AN ENVIRONMENTAL EDUCATION TECHNIQUE FOR
DEMONSTRATING OZONE POLLUTION EFFECTS ON VEGETATION

A Thesis in
Environmental Pollution Control

by
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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 2008
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Abstract

Ozone pollution is a major worldwide environmental issue, affecting the environment, human health, and economics. Health problems associated with ozone pollution include coughing, congestion, chest pain, and throat irritation; and can worsen respiratory diseases such as asthma, bronchitis, and emphysema. The annual estimated economic loss due to ozone pollution in the United States is $1-2 billion and even larger in other countries around the world.

Ozone pollution is formed around large urban areas and its main components include nitrogen oxides and volatile organic compounds. Sources of these chemicals are industries, car emissions, electric utilities, gasoline vapors, and chemical solvents. When ozone is formed it can be carried downwind hundreds of miles and usually effects suburban and rural areas. Because of this, the agricultural and commercial forestry sectors are largely impacted by this pollutant. Injuries on vegetation due to ozone include stipple, chlorotic mottle, tipburn, premature defoliation, and reduced crop yields. Although ground level ozone is a major pollutant in many countries around the world, there are no existing educational modules to teach individuals about this important pollutant.

This research resulted in the development of a teaching module that can be implemented into high school level curricula to educate students and the public on the effects of ground level ozone on vegetation. The research facility utilized for this project was the Air Quality Learning and Demonstration Center located at the Penn State University Arboretum. The methods used to conduct this research were broken into four phases. Initially, photographs showing plant injury due to ozone were analyzed along with weather and air pollution data collected at the research facility, this data was then used for the development of the teaching module. Next, pre-service teachers about to begin their student teaching were presented with the teaching module. Prior to being presented with the module, these students completed a pre-module quiz, which tested their knowledge on the subject matter. After the module, the students were given a post-module quiz, which was identical to the pre quiz. Both the pre and post-module quiz were analyzed to determine the effectiveness of the teaching module. A paired t-test was used for statistical analysis, which demonstrated that there was an increase between the pre and post quiz means (p=0.000, mean pre-quiz=6.63, mean post-quiz=13.06, n=16). After being tested the module was uploaded onto a website for the public to access.
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Acknowledgments

The author would like to express her sincere appreciation to her advisor Dr. Dennis Decoteau and the members of her committee, Dr. Tracy Hoover and Dr. Donald Davis. Thank you all for your support, guidance, and knowledge.

The author would also like to thank the Pennsylvania Department of Environmental Protection, Bureau of Air Quality and the United States Environmental Protection Agency for funding this research.

Additional thanks to the Pennsylvania State University, College of Agricultural Sciences and the Department of Plant Pathology for the use of the Penn State Air Quality Learning and Demonstration Center.
Chapter 1: Introduction and Justification

Air pollution has been a major issue in the United States for decades, and our country’s environmental and economical health are impacted by this pollution each year. Although the Clean Air Act of 1970 and several following amendments helped to implement policies and programs to reduce some of the harmful pollutants entering our atmosphere, other pollutants continue to be a major problem to environmental health. One of these pollutants, which each year causes severe damage to trees, agricultural crops, and vegetation all over the world, is ground level ozone. This pollutant greatly affects the Northeastern region of the United States and in particular Pennsylvania (Skelly, 2000). Pennsylvania is downwind from several ozone precursor sources in the Midwest, such as large industries and vehicle emissions, which makes ozone one of the most important air pollutants in the state.

Each year agricultural crops and forested areas all over the world suffer damage from ozone pollution. Annually, this damage causes an estimated $1-2 billion in economic loss for the United States (Murphy et al., 1999) and up to $5 billion in some East Asian countries (Wang et al., 2004). In Pennsylvania, the agricultural sector brings in over $4 billion dollars annually (USDA, 2007). Approximately $1.7 billion is from crop production alone, which suggests that the state’s economy can be largely affected by decreases in crop production due to ozone pollution. Scientific studies have indicated that symptoms of plant injury due to ozone include leaf stipple, chlorotic mottle, tipburn, late season leaf yellowing, premature defoliation, and decreased crop yields (Skelly, 2003).
In the state of Pennsylvania there is enough potential for economic and environmental damage that several studies researching ozone pollution and its effects on vegetation have been, and are currently, being conducted (Skelly, 2000 and Yuska et al., 2003). One of these projects involves the Air Quality Learning and Demonstration Center (Learning Center) at the Penn State Arboretum. The Learning Center is the first of its kind in the country and a wonderful resource for individuals to learn about air pollution and its effects on native and agricultural plant species. The Learning Center opened in September of 2003 with the purpose of providing environmental education to local schools, school teachers, and organizations. Within the center there is a teaching pavilion equipped with audio-visual and internet capabilities so that classes can be held on site. The center also contains ozone sensitive vegetation species, which have been planted, along with sulfur dioxide sensitive species. Open-top chambers containing ozone sensitive vegetation have been constructed so individuals can observe techniques used in air pollution research and view plant injury due to ozone. The Learning Center is also an official Pennsylvania Department of Environmental Protection (DEP), Bureau of Air Quality Monitoring Station.

Education is a key factor in the protection of our environment, especially concerning younger generations. “Science and environmental education can be taught as an integral unit to help students learn about environmental problems, appreciate the complexity of these issues, and help overcome the popular belief that science is only for scientists” (Brody et al., 1989). The more individuals learn about environmental issues affecting our resources and therefore our economy; the more emphasis will be placed on protecting what remains. Public opinions and attitudes are crucial to the conservation of
our natural resources (Newton, 2001). Lack of research in the area of environmental education on the subject of tropospheric ozone suggests that student and public awareness on the topic is rather low. The Learning Center is a wonderful step in furthering environmental education in Centre County and the state of Pennsylvania as a whole.

The ozone season in Pennsylvania is usually mid-April through late October, which is when the highest ozone levels occur and cause the greatest amount of vegetation injury. During the 2007 ozone season, a series of photographs were taken for five ozone sensitive forest and agricultural species located at the Learning Center. As a portion of this research, these photographs along with the DEP weather and air pollution data have been analyzed and are now part of an environmental education module.

There are currently very few known programs in the U.S. designed to teach high school students about ozone pollution and no known programs to teach its effects on vegetation. Because schools are not in session during the height of the ozone season (summer) it is difficult to show students the development of symptoms in real time. An exercise where the student can compare the photographs with the DEP weather quality data to determine when and why ozone symptoms occur would be an opportunity for them to learn about ozone in a classroom, any time of the year. Therefore, the objective of this thesis is to develop an effective teaching module that can be used to educate high school level individuals on the subject of ground level ozone pollution and its effects on vegetation. The implementation of this module into high school science curricula across the state and even across the country would allow thousands of students to gain a better understanding of this important environmental issue.
Chapter 2: Literature Review

2.1 Introduction

This research resulted in the development of a teaching module that will be used for educating individuals on the effects ambient ozone pollution has on vegetation. The issues to be covered by the literature review include: ozone formation, plant injury caused by ozone, effects of ozone on the economy, effects of ozone on human health, environmental education, and environmental education techniques. These topics will help demonstrate the importance and necessity of the research described in this thesis.

2.2 Ozone Formation

Ozone (O₃) “forms when an atom of oxygen, O, usually produced in the troposphere by solar photodissociation of nitrogen dioxide (NO₂), combines with molecular oxygen (O₂)” (National Research Council, 1992). The majority of earth’s ozone is located in the stratosphere and is commonly referred to as the ozone layer. This layer has proven vital to our well being by protecting humans and animals from much of the damaging ultraviolet light emitted from the sun. Since the discovery of a hole in the ozone layer during the 1970s this environmental issue has made headlines across the world. Students are taught about the ozone hole in school, through educational videos and current events. Due to this education individuals across the country have taken action to stop the hole from becoming larger by decreasing emissions of chlorofluorocarbons (CFCs), the main cause of the ozone hole formation. Where the ozone layer hole has been a well known environmental issue for over 30 years, the formation of tropospheric or ground-level ozone, and its effects on our earth, is a subject that has not received nearly as much attention.
Ground-level ozone is considered to be one of the most problematic air pollutants in the United States as well as in many other countries around the world. The primary precursors that lead to the formation of tropospheric ozone are oxides of nitrogen (NOx) and volatile organic compounds (VOCs) (National Research Council, 1992). Other factors controlling ozone formation include wind speed and direction, terrain, temperature, and time of year; the ozone season occurs during summer months due to appropriate meteorological conditions. “In the eastern United States and Europe, the worst ozone pollution episodes occur when a slow-moving, high-pressure system develops in the summer, particularly around the summer solstice” (National Research Council, 1992). Tropospheric ozone usually forms downwind of large urban areas, where industries, car emissions, electric utilities, gasoline vapors, and chemical solvents contribute the NOx and VOCs necessary for ozone production (EPA, 2007). This pollutant is commonly associated with poor visibility or smog affects in areas with high ozone levels as demonstrated below (Figures 2.1-2.2). Often times the areas downwind are rural, and as a result, agricultural and forested areas can be greatly affected by this air pollutant.
2.3 Plant Injury Caused by Ozone

There have been many studies that have researched effects of ground level ozone on terrestrial systems (Skelly, 2000; Yuska, 2003; Manning, 2005). The results have
shown that common plant injury includes stipple, chlorotic mottle, tipburn, premature defoliation, and reduced crop yields. Stipple is a symptom that occurs on broad leaf plants and appears as “minute tan, brown, red, purple, or black coloration” on the leaf surface (Figures 2.3-2.4). This injury typically occurs between the veins and only on the top side of the leaf (Figure 2.5) (Skelly, 2000). Chlorotic mottle and tipburn are symptoms that occur on coniferous species. Chlorotic mottle appears as “small patches of yellow tissue surrounded by apparently healthy tissue”, and tipburn is characterized as necrosis of the needle tip, which will many times break off as the season progresses leaving the needle shorter than others (Skelly, 2000). These symptoms have been determined through research using ozone bioindicators, plant species that are overly sensitive to ozone pollution. One such study was conducted by Yuska et al. (2003) using black cherry and common milkweed to determine plant injury due to ozone in central Pennsylvania. Ozone bioindicators commonly found in the Northeastern U.S. include black cherry, white ash, yellow poplar, eastern white pine, sassafras, blackberry, big leaf aster, common milkweed, and spreading dogbane (Skelly, 2000).
Figure 2.3 Black Cherry showing early season leaf stipple (Skelly, 2000).

Figure 2.4 Common milkweed showing advanced leaf stipple (Skelly, 2000).
Figure 2.5 Common milkweed showing advanced leaf stipple. Picture demonstrates that stipple occurs only on surface of leaf, not underneath (Skelly, 2000).

Injury to agricultural plant species often results in reduced crop yields. This occurs because “ozone enters plant leaves through the stomatal openings in the leaf surface and then produces byproducts that reduce the efficiency of photosynthesis” (Murphy et al, 1999). These crop reductions have greatly affected agriculture in many countries all over the world. Heck et al. (1982); as reported by Murphy et al. (1999) stated “Research suggests that ozone, either alone or in combination with nitrogen dioxide and sulfur dioxide, may be responsible for up to 90% of U.S. crop losses resulting from air pollution” (Figure 6). Both the decrease in crop yields and destruction of several commercial forest species such as black cherry and yellow poplar have affected these ecosystems and also the related economies.
2.4 Effects of Ozone Pollution on the Economy

Several studies, world-wide have been conducted to evaluate the economic damage ozone pollution can cause, especially in the agriculture and commercial forestry sectors of the affected countries (Kuik et al., 2000; Murphy et al., 1999; Shankar et al., 2005; Wang et al., 2004). One such study found that a 25% decrease in ambient ozone would yield an economic benefit in the U.S. of at least $1-2 billion each year (Murphy et al, 1999). Another study conducted by Murphy et al. (1999) determined that economic “benefits to the agricultural sector from completely eliminating ozone precursor emissions from motor vehicles ranges between $3.5 and $6.1 billion annually”. It should be noted that the economic effects of ozone on agriculture are not only being felt by the farmers but also by the individuals purchasing the effected produce. A study conducted in the Netherlands by Kuik et al. (2000) used an economic model to determine benefits that a decrease in ozone pollution would yield for both agricultural producers and
consumers. The results showed that benefits for the consumers were more than twice that for the producers (Kuik et al, 2000). Research conducted in China by Wang et al. (2004) analyzed economic effects of ozone on grain production. The results suggested that East Asian countries in 1990 had economic reductions of almost $5 billion (U.S.) due to crop damage (Wang et al, 2004). These research studies demonstrate how ground level ozone is a worldwide economic problem and could continue to be until there is a decrease in ozone pollution levels; however the economy is not the only issue affected by this pollutant.

