

LICHENS



THEME: Lichens and Air Quality

BEST TIME TO PLAN TRIP: Fall or Spring

UNIT RATIONALE

There are many species of algae and fungi, but when certain species of fungi join with certain species of algae in a symbiotic relationship, they become a unique organism called a lichen. This unit is on lichens and how they are used as bioindicators of poor air quality. It is important to monitor our lichen composition so we can see if we are losing biodiversity with the less tolerant species dying out and being replaced by the more tolerant species. During this study students will observe and identify the growth form of the lichens on the assigned tree and determine the percentage of lichen coverage of each growth form. Students will better understand different lichen growth forms, their unique symbiotic relationship, and their use as bioindicators.

NORTH CAROLINA CURRICULUM CORRELATIONS

EARTH/ENVIRONMENTAL SCIENCE GOALS AND OBJECTIVES (9TH GRADE)

Competency Goal 1: The learner will develop abilities necessary to do and understand scientific inquiry in the earth and environmental sciences.

- 1.01 The learner will identify questions and problems in the earth and environmental sciences that can be answered through scientific investigations.
- 1.02 The learner will conduct scientific investigations to answer questions related to earth and environmental science.
- 1.04 The learner will apply safety procedures in the laboratory and in field studies
- 1.06 The learner will identify and evaluate a range of possible solutions to earth and environmental issues at the local, national, and global level.

Competency Goal 2: The learner will build an understanding of lithospheric materials, tectonic processes, and the human and environmental impacts of natural and human-induced changes in the lithosphere.

- 2.07 The learner will analyze the sources and impacts of society's use of energy.

Competency Goal 5: The learner will build an understanding of the dynamics and composition of the atmosphere and its local and global processes influencing climate and air quality.

- 5.03 The learner will analyze global atmospheric changes including changes in CO₂, CH₄, and stratospheric O₃ and the consequences of these changes.

BIOLOGY GOALS AND OBJECTIVES (10TH GRADE)

Competency Goal 1: Learner will develop abilities necessary to do and understand scientific inquiry.

- 1.01 The learner will identify biological problems and questions that can be answered through scientific investigations.
- 1.02 The learner will conduct scientific investigations to answer biological questions.
- 1.03 The learner will formulate and revise scientific explanations and models of biological phenomena using logic and evidence.
- 1.04 The learner will apply safety procedures in the laboratory and in field studies.

Competency Goal 4: Learner will develop an understanding of the unity and diversity of life.

- 4.01 The learner will analyze the classification of organisms according to their evolutionary relationships.
- 4.03 The learner will assess, describe, and explain adaptations affecting survival and reproductive success.

Competency Goal 5: Learner will develop an understanding of the ecological relationships among organisms.

- 5.01 The learner will investigate and analyze the interrelationships among organisms, populations, communities and ecosystems.
- 5.03 The learner will assess human population and its impact on local ecosystems and global environments.





AP BIOLOGY GOALS AND OBJECTIVES

Competency Goal 1: The learner will develop abilities necessary to do and understand scientific inquiry.

- 1.01 The learner will identify questions and problems that can be answered through scientific investigations.
- 1.02 The learner will conduct scientific investigations to answer questions about the physical world.
- 1.03 The learner will formulate and revise scientific explanations and models using logic and evidence.
- 1.04 The learner will apply safety procedures in the laboratory and in field studies.

Competency Goal 6: The learner will develop an understanding of the unity and diversity of life.

- 6.03 The learner will analyze and apply current phylogenetic classification.
- 6.04 The learner will analyze evolutionary relationships.
- 6.05 The learner will examine the structure and function of plants and animals.

Competency Goal 7: The learner will develop an understanding of basic ecological principles.

- 7.01 The learner will analyze population dynamics.
- 7.02 The learner will examine the actions and interactions of communities and ecosystems.
- 7.03 The learner will assess current global issues.

AP EARTH AND ENVIRONMENTAL SCIENCE (APES) GOALS AND OBJECTIVES

Competency Goal 1: The learner will develop abilities necessary to do and understand scientific inquiry.

- 1.01 The learner will identify questions and problems in the earth and environmental sciences that can be answered through scientific investigations.
- 1.02 The learner will conduct scientific investigations to answer questions related to earth and environmental science.
- 1.03 The learner will formulate and revise scientific explanations and models using logic and evidence.
- 1.04 The learner will apply safety procedures in the laboratory and in field studies:

Competency Goal 2: The learner will build an understanding of the interdependence of Earth's systems.

- 2.04 The learner will investigate the atmosphere.
- 2.05 The learner will investigate the biosphere.

Competency Goal 4: The learner will build an understanding of the distribution, ownership, use and degradation of renewable and nonrenewable resources.

- 4.04 The learner will analyze biological resources.

Competency Goal 5: The learner will build an understanding of air, water and soil quality.

- 5.01 The learner will analyze the sources of major pollutants.
- 5.02 The learner will investigate the effects of pollutants.
- 5.03 The learner will analyze and investigate pollution reduction, remediation and control measures.
- 5.05 The learner will analyze impacts on human health.

Competency Goal 6: The learner will build an understanding of global changes and their consequences.

- 6.01 The learner will investigate human effects and consequences on the atmosphere.

Competency Goal 7: The learner will build an understanding of environmental decision making.

