preparation

Students form research teams, view a map of the investigation site, select study plots, and list observations or measurements to gather. They watch a demonstration of worm sampling and discuss the importance of sampling consistency.

Materials:

- ☐ map of investigation site
- ☐ study plot markers (e.g., surveyors flags)
- ☐ worm sampling equipment:
  - earthworm sampling protocol (Handout # 6)
  - 50 x 50 cm quadrat
  - heavy duty scissors or pruners
  - medium bucket
  - water
  - 5 lb. bag of fresh powdered mustard seed (enough for whole class)
  - 1 small plastic container for scooping
  - gloves
  - forceps
  - small zipper baggie or jar of dechlorinated water
  - permanent marker
- ☐ paper towels
- ☐ tips for quick-ID of worms (optional – found in Background for Teachers)
- ☐ ethanol 75% and formalin 5% (optional)
- ☐ airtight glass jars (optional)

Preparation:

1. Create a hand-drawn map of the investigation site, including details of ground cover, vegetation, traffic, shade, etc. (If time permits, students may create this map instead.) Contact the land owner or manager to get permission for class study. Make sure the site is supervisable and safe.

2. Make quadrats: (A) for each team, buy 4 x 50cm pvc pipe and 4 elbow joints; create a square and secure joints with plumbers caulk. (B) Tie wire or surveyors tape around railroad spikes or equally long nails at 50cm intervals to make a square. (C) make a quadrat at the site using string and nails or stakes (see instructions in NAEE *Worm Worlds*, in the Resources)

3. Purchase a large (5lb) bag of powdered mustard seed from an Indian grocery – it must be fresh (ground within the year).

4. If using a 5-gallon bucket, mix water with 1 cup mustard powder and take along a container for scooping the slurry. If using 2-liter bottles or 1-gallon jugs, mix 1 tablespoon powder and you can pour right from the bottle – you won't need the pouring container. You will, however, need funnels or to show you students how to roll paper into a funnel to get the powder inside. (NAAEE supplies sprinkler heads for 1-gallon jugs, call 513-676-2514.)

5. Practice the worm sampling procedure once yourself. Get into the habit of counting worms as you collect them. Always wear gloves when handling soil.

6. Note: if your class decides to take on worm identification, prepare for two additional tasks: quick-ID, and worm fixing. To quickly classify an earthworm as exotic or native, use the general tips in the Background for Teachers. *The tips are not foolproof, nor are they without exception. Worm identification is very tricky!* To fix worms, you will need ethanol and formalin, and the jars for storage.

Procedure:

1. Divide students into teams of two or three. Provide maps of the investigation site and discuss what mini-habitats within the site might yield different numbers of earthworms. Mini-habitats might include leaf-covered, shady, garden, near bushes, etc. Teach students the term study plot to call the different habitats that teams will sample. Label and number study plots on a large version or overhead transparency of the map. If desired, use surveyors' flags to mark the study plots at the investigation site. Assign teams to study plots.

2. Make sure students understand why they will be sampling worms at different mini-habitats on the site. This is a good time to review the investigation question: What effect does habitat have on earthworm population? Create a class list of habitat factors the students think might affect earthworm population. Create separate lists for factors that are observable and those that are measurable. Use the lists to create a data sheet for the investigation days. (Note: students may decide that the mass of worms is important to measure. Weighing worms requires adding extra steps to the basic protocol that must also be demonstrated: blotting the worms and weighing them either at the site or back in the classroom.)

3. Provide copies of the earthworm protocol (Handout #6). Demonstrate worm sampling for the students using the protocol. Emphasize being gentle when transferring worms from soil to the water, and on keeping count of worms as you collect them. Worms should either be fixed or transferred to a suitable habitat in the classroom the same day they are collected.

4. Ask students how they can compare their results from one study plot to another. Pantomime, demonstrate, or describe a student who decides to count worms from outside as well as inside the quadrat. Students may think of other examples of inconsistent technique and discuss why consistency is important to the project.

5. Optional: If the class plans to fix the worms in ethanol and formalin, discuss the ethics of euthanizing worms for science and then demonstrate fixing procedure. (Note the basic protocol does not require killing the worms). There are trade-offs here: fixed worms are easier to identify, but live worms can be kept in the classroom for future observation.

6. Curriculum Extension (see section below): If earthworm species become an important part of the class investigation, find out how students can investigate issues surrounding invasive species.