2.5 Effects of Ozone Pollution on Human Health

Several studies have been conducted to determine health effects caused by ambient ozone pollution exposure (Korrick et al, 1998; Girardot et al, 2006; and Stern et al, 1993). Ozone can result in respiratory problems such as coughing, congestion, chest pain, and throat irritation; and can worsen respiratory diseases such as asthma, bronchitis, and emphysema (EPA, 2007). One study done by Stern et al. (1993) tested respiratory health of children living in ten rural communities located in Canada, five in central Saskatchewan (a low sulfate and ozone level area), and five in Ontario (a moderate ozone level area). The two major parameters that were measured to determine pulmonary function in this experiment were forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV$_{1.0}$). The results of this study showed that “statistically significant decrements in the pulmonary volume parameters, FVC and FEV$_{1.0}$, of preadolescent children residing in southwestern Ontario are associated with moderately elevated ambient concentrations of sulfate and ozone” (Stern et al, 1993). Individuals most susceptible to health problems caused by ozone are children, elderly and, since
ozone is a ground-level pollutant, individuals who work or exercise outside during the ozone season (PA DEP, 2007). The seriousness of both human health and economic problems that the world is suffering is amplified by the fact that many individuals are not aware that these problems exist.

### 2.6 General Introduction to Environmental Education

The environmental education movement began in the 1970s in colleges and universities. Soon after, environmental education was implemented into many high school science curriculums so that students could better understand important issues affecting the world’s environmental health. Around the same time, many of the country’s environmental laws were developed and passed, such as the Clean Air and Clean Water Acts.

In the mid-1900s environmentalists such as Rachel Carson and Jacques Cousteau began informing the public about environmental issues through books and documentaries. Today, people have come to understand that one of the key components to maintaining a healthy environment is public awareness and education. Since “conservation of natural resources is inextricably bound to public attitudes and opinions” it is important that the public understands the current environmental issues (Newton, 2001). It is also very important that students become aware of these issues, since they are the future leaders and decision makers of the country. “The earlier in life environmental education begins, the better” (Newton, 2001). The new question regarding environmental education is how to present it in a way that makes it interesting and understandable to both students and the public.
2.7 Environmental Education Techniques

In recent years the enrollment in environmental majors and courses has dropped and one of the reasons suggested is that the subject matter is often taught in a manner that does not evoke interest (Cunningham and Stubbs, 2003). Students learn about environmental issues in grade school and high school and feel that they know all there is to know, however when surveyed on specific issues they still lack clear understanding of the subject. When Brody et al. (1989) conducted a study on “Student Knowledge of Scientific and Natural Resource Concepts Concerning Acidic Deposition” they found that many students didn’t understand key components of the subject even though they had been introduced to the issue in class (Brody et al, 1989).

There are currently several educational tools used to teach students and the public about environmental issues. Some traditional techniques being used by federal agencies such as the Natural Resources Conservation Service (NRCS) include documents, videotapes, posters, and in-class presentations for students (Newton, 2001). In the past, these traditional techniques have been effective tools for public outreach and student education. However, over the past decade on-line technology has become readily available to the public, which has resulted in more web-based education.

Due to this increase in internet activity some federal agencies have strayed away from traditional teaching techniques and now use web-based tools for student and public education. For example, the Environmental Protection Agency (EPA) has a link on their web site titled Educational Resources, which leads the user to several interactive web sites developed to teach different age groups about environmental issues. Many colleges and universities are also using the web for educational purposes. The University of
Florida, Department of Environmental Horticulture has implemented web-based instruction of many of their courses to help teach plant identification, propagation, and urban horticulture. A recent web development is a virtual garden where students can take a tour of a garden on the internet and click on plants to view them more carefully and identify them (Wilson and Danielson, 2005). The internet is also used as a teaching aid for institutions such as the Air Pollution Training Institute (APTI), which has “been the primary source of training for all governmental air pollution personnel since 1970” (Schueler, 1996). APTI, along with North Carolina State University, designed a new curriculum using the internet to train personnel about air pollution via distance learning. Soon after the new curriculum was developed, student registrations indicated a preference for distance learning telecourses over both the short courses and self-study courses that were previously offered (Schueler, 1996). The examples presented above provide an overview of how on-line and computer based programs have become a primary educational tool for teaching environmental subjects in schools, universities, federal agencies, and institutions.

2.8 Pennsylvania State Academic Standards

The Pennsylvania State Department of Education has developed state Academic Standards for twelve separate areas of learning. These include standards for arts and humanities; final form career education and work; civics and the government; economics; environment and ecology; family and consumer sciences; geography; health, safety and physical education; history; mathematics; reading, writing, speaking, and listening; and science and technology. The purpose of these standards is to lay out a framework of what students in varying grade levels should know and be able to do by the end of those
school years. They serve as guidelines for educators to make sure that their curriculum is teaching students what they should be learning at the appropriate time. By following these standards, educators are also ensuring that the same information is not being taught in more than one grade level.

The standards for environment and ecology were most recently updated on January 5, 2002. “Environment and Ecology places its main emphasis in the real world. It allows students to understand, through a sound academic content base, how their everyday lives evolve around their use of the natural world and the resources it provides” (PDE, 2008). The research described in this thesis utilized these standards for environment and ecology to develop a module that can effectively educate students on an important environmental issue. To see a list of the environment and ecology standards fulfilled by this research see Appendix B.
2.9 State-of-the-Art

Several studies have been conducted to determine effectiveness of teaching modules for environmental issues such as acidic deposition, aquatic resources management, general air pollution, and environmental assessment (Brody et al., 1989; Sinclair and Diduck, 1995; Newton, 2001; Cunningham and Stubbs, 2002; Wilson and Danielson, 2005). However, in completing this literature review, no in depth educational tools used for teaching individuals about the effects of ground level ozone pollution on vegetation were found. The lack of educational tools regarding this environmental issue suggests that the level of student and public awareness on the subject is also lacking. Therefore, the purpose of this research was to develop an effective, computer based, environmental education module that can be used to teach individuals about the effects of ground level ozone pollution on vegetation.
Chapter 3: Methodology

3.1 Introduction

This research focused on the development and testing the effectiveness of a teaching module, used to educate individuals about ground level ozone pollution and its effects on vegetation. The methods used to conduct this research are discussed in this section of the thesis. Topics presented include a detailed flowchart of the methodology; a description of the research facility; and a detailed explanation of each of the four phases of the research project. Each section will also include appropriate tables, photographs, and figures.

3.2 General Overview of Flowchart

The overall plan for conducting this research was divided into four different phases as shown in Figure 3.1. The first phase involved evaluating weather data containing ozone levels and photographs of plant injury. Both sets of data were collected during the 2007 ozone season (mid-April through October) at the Air Quality Learning and Demonstration Center located at the Pennsylvania State University Arboretum. Phase one also involved determining a connection between the weather data and plant injury data quantified from the photographs.

The second phase involved the development of the teaching module, along with the pre-module and post-module quizzes. These quizzes were used to test the participants’ knowledge of ozone pollution both before and after having the module presented to them. The module and quizzes were designed for high school level education.
Phase I. Collection and Analysis of Photographs, Weather and Air Pollution Data

- Analyze photographs of plant injury to determine those most suitable for teaching module
- Evaluate weather data

Phase II. Development of Teaching Module, Pre and Post-Module Quizzes

- Use analyzed data to develop a teaching module demonstrating effects of ground level ozone pollution on vegetative growth
- Develop pre/post-module quiz

Phase III. Implementation of Teaching Module

- Receive permission from the Office of Research Protection to use human participants in study
- Schedule presentation slot to present to Agricultural and Extension Education (AEE) 313 class
- Distribute pre-module surveys to pre-service teachers
- Present module to pre-service teachers in AEE 313
- Distribute post-module quiz to pre-service teachers

Phase IV. Post-Module Data Analysis

- Perform a paired t-test with the pre and post-module quizzes to determine effectiveness of module
- Gain feedback from pre-service teachers
- Upload module onto the internet for public use

Figure 3.1. Methodology Flowchart for Research in Developing Effective Teaching Module.
The third phase involved implementation of the teaching module. In this phase, it was necessary to complete an application and receive permission from the Office of Resource Protection to use human participants for the research. Next, a slot was reserved to present the module in the Pennsylvania State University (Penn State) Agricultural and Extension Education (AEE) 313 course. The students in this course and participants of this study were pre-service student teachers who were about to begin their student teaching term. The next steps of this phase were for the participants to take the pre-module quiz, followed by the presentation of the module and then the completion of the post-module quiz.

The fourth phase involved analysis of the pre and post-module quizzes to determine the effectiveness of the teaching module. The statistical test used during this phase was a paired t-test. This phase also included gaining feedback from those student teachers who implemented the module into their curriculum and uploading the module onto the internet for public use.

3.3 Description of Research Facility

The research facility, which was used for this study, is the Air Quality Learning and Demonstration Center (Learning Center) located at the Penn State Arboretum, University Park, PA (Figure 3.2). The Arboretum property can be accessed by foot from the McKee Street/Clinton Avenue bike path as it traverses Big Hollow; from Big Hollow Road between the Mushroom Test Facility at the edge of campus and the Army Reserve Center along Fox Hollow Road; from the termination of East Aaron Drive in the College Heights neighborhood; and from Toftrees along the Bellefonte Central Railroad grade (PSU, 2007). The Learning Center itself is on Air Quality lane, within the Arboretum.
Figure 3.2 Map showing the location of the Air Quality Learning and Demonstration Center within the Penn State Arboretum and in relation to the Penn State Campus (Source: PSU, 2007).
The Learning Center (Figure 3.3) opened in September of 2003 with the purpose of providing environmental education to local schools, school teachers, and organizations.

Within the Learning Center there is a teaching pavilion (Figure 3.4-3.5) equipped with audio-visual and internet capabilities so that classes can be held on site. The Learning Center also contains ozone sensitive vegetation species, which have been planted, along with sulfur dioxide sensitive species. During the ozone season, which usually lasts from mid-April through October in Pennsylvania (PA), individuals are able to view the effects this pollutant has on vegetation while they are visiting the Learning Center. Open-top chambers containing ozone sensitive vegetation species have been constructed so...
individuals can observe first hand techniques used in air pollution research and plant injury (Figure 3.6). The Learning Center is also an official Pennsylvania Department of Environmental Protection (DEP), Bureau of Air Quality Monitoring Station (Figure 3.7). The data collected include temperature, wind speed and direction, precipitation, soil moisture, and visibility, as well as the air pollution data, which is described in detail in section 3.4.2. Data for this project were collected during the 2007 ozone season from these open top chambers, other ozone sensitive vegetation growing at the Learning Center and the DEP weather station.

Figure 3.4 Teaching Pavilion at Learning Center (Source: Decoteau, 2006).
Figure 3.5 Summer class being taught at the Learning Center (Source: Chrzanowski).