- 7.03 The learner will recognize significance of major environmental laws and regulations





TABLE OF CONTENTS

Activity	Page
Unit Rationale/State Learning Standards	1-2
Table of Contents	3
Planning your Trip and Safety Considerations	4
Background Information.....	5
Map to Purchase Knob.....	6
Pre-Site Activities	
Vocabulary and Video podcasts	7-8
Lichen Information.....	9
Lichen Growth Forms	10
On-Site Activity	
Park Ranger Directed Lessons: Lichen Study	11
Post-Site Activities	
Lichen Sensitivity to Nitrogen and Sulfur Dioxide	12
Air Quality Updates	13
Lichen Sensitivity Worksheets	14-19
Lichen Sensitivity Worksheet Answer Key	20-23





PLANNING A SUCCESSFUL TRIP

SCHEDULE FOR A DAY OF ACTIVITIES IN GREAT SMOKY MOUNTAINS NATIONAL PARK AT PURCHASE KNOB

- Meet park ranger at Purchase Knob
- Use restrooms
- Large group introduction
- Break into two groups
- Participate in activities
- Lunch
- Switch groups
- Large group conclusion

• Check the weather before you go. Lunch will be eaten outside.

• School buses can park at the program site.

• The pre-visit activities included in this packet are specific to the theme of your program and should be presented prior to your scheduled visit. The post-visit activities are designed to reinforce and build upon the park experience.

• A map to the Appalachian Highlands Science Learning Center Purchase Knob can be found on page 6

• All students, teachers, and chaperones will meet the park rangers at the Appalachian Highlands Science Learning Center at Purchase Knob.

• The maximum number of students for this trip is 60. We require an adult or teacher for every ten students to create a positive and rewarding experience. The on-site instruction is conducted by a park ranger. However, your assistance is needed with discussion and discipline. Please feel free to contact the park at (828) 926-6251 if you have any further questions.

•Dressing for the Weather

Please remind your students to wear appropriate footwear and clothing for an extended outdoor program. Short pants, flip flops, or sandals are not recommended. Temperatures in the mountains can be 10-15 degrees colder than at your school. You may wish to alter portions of the program should inclement weather appear.

•Restrooms and Water

Restrooms and water fountains will be available at the program site.

•Lunch

Lunches will be eaten picnic style on the grounds of the Learning Center. Lunches should be put in a box for storage and kept on the bus until needed. Lunches, snacks, and drinks should be provided by the students. There are no concessions at Purchase Knob.

•Safety

Purchase Knob is a remote location, far from any medical facilities. Students will spend most of their time away from buildings, so please bring a cellular phone. Notify the park ranger of any special concerns or medical conditions including students with allergies, asthma or other medical conditions.

•Cancellation

Should anything unforeseen occur preventing you from keeping your appointment, please contact the park at (828) 926-6251 to notify us of your late arrival or cancellation.





BACKGROUND INFORMATION

Park Description:

The National Park Service is charged with the management and preservation of the nation's most precious natural and cultural resources. These resources are woven into our natural heritage, and they provide opportunities for recreation, appreciation of beauty, historical reflection, cultural enrichment, and education.

Great Smoky Mountains National Park is one of the largest protected land areas east of the Rocky Mountains. With over 500,000 (800 square miles) acres of forest, the Smokies contain an enormous variety of plants and animals. In terms of biological diversity, a walk from a mountain's foot to its peak is comparable to the 2,000 mile hike on the Appalachian Trail from Georgia to Maine.

Because the National Park Service is charged with protecting resources and natural systems, the park engages in comprehensive research programs, such as air quality monitoring, to foster an understanding of park resources and to show how they are affected by local, regional, and global influences. Since the Smokies are so biologically diverse, the park is designated as an International Biosphere Reserve by the United Nations. The international system contains over 320 reserves in over 80 countries with the primary objectives of conserving genetic diversity and coordinating environmental education, research, and monitoring.

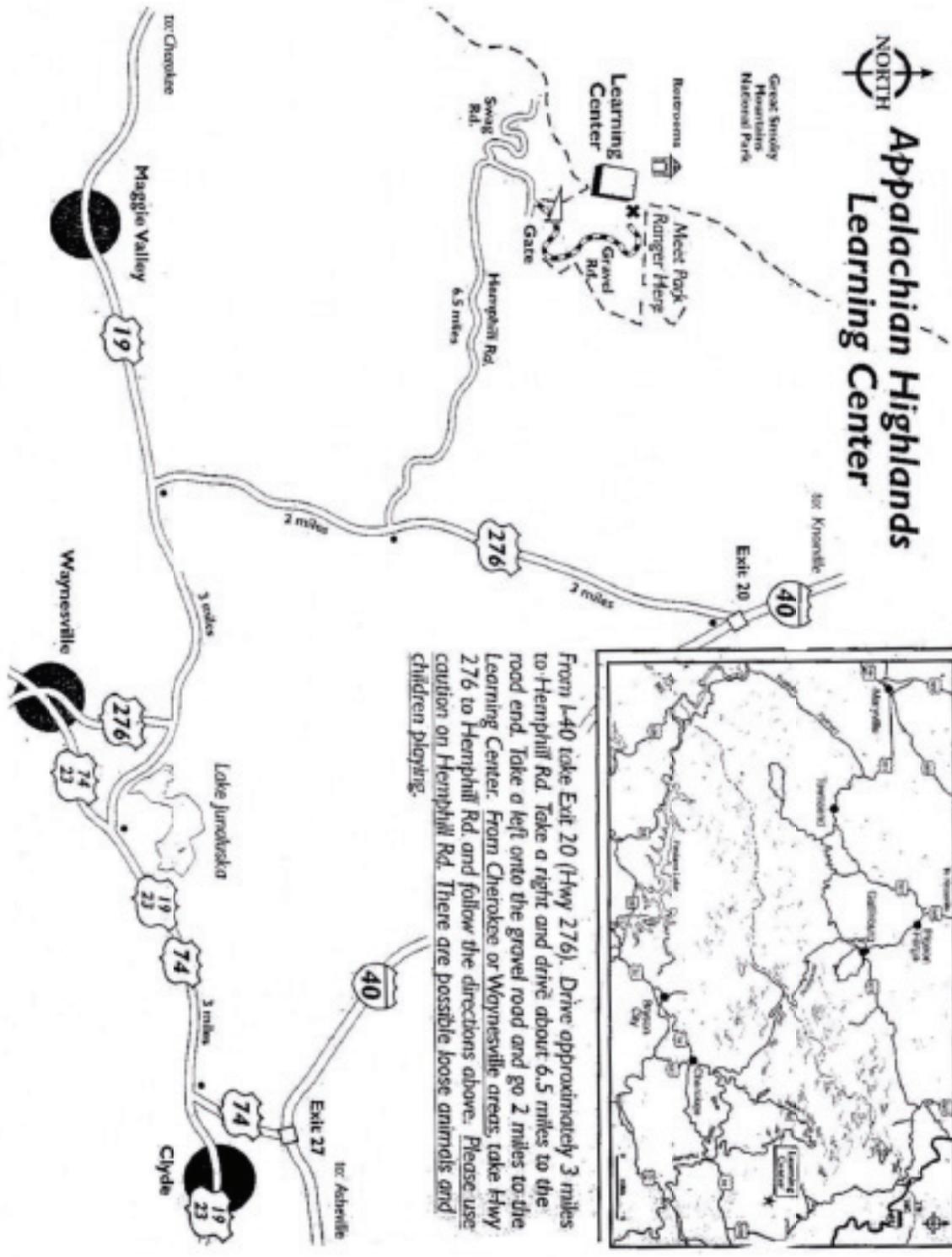
The Smokies also have a rich cultural history. Native Americans have lived in this area for thousands of years, and permanent white settlement began around 1800. The coming of commercial logging around 1900 stripped trees from two-thirds of what is now park land. Established in 1934, the park was created from more than 6,000 tracts of private and commercial land that was bought mostly with money raised and privately donated. Centrally located within a two-day's drive for half of the nation's population, Great Smoky Mountains National Park has the highest visitation of all the national parks in the country.