Days 5 – 7: Earthworm Investigation

Students sample earthworms from their investigation site, and record observations about the site. The next day, they process their results.

Materials:

- ☐ worm sampling equipment for each team (see Day 4)
- ☐ Data Table (Handout #7) for recording observations and measurements
- ☐ optional: worm ID and fixing materials (see above)
- ☐ digital camera

Preparation:

1. Invite the scientist to attend the collection day with the students.

2. Gather sets of material or lay out in an assembly line fashion. Let students take responsibility for mixing their own mustard slurry.

3. Create the data table (Handout #7) using the class list of habitat factors from Day 4.

4. Optional: if it is too much to carry fixing agents to the field, consider keeping the worms in a cooler until you get to the classroom. Set up a fixing station in the classroom.

5. Arrange time in computer lab for processing data.

Procedure:

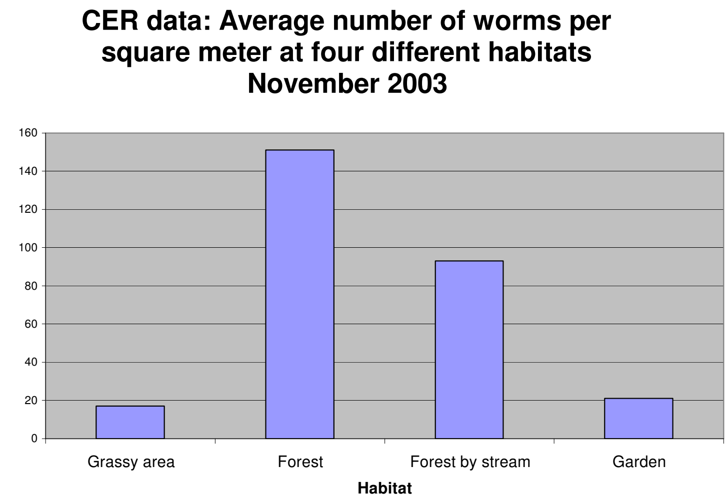
1. Supervise students gathering materials, sampling, counting, and fixing worms as per the sampling protocol. Take pictures! See an example of a student data sheet (page 1, page 2) (see Student Work Sample #1).

2. Guide students in processing their data. First, students should understand that their quadrats were only one-quarter meter square. Scientists express earthworm populations in terms of number per square meter, so students should multiply every earthworm count by four.

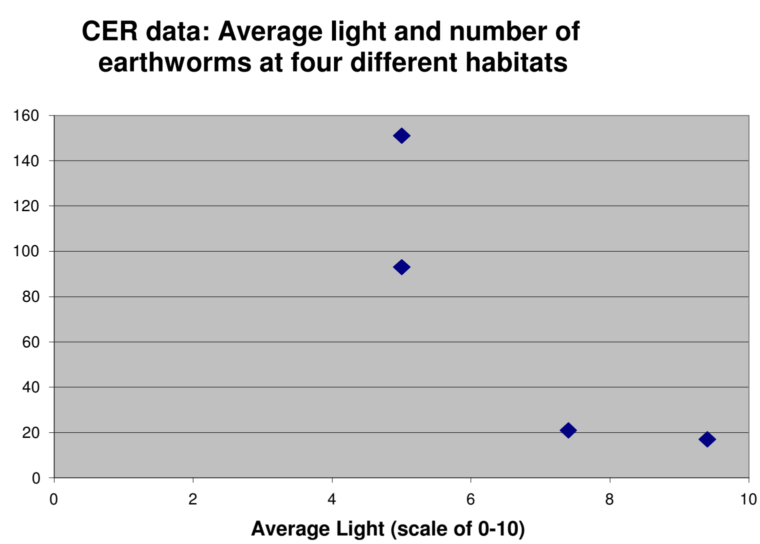
3. Make data from every study plot available to every student, either by having each team record results on a large class chart, or by compiling the results on one page that can be photocopied and distributed. (See example of class spreadsheet created by teacher, see Student Work Sample #2).

4. Students may find it overwhelming to work with all of the raw data, if large amounts of data were produced, as in the example. Students may work together or in pairs to summarize the average values for each measured variable and create one small table of data. (In this example of a data summary sheet (see Student Work Sample #3), decimals were rounded to the nearest whole number.)

5. Guide students in displaying their data. For example, students may make a simple bar graph of total average density (earthworms per square meter) for each habitat (grass, forest, etc.).