Figure 3.6 Open top chamber in the Learning Center (Source: Decoteau, 2006).
3.4 Phase I: Collection and Analysis of Photographs, Weather and Air Pollution Data

This phase of the research involved the collection of data, which was used in the teaching module and will be described in three sections. The first section will describe the methods used to take the photographs. The second section will describe collecting the weather and air pollution data. The third section will describe how the data were evaluated to find a connection between the vegetation injuries observed in the photographs and the elevated levels of ozone observed in the air pollution data. The data which were used to determine this connection were collected at the research facility during the summer months of June-August 2007.

3.4.1 Photographs of Ozone Induced Plant Injury

The Learning Center located at the Arboretum at Penn State University contains two open-topped chambers as shown above in Figure 3.3. Chambers such as these are often used in air pollution research to control experimental factors, such as the amount of pollution able to enter the chamber. Each year the chambers at the Learning Center are
planted with ozone sensitive species such as common milkweed, Chambourcin grapes, pinto beans, and La Chipper potatoes. Each chamber also contains a black cherry tree which was planted when the Learning Center opened in 2003 and remains in the chamber year round. One of these chambers is filtered to eliminate approximately fifty percent of the ozone pollution entering and the other is not filtered, which means that all of the ambient ozone is entering into the chamber. Therefore, vegetation in filtered chamber grows much better than that in the unfiltered chamber as seen in Figures 3.8-3.9.

Figure 3.8 Vegetation growing in filtered chamber (Source: Chrzanowski).

Figure 3.9 Vegetation growing in non-filtered chamber (Source: Chrzanowski).
The ozone season in Pennsylvania usually lasts from mid-April through October, and it is during this time that symptoms occur on ozone sensitive plant species. However, symptoms usually do not appear on vegetation until after several days of ozone levels above 60 ppb, which makes it unnecessary to begin documenting leaves early in the season. Therefore, beginning in June a series of photographs were taken each week of several ozone sensitive species within the Learning Center. These photographs were meant to capture any symptoms, such as stipple, that appeared during that week.

The vegetation species photographed were common milkweed, black cherry, yellow poplar, Chambourcin grapes, and tobacco. Eight common milkweed (*Asclepias syriaca*) plants were tagged and photographed, six were from the ambient and open air chambers and two were from the filtered chamber to use as a comparison. Five black cherry (*Prunus serotena*) branches were tagged and photographed from three trees, one in an open air chamber and two within the Learning Center ambient air garden (Figure 3.10). Five yellow poplar (*Liriodendron tulipifera*) branches were tagged and photographed from two different trees along the perimeter of the Learning Center. Four Chambourcin grape (*Vitis spp.*) branches were tagged and photographed from four different plants within the Learning Center agricultural garden (Figure 3.11). Three different tobacco (*Nicotiana tabacum*) plants were tagged and photographed from within the agricultural garden. For each week a log was maintained, containing the number of leaves photographed on each plant, the location of the plant, any ozone symptoms that were visible, and the maximum ozone level which occurred during that week. An example of one of these logs is located within Appendix E of this thesis. During the initial selection of leaves, each leaf photographed was given a number so that the same
leaves were photographed each week. If a leaf were to die, it would be replaced by a new numbered leaf and this change was noted in the weekly log.

Figure 3.10 One of the tagged cherry trees within the Learning Center open air garden (Source: Chrzanowski).

Figure 3.11 Agricultural garden located within the Learning Center (Source: Chrzanowski).

Within the Learning Center agricultural garden various ozone sensitive vegetation species were planted along side ozone resistant varieties of the same species. During the months of July and August, photographs were taken to document the growth difference between the ozone sensitive and ozone resistant varieties (Figures 3.12-3.13).
3.4.2 Weather and Air Pollution Data

As previously mentioned, the Learning Center is also an official DEP air quality monitoring station. This station collects weather data on temperature, wind speed and direction, solar radiation, relative humidity, precipitation, soil moisture, and visibility on
It also collects air pollution concentrations for nitrogen dioxide (NO₂), nitrogen oxides (NOx), carbon dioxide (CO₂), carbon monoxide (CO), particulate matter (PM₁₀ and PM₂.₅), and ozone (O₃) (AQLDC, 2007 and PA DEP, 2007). These data are collected and archived year round so that they can be accessed at a later time. Ozone data are also collected in each open top chamber both non-filtered and filtered.

3.4.3 Analysis of Photographs and Weather and Air Pollution Data

Initially the photographs were analyzed and the different stages of plant injury were documented in the weekly log. The technique used for this was to individually examine each photograph and determine when injury occurred for each plant. The stages will be when injury first appears, when injury is very noticeable, and death of the plant material.

After analyzing the photographs, the air pollution data were evaluated to determine if high levels of ozone pollution were present leading up to the dates when symptoms occurred. Since other environmental factors can have an effect on how much or when symptoms occur, certain weather data were also evaluated. The primary data of concern were ozone (ppb), temperature, and precipitation. After analysis of the photographs and evaluation of the air pollution and weather data select graphs and photographs were placed aside to be used in the development of an in class activity for the educational module.

3.5 Phase II: Development of Teaching Module and Pre/Post-Module Quiz

This phase of the research involved the development of the teaching module that can be used to educate high school level individuals on the topic of ground level ozone.
pollution. During this phase, a pre/post-module quiz was also developed, which was used during the third phase of this research to test the effectiveness of the module.

3.5.1 Teaching Module Development

The teaching module that was developed during this phase was initially presented to students in The Pennsylvania State University (Penn State) Agricultural and Extension Education (AEE) 313 course, however is meant for use in high school curricula. The length of this module is just under three hours long, however including in class activities and the quiz could be taught in approximately one week depending on the teacher and class duration. The contents of the module include a module overview; two power point presentations, both containing thirty eight slides; a homework assignment; in class activity; a quiz to test the students after completing the module; and an answer key for both the in class activity and quiz (Appendix C). The module was developed with the purpose of effectively educating individuals on the topic of ground level ozone pollution by demonstrating its effects on vegetation as well as attempting to meet academic standards for the state of Pennsylvania. The standards that were met in this module are listed in Appendix B.

The purpose of the module overview is to provide the educators using the module with, the purpose of the module, its contents, suggestions on how to teach the module, and a list of references used in its development. The first power point presentation in this module has the following objectives:

Students will be able to:

- Define air and air pollution
- Explain the history of air pollution and air pollution regulations in the U.S.
- Differentiate between two types of ozone
- Understand the importance of learning about ozone pollution
Describe four types of air pollution sources

Explain how ozone pollution is formed and its effects on Pennsylvania

This lesson meets all of the above objectives and provides an overview of ground level ozone, how the pollutant is formed and transported and its importance to the economy and human and environmental health, topics which were discussed during the Literature Review chapter of this thesis.

The second power point presentation in this module has the following objectives:

Students will be able to:

- Understand and explain the important plant processes of photosynthesis, respiration, and transpiration
- Define stomata and their role in plant processes
- Explain how ozone pollution enters plants
- Describe ozone effects on vegetation
- Define a bioindicator
- Understand current ozone research methods
- Explain benefits of ozone pollution research

This lesson meets all of the above objectives and focuses on how ozone pollution effects vegetation. This second lesson contains several photographs as well as a video that were taken at the Learning Center during the 2007 ozone season, which are meant to help the student visualize the symptoms as they’re learning about them. Both of the power point presentations contain several photographs, charts, animations, graphs and activities as to keep the students engaged and cater to all learning type techniques. For the benefit of the educators who are going to use the module, under each slide in the power point presentations all information that they would need to know in order to properly teach the module and any suggestions were written in the notes section.

The next section of the module is an in class activity that was developed utilizing the photographs and real time weather and air pollution data, which were analyzed in the
first phase of this research. The purpose of this activity is to allow the students to use the knowledge that they gained during the power point presentations so that they can better understand the environmental impacts of ozone pollution. The activity is meant to be fun yet educational at the same time and contains photographs and charts (Appendix C).

By the end of the module the students will be able to determine the connection between the plant injury and ozone levels when shown photographs and weather and air pollution data. They will also be educated on what they can do to help reduce ozone pollution so that they can take what they learned out of the classroom. The format of the module activity is a word document so that every year a new set of photographs and weather data can replace the previous year’s data to keep the module updated with current information. Sources used for the development of this module included the US EPA, US Department of Agriculture, PA DEP and Learning Center websites as well as lecture notes from Dr. Dennis Decoteau, professor of Penn State’s Air Pollution Impacts to Terrestrial Systems course (ERM and PPATH 430). This module has been uploaded onto the Learning Center website so that educators can download it off of the internet and use it in their classroom.

3.5.2 Pre/Post-Module Quiz Development

The type of testing instrument that was used for this research was decided after meeting with the Penn State Statistical Consulting Center and the research committee for this project. The instrument used was a fifteen question, multiple choice quiz, that was used to determine the individuals’ knowledge on the subject matter prior to and after being presented with the above teaching module (Appendix D). Both the pre and post module quizzes were identical in order to accurately test the effectiveness of the module.
and for statistical purposes. After the development of the quiz a preliminary test was run on five individuals who had no previous knowledge of the subject to determine if they were able to guess the correct answers. The quiz was also submitted for review to the three members of this research committee. Following the preliminary testing and review of the quiz, necessary revisions were made. A copy of this pre/post module quiz is located in the Appendix of this thesis. This information will be used in phase four of the research during the statistical analysis.

3.6 Phase III: Implementation of Teaching Module

During this phase of the research the teaching module was presented and pre/post module quiz was used to collect the data needed for testing the effectiveness of module.

3.6.1 Pre-Module Preparations

Prior to the presentation of the ozone module certain preparations had to be made. These preparations included filling out an Office of Research Protections (ORP) application to get permission for use of human subjects in research; completing the Institutional Review Board Educational Training for Human Participant Research to gain permission to present the module for research purposes; and contacting the Penn State Agricultural and Extension Education (AEE) 313 course instructor to schedule a time to present the module during the course. A copy of the, informed consent form and e-mail stating that my research is exempt from IRB review are located in Appendix A of this thesis (IRB# 26701).

3.6.2 Presentation of Teaching Module

The presentation of the ozone module during the AEE 313 course took place on January 10, 2008. The students in this course and participants of this study (n=16) were
pre-service student teachers who were about to begin their student teaching term. The module was presented exactly how the teachers would be expected to present it in their classrooms. This allowed the participants to learn the information themselves prior to teaching it. Before the presentation, the purpose of the study was explained to the participants and they were asked to sign the informed consent form if they agreed to allow their scores to be used. All students agreed to participate and were then given the pre-module quiz. Following the quiz, the class was presented with the first power point presentation, followed by a short break, the second power point presentation, and then the in class activity which they were allowed to work on in groups. At the completion of the activity, the answers were discussed as a class, any last minute questions were answered, and the students were given the post-module quiz complete.

3.7 Phase IV: Post-Module Data Analysis

This phase of the research involved the statistical analysis of the pre and post module quizzes to determine the effectiveness of the module. It also involved gaining feedback on student response to the module from the student teachers who implemented it into their curriculum. The last step in this phase was to have the module uploaded onto the Air Quality Learning and Demonstration Center website for use by the general public and educators.

3.7.1 Comparison of Pre-Module Surveys and Post-Module Quizzes

The first step of this phase was to grade each participant’s pre and post-module quiz. After the quizzes were graded, a paired t-test was conducted using the Minitab program to determine the effectiveness of the teaching module. The statistical method used for this phase was determined after meeting with the Penn State Statistical
Consulting Center. The results from this statistical analysis will be discussed in the results chapter of this thesis. During this phase feedback was also gathered from those student teachers who implemented the module into their curriculums. This feedback will be mentioned in the discussion portion of the research thesis but was not be included in the statistical analysis.

3.7.2 Upload Teaching Module onto the Internet

After the completed teaching module was tested for its effectiveness in educating individuals on the subject of ground ozone pollution it was uploaded onto the Air Quality Learning and Demonstration Center website. The purpose of this final step is to make the module accessible to teachers, students, and the general public to help educate individuals on ozone pollution and its effects on vegetation.