Purchase Knob Description:

The Purchase Knob property, over 530 acres in size, was donated to Great Smoky Mountains National Park by Katherine McNeil and Voit Gilmore in January 2001. Situated at an elevation of over 5,000 feet, the area contains old-growth forests, mountain meadows and high elevation wetlands. It also rests on geological formations that aren't found anywhere else in the park, lending to a unique and diverse habitat for the study of plants and animals. The house is the location of the Appalachian Highlands Science Learning Center, whose mission is to provide a space for researchers to perform biological inventory and monitoring while offering education programs for students and teachers on these same subjects.



MAP TO PURCHASE KNOB



PRE-SITE ACTIVITY

LICHEN INFORMATION



Grade Level: High School

Subject Area: Science

Activity time: 60 minutes

Setting: Classroom

Skills: Analyzing, Applying, Categorizing, Comparing, Describing, Discussing,

Vocabulary:

• **Algae:** a photosynthetic organism that lacks the complex reproductive structures of mosses, liverworts, and vascular plants.

• **Chlorosis:** the loss of the green plant pigmentation, chlorophyll, essential in photosynthesis. Appears as a yellowing of leaf tissue.

• **Crustose:** crust-like lichen growth form with the lower surface growing on and among the particles of its substrate (rocks, bark...). Crustose lichen cannot be removed from the substrate in one piece.

• **Foliose:** leaf-like lichen growth form with a flattened body and distinguished upper and lower surfaces.

• **Fruticose:** shrubby or hair-like lichen growth form with no distinguishable upper and lower surface. Fruticose lichen either stands erect or hangs down from its substrate.

• **Fungus:** an organism that lacks chlorophyll and reproduces by spores.

• **Lichen:** a mini-ecosystem consisting of at least two organisms: a fungus and a photosynthetic partner (algae or cyanobacteria).

• **Moss:** members of the plant kingdom, that have tiny green "leaves" composed of cells that contain chloroplasts. Mosses are generally grassy green.

• **Photosynthesis:** the process by which green plants containing chlorophyll use the energy of sunlight to produce carbohydrate (sugars).

• **Sulfur Dioxide (SO_x):** a gas produced by burning coal, most notably in coal-fired power plants and the production of paper. Sulfur dioxide plays an important role in the production of acid rain and haze.

• **Stomata:** tiny openings in a leaf surface through which gaseous interchange takes place.

• **Symbiosis:** the living together of unlike organisms; it may be for mutual benefit or it may not.

• **Thallus:** the vegetative body of a lichen consisting of both algal (or cyanobacterial) and fungal components.

Materials:

• Vocabulary and Definitions worksheet (page 9)

• Lichen information worksheet (page 10)

• "Lichen Growth Forms" worksheet (page 11)

• Computer with internet connection.

Objectives:

1) be introduced to vocabulary and definitions relating to lichens

2) gain an overall view of the importance of lichens

3) be introduced to the three main lichen growth forms

4) understand the biodiversity of Great Smoky Mountains National Park

Background:

Present the lichen story to the class: Once there was a fine carpenter named Freddy Fungus, and he could build a home using any material. But Freddy was helpless when it came to feeding himself, because he couldn't cook. Then along came chef Alice Algae, who could whip up fabulous food right out of thin air. But alas, Alice needed a home. When Freddy and Alice met they took an immediate lichen to each other. And although their marriage was sometimes on the rocks and out on a limb, they lived symbiotically ever after. Freddy and Alice's tale is a classic way of describing the symbiotic partnership within lichens, unique "dual organisms" composed of fungus and algae.