6. Students may also plot density versus each measured variable (e.g., temperature). This kind of display can reveal patterns that may help explain why certain habitats had more worms than others. For example, if habitats that were driest also had low numbers of worms, then students can say they have evidence that worms do not thrive in dry soil. However, if you use a qualitative or inferior tool to measure temperature, moisture or light, then the plots will be equally subjective and open for interpretation.



7. Be sure to ask students to consider any other factors they observed when drawing conclusions. For example, if the forested study plot also had fallen leaves and loose soil, students should explain how those factors contribute to making the forest floor habitable for earthworms. Always return to the question, How does habitat affect the number of earthworms? (See Interpreting Results from 2003 section below - interpretations of 2003 data)

8. At this point, students should have completed at least a graph and a short conclusion. Students may enjoy the opportunity to present their findings in a simple presentation to the class. This can be the "Preliminary Findings Symposium".

Part 3 - Using BES Data & Follow-Up

Days 8 - 9: BES Data Comparison

Students compare their findings to BES data on earthworm populations. They note measurements that BES scientists made and make plans for a modified investigation. (See Alternative Methods)

Materials:

- ☐ Internet access to BES website www.beslter.org
- ☐ Optional: handout of BES data tables and graphs (BES Data from 2003, see Figure 16).
- ☐ Class data summary sheet and/or student-produced graphs from Day 7

Preparation:

1. Reserve computer time or LCD projector for students to view online data. Preview current BES data with student data in hand to anticipate similarities and differences.

2. Generate a list of questions for reflection and/or discussion (see #1 below).

3. Make sure all students have a copy of the class data in some form.

Procedure:

1. Remind students that the purpose of comparing their data to that of other scientists is to determine whether earthworm results in their community corroborate or negate the results from communities previously studied in Baltimore. Keeping that in mind, as students spend time looking at the graphs on-line, they may find more differences than similarities between their results and scientific results. Some questions to consider posting for student reflection and discussion include:

   a. Read the introduction sections of the earthworm pages on the website. Summarize the research goals of BES scientists who are studying earthworms in Baltimore. How are their goals different from our goal in doing this investigation? Does our investigation help answer any of the scientists' questions?

   b. Choose one earthworm graph or table from the BES website that includes data for habitat similar to the ones we investigated. Was the habitat with the most worms the same for each investigation?

   c. If not, what other factors might have contributed to the difference in distribution of earthworms in each investigation site?

d. Choose one BES graph. Thoroughly describe the data in that graph. Which habitat had the least worms? Most? How many study plots were sampled to calculate the average? When were the worms collected?
e. List factors that the scientists measured that we did not measure.
f. Choose one BES table or graph. Write at least three interpretations you can draw from the results.
g. Choose one BES table. Display the information in the table using an appropriate graph or chart.
h. Why do you think the scientists measured worm biomass at Cub Hill in the summer of 2002? (If the class did not measure biomass…) Would measuring biomass enhance our data?
i. Imagine that BES agrees to put our data on the BES website. Write an explanation of how our data increases scientific knowledge of earthworms in urban habitats.

2. Make a class list of factors that the scientists measured, but that the class did not measure, such as biomass, or collecting worms from a playing field.

3. Guide students to modifying their investigation. Students may want to go back to the same study plots and collect additional data as well as another round of worms; or they may decide they need to collect the same information from new habitats.

Days 10 - 11: Return to Investigation

Students return to their sites and make the new measurements they decided on. The next day they process their results. The class discusses possible explanations for results.

Materials:

- ☐ worm sampling equipment for each team (see Day 4)
- ☐ data table for recording observations and measurements
- ☐ additional tools (thermometer, light or moisture meter, scale) as needed
- ☐ digital camera

Preparation:

1. Prepare new data table in advance, based on the class revisions to the observations and data they want collected.

Procedure:

1. Supervise students collecting worms and observations/measurements.

2. Guide students in processing and displaying data.

3. Help students select and discuss factors that had the largest impact on earthworm population, based on the experimental results. Making careful interpretations is very important to students' understanding the significance of results (see Interpretations from 2003 in section below).

4. If time allows, email student conclusions to the scientist for feedback.

5. Optional: If worms have not been identified, ask the scientist if he/she would be willing to have them identified in the laboratory and return the results. (See example of worm identification results, Student Work Sample #4.)

Part 4 – Assessment

Days 12 – 16: Report to Scientist

Students prepare reports for scientist on earthworm distribution and habitat characteristics in urban ecosystems. They also predict the outcome of future investigations based on their findings.