3.8 Summary of Methodology

This research was divided into four phases; Collection and Analysis of Photographs, Weather and Air Pollution Data, Development of Teaching Module and Pre/Post-Module Quiz, Implementation of Teaching Module, and Post-Module Data Analysis. These four phases which have just been described in detail were necessary for the successful completion of this project and the fulfillment of its objectives.
Chapter 4: Results

4.1 Photograph Results

The initial plan in this study was to document photographs of ozone injury occurring on several ozone sensitive plant species during the 2007 Pennsylvania ozone season. These photographs were then going to be incorporated into the ozone module along with the weather and air pollution data collected. However, of the five sensitive species photographed only two showed obvious ozone symptoms. The two species that had visible injury were tobacco (*Nicotiana tabacum*) and Chambourcin grapes (*Vitis spp.*), whereas the black cherry (*Prunus serotena*), yellow poplar (*Liriodendron tulipifera*), and common milkweed (*Asclepias syriaca*) showed no signs of ozone injury. Two other species within the Learning Center that were not being photographed on a weekly basis did show injury, trumpet creeper (*Campsis radicans*) and pinto (snap) beans (*Phaseolus vulgaris*). When injury became visible on these species photographs were taken for the purpose of including them in the module.

4.2 Ozone Module Results

The statistical analysis used to test the effectiveness of the ozone module was a paired t-test as recommended by the Penn State Statistical Consulting Center and the program used to conduct the paired t-test was Minitab student release 14.

Paired t-test Hypotheses:

Null Hypothesis: The mean difference between the two quizzes will be equal to zero.

\[ H_0: \mu_d = 0 \]

Alternative Hypothesis: The mean difference between the two quizzes will not be equal to zero.

\[ H_a: \mu_d \neq 0 \]
The results of the paired t-test showed that the confidence interval {95% CI for mean difference: (-7.60444, -5.27056)} for the mean difference between the two quizzes did not include zero, which suggests a difference between them. The small p-value (p=0.000) further suggests that the data are inconsistent with $H_0: \mu_d = 0$, which means that there is a difference between the two quizzes. Specifically, participants did better on the Post Quiz (mean = 13.06) than on the Pre Quiz (mean = 6.63). Thirteen out of the sixteen participants received over 80% on the post quiz, whereas none of the sixteen participants received over 80% on the pre quiz (Table 4.1). The mean of 13.0625 for the post quiz yields an average score of 87% for the post quizzes.

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Table 4.1 Data results for pre and post quizzes
Chapter 5: Discussion

The results of this study demonstrated that the research objective stated in the introduction of this thesis was fulfilled. An effective teaching module was developed that can be used to educate high school level individuals on the topic of ground level ozone pollution and its effects on vegetation. The module was determined to be effective by using a paired t-test to compare a pre and post module quiz that the sixteen research participants completed.

Both the development and implementation of the ozone module proved to be successful in fulfilling the study’s objective. However, the goal of obtaining photographs of ozone induced vegetation injury on five different species within the Learning Center was not achieved. Vegetation injury appeared on two of the five species photographed, tobacco and Chambourcin grapes, whereas, the black cherry, common milkweed, and yellow poplar showed little to no visible injury during the 2007 ozone season. The reason for this lack of injury was most likely due to lower than normal ozone pollution levels during the study period. The highest ozone level experienced was 90 ppb, which only occurred once during the season. Therefore, the relatively low ozone pollution levels were not enough to cause symptoms on the black cherry, common milkweed, and yellow poplar.

Unfortunately, time constraints did not allow for additional individuals to be presented with the module. The use of sixteen research participants was not sufficient to make the results of this study statistically significant. If additional time were allotted, testing the module on a greater number of individuals within the intended audience (high school students) would have been ideal. However, the results of this study suggest that
testing the module on additional students would produce a similar outcome. Therefore, this research was successful in achieving its objective and resulted in an educational module that is now available to educators nationwide for use in their classrooms.

Several of the AEE 313 students who were presented with the module, expressed interest in using it during their student teaching term during the spring of 2008 and feedback was received from three of these individuals. One student teacher used the module in a plant science class that contained twenty three students. Feedback from this teacher was “the students did enjoy it and found the information surprising and interesting…they really thought it was neat that they could check the ozone level in their area and see surrounding areas”. The second teacher who provided feedback was using the module in their greenhouse class, consisting of twenty eight students. Unfortunately, due to the structure of the class the student teacher was not able to present the module all at one time but instead in fifteen minute increments. Therefore, this individual could not provide much detail on the students’ reaction to the module. The third individual who provided feedback taught the module during a plant physiology portion of their class, which contained eight students. This student teacher said about the module, “it not only tied everything I taught in the unit together, it allowed students to learn about the effect of ozone on these plant processes. The students really enjoyed the links to the internet and all the graphics”. However, this teacher also mentioned that the students didn’t do very well on the quiz, which she found confusing, considering the students interest in the subject matter. Although some feedback was negative, the majority was positive and provided further evidence that the ozone module can be successfully incorporated into high school curricula.
Since the ozone module has been tested and is already being used in high school classrooms, the next step is to make it available for use by as many educators as possible. Therefore, plans to disseminate the module are as follows. All of the module documents have been uploaded onto the Learning Center website for access by educators and the general public. The link to this website has been sent out on a list serve to all agricultural education teachers in the state of Pennsylvania. This link can also be uploaded onto websites of appropriate university departments, such as Penn State University’s Department of Horticulture. This research and the internet link to the module can also be presented in the form of a poster at conferences. A poster has already been presented at the Penn State College of Agriculture and Gamma Sigma Delta Research Exhibit and will be presented in June of 2008 at the annual North American Colleges and Teachers of Agriculture (NACTA) conference. Through this dissemination plan and the continued use of the module by the student teachers and their host teacher, it is expected that the number of students exposed to the module will continue to grow and far exceed the already seventy five students who have learned the information.
References


Appendix A

Penn State University Institutional Review Board (IRB)
Documents (IRB# 26701)
Informed Consent Form for Social Science Research

Title of Project: Environmental Education Techniques for Demonstrating Ozone Pollution Effects on Vegetation

Principal Investigator: Sabrina Chrzanowski, Graduate Student
103 Tyson Building (mailbox)
University Park, PA 16802
215-630-5963; slc280@psu.edu

Advisor: Dr. Dennis Decoteau
18 Tyson Building (office)
University Park, PA 16802
814-865-5587; drd10@psu.edu

1. Purpose of the Study: The overall goal of this project is to develop a teaching module designed to effectively educate high school students and the general public about the effects of ground level ozone pollution on plant development. The purpose of your participation will be to test the effectiveness of the module.

2. Procedures to be followed: You will be asked to take two 15 question quizzes. The first quiz will be before the module presentation and the second quiz will follow the module presentation.

3. Benefits: You will learn valuable information about ground level ozone pollution, a subject that you may or may not be familiar with. You will also be given new teaching material, including a homework assignment, activities, and quiz that can be incorporated into your own curriculum.

4. Duration: This portion of the course will take no longer than three hours.

5. Statement of Confidentiality: Your participation in this research is confidential. The data will be stored and secured at Tyson Building in a file. No personal information will be collected during this study, therefore, in the event of a publication or presentation resulting from the research, no personally identifiable information will be shared.

6. Right to Ask Questions: Please contact Sabrina Chrzanowski at 215-630-5963 with questions, complaints or concerns about this research.

7. Voluntary Participation: Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise.

You must be 18 years of age or older to take part in this research study. If you agree to take part in this research study and the information outlined above, please sign your name and indicate the date below.
You will be given a copy of this consent form for your records.

______________________________________________ _____________________
Participant Signature       Date

______________________________________________ _____________________
Person Obtaining Consent    Date
Copy of e-mail confirming that this research (IRB# 26701) is exempt from IRB review

Hi Sabrina,

The Office for Research Protections (ORP) has reviewed the above-referenced study and determined it to be exempt from IRB review. You may begin your research. This study qualifies under the following category(ies):

Category 2: Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observations of public behavior unless: (i) information obtained is recorded in such a manner that human participants can be identified, directly or through identifiers linked to the participants; and (ii) any disclosure of the human participants’ responses outside the research could reasonably place the participants at risk of criminal or civil liability or be damaging to the participants’ financial standing, employability, or reputation. [45 CFR 46.101(b)(2)]

PLEASE NOTE THE FOLLOWING:

• Include your IRB number in any correspondence to the ORP.

• The principal investigator is responsible for determining and adhering to additional requirements established by any outside sponsors/funding sources.

• Record Keeping
  
  o The principal investigator is expected to maintain the original signed informed consent forms, if applicable, along with the research records for at least three (3) years after termination of the study.

  o This will be the only correspondence you will receive from our office regarding this modification determination.

  ▪ MAINTAIN A COPY OF THIS EMAIL FOR YOUR RECORDS.

• Consent Document(s)

  o The exempt consent form(s) will no longer be stamped with the approval/expiration dates.

  o The most recent consent form(s) that you sent in for review is the one that you are expected to use.

• Follow-Up

  o The Office for Research Protections will contact you in three (3) years to inquire if this study will be on-going.

  o If the study is completed within the three year period, the principal investigator may complete and submit a Project Close-Out Report. (http://www.research.psu.edu/orp/areas/humans/applications/closeout.rtf)
Revisions/Modifications

- Any changes or modifications to the study must be submitted to the Office for Research Protections on the Modification Request Form - Exemption available on our website:
  
  http://www.research.psu.edu/orp/areas/humans/applications/modrequest.rtf
  
- Modifications will not be accepted unless the Modification Request Form is included with the submission.

Please do not hesitate to contact me if you have any questions or concerns.

Thank you,

Andrea

Andrea R. Seisler, MBE
Compliance Coordinator
Office for Research Protections
The Pennsylvania State University
201 Kern Graduate Building
University Park, PA16802
Telephone: 814-865-1775
Fax: 814-863-8699
http://www.research.psu.edu/orp/
Appendix B

Pennsylvania State Academic Standards Fulfilled by Ozone Module
Ozone Module Lesson One:

This module helped to fulfill the Academic Standards for Environment and Ecology:

Environmental Health
- 4.3.7
  - A. Identify environmental health issues
    - Identify various examples of long-term pollution and explain their effects on environmental health
  - B. Describe how human actions affect the health of the environment
    - Identify residential and industrial sources of pollution and their effects on environmental health
    - Explain the difference between point and nonpoint source pollution
    - Explain how nonpoint source pollution can affect air quality

- 4.3.10
  - A. Describe environmental health issues
    - Identify the effects on human health of air pollution and the possible economic costs to society.

- 4.3.12
  - A. Analyze the complexity of environmental health issues.
    - Explain the relationship between wind direction and velocity as it relates to dispersal and occurrence of pollutants

Humans and the Environment
- 4.8.10
  - C. Analyze how human activities may cause changes in an ecosystem.
    - Analyze and evaluate changes in the environmental that are the result of human activities.

- 4.8.12
  - C. Analyze how pollution has changed quality, variety and toxicity as the United States developed its industrial base.
    - Analyze historical pollution trends and project them for the future.

