

CORNELL SCIENTIFIC INQUIRY SERIES

TEACHER'S GUIDE

Invasion Ecology

BY THE ENVIRONMENTAL INQUIRY LEADERSHIP TEAM

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STUDENT EDITION

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INTRODUCTION

ENVIRONMENTAL INQUIRY

Invasion Ecology is part of the Environmental Inquiry (EI) curriculum series developed at Cornell University to enable high school students to conduct authentic environmental science research. The goals of EI are for students to

1. Develop research skills
2. Use their newly acquired skills to conduct environmental sciences research projects of their own design focusing on topics relevant to their local communities
3. Participate in communities of peer student scientists
4. Enhance their understanding of scientific content and process

Rather than learning science as a static body of facts, EI students experience the research process through which scientific understandings are formed and revised. Instead of memorizing a “scientific method,” they discover for themselves the multifaceted nature of scientific research. And through studying problems relevant to their communities, they discover interconnections between science and society.

MEETING THE STANDARDS

The contemporary movement for science education reform calls for the teaching of science to reflect more closely the way in which science is practiced. According to the *National Science Education Standards* (National Research Council [NRC] 1996), the central strategy for teaching science should be to engage students in authentic inquiry or research.

Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with the processes of inquiry, including asking questions, planning and conducting an investigation, using appropriate tools and techniques, thinking critically and logically about the relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments.

(NRC 1996, 105)

The Science as Inquiry Standards call for all students to develop the following abilities:

- Identify questions and concepts that guide scientific investigations
- Design and conduct scientific investigations
- Use technology and mathematics to improve investigations and communications
- Formulate and revise scientific explanations and models using logic and evidence
- Recognize and analyze alternative explanations and models
- Communicate and defend a scientific argument

(NRC 1996, 175-6)

INTRODUCTION

Using a stepwise approach, EI activities help students gain all these abilities as they design and carry out investigations and exchange ideas about their results with peer student scientists. A progression of worksheets guides students through each step of the inquiry process, providing structure but flexibility in designing and conducting meaningful projects. Students engaged in EI ecology research also will learn concepts and skills covered in other standards, including Science in Personal and Social Perspectives, History and Nature of Science, Life Science, and other areas. (See Table 1.)

WHY INQUIRY?

In addition to being integral to the *Standards*, understanding how scientists conduct research is essential for students as they become citizens capable of participating in a democracy. Like the general public, students often view science as a set of exercises with only one right answer. This leads to confusion when scientists publicly disagree about contentious issues such as global warming, food safety, or the impact of invasive species. How can both sides of the argument be right or scientific?

Once students have had the experience of carrying out their own research, they will understand better the challenges involved in addressing ecological questions and the reasons why scientists can't always come up with definitive answers. At the same time, they will understand that scientists work collaboratively, through a system called peer review, to ensure published results are the best answers they can find using present knowledge and technology. Students also will understand that, although science may not provide all the answers, it does provide a well-defined process for carrying out and reviewing research to reach the best explanations. Finally, because inquiry is both a social and creative process, it is an effective means of learning for students with a wide range of interests, learning styles, and achievement levels.

AUDIENCE

Invasion Ecology can be used as a module in biology, environmental science, ecology, botany, research, and general science courses, or as a resource for individual student research projects. In a growing number of schools, integrated science and environmental science are taught as introductory high school science courses. *Invasion Ecology* also works well in these classes because it does not assume detailed prior knowledge of the science disciplines and is based on thought-provoking hands-on activities.

The background text and research techniques in *Invasion Ecology* can be adapted for courses ranging from seventh grade through advanced placement science. Although research experiences commonly are reserved for advanced students, the EI curriculum series is designed to extend these opportunities to all students, including those who have not flourished in more traditional "college preparatory" science courses. EI pilot testing has shown that students who are not accustomed to thinking of themselves