Procedure:

This lesson will introduce lichens and their characteristics. Students should individually read the lichen vocabulary/definitions worksheet (page 9). Answer any questions that may come up after the vocabulary is read. If any questions arise that you feel unsure about answering, write them down and have the students ask them of the ranger during the field trip. Have the stu-



VOCABULARY AND DEFINITIONS FOR LICHEN STUDY



dents read the “Lichen Information” worksheet (page 10). Additionally, students should be able to identify the three main lichen growth forms by sight after viewing the “Lichen Growth Forms” worksheet (page 11).

View the following videos as a class to prepare for the Lichen field trip.

To view the Lichen Science Friday video go to
<http://www.sciencefriday.com/program/archives/201011124>

To view the Biodiversity podcast video go to
<http://www.thegreatsmokymountains.org/eft/10modules.html>. Turn the microscope knob that appears on the computer screen to Section 1, Understanding Biodiversity. Click “Watch Video” and view video.





LICHEN INFORMATION

What is a Lichen?

There are many species of algae and fungi, but when certain species of fungi join with certain species of algae, they become a unique organism called a lichen. Scientists can identify each different combination by the characters of its thallus (the point where the algae and fungus join). The algae and fungus work so closely together, each union has its own lichen species name.

What Role do Lichens Serve?

Lichens can grow in places where most other organisms can't. They can attach themselves to bare rock, bark, sand, animal bones and soil, growing on surfaces that would be inhospitable for most other forms of life. They have a special survival technique that allows them to shut down when conditions are too harsh such as extreme heat, cold or drought. Thus, lichens are the stepping stone, slowly beginning the process of creating a soil and organic matter foundation for other things to grow upon by processing nutrients from the air and providing a place for plants to sink their roots.

Most lichens grow very, very slowly, often less than a millimeter per year. Some lichens are thought to be the oldest living things on Earth. Lichens are also very diverse, with over 3,000 species found in North America. Lichen diversity tends to be at its highest in ecosystems that have had the least amount of disturbance. Because of this, lichen diversity can tell scientists a story of how pristine (undisturbed) a particular area is.

Why Should I Care About Lichens or Why Like Lichens?

Lichens are important in many ways:

- ◆ Drug companies make antibiotics from lichen substances.
- ◆ Lichens are home to many different types of spiders, mites and insects.
- ◆ Lichens have been used as a natural dye to color wool and wood since the 16th century.
- ◆ Many lichens are edible, it is said that George Washington's troops at Valley Forge ate a protein soup made from lichens during the harsh winter.

How Are Lichens Used in Biological Monitoring?

A biological indicator (or bioindicator) is a living organism that reflects the quality of the environment. Biological monitoring (or biomonitoring) describes the use of bioindicators to evaluate various environmental conditions. Lichens have been found to be bioindicators for the general atmospheric conditions since they absorb water and nutrients from the air (including pollution) over their entire surface. The effect of air pollution on lichens includes:

- ◆ bleaching (the loss of chlorophyll in the algal cells)
- ◆ development of a red coloration
- ◆ blackening
- ◆ stunted growth or a decline in growth rate
- ◆ development of tiny lobes along margins
- ◆ failure to produce fruiting bodies
- ◆ loss of sensitive species with a possible replacement by tolerant species



Lichen Growth Forms

(overall shape and configuration of the lichen body)

- **FOLIOSE (leaf-like)**

- flattened body
- distinguished upper and lower surfaces



- **FRUTICOSE (shrubby or hair-like)**

- grow erect or hang straight down
- no distinguishable upper and lower surfaces



- **CRUSTOSE (crust-like)**

- lower surface grows on and among the particles of the substrate
- cannot be removed from the substrate in one piece



Great Smoky Mountains National Park

ON-SITE ACTIVITY

LICHEN STUDY



Grade Level: High School

Subject Area: Science

Activity time: 75 minutes

Setting: Outside in the park

Skills: Analyzing, Applying, Categorizing, Collecting information, Comparing, Contrasting, Discussing, Hypothesizing, Inferring, Measuring, Summarizing

Materials:

- data sheets
- compasses
- grid transparency
- lichen guide
- forest measuring tape
- string

Objectives:

- 1) describe the three main growth forms of lichens
- 2) explain why lichens should be monitored
- 3) gather baseline data by determining the percent of lichen coverage on selected tree species
- 4) determine if there is any change in lichen coverage over time (long-term)
- 5) attempt to correlate any changes in lichen coverage to environmental factors such as air quality/atmospheric pollution (sulfur dioxide, ground level ozone, acid rain)

Background:

A bioindicator is a species that reacts so strongly to a pollutant or a change in its environment that it can be used to determine the effects of that pollutant. Biomonitoring is when you check the health of the indicator species over time to see a longer term effect from exposure. Lichens have been used to directly measure the results of an excess of sulfur dioxide in the air.

In the Smokies, though we have been studying air quality since 1988, we are really just starting to use biomonitoring of lichens. To do this, it is important to know what we have (baseline data) in order to understand how it is being affected by air pollution.

Procedure:

Each group will be assigned a tree; it is your job to identify the tree species, use the guides provided to identify the types of lichens you observe and then use the grid to determine the percentage of each lichen type.

Not all lichens respond to air pollution in the same way. One type of lichen actually thrives in polluted areas. It is important to monitor our lichen composition so we can see if we are losing biodiversity with the less tolerant species dying out and being replaced by the more tolerant species.