Environmental Laws and Regulations
- 4.9.7
  - A. Explain the role of environmental laws and regulations
    - Identify and explain environmental laws and regulations (Clean Air Act)

- 4.9.12
  - A. Analyze environmental laws and regulations as they relate to environmental issues.
    - Analyze and explain how issues lead to environmental law or regulation
Ozone Module Lesson Two:

This module helped to fulfill the Academic Standards for Environment and Ecology:
Environmental Health

- 4.3.7
  - A. Identify environmental health issues
    - Identify various examples of long-term pollution and explain their effects on environmental health
- 4.3.10
  - A. Describe environmental health issues
    - Identify the effects on human health of air pollution and the possible economic costs to society.
  - B. Explain how multiple variables determine the effects of pollution on environmental health, natural processes and human practices.
    - Identify and explain ways of detecting pollution by using state-of-the-art technologies
- 4.8.10
  - C. Analyze how human activities may cause changes in an ecosystem.
    - Analyze and evaluate changes in the environmental that are the result of human activities.
Appendix C

Module Documents
Ozone Pollution Module Overview

The purpose of this module is to effectively educate individuals on the topic of ground level ozone pollution by demonstrating its effects on vegetation. The module consists of nine documents which are as follows:

Ozone Pollution Module Overview
Ozone Module Power Point: Lesson One
Ozone Module Power Point: Lesson Two
Air Quality Learning and Demonstration Center Video
Environmental Crime Scene Investigation Activity
Environmental Crime Scene Investigation Activity Answer Key
Ozone Module Homework Assignment
Ozone Quiz
Ozone Quiz Answer Key

With the above documents the instructor should be able to successfully fulfill the purpose of this module and their students should be educated on the topic of ground level ozone pollution.

Suggestions:
The instructor will find that both power point presentations are rather long, both lessons consist of 38 slides. If a class period is 50 minutes or less, it is recommended that these lessons are broken into one and a half or two periods as opposed to one class period for each. However, with this, the instructor may use their own discretion.

Each power point presentation has animation schemes set up with the slides; these have been set up for both organization and class participation purposes. The instructor will find several questions within each power point, it is recommended that the teacher use the animation to their benefit and bring up the question prior to the answer. By asking these questions in class and having the students provide the answer first, it will provoke class participation and force the students to think about and tie together the information that they have been learning.

The instructor will find a module homework assignment which is designed to be completed primarily online. If any students do not have online access you may restructure the homework assignment at your will. This assignment is also designed so that it may be handed out at the end of the first class period; it is up to the instructor as to how much time the students are allotted to hand the in assignment.

There are three slides over the course of the two lessons where it is beneficial to have online access within the classroom. If online access is available to you, be sure and try each link prior to teaching the module so that you are aware of how to navigate within each website. These links are placed in the module as small interactive activities and to provide greater clarity to the topic being discussed. However, if internet access is not available it is not essential that the links are used. *Concerning the Learning Center
video it is highly recommended to save time and ensure better quality that the video be downloaded and saved onto the computer and played at least once prior to class.

Below each slide in the power point presentations notes have been written. These notes are there for the instructors benefit; please be sure to read all of the notes before presenting the lessons because there may be information or suggestions provided that are not within the slide itself.

The Environmental Crime Scene Investigation is meant to be completed after both power point lessons are done; it is set up as an activity to wrap up the information that the students learned during the two lessons. There are five questions at the end of the activity and you have been provided with an answer key to those questions.

A quiz to test the students’ knowledge on the topic after completion of the module along with an answer key has been provided. This is a 15 question multiple choice quiz which asks a wide range of questions specifically from the lessons within the module.

Below are a list of references used in development of this module and if further information is required these are all excellent sources to consult.

References


Heck et al. 1983. Environmental Science and Technology 17:572A


PA Department of Environmental Protection. 2007. http://www.depweb.state.pa.us/dep/site/default.asp

Penn State Air Quality Learning and Demonstration Center. 2007. http://www.aireffects.psu.edu/learning/index.htm


Ozone Module: Lesson One-Slides and Notes for Teachers

Slide 1

Slide 2

This slide provides several objectives so that the students are aware of what they are going to learn over the course of this presentation.

Slide 3

This and the following slides list each Pennsylvania State Academic Standard that will be covered during the course of this presentation.
Slide 4

Pennsylvania State
Academic Standards

- This module will help fulfill the Academic Standards for Environment and Ecology: Humans and the Environment
- 4.8.10
  - E. Analyze how human activities may cause changes in an ecosystem.
  - A. Analyze and evaluate changes in the environment that are the result of human activities.
- 4.8.12
  - C. Analyze how pollution has changed quality, variety and toxicity as the United States developed its industrial base.
  - A. Analyze historical pollution trends and project them for the future.
- Environmental Laws and Regulations
- 4.9.7
  - A. Explain the role of environmental laws and regulations
  - Identify and explain environmental laws and regulations (Clean Air Act)
- 4.9.12
  - A. Analyze how environmental laws and regulations affect environmental issues.
  - Analyze and explain how issues lead to environmental laws or regulations.

Slide 5

What is Air?

Air is defined as the tasteless, odorless, and invisible mixture of gases that surrounds the earth.
- 78% Nitrogen
- 21% Oxygen
- .03% Carbon Dioxide
- <1% Argon (inert)
- Water Vapor

Suggestion: To provoke student participation bring up the slide title by itself first, “What is Air?” and ask the students if anybody can try to answer that for you. Then bring up the rest of the slide, give them the definition and go over the gases that make up the air we breathe. The animation is set for this slide so that the title will come up by itself first without the rest of the slide.

Slide 6

What is Air Pollution?

Air is said to be “Polluted” when it is no longer tasteless, odorless, colorless
- Gaseous or particulate substances released into the atmosphere in sufficient quantities or concentrations to cause injury to plants, animals, or humans.
- Typically emitted into the atmosphere and transported from the source to the affected organism.

Suggestion: As with the previous slide, to provoke student participation bring up the slide title by itself first, “What is Air Pollution?” and ask the students if anybody can try to answer the question for you. After you get a few answers bring up the rest of the slide and go over the definitions and descriptions of air pollution. The animation is set for this slide so that the title will come up by itself first without the rest of the slide.
Slide 7

**History of Air Pollution in the United States**

- **Late 1800’s**: Industrial revolution in the U.S. caused a major increase in air pollution emissions
- **1943**: First recognized episodes of smog occurred in Los Angeles
- **1948**: The first known air pollution disaster in the U.S. occurred in Donora, PA

This slide is a good introduction to the next few slides which discuss a couple bad air pollution episodes that occurred in the 1940s. U.S. industrial revolution began after civil war – boom period between 1860-1890.

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Slide 8

**History of Smog**

1943: First recognized episodes of smog occurred in Los Angeles. Visibility was only three blocks and people suffered from itchy eyes, respiratory discomfort, nausea, and vomiting. The phenomenon was termed a "gas attack" and blamed on a nearby butadiene plant.

This slide can be used as an example of what air pollution was like prior to any U.S. Air Pollution Regulations.

---

Slide 9

**Donora, PA - 1948**

Location: Western, PA on the Monongahela River

The next two slides demonstrate another good example of air pollution in the U.S. prior to Air Pollution Regulations and if presenting in PA it hits closer to home.

**Suggestion**: Ask students if any of them know where Donora, PA is located or have heard of it.

This map shows where Donora is located in relationship to several other Western, PA towns.
Several specific events both in the US and abroad have directly affected the history and policy of air conservation and air pollution control and regulation in the US.

In 1948, An air inversion in the narrow river valley of Donora, PA and surrounding areas trapped air pollutant emissions from the local zinc works and smelting operation as well as other local sources of sulfur, carbon, and heavy metals.

The pollutants were trapped close to the ground preventing dispersion of pollutants, As a result 20 people died, and 40% of the towns inhabitants became sick.

This slide covers the major Air Pollution Legislation that has been passed in the U.S. from 1955-2002

**Air Pollution Control Act**

Purpose: Authorized federal funds to assist states in air pollution research and training air pollution control agency personnel (Extended in 1959 and 1962)

**The Air Quality Act of 1967**

(Precursor to the 1977 Clean Air Act)

Designation of state air quality control regions

Investigated adverse health effects of pollutants so that proper regulations could be set.

Researched viable air pollution control techniques
**Clean Air Act Amendments**

Established three classes of clean air areas

- **Class I**: Little to no air quality deterioration allowed.
  
  Includes National Parks forests, wilderness areas.

- **Class II**: More pollution is permitted but still not large amounts.

- **Class III**: Air pollution is permitted but not to exceed the NAAQSs.

**Another Goal Established:**

The protection and enhancement of visibility in National Parks and Federal wilderness Areas.

---

**Clean Air Act of 1990**

- Outlined methods and technologies to control common air pollutants.

- Maximum Available Control Technologies determined for industrial facilities emitting toxic substances

- Regulations put in place for the MACTs to be installed

**Particulate Matter**: Considered inhalable at PM$_{10}$ and respirable at PM$_{2.5}$ Standards strengthened again in 2007

---

**The Clean Air Act of 1970**

- Required U.S. Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants:
  - ozone
  - lead
  - carbon monoxide
  - sulfur dioxide
  - nitrogen dioxide
  - particulate matter

**1970**

As a direct result of failed attempts at legislative control strategies for air pollution, EPA was established as an Independent executive branch of the Federal government.

NAAQS were established for 6 criteria pollutants.

These national standards were primarily, which means that their purpose was to protect human health.

For the first time in US history, Industries, manufacturers, power generation companies, any other major emitters of air pollutants were directly responsible for controlling the type and amount of pollutant they produced.

This was achieved and governed primarily by air pollution control programs
Ozone

- Two Types:
  - Stratospheric
    - "Ozone Layer"
    - ~15-50 km
  - Tropospheric
    - "Bad Ozone"
    - ~0-15 km

All ozone is within the first 50km of the earth's atmosphere.

**Stratospheric ozone:** Helps protect us from harmful UV radiation from the sun. Very important. When people think of ozone, many times this is what they think of. This is the “good ozone”. The “ozone layer” is made up of stratospheric ozone.

**Tropospheric ozone:** What we’re going to talk about in more detail. This is the “bad ozone”, found at ground level that damages vegetation, human health, and economies.

Another graphic demonstrating the separation of “good” and “bad” ozone. It is very important that the students understand that we are talking about tropospheric (bad) ozone.
More detail about the differences between the ozone layer and tropospheric ozone.

This is also a world wide problem, China is loosing much more than we are, approximately $5 billion U.S. dollars each year due to ozone damage to vegetation.

There are several reasons why it is important to learn about ozone pollution, this slide describes the economic effects of ozone pollution.

Research has demonstrated that every year in the United States, approximately $1-2 billion is lost due to ozone damage on vegetation, primarily in the agriculture and forestry sectors.

*To put this in perspective for the students, compare $1-2 billion lost annually to the $1.7 billion that PA produced in crop sales in 2006. In other words, the amount of money being lost due to ozone effects on vegetation practically eliminates all revenue made in crop sales by PA.
Slide 18

Importance Cont.

- **Health Issues**: Respiratory Problems
  - Coughing
  - Congestion
  - Chest Pain
  - Throat Irritation
  - Worsens respiratory diseases such as asthma, bronchitis and emphysema

Some information about ozone effects on human health

- Ozone exposure for 6-12 months induces cell injury, lung edema, and inflammation in a time-dependent fashion.

- Long-term exposure to ozone is associated with fibrotic changes resulting in a smaller, stiffer lung.

- Structural damage is often seen at the junctions of the terminal airways, where the important mucus lining soon disappears altogether.

Slide 19

If internet service is available, click on title, it is a link to the Air Quality Index page on the EPA website. Once in the site you can use the drop box to look up the state you are in and show students what the ozone and particulate matter levels are at that time, in their area. You can also make the search more specific by looking up a particular city that is close to you. This makes the AQI easier to understand if they can see it working.

<table>
<thead>
<tr>
<th>Air Quality Index</th>
<th>Levels of Health Concern</th>
<th>Health Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>0-50</td>
<td>Air quality is considered satisfactory and air pollution poses little or no risk.</td>
</tr>
<tr>
<td>Moderate</td>
<td>51-100</td>
<td>Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a small number of people who are unusually sensitive to air pollution.</td>
</tr>
<tr>
<td>Unhealthy for sensitive groups</td>
<td>101-150</td>
<td>Members of sensitive groups may experience health effects. The general public is not likely to be affected.</td>
</tr>
<tr>
<td>Unhealthy</td>
<td>151-200</td>
<td>Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.</td>
</tr>
<tr>
<td>Very Unhealthy</td>
<td>201-300</td>
<td>Health alert: everyone may experience more serious health effects.</td>
</tr>
<tr>
<td>Hazardous</td>
<td>&gt;300</td>
<td>Health warnings of emergency conditions. The entire population is more likely to be affected.</td>
</tr>
</tbody>
</table>
Slide 20

Environmental cont.

- Ozone pollution can cause a variety of injury on vegetation, including agricultural crops and commercial forestry species.
  - Stemline
  - Chlorotic Mottle
  - Reduced crop yields
  - Premature defoliation
- Injury such as these can in turn affect the economy of the agricultural and commercial forestry sectors.

We will go into more detail about this in the next lesson, however it is important to briefly mention environmental problems stemming from ozone pollution when discussing importance of studying this topic.

* Agriculture very important in PA, over 1 billion a year in crop sales
* Commercial Forestry also very important, especially in the North Central Region where there is a lot of Black Cherry (ex. Kane, PA)

Slide 21

Point Sources

- Generally a major facility emitting pollutants from identifiable sources (pipe or smoke stack). Facilities are typically permitted.

The next series of slides covers four different types of air pollution sources, point sources, area sources, mobile sources, and natural sources. All of the information needed is on each slide and accompanied by pictures of the source type being discussed.

**Point Sources:** Anywhere that it is recognizable that a pollutant is being emitted directly from that source

**Examples:**
- Power Plants
- Industry Plants

Slide 22

Area Sources

- Any low-level source of air pollution released over a diffuse area (not a point) such as consumer products, architectural coatings, waste treatment facilities, animal feeding operations, construction, open burning, residential wood burning, and char broilers

**Area Sources:** Definition is in the slide

**Examples:**
- Paint, either commercial painting or painting being done by private citizens
- Gasoline Pumps
- Residential wood burning
  (other examples are in slide)
Mobile Sources: There are two types on-road and non-road.

On-road Examples:
- Cars
- Trucks
- Motorcycles

Non-road examples:
- Farm equipment
- Locomotives
- Watercraft
- Buses
- Snowmobiles

Natural Sources: Any non-anthropogenic (human made) pollution source

Examples:
- Wildfires
- Volcanoes
- Wind blowing dust

Pollutants can be broken into two classifications, primary pollutants and secondary pollutants.

Primary pollutants are directly emitted from a source (ex. Power plant stack)

Secondary pollutants are formed from the combination of two or more primary pollutants. Ozone is a secondary pollutant.
The primary pollutants that form a secondary pollutant are called precursors. It is important that the students understand that ozone is a secondary pollutant and that its precursors are Oxides of Nitrogen (NOx) and Volatile Organic Compounds (VOCs).

A secondary pollutant is always formed by precursors.

**Suggestion:** To stimulate student participation you could ask if any students know what precursors are before you bring up the answer.

The purpose of this slide is to teach the students how ozone is formed. The pie charts above show the sources of each of the precursors (NOx and VOCs). The primary sources are as follows:

- **NOx**
  - Motor Vehicles
  - Industrial/Commercial Processes
  - Utilities (ex. Power Plants)
- **VOCs**
  - Motor Vehicles
  - Industrial/Commercial Residential Fuel Combustion
  - Consumer Solvents

The bottom equation is to show how ozone is formed. When NOx and VOCs are present in the air along with sunlight and heat, ozone is formed. This is why the ozone season in PA is April through October, ozone primarily forms during the hot summer months.
Activity

It may be a good idea to review the sources of both NOx and VOCs so that the students can think about what they could do to reduce the precursors that form ozone pollution. **Suggestion:** go over some of the students’ answers out loud in class so that the other students can hear answers that they might not have thought of.

Possible Answers:
- Conserve energy by: turning off lights, setting computers to power save modes, etc.
- Carpool, to school, to work, etc.
- Use public transportation, ride a bike, walk
- Keep vehicles tuned up to help with better fuel economy
- Use environmentally safe cleaning products and paints (household products)

This is a picture of an air pollution plume leaving the east coast of the U.S. Use this to demonstrate how air pollution can be transported great distances, depending on weather patterns.
To start this animation simply click on it and it will move. This animation demonstrates how ozone precursors move and can be transported with the weather patterns. You can watch the ozone concentrations (in ppb) go up and down as the precursor particles move around by observing the change in color (notice the legend on the right). By showing this animation students can better understand ozone transport.

This slide lists the six primary factors which affect ozone concentrations in a particular area.

Concentration and ratio of NOx and VOCs: The more precursors available, the better the chance of experiencing higher levels of ozone pollution

Terrain: Mountains can serve as barriers to air pollution, stop the wind flow so that a pollution event occurs on one side of the mountain but not the other. Valleys can serve to trap pollution especially if there is an inversion layer (warm air above cold air traps the pollutant in the valley)

Stagnant conditions: If air pollution gets trapped in a valley, stagnant weather conditions could keep that air pollution in the valley for days or weeks even if a front does not come through to push it away. This is why the air pollution episode at Donora, PA became so bad, air could not escape from the valley until a front came through.

Wind speed and direction: Where wind is coming from and how fast, can affect the concentrations of precursors available to form ozone pollution in a particular area. For example if central PA is receiving winds from the Ohio River valley where there are large amounts of ozone precursors being emitted then it is very likely that high levels of ozone pollution could form.

Temperature: The ozone season occurs during the warmer months of the year because warm air and sunlight are necessary to produce high ozone levels

Time of year: As mentioned before the ozone season for PA is April-October and the primary ozone months are June-August due to the weather conditions.
Slide 32

This slide demonstrates in more detail how topography, mountains and valleys, can serve as barriers or pockets for air pollution and can drastically change the way in which air pollution affects a particular area.

Slide 33

Most of the pollution that affects PA was not actually generated in the state. It comes from the Ohio River Valley mostly and other sources to the west of us. The reason that rural PA is in bold is because this module is focusing on ozone pollution effects on vegetation and rural PA is where the effected vegetation is located.

Slide 34

This map is demonstrating how weather patterns push emissions from vehicles, industries and electrical utilities generated to the west of us over to PA and the rest of the mid-Atlantic region.
Slide 35

Where is vegetation most affected?

- Rural Areas
  - Agriculture
  - Commercial Forestry

In Pennsylvania, ozone is the pollutant that most negatively affects vegetation.

Cities are affected because of human health effects of large amounts of ozone, however, in rural PA the main concern is for vegetation effects. The ozone is transported into these areas from long distances and there are major effects on agricultural crops and tree species important to the PA commercial forestry industry (ex. Black Cherry).

Slide 36

Summary

- Air is said to be "Polluted" when it is no longer tasteless, odorless, colorless
- Two types of ozone, Stratospheric (good) and Tropospheric (bad)
- Ozone pollution has major effects on economics, human health, and environmental health.
- Ozone is a secondary pollutant and its precursors are NOx and VOCs.
- Precursors of ozone reach PA by long distance transport from areas to the west (ex. Ohio Valley)
- Environmental health is most effected in rural areas.

This slide provides a quick review of the topics that were discussed during this presentation.

Slide 37

References

- Penn State Air Quality Learning and Demonstration Center. 2007. http://www.aireffects.psu.edu/learning/index.htm

Slide 38

Acknowledgments

- Thank you to both the Pennsylvania Department of Environmental Protection, Bureau of Air Quality and the United States Environmental Protection Agency for funding the research project that resulted in the development of this module.
- Additional thanks to the Pennsylvania State University, College of Agricultural Sciences and the Department of Plant Pathology for the use of the Penn State Air Quality Learning and Demonstration Center.
Slide 1

Ozone Module: Lesson Two-Slides and Notes for Teachers

Slide 2

This slide provides several objectives so that the students are aware of what they are going to learn over the course of this presentation.

Slide 3

This slide lists each Pennsylvania State Academic Standard that will be covered during the course of this presentation.
Slide 4

Important Plant Processes
- To understand ozone’s effect on vegetation we must first review a few important plant processes.
  - Photosynthesis
  - Respiration
  - Transpiration

The first portion of this lesson provides an overview of three important plant processes, photosynthesis, respiration, and transpiration.

It is important to understand the basics of these processes before one can understand how ozone pollution effects vegetation.

Slide 5

Photosynthesis
- Photosynthesis is the only process of biological importance that can absorb and chemically store energy from the sun
  - Photosynthesis Overall Reaction:
    - \(6\text{H}_2\text{O} + 6\text{CO}_2 + \text{light energy and chlorophyll} \rightarrow \text{C}_6\text{H}_12\text{O}_6 + 6\text{O}_2\)
  - Components of the reaction:
    - \(\text{H}_2\text{O} - \text{Water}\)
    - \(\text{CO}_2 - \text{Carbon Dioxide}\)
    - \(\text{C}_6\text{H}_12\text{O}_6 - \text{Glucose (Simple Sugar/Carbohydrate)}\)
    - \(\text{O}_2 - \text{Oxygen}\)

Photosynthesis is very important to understand since it is the process by which plants are able to receive and store energy needed to grow and develop.

Due to the necessity of chlorophyll, photosynthesis can only take place through the green part of the plant (the leaves) and therefore occurs mostly in the spring and summer, which is the same time that ozone pollution is at its highest levels.

Slide 6

Photosynthesis cont.
- Where does photosynthesis occur?

This graphic demonstrates where photosynthesis occurs (the leaf), what components of the reaction go into the leaf (sunlight, water, and carbon dioxide) and what the products of the photosynthesis are (oxygen and glucose).

The purpose of this graphic is to simplify the process of photosynthesis for the students and show them what goes into the reaction and what comes out.
Respiration is the release of energy from glucose or other organic substances that were stored during photosynthesis. During respiration, sugar starch and oxygen is turned into carbon dioxide and energy. Every cell needs to respire in order to produce the energy it needs.

Respiration is basically the opposite of photosynthesis, the components are the same they are just in a different order in the reaction; the products of photosynthesis (glucose and oxygen) are now what goes into the reaction.

The main reason that the students should understand both photosynthesis and respiration for this lesson is so that they can understand that there is gas exchange occurring in both processes.

The purpose of this graphic is to simplify the process of respiration for the students.

It occurs in the leaf, the reactants are glucose and oxygen (products of photosynthesis) and the products are water, carbon dioxide, and energy (reactants of photosynthesis).
Slide 9

Stomata

- Stomata: Pores located on the leaf surface used during plant processes to regulate the amount of gases entering and leaving the leaf.
- Stomata can open or close to increase or decrease the amount of gases entering the leaf.
- During photosynthesis and respiration all gas exchange occurs through the stomata.

It is important for the students to understand that all of these reactions occur within small pores in the leaves called stomata.

These stomata are the location of all gas exchange that occurs within the leaf.

Slide 10

Transpiration

- The loss of water vapor from the plant.
  - Most is lost through the stomata.
  - Can also be lost from stems, flowers, and roots.

- Responsible for:
  - Movement of water and nutrients through the plant.
  - Cooling of the leaves.

Transpiration is the process by which plants lose water vapor. Just as with photosynthesis and respiration the majority of this water vapor is lost through the stomata.

Transpiration is also responsible for movement of water and nutrients through the plant and the cooling of the leaves, which makes it another extremely important plant process. When water is being drawn up through the plant to escape through the leaves nutrients are also being carried through the plant with the water.

We will go into more detail about why transpiration is important with regards to ozone pollution within the next slides.
Environmental Factors Affecting Transpiration

- Water Availability
- Temperature
- Relative Humidity
- Carbon Dioxide

Relative Humidity: If the relative humidity is high outside the plant then less transpiration will occur because the air is already saturated with water vapor.

All of these factors will be discussed in greater detail over the next four slides, however below is an overview of each.

Water Availability: If there is not enough water available to the plant (dry or drought conditions) then the stomata will close and transpiration rates will slow down or stop.

Temperature: The hotter the temperature, the higher the transpiration rate (ex. Humans perspire more when hot)

Carbon Dioxide: If there are high amounts of CO2 within the leaf (intercellular) then the stomata will open to release CO2 and in turn the transpiration rate will also increase. If CO2 within the leaf is low then the stomata will close and transpiration rates will decrease.

It is also important to understand that if the plant cannot get enough water during dry or drought conditions then the stomata automatically shut to decrease the amount of transpiration occurring.

Water Availability

- Water Use Efficiency: There must be a balance between water loss and carbon gain during plant processes.
- When the plant cannot get enough water during drought or dry conditions, normal processes such as photosynthesis and respiration will not occur as often to prevent additional water loss through stomata.

Plants produce glucose (C₆H₁₂O₆) for energy during photosynthesis and produce CO2 during respiration, carbon is constantly being released and taken in through the stomata during photosynthesis and respiration. Therefore it is important to realize that during these processes, since the stomata are open, transpiration is also occurring, yet water is a necessary component for both plant processes. That is the importance of understanding “water use efficiency.”
**Temperature and Humidity**

- **Temperature:**
  - In general: A higher temperature = a larger stomatal opening and a higher transpiration rate.
  - To a point… (~35°C)

- **Humidity:**
  - In general: A higher relative humidity of air = lower transpiration rate.

**Temperature:** The hotter the temperature, the higher the transpiration rate (ex. Humans perspire more when hot)

**Relative Humidity:** If the relative humidity is high outside the plant, then less transpiration will occur because the air is already saturated with water vapor.

Although there are always exceptions this is the general rule.

**Carbon Dioxide**

- Plants respond to intercellular CO₂ vs. CO₂ at leaf surface.
  - High [CO₂]: stomates close.
  - Low [CO₂]: stomates open.

- Excessive water loss overrides everything = stomates close.

**Carbon Dioxide:** If there are high amounts of CO₂ within the leaf (intercellular) then the stomata will close in order to stop plant processes that produce CO₂ and in turn the transpiration rate will also decrease. If CO₂ within the leaf is low then the stomata will open so that the plant can produce more CO₂ and transpiration rates will increase.

This slide begins to tie everything together.

**Suggestion:** Ask the students the question in the slide before bringing up the answer to provoke class participation and see if they can put everything they just learned together.

It is important that they understand that all gas exchange occurs through the stomata and if other gases are getting into the plant such as carbon dioxide and water nothing is stopping harmful gases such as ozone pollution to also enter the plants.
Slide 16

This graphic is meant to simplify how ozone enters the plant, through the stomata during normal plant processes such as photosynthesis and respiration.

Slide 17

All of the necessary information on for this slide is on the slide.

**Suggestion:** Ask the question on the slide prior to bringing up the answer to force the students to think about all that they have just learned. Help them to get the answer if necessary but do not give it to them, they should be able to answer this question.

Slide 18

The following series of slides describes symptoms and injury on vegetation caused by ozone pollution.

**Stipple:** One of the most common visual symptom of ozone pollution. Occurs on broad leaved plants and appears as a minute brown, tan, purple, red or black coloration. Occurs only on the top side of the leaf and in between the veins.

**Chlorotic Mottle:** Appears as small patches of yellow tissue surrounded by apparently healthy tissue.

There are additional symptoms of ozone pollution, however these are the most common.
Slide 19

**Stipple**

- Occurs on broad leaved plants
- Appears as a minute brown, tan, purple, red or black coloration
- Occurs only on the top side of the leaf and in between the veins

More detail regarding stipple, all the necessary information is on the slide.

---

Slide 20

**Stipple**

- Pinto bean leaf showing stipple and demonstrating that it only occurs on the upper surface of the leaf.
- Common milkweed showing stipple and demonstrating that it only occurs on the upper surface of the leaf.
- Pinto bean leaf showing stipple and demonstrating that it only occurs on the upper surface of the leaf.

More photographs demonstrating ozone induced stipple. Be sure to point out to the students that the injury occurs both in between the veins, not on them and only on the upper surface of the leaf.

---

Slide 21

**Reduced Crop Yields**

Graph demonstrating the decrease in crop yields on sensitive species due to elevated levels of ozone pollution.

Graph demonstrating the decrease in crop yields on sensitive species due to elevated levels of ozone pollution.
Photographs demonstrating the difference in height between sensitive and resistant varieties of both tobacco and pinto beans (both are crops sensitive to ozone pollution).

This slide describes that injury on vegetation is caused by a chronic exposure to elevated levels of ozone pollution.

There are very few plants that will show injury immediately (tobacco is one of the few) the majority of sensitive plants will not show injury until late in the ozone season.

You will first notice injury on the oldest leaves because they have been exposed to ozone for the longest amount of time.

It is important to understand the purpose of bioindicators since they are commonly used in experiments dealing with ozone pollution effects on vegetation.

Bioindicators are used for many environmental research projects not just those dealing with ozone pollution.

This slide has listed the most common PA ozone bioindicators although it should be understood that there are others not mentioned in this list.
Slide 25

What makes a good ozone bioindicator?

- Sensitive to ozone
- Produce consistent and easily recognizable symptoms in response to ozone
- Easy to recognize by field crews
- Widespread in areas of interest
- Have no major, annual pests

This slide describes what researchers look for in a species when trying to choose bioindicators for their studies.

Slide 26

Why are bioindicators important?

- They are important tools used for air pollution research

What other methods are used for ozone pollution research?

- Open top chambers
- Passive Sampling Devices
- Continuous (real-time) ozone monitors
- Field Plots (using bioindicators)

Passive Sampling Devices: Ozone diffuses into sampler, contacts nitrite-coated filter that reacts with ozone to form nitrate, filter sent to lab to be analyzed. This is a good, cost effective method of determining ozone levels in remote locations, however when attempting to determine the effects of ozone pollution on vegetation open top chambers are still more effective.

Continuous Ozone Monitors: Devices used to determine the amount of ozone pollution in a particular area, cannot be used in remote locations unless electricity is available. More reliable than Passive Sampling Devices.

Bioindicators are important tools used in ozone pollution research but often times they are used in conjunction with other methods such as those listed in this slide. Open top Chambers: Chambers which have been planted with bioindicators of ozone pollution and have an open top so that rain can still reach the plants within them. Outside air is pushed into the chamber by a blower, one chamber is usually charcoal filtered so that 50% of the ozone pollution is taken out and the other chambers have ambient air blown into them. These chambers are a good method of demonstrating ozone effects on vegetation by comparing the growth and crop yields between the filtered chamber and the ambient air chambers. Open top chambers are one of the most effective methods in demonstrating ozone pollution effects on vegetation.

Field Plots: Unlike the previous two methods, field plots can be used to determine ozone pollution effects on vegetation however since they are open plots, it is not possible to do a comparison between vegetation grown in filtered air and species grown in ambient air. Therefore, open top chambers are still more effective in demonstrating ozone pollution effects on vegetation.
This is the introduction to the Air Quality Learning and Demonstration Center, located at the Penn State Arboretum. The following slides go into more detail about what is located at the Learning Center and the research that is being done there.

Show Learning Center Video during this slide

If high speed internet is available, click on the picture to open a link to the Air Quality Learning and Demonstration Center video however, it is recommended that the video is downloaded and played at least once prior to presenting in class for best quality. If high speed internet is not available you may use the Learning Center Video given to you on the disk or download the video from this link prior to class while on an internet capable computer and show it now.

This slide provides more details and a photograph of open top chambers.

The Learning Center contains two open top chambers, one which is charcoal filtered and therefore 50% of the ozone in the air is filtered out before entering the chamber and the other is not filtered which means that all of the ozone pollution in the air is also entering the chamber.

Each of these chambers are planted with ozone sensitive species each year such as chambourcin grapes, black cherry trees, common milkweed, and pinto beans.
Slide 29

Monitoring for Air Pollutants

- Located at the Learning Center: PA Department of Environmental Protection (DEP), Bureau of Air Quality Monitoring Station
- Monitors and collects weather data and pollution levels, including ozone.

If the internet is available click on picture to open up the DEP monitoring website and see what current ozone levels are in the monitoring location closest to you.

Within this trailer there is equipment which monitors pollutants such as ozone, sulfur dioxide, and nitrogen oxides and weather data such as wind speed and direction, temperature, and relative humidity.

Slide 30

Monitoring Visibility

Ozone is commonly associated with poor visibility or smog effects in areas with high ozone levels as demonstrated below.

These photographs were taken at the Learning Center in 2003 and demonstrate how high ozone levels can effect visibility.

In the first photograph the ozone levels are only 48ppb (normal) and you can clearly see Mt. Nittany in the background; in the second photograph (only four days later) ozone is at 102ppb (high) and Mt. Nittany is barely visible.

Slide 31

Benefits of Ozone Research

- Economic benefits:
- According to the Agricultural Overview for PA, the 2006 value of production for crops was $1,737,536,000, which demonstrates the importance of agriculture to the PA economy.
- Several economically important PA crops are ozone sensitive:
  - Corn for grain: $415,776,000
  - Soybean: $97,750,000
  - Tobacco: $26,223,000
- If ozone levels were decreased, there is potential for a substantial increase in PA crop production and value.

This slide discusses is the first of several describing the benefits of studying ozone pollution.

Since ozone damages crops and certain important forestry products (black cherry) it is important to study ozone pollution so that we can figure out how to decrease it and boost our economy.
This slide which continues on the topic of economic benefits to studying ozone pollution discusses benefits to the forestry sector which brings in a very large amount of revenue to the state of PA.

As with agriculture, a decrease in ozone pollution could mean a sizable increase to the PA economy.

This picture demonstrates the difference between three varieties of black cherry trees growing next to each other. One is ozone resistant and growing quite well, one is somewhat ozone sensitive and showing injury, and the last is very sensitive to ozone and almost completely defoliated.

Additional benefits to studying ozone pollution include health benefits.

A decrease in ozone pollution would also mean a decrease in ozone induced medical problems such as respiratory illnesses, chest pain, and also a better way of life to some due to less hospital visits, less money spent on medical bills, and a longer life.
Environmental Benefits

- Common Milkweed: Monarch Butterfly caterpillars primary food source

There are several environmental benefits to studying ozone pollution such as healthier forest stands of sensitive species such as black cherry, yellow poplar, and white ash. However, another large benefit would include a healthier monarch butterfly population.

Monarch butterflies primary food source is common milkweed, which can be extremely sensitive to ozone pollution. Therefore, a decrease in ozone pollution could mean an increase in monarch butterfly populations.

Summary

- Ozone enters plants through stomata during important processes such as photosynthesis and respiration.
- Common effects of ozone on vegetation include stipple, chlorotic mottle, decreased crop yields, and premature defoliation.
- Common and effective research techniques include open-top chambers and bioindicators.
- There are several important reasons to study ozone pollution including benefits to the economy, human health, and the environment.

This slide provides a quick review of the topics that were discussed during this presentation.

References

- PA Department of Environmental Protection. 2007. http://www.depweb.state.pa.us/dep/site/default.asp
- Penn State Air Quality Learning and Demonstration Center. 2007. http://www.aireffects.psu.edu/learning/index.htm

Acknowledgments

- Thank you to both the Pennsylvania Department of Environmental Protection, Bureau of Air Quality and the United States Environmental Protection Agency for funding the research project that resulted in the development of this module.
- Additional thanks to the Pennsylvania State University, College of Agricultural Sciences and the Department of Plant Pathology for the use of the Penn State Air Quality Learning and Demonstration Center.
Ozone Module Activity

Environmental Crime Scene Investigation: ECSI

**Purpose:** The purpose of this exercise is to use the knowledge that you have gained about ozone pollution to help solve an environmental crime scene using clues such as photographs and graphs showing weather data and ozone levels. Using these clues, you should be able to explain why and when the crime (ozone damage) occurred.

**Background:** You are a member of the Environmental Crime Scene Investigation unit for the Pennsylvania State Police Department. In August you get a phone call with the message that a local pinto bean farmer has found mysterious spots on his bean leaves. He informs you that these spots have appeared other years as well and usually in conjunction with less than average crop production. The farmer is worried that there is a correlation between these spots and a decreased crop yield and he cannot afford to have another bad year. It is your job to use the photographs and clues that you are given to answer the questions needed to determine what caused these spots and if there is a correlation between the spots and the farmer’s decreased crop yields.

**Location of the Crime Scene:** This farm is located downwind from the city of Pollutealot, PA, where there are several electric utility companies, heavy traffic, and miles of urban sprawl surrounding the city limits.

**The Crime Scene:** Below you will find photographs of the farmer’s injured pinto bean leaves.

**Injured Pinto Bean Leaves**

![Top side of injured leaf](image_url)
Clues:
Below you have a series of ozone level graphs and precipitation graphs that you can use as clues to answer the questions below.
Ozone Level Graphs (June-August)

June Ozone Levels (ppb)

July Ozone Levels (ppb)

August Ozone Levels (ppb)
Precipitation in Inches (June-August)

June Precipitation

Total Precipitation for the month of June: 3.70 in.

July Precipitation

Total Precipitation for the month of July: 4.22 in.
Total Precipitation for the month of August: **5.84 in.**

Total Precipitation for the season: **13.76 in.**
Questions

1) How can you tell that the foliar injury on the pinto beans is from ozone pollution?

2) Why didn’t the symptoms occur until August even though ozone levels in June and July were above normal background ozone levels of 30-40 ppb?

3) How could the low precipitation levels from this year effect when the injury occurred?

4) Provide an explanation for why there may be a decreased crop yield associated with ozone induced foliar injury on the pinto beans.

5) Knowing where the farm is located, downwind of a large city, list some possible sources of the two precursors of ozone pollution and make sure to specify which precursor (NOx or VOCs) the source would contribute to.
1) **How can you tell that the foliar injury on the pinto beans is from ozone pollution?**
   You can tell that the injury on the leaves is due to ozone pollution for several reasons. First, the injury (stipple) occurs only on the upper side of the leaf; second, the stipple only occurs in between the veins on the leaf. Both of these symptoms are extremely characteristic of ozone pollution.

2) **Why didn’t the symptoms occur until August even though ozone levels in June and July were above normal background ozone levels of 30-40 ppb?**
   Most likely, the ozone symptoms didn’t occur until August because ozone injury occurs in most sensitive plants after chronic or long term exposure to elevated levels of ozone pollution. Injury is not going to occur after just one or two days of exposure unless the conditions are just right and the ozone levels are above 100ppb.

3) **How could the low precipitation levels from this year effect when the injury occurred?**
   Low precipitation levels would mean low moisture content in the soil around the plants. When the plant cannot get enough water their basic processes such as photosynthesis and respiration will slow down because they cannot afford to lose water through their stomata (transpiration). If there is not a lot of photosynthesis and respiration occurring then there is not much opportunity for the ozone to enter the leaf through the stomata and cause injury.

4) **Give an explanation for why there may be a decreased crop yield associated with ozone induced foliar injury on the pinto beans.**
   There may be a decreased crop yield due to ozone injury because the plant is spending energy trying to repair itself and protect itself from the ozone that it should be spending on producing beans for reproduction.

5) **Knowing where the farm is located, downwind of a large city, list some possible sources of the two precursors of ozone pollution and make sure to specify which precursor (NOx or VOCs) the source would contribute to.**

<table>
<thead>
<tr>
<th>NOx</th>
<th>VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Utilities</td>
<td>Motor Vehicles</td>
</tr>
<tr>
<td>Motor Vehicles</td>
<td>Consumer Products (ex. spray paint)</td>
</tr>
<tr>
<td>Fuel Combustion</td>
<td>Industrial and Commercial Processes</td>
</tr>
</tbody>
</table>
Homework Assignment
Understanding the importance of monitoring air pollutants based on an example/episode in history where air pollutants caused injury or death

Learning Outcomes
Students will be able to:
- Define air pollutant
- Identify the major types and causes of air pollutants
- Understand the importance of monitoring the major air pollutants
- Review the National Air Quality standards
- Discuss an important air pollution episode that has occurred

Problem
- Air pollutants are found to some degree in all places around the world
- Air pollution varies according to location, season, and weather
- Specific air pollutants are monitored in certain areas
- Documented episodes of “bad” air quality days or events
- Air quality standards have been set by the government for various air pollutants

Task
In a written report (using the internet as your primary resource engine):
- Review the history of an air pollution episode and write a summary of the episode. Within the summary you should answer/discuss the following questions about the episode you are reporting on:
  - What were the air pollutants of concern?
  - How and where were the air pollutants monitored?
  - Why did the levels of the air pollutants build up to dangerous levels during the episode?
  - What were some of the reported human, animal and plant injury/damage as a result of the episode?
  - Does the damage appear consistent with our knowledge of air pollutants effects?
  - Is there any air quality data reported for the episode, and if so compare the levels reported with the US air quality standards for those pollutants?
  - What plans have been put in place to prevent an episode like this from occurring in the future?

Please list web pages from which the above information was gleamed
Appendix D

Research Instrument: Pre/Post Module Quiz
Pre/Post Module Quiz

Participant ID: ______________________

1) What is tropospheric ozone?
   a) A naturally occurring gas in our atmosphere that protects us from harmful UV radiation.
   b) A harmful pollutant found at ground level which is formed from nitrogen oxides and volatile organic compounds.
   c) A harmful pollutant found at ground level which is formed by the combination of fluorine and chlorine gases.
   d) A harmful pollutant found in the upper atmosphere which is formed from nitrogen oxides and chlorine gas.

2) The Clean Air Act of 1970 required the U.S. Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards for six common air pollutants. Which of the following lists all six pollutants?
   a) ozone, lead, nitrogen dioxide (NO₂), carbon monoxide (CO), respirable particulate matter (PM), sulfur dioxide (SO₂)
   b) ozone, lead, nitrogen dioxide, carbon dioxide (CO₂), mercury, respirable particulate matter
   c) nitrogen dioxide, carbon monoxide, chlorine, fluorine, mercury, lead
   d) ozone, carbon monoxide, chlorine, respirable particulate matter, mercury, sulfur dioxide

3) Ozone pollution is considered to be a:
   a) Primary pollutant
   b) Precursor
   c) Secondary pollutant
   d) None of the above

4) The areas in the United States where vegetation is most affected by ozone pollution are:
   a) Swamp and wetland areas
   b) Rural areas
   c) Arctic tundra
   d) Large urban areas

5) Which of the following is a factor that would affect the concentration of ozone pollution in a particular area?
   a) Temperature
   b) Time of year
   c) Concentration and ratio of precursors
   d) Terrain
   e) All of the above
6) The primary precursors of ozone are:
   a) Chlorine and Fluorine Gases
   b) Chlorine Gas and Nitrogen Oxides (NOx)
   c) Nitrogen Oxides and Volatile Organic Compounds (VOCs)
   d) Particulate Matter and Nitrogen Oxides

7) Ozone-induced plant injury includes:
   a) Stipple and reduced crop yields
   b) Chlorotic mottle and premature defoliation
   c) Tipburn
   d) Only (a) and (b)
   e) All of the above

8) Ozone injury on broad leaf vegetation always occurs:
   a) Between the veins and on the underside of the leaf
   b) On the veins and on the upper side of the leaf
   c) On the veins and on the underside of the leaf
   d) Between the veins and on the upper side of the leaf

9) What is a bioindicator?
   a) An individual whose job is to identify ozone injury on vegetation
   b) A biological group or species that is used to monitor the health of an ecosystem or environment
   c) An instrument used to detect changes in the health of an ecosystem or environment
   d) None of the above

10) Which of the following is NOT an ozone-sensitive plant species?
   a) Black Cherry
   b) Common Milkweed
   c) White Oak
   d) Yellow-Poplar
   e) Wild Grape

11) The use of ________ is the most effective way to conduct experiments determining ozone effects on vegetation.
    a) Passive-sampling devices
    b) Open-top chambers
    c) Field plots
    d) Continuous (real-time) ozone monitors

12) Which of the following is NOT a possible health effect of ozone pollution?
    a) Coughing and congestion
    b) Difficulty in breathing
    c) Lung cancer
    d) Worsening of respiratory diseases (ex. asthma and emphysema)
13) The average annual economic loss suffered by the United States due to ozone pollution damage to vegetation is:
   a) $250,000-$500,000
   b) $1-2 million
   c) $5 million
   d) $1-2 billion
   e) $5 billion

14) Which two industries experience the most economic damage due to ozone pollution?
   a) Agriculture and Golf Courses
   b) Commercial Forestry and Automotive
   c) Agriculture and Commercial Forestry
   d) Electric Utilities and Golf Courses
   e) Automotive and Electric Utilities

15) What can you do to help reduce ozone pollution?
   a) Use more energy efficient household appliances
   b) Drive fuel efficient vehicles
   c) Use energy efficient light bulbs
   d) Two of the above
   e) All of the above
Key: Ozone Quiz

1) (B)
2) (A)
3) (C)
4) (B)
5) (E)
6) (C)
7) (D)
8) (D)
9) (B)
10) (C)
11) (B)
12) (C)
13) (D)
14) (C)
15) (E)
Appendix E

Example of Weekly Photograph Log
Week 8 Summary (8-8-07)

Trees and Non-Ag Plants:

Common Milkweed:
1-3: Non-filtered Chamber
   (1): 5 Leaves
   (2): 6 Leaves
   (3): 5 Leaves
4-6: Open Plot Chamber
   (4): 5 Leaves (Note: New leaves 1 and 3)
   (5): 4 Leaves (Note: New leaves 1 and 3)
   (6): 5 Leaves
7-8: Filtered Chamber (Use for Comparison)
   (7): 6 Leaves (Note: New leaves 1, 2, and 4)
   (8): 5 Leaves (Note: New leaves 1 and 2)

Black Cherry:
1 and 3: Open Plot Chamber
   (1): 6 Leaves
   (3): 5 Leaves
2, 4, and 5: Ambient Air (center garden)
   (2): 6 Leaves (Note: New leaf 1)
   (4): 6 Leaves
   (5): 5 Leaves

Yellow-Poplar:
1-3: Next to Learning Center Sign
   (1): 3 Leaves
   (2): 5 Leaves
   (3): 4 Leaves
4-5: Next to Water Tank
   (4): 3 Leaves
   (5): 3 Leaves

Agricultural Plants:

Tobacco:
1-4: In Garden
   (1-4): 3 Leaves on Each Plant

Chambourcin Grapes:
1-4: In Garden (Note: Grape 3, new leaf 1)
   (1-4): 4 Leaves on Each Plant
Visible Injury:

*Tobacco plant 3, leaf 1, new ozone injury and yellowing of leaf
*Tobacco plant 4, leaf 1, new ozone injury and yellowing of leaf; new ozone injury on leaf 2
*Large amounts of beetle damage to grape plant one, leaves 1-4
*Beetle damage to grape plant 2, leaf 3

Max Ozone 8/2-8/8: 90 ppb
Appendix F

Select Photographs of Ozone Injury on Vegetation
Photographs of Ozone Damaged Vegetation Taken at the Air Quality Learning and Demonstration Center

Chambourcin Grape (*Vitis spp.*)

Visible stipple on Chambourcin Grape leaves.

Trumpet Creeper (*Campsis radicans*)

Trumpet Creeper showing visible ozone induced stipple.  Undamaged underside of trumpet creeper leaf, demonstrating that injury is in fact stipple.

Photograph Source: Chrzanowski
Tobacco (*Nicotiana tabacum*)

Clean tobacco leaf.  
Close up of ozone injury on tobacco.

Pinto (snap) beans (*Phaseolus vulgaris*)

Visible ozone induced stipple on pinto (snap) beans.

Photograph Source: Chrzanowski