Materials:

- ☐ As needed

Preparation:

1. Select a format for student reporting – poster, written report, oral report, etc. Click on a link to see an example of a brief essay assignment (Student Handout #8), or an extended report assignment (Student Handout #9). Student teams can work together on deciding what belongs in a formal report, and then each can write one section.

2. Enlist the aid of the writing teacher to reinforce the writing process for written reports.

3. Instead of each student writing a full report, teams of students can write small sections of a full report and combine all sections with graphs and photos for a collective poster. See an example of a cooperative report (Student Work Sample #5).

4. If giving presentations, try to arrange for the scientist, school administrators, and parents to attend.

Procedure:

1. The final report may take any number of forms. Based on the ability of your students, plan a reasonable final report. The final report should serve as a way for students to communicate their findings, a fundamental skill in science, and also an evaluation tool for you. The report creation and presentation stage is also ideal time to invite a scientist to the classroom. The scientist might provide some suggestions on Day 12 about how students can present their findings. Or, you may decide on the report format as a class and invite the scientist on the last day of the project.

2. Suggested final reports:

   a. Assign each student a written report, such as an essay contest summarizing results. See examples of satisfactory, good, and great essays (Student Work Samples #6, 7 and 8).

b. Advanced students may benefit from writing a formal report, using a scientific paper as a rough model. This process takes days of revision and teacher and peer review.

c. Create a class poster through collective effort. Split the class into groups. Each group chooses to work on one portion of a formal report. Combine all groups' writing, graphs, and photos onto one large poster board. See an example of a cooperative report (Student Work Sample #5), and the final poster (Student Work Sample #9).

d. Students may get excited and want to create informational placards for the property they studied. Have them select information they consider important for people to know about soil, earthworms, habitats; and information that is just plain fascinating, like the exotic species origins in Baltimore. Ask permission to install the placards permanently on the property.

e. If you have access to a digital camera, students may like to make a photo-journal of their research for the Internet. Even more helpful to future student groups would be high-quality photographs of various earthworm species. The more experience students get with seeing examples of Asian and European worms, the better they will be at quick identification in the field.

f. Some students benefit from using visuals to organize their ideas. Encourage them to create a concept map of any relationships they discovered between earthworm habitat and earthworm populations. The concept map would also help students reflect on the investigation process by retracing the steps from their original hypothesis, investigation, and results to new hypotheses and investigations, and so on.

g. Results may also be reported in creative formats: diorama, posters, skits, radio show, etc.

h. If worms were preserved, they should be displayed appropriately. A printed slip of paper can be placed in the preservative solution as a label. See examples of stream fixed worms from a stream site and field site.

See what students had to say about this project: Student Survey 2003.

Investigations in Urban Soils: Earthworm Populations

Interpreting Results from 2003 – Teacher's Commentary

In November of 2003, my class of 23 6th grade students investigated the effects of environmental factors on population density of earthworms. We had the luxury of taking four days, for two hours each day, to conduct the investigation. Rather than selecting one site that contained four or more habitats for us to compare, we chose four different sites: a garden, a forest on a hill, a minimally managed lawn in a public park, and the forest by a stream. At each site, we sampled at 6 or 7 study plots that were similarly situated. This reduced variation within a habitat and increased repetition for each habitat. We also were able to visit our habitats at roughly the same time of day within a seven-day period, which also added some amount of control. Many classes may not be able to spare as much time as we did, and will have less repetition and control. Differences in results from different groups' study plots at the same site will generate questions that are interesting to discuss.

When interpreting the data, first look for what the data tells right away. Our 2003 data (see Student Work Sample #2) immediately reveals the benefit of being able to replicate sampling at one site. At each habitat, the density results did not vary much from group to group, although there were outliers in each habitat. Soil and air temperature also did not vary. Next, the average density of each habitat is distinctly different from that of other habitats (we did not calculate significance). Right away, you can tell that the forested areas both had higher earthworm density than either the lawn or garden.