POST-SITE ACTIVITY

LICHEN SENSITIVITY TO NITROGEN AND SULFUR DIOXIDE



Grade Level: High School

Subject Area: Science

Activity time: 30 minutes

Setting: Classroom

Skills: Analyzing, Applying, Calculating, Comparing, Connecting, Contrasting, Hypothesizing, Inferring, Summarizing

Materials:

- “Lichen Sensitivity Activity” (4 pages)
•Pen/pencil

Objectives:

- 1) determine the differences between oligotrophs, eutrophs, and mesotrophs
- 2) discover how climate affects nitrogen sensitivity
- 3) determine the lichen responsiveness to nitrogen and sulfur containing pollutants,
- 4) review the primary sources of sulfur and nitrogen.

Background:

Lichens vary in sensitivity to both nitrogen and sulfur dioxide. This activity is to help students understand these sensitivity differences to nitrogen and sulfur containing pollutants and to review the primary sources of sulfur and nitrogen.

Procedure:

The students should read the “Air Quality Updates” and individually complete the “Lichen Sensitivity Activity” worksheets. Once the class has completed the activity individually, compare answers as a group. Answer any remaining questions.

Resources:

- 1) “United States Forest Service: National Lichens & Air Quality Database and Clearinghouse”
<http://gis.nacse.org/lichenair/>
- 2) SAMI Final Report_0802.pdf



AIR QUALITY UPDATES



The Clean Air Act Extension of 1970 (84 Stat. 1676, Public Law 91-604) is a United States federal law that requires the Environmental Protection Agency (EPA) to develop and enforce regulations to protect the general public from exposure to airborne contaminants that are known to be hazardous to human health. This law is an amendment to the Clean Air Act (CAA) originally passed in 1963. Congress passed the core provisions of the Clean Air Act in 1970. The law was amended in 1977 and again in 1990 to extend deadlines but also to specify new strategies for cleaning up the air. The basic framework of the law and its public health objective have remained intact. In the creation of the act the federal government charges the Environmental Protection Agency with enforcing the CAA in 49 states (California is exempt). However, the EPA has allowed the individual states to elect responsibility for compliance with and regulation of the CAA within their own borders in exchange for funding.

The Southern Appalachian Mountains Initiative (SAMI) is a voluntary public-private regional partnership working to improve air quality. Eight Southeastern States lead SAMI (Figure 1.1). They are Alabama, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. SAMI assembled an inventory of air emissions across the eastern United States at the county level. From lawn mower to locomotive pollution, emissions were projected from 1990 through 2040. Emissions for two families of strategies (“A” and “B”) were developed. Strategies A1 and A2 describe controls currently required under the Clean Air Act, including acid rain controls, the 1-hour ozone standard, highway vehicle and fuel rules, and regional reductions of nitrogen oxides from utilities and large industrial sources. Some provisions of future programs, such as the controls likely to be required under the fine particle standards, 8-hour ozone standard, and the Regional Haze Rules were not included in the “A” strategies because of uncertainty surrounding the nature of the needed controls. The B1, B2 and B3 strategies reflect increasingly stringent additional controls on all sources of emissions. For example, the B1 strategy requires an 80% reduction in industrial sulfur dioxide emissions by 2010 and 90% by 2040. B3 requires a 98% reduction by 2040. On-road mobile sources were projected to meet Tier 2 standards in 50% of the light duty mobile sources fleet under strategy B1 in 2010. For B3 SAMI projected the effect of the entire light duty fleet being converted to zero emission vehicles by 2040.

North Carolina’s General Assembly enacted legislation in 2002 that could provide a model for other states in controlling multiple air pollutants from old coal-fired power plants. The Clean Smokestacks Act, signed by Governor Mike Easley in June 2002, requires power companies to reduce their smog- and haze-forming emissions by approximately three-fourths over the next decade. Under the act, coal-fired power plants must achieve a 77 percent cut in nitrogen oxide (NO_x) emissions by 2009 and a 73 percent cut in sulfur dioxide (SO₂) emissions by 2013. Additionally, North Carolina power companies must achieve these emission reductions in-state; no cap-and-trade practices allowed. Also, utilities may not sell cap-and-trade credits to neighboring states, reducing the amount of pollution coming into North Carolina. Additionally, power companies must reduce their nitrogen oxide emissions year-round, not just during peak ozone season, as per federal mandate. Finally, the Act requires that North Carolina do its utmost to ensure that neighboring states pass similar air quality standards.

In 2009 North Carolina’s Progress Energy placed in service the last environmental compliance project under the first phase of the Clean Smokestacks Act emission reductions, which included projects at Progress Energy’s Asheville, Lee, Mayo and Roxboro plants.





LICHEN SENSITIVITY WORKSHEET

1. Analyze Table 1. Determine the VOC percentages for each of the VOC emission sources.

Table 1: State Emissions Summary for the eight SAMI southeastern states (VOC emission in thousand tons per year).

Emissions Source	1990 VOC	% of Total VOC	2010 VOC	% of Total VOC	Difference
Utilities	6	_____	10	_____	_____
Industrial Point	689	_____	668	_____	_____
Highway Vehicles	1,183	_____	798	_____	_____
Nonroad	355	_____	296	_____	_____
Area	1,417	_____	1,443	_____	_____
Total	3,651	100	3,216	100	_____

2. What is the primary source for VOC emissions in the southern United States?

3. What emissions source will have the largest projected reduction in VOC emissions by 2010 due to the Clean Air Act?

4. Analyze Table 2. Determine the NOx percentages for each of the NOx emission sources.

Table 2: State Emissions Summary for the eight SAMI southeastern states (NOx emission in thousand tons per year).

Emissions Source	1990 NOx	% of Total NOx	2010 NOx	% of Total NOx	Difference
Utilities	1,585	_____	977	_____	_____
Industrial Point	550	_____	556	_____	_____
Highway Vehicles	1,285	_____	792	_____	_____
Nonroad	497	_____	490	_____	_____
Area	383	_____	450	_____	_____
Total	4,300	100	3,265	100	_____

5. What is the primary source for NOx emissions in the southern United States?

6. What emissions source will have the largest projected reduction in NOx emissions by 2010 due to the Clean Air Act?



7. Analyze Table 3. Determine the NO_x percentages for each of the NO_x emission sources.

Table 3: State Emissions Summary for Washington and Oregon in 2002 (NO_x emission in thousand tons per year).

Emissions Source	N-NO _x	% of Total N Emissions
Utilities	22	_____
Industrial Point	4	_____
Highway Vehicles	93	_____
Nonroad	62	_____
Area	7	_____
Total	188	100

8. What is the primary source for NO_x emissions in Oregon and Washington?

9. How are the NO_x emission sources percentages different in the Northwestern United States versus the Southeastern United States?

10. Why are decreases of nitrogen-containing pollutants harder to achieve than sulfur dioxide pollutants?

11. Analyze Table 4.

Table 4: Summary of the Lichen Type in response to Total Nitrogen Deposition

Total N Deposition (kg N/ha/y)	% Oligotrophs	% Oligotrophs and Mesotrophs	% Eutrophs
2.5	53	91	9
3.1	44	80	20
3.4	30	66	34
4.1	25	53	47
4.3	18	9	61

What correlations can be made between the Total Nitrogen Deposition and percentage of Oligotrophs, Oligotrophs and Mesotrophs, and Eutrophs as seen in Table 4?





12. Analyze Table 5. Determine the SO_x percentages for each of the SO_x emission sources.

Table 5: State Emissions Summary for the eight SAMI southeastern states (SO_x emission in thousand tons per year).

Emissions Source	1990 SO _x	% of Total SO _x	2010 SO _x	% of Total SO _x	Difference
Utilities	4,710	_____	3,270	_____	_____
Industrial Point	671	_____	662	_____	_____
Highway Vehicles	33	_____	29	_____	_____
Nonroad	121	_____	157	_____	_____
Area	464	_____	524	_____	_____
Total	5,998	100	4,641	100	_____

13. What is the primary source for SO_x emissions in the southern United States?

14. What emissions source will have the largest projected reduction in SO_x emissions by 2010 due to the Clean Air Act?

15. Analyze Table 6. Determine the SO_x percentages for each of the SO_x emission sources.

Table 6. Summary of Oregon and Washington sulfur emissions in 2002. (SO_x emission in thousand tons per year).

Emissions Source	S-SO ₂ (tons/y)	% of Total S Emissions
Utilities	31	45
Industrial Point	6	9
Highway Vehicles	5	7
Nonroad	20	29
Area	7	10
Total	69	100

16. What is the primary source for SO_x emissions in Oregon and Washington?

17. How are the SO_x emission sources percentages different in the Northwestern United States versus the Southeastern United States?



Key to Lichen Sensitivity Nitrogen Ratings

Nitrogen Requirement: O = oligotroph, M = mesotroph, E = eutroph

Lichen Oligotrophs

Oligotrophs are most frequently encountered where total nitrogen deposition is between 0.5 to 2.5 kg N/ha/y. They are increasingly difficult to find as deposition increases above 2.5 kg N/ha/y. Oligotrophs are generally adapted to acidic substrates in cold, high-precipitation, nutrient-poor environments. Many of the large pendant, filamentous lichens in the genera *Alectoria* (as seen on right of page), *Bryoria*, *Ramalina*, and *Usnea* are oligotrophs. They achieve a rather large biomass in old growth forests where they play important functional roles as winter forage, nesting material, insect habitat, and also help moderate humidity and nutrient deposition. Many of the largest, leafy lichens in the nitrogen-fixing genera *Lobaria* (as seen on right of page), *Nephroma*, *Pseudocyphellaria*, and *Sticta* are also oligotrophs. In old growth and riparian forests that are otherwise nitrogen-limited, they contribute fixed N and provide nutritious forage for insects and mammals.



Alectoria imshaugii



Lobaria pulmonaria

18. As nitrogen deposition increases, what is the effect on lichen oligotrophs?

Lichen Mesotrophs

Mesotrophs are most frequently encountered in moderate nutrient regimes, 2.5 to 4.5 kg N/ha/y, and the probability of encountering them declines as N deposition exceeds 4.5 or drops below 2.5 kg N/ha/y. These species are most often found in moderate environments, on either hardwoods or conifers, typically on valley floors and low to mid elevation forests with moderate nutrient availability, less leaching from precipitation, and warmer minimum temperatures. A mesotroph example from the genera *Nephroma* is seen on right of page.



Nephroma occultum

19. In what type of environment are lichen mesotrophs found?

Lichen Eutrophs

Eutrophs tolerate and even thrive at N deposition loadings above 4.5 kg N/ha/y. Also known as 'nitrophytes' or 'nitrophiles,' in nature they thrive in environments with enhanced nutrient availability. Some of their natural habitats include mineral rich, alkaline substrates such as limestone or seashore rocks, and environments with concentrated nitrogen input such as rocks and branches under bird or small animal nests or perches. These lichens are often seen growing on barns or on trees in agricultural fields where there is an ample supply of ammonia from animal wastes or fertilizers. Most prefer hardwood substrates, but, if N deposition is high enough, many will also grow on conifer bark. Eutrophs include the orange lichens such as *Xanthoria* (as seen on right of page) and *Xanthomendoza* as well as the small gray rosette lichens such as *Physcia* (as seen on right of page), *Physconia*, and *Phaeophyscia* and some of the camouflage lichens (*Melanelia*, *Melanohalea*, *Melanelixia*). Eutrophic lichens tend to be rather small in size and adhere tightly to their substrates, producing a relatively small biomass compared to oligotrophic and mesotrophic species.



Xanthoria elegans

20. As nitrogen deposition increases, what is the effect on lichen eutrophs?



Physconia enteroxantha



Community responses

Lichens are very responsive to nitrogen, an essential nutrient for all living organisms. Epiphytic lichens, those that derive moisture and nutrients from the air and rain and usually grow on another plant, obtain nitrogen from atmospheric sources; from ammonium, nitrate and nitric acid dissolved in rain, fog and snow, or canopy throughfall (leaf wash from higher branches) or from direct dry deposition of N-containing particulates or gases such as ammonia, nitrogen oxides, or nitric acid vapor. Adding nitrogen to the environment tends to shift lichen community composition dominance from oligotrophic to eutrophic species. Although there may be no net loss in biodiversity due to excess nitrogen in the environment, adverse effects may result as integral ecological roles are lost due to their substitution by eutrophic species. These lost roles include serving as winter forage, nesting materials, insect habitat, fixing nitrogen, and moderating humidity.

21. Adding nitrogen to the environment tends to shift lichen community composition dominance to what type of species?

Temperature and precipitation interactions

Climate can be expected to affect nitrogen sensitivity. For example, lichens that are typically found within a moderate temperature zone may be found in a colder one (i.e. more stressful) if extra nitrogen is available. Because nitrogen is best absorbed when a lichen is wet, lichens are more responsive to the concentrations (mg/l) dissolved in the water with which they are wetted than to total deposition or loading (kg N/ha/y). Therefore a given lichen is likely to tolerate deposition greater than that at the peak detection frequency in high precipitation areas, and a lower loading in low precipitation areas.

22. How does climate affect nitrogen sensitivity?

Key to Lichen Sensitivity Sulfur Dioxide Ratings

Sulfur Dioxide Sensitivity: S = sensitive, I = intermediate, T = tolerant.

- * Sensitive = SO_2 - 'sensitive' lichens tolerate mean annual SO_2 concentrations from 5 to 15 ppb SO_2 .
- * Intermediate = Similarly, lichens of 'intermediate' SO_2 sensitivity tolerate 16-30 ppb SO_2 .
- * Tolerant = Lichens rated 'tolerant' can tolerate SO_2 concentrations above 30 ppb.

Sulfur dioxide sensitive lichens tolerate mean annual concentrations up to 5 to 15 ppb SO_2 ; lichens of intermediate sensitivity tolerate between 15 to 30 ppb SO_2 ; lichens rated 'tolerant' can tolerate mean annual SO_2 concentrations greater than 30 ppb. Within each category, some lichens may tolerate only part of the range, e.g. some 'sensitive' species may tolerate only 5 ppb while others may tolerate up to 15 ppb. Sensitivity at a given site may be moderated or intensified by climate, degree of exposure (forest floor vs. ridge top), and other environmental stressors and influences.





Lichen response to S-containing pollutants

Although there are only a few places in the Pacific Northwest where ground level SO₂ concentrations may still be high enough to harm lichens, lichen responses to sulfur dioxide are fairly well understood. This is because many surveys were completed in Europe and North America during the 1970s and 1980s, when SO₂ was often the dominant air pollutant affecting lichens. Sulfur dioxide affects lichens by disrupting important physiological processes. It is easily absorbed by lichens and, dissolved in cellular cytoplasm, has an acidifying effect. Enzyme mediated physiological processes such as photosynthesis and respiration are very sensitive to pH and are impaired by added acidity. All lichens are thus sensitive to sulfur dioxide, although some are more sensitive than others. The net effect on lichen communities is always a decrease in diversity as sensitive species are lost but no new species replace them.

23. How does sulfur dioxide affect lichens?

How to assess air quality using lichen SO₂ ratings

The presence of sensitive species is a good indication that average annual SO₂ levels are < 15 ppb. If only tolerant species are present, then average annual SO₂ levels are probably >30 ppb. If you are sampling along a gradient, e.g. a transect from a point source, and no other air pollutants are changing with distance, then the proportions of sensitive and intermediate species should increase with distance from the source, as should the total number of species. A lichen desert can result from very high ambient SO₂ concentrations. In such cases, only tolerant species will exist closest to the source.

24. How would a person assess air quality using lichen SO₂ ratings?

LICHEN SENSITIVITY WORKSHEET

ANSWER KEY



1. Analyze Table 1. Determine the VOC percentages for each of the VOC emission sources.

Table 1: State Emissions Summary for the eight SAMI southeastern states (VOC emission in thousand tons per year).

Emissions Source	1990 VOC	% of Total VOC	2010 VOC	% of Total VOC	Difference
Utilities	6	<u>0.2</u>	10	<u>0.003</u>	<u>+4</u>
Industrial Point	689	<u>19</u>	668	<u>21</u>	<u>-21</u>
Highway Vehicles	1,183	<u>32</u>	798	<u>25</u>	<u>-385</u>
Nonroad	355	<u>10</u>	296	<u>9</u>	<u>-59</u>
Area	1,417	<u>39</u>	1,443	<u>45</u>	<u>+26</u>
Total	3,651	100	3,216	100	

2. What is the primary source for VOC emissions in the southern United States?

Area.

3. What emissions source will have the largest projected reduction in VOC emissions by 2010 due to the Clean Air Act?

Highway Vehicles.

4. Analyze Table 2. Determine the NOx percentages for each of the NOx emission sources.

Table 2: State Emissions Summary for the eight SAMI southeastern states (NOx emission in thousand tons per year).

Emissions Source	1990 NOx	% of Total NOx	2010 NOx	% of Total NOx	Difference
Utilities	1,585	<u>37</u>	977	<u>30</u>	<u>-608</u>
Industrial Point	550	<u>13</u>	556	<u>17</u>	<u>+6</u>
Highway Vehicles	1,285	<u>30</u>	792	<u>24</u>	<u>-493</u>
Nonroad	497	<u>12</u>	490	<u>15</u>	<u>-7</u>
Area	383	<u>9</u>	450	<u>14</u>	<u>+67</u>
Total	4,300	100	3,265	100	

5. What is the primary source for NOx emissions in the southern United States?

Utilities.

6. What emissions source will have the largest projected reduction in NOx emissions by 2010 due to the Clean Air Act?

Utilities.





7. Analyze Table 3. Determine the NO_x percentages for each of the NO_x emission sources.

Table 3: State Emissions Summary for Washington and Oregon in 2002 (NO_x emission in thousand tons per year).

Emissions Source	N-NO _x	% of Total N Emissions
Utilities	22	12
Industrial Point	4	2
Highway Vehicles	93	49
Nonroad	62	32
Area	7	4
Total	188	100

8. What is the primary source for NO_x emissions in Oregon and Washington?

Highway vehicles.

9. How are the NO_x emission sources percentages different in the Northwestern United States versus the Southeastern United States?

In the Southeastern United States the highest NO_x emission source was utility while in the Northwestern United States the highest NO_x emission source is highway vehicles and nonroad.

10. Why are decreases of Nitrogen-containing pollutants harder to achieve than sulfur dioxide pollutants?

While utility is an important source of NO_x especially in the Southeast, highway vehicle and nonroad sources account for the majority of emissions in the Northwest. Therefore, compared to sulfur dioxide, decreases of N-containing pollutants are harder to achieve because they are more directly tied to population size (amount of fossil fuel burned per person).

11. What correlations can be made between the Total Nitrogen Deposition and percentage of Oligotrophs, Oligotrophs and Mesotrophs, and Eutrophs as seen in Table 4?

As mean N deposition increases, the mean proportion of the epiphytic lichen community composed of eutrophs increases and the proportion comprised by oligotrophs and mesotrophs decreases.



12. Analyze Table 5. Determine the SO_x percentages for each of the SO_x emission sources.

Table 5: State Emissions Summary for the eight SAMI southeastern states (SO_x emission in thousand tons per year).

Emissions Source	1990 SO _x	% of Total SO _x	2010 SO _x	% of Total SO _x	Difference
Utilities	4,710	79	3,270	70	-1440
Industrial Point	671	11	662	14	-9
Highway Vehicles	33	0.5	29	0.6	-4
Nonroad	121	2	157	3	+36
Area	464	8	524	11	+60
Total	5,998	100	4,641	100	

13. What is the primary source for SO_x emissions in the southern United States?

Utilities.

14. What emissions source will have the largest projected reduction in SO_x emissions by 2010 due to the Clean Air Act?

Utilities.

15. Analyze Table 6. Determine the SO_x percentages for each of the SO_x emission sources.

Table 6. Summary of Oregon and Washington sulfur emissions in 2002. (SO_x emission in thousand tons per year).

Emissions Source	S-SO ₂ (tons/y)	% of Total S Emissions
Utilities	31	45
Industrial Point	6	9
Highway Vehicles	5	7
Nonroad	20	29
Area	7	10
Total	69	100

16. What is the primary source for SO_x emissions in Oregon and Washington?

Utilities. Currently the region's two coal-fired electric utilities are the largest remaining regional point sources. Sulfur dioxide (SO₂) has declined substantially in the Pacific Northwest states and elsewhere in the U.S. since implementation of the federal Clean Air Act. Emission controls on point sources have been very effective in reducing regional SO₂ emissions.





17. How are the SO_x emission sources percentages different in the Northwestern United States versus the Southeastern United States?

Both in the Southeastern United States and in the Northwestern United States the highest NO_x emission source were utilities.

18. As nitrogen deposition increases, what is the effect on lichen oligotrophs?

As nitrogen deposition increases above 2.5 kg N/ha/y, lichen oligotrophs become increasingly difficult to find.

19. In what type of environment are lichen mesotrophs found?

Lichen mesotrophs are found in moderate environments in low to mid elevation forests with moderate nutrient availability and warmer minimum temperatures.

20. As nitrogen deposition increases, what is the effect on lichen eutrophs?

Lichen eutrophs tolerate and even thrive at N deposition loadings above 4.5 kg N/ha/y.

21. Adding nitrogen to the environment tends to shift lichen community composition dominance to what type of species?

Adding nitrogen to the environment tends to shift lichen community composition dominance from oligotrophic to eutrophic species.

22. How does climate affect nitrogen sensitivity?

Lichens that are typically found within a moderate temperature zone, may be found in a colder one (i.e. more stressful) if extra nutrient nitrogen is available. Because nitrogen is best absorbed when a lichen is wet, lichens are more responsive to the concentrations (mg/l) dissolved in the water with which they are wetted than to total deposition or loading.

23. How does sulfur dioxide affect lichens?

Sulfur dioxide affects lichens by disrupting important physiological processes. It is easily absorbed by lichens and, dissolved in cellular cytoplasm, has an acidifying effect. The net effect on lichen communities is always a decrease in diversity as sensitive species are lost but no new species replace them.

24. How would a person assess air quality using lichen SO₂ ratings?

The presence of sensitive species is a good indication that average annual SO₂ levels are < 15 ppb. If only tolerant species are present, then average annual SO₂ levels are probably >30 ppb.