Then, look for what the data might be telling you. There are some universal principals that students may be able to grasp. For example, areas with leaf litter had higher numbers of earthworms (even within a site). Students should be able to understand that earthworms eat leaf litter and are going to populate the soil right under the leaves. Students may not realize that the leaf litter also provides a cover from light, so worms may be active closer to the surface, and therefore more readily appear during mustard sampling (Szlavecz, per. Comm. 2004)

The amount of light that falls on the surface, which we measured, is not as important as it might seem. Earthworms do move away from light (are photophobic) but they can do that by moving deeper into the soil. The high light in some areas may, however, indicate that other conditions are different, such as soil temperature and the availability of leaves. (Szlavecz, per. Comm. 2004)

We did notice large differences in the size of earthworms we collected. Almost all of the worms collected were juvenile, but these ranged in size from threadlike to some that were the diameter of drinking straws – perhaps older juveniles, or a larger species. An additional layer of data would have been added by measuring biomass and comparing that to population density. Which habitat had the smallest earthworms? Why were there so many juveniles? If we had sampled in the spring or summer, would the biomass, density, or number of adults be different? (note: preserved specimens can be weighed and a conversion factor used to calculate live biomass) (Szlavecz, per. Comm. 2004)

It is instructive to look at the difference between air and soil temperature, especially in habitats where they are different. In our first habitat, the air temperature (27ºC) would have been fatal for earthworms, but the soil temperature was cooler. This is one reason earthworms stay in the soil: its temperature, and moisture, fluctuate less rapidly than air. In our garden site, the soil temperature was warmer than the air for the same reason: it takes soil a few days to catch up to the air temperature, which it did few days later, at our last site.

Personal communication by email with Dr. Katalin Szlavecz, Johns Hopkins University, January 2004.

Investigations in Urban Soils: Earthworm Populations

Curriculum Extensions

Earthworm and Decomposition Activities

Students may not know how hungry earthworms are for dead plant material, and what product they leave behind (castings). A number of activities can introduce students to earthworms' role in decomposition:

1. *Worm farm in the classroom*: build a simple worm box, add the suggested worm food, and toss in some worms. Observe how the worms transform scraps and leaves to rich brown "soil". (Sources: City Safaris by Carolyn Shaffer and Erica Fielder, Sierra Club Books, San Francisco, 1987; Worming Students into Science by Muhammad Hanif and Tammy Harrod, Science and Children, Jan. 1997, p25-27; also try Maryland Department of the Environment, Waste management Admin. http:"www.mde.state.md.us)
2. *Litterbag experiment*: Test the rate of decomposition and appearance of leaves with and without earthworms. Divide fallen leaves equally among three different bags. One bag is made from a nylon stocking that prevents all but microbes and the smallest organisms to enter. A second bag is made from plastic burlap, the kind onions come in; larger invertebrates should be able to enter, but not earthworms. The third bag is made from a material with a very open weave like the sleeves for Christmas trees; anything can enter this bag. Make sure to have a minimum of three replicates for each treatment. Clear a small patch of soil in an undisturbed place and spread the three bags flat. It is important to make sure that the leaves are moist throughout the experiment. Find a place among a patch of trees or a shady area. Also, put enough leaves into the bags so there is some thickness – they should not be completely flat, but should be similar to a layer of leaf litter in a forest. Check periodically for signs of earthworms and other decomposers. After a few months measure the results in terms of mass lost or surface area lost from leaves, or make comparative observations of how the leaves look in the three bags. Discuss the effect of earthworms on decomposition. This experiment is best done in the fall (late October), especially if your site has predominantly European earthworms. In the fall, leaves are falling and many soil animals are active. If you know your site has mostly Asian worms, the warmer months of summer or early fall might be better. (Dr. Szlavecz, personal comm.. 2003)

Earthworms and Invasive Species

A look at BES data on the website reveals that exotic earthworm species are a hot topic. As a result, students might be very interested in determining species composition of their earthworm populations. Unfortunately, species identification is very challenging without fixing the worms and examining them under dissection microscopes – or years of such experience.

Keep in mind, also, that the vast majority of earthworms found in Baltimore thus far are exotic anyway, and students might not find much diversity within their selected site.

However, this is an ideal time for students to learn how exotic earthworms are introduced and dispersed, and to discuss reasons for high numbers of exotic earthworms in urban areas. As an extension, students can also learn about *invasive* species of organisms (consult the information-rich and species-specific www.invasivespecies.gov) as a basis for a debate on whether exotic earthworms should be considered invasive. Fuel for this debate may come from investigating signs of negative effects of earthworm activity. If such signs are not readily recognizable at your site, provide articles from other cities where earthworms are raising concern (Nixon, W. 1995. As the Worm Turns. *American Forests*, Autumn 34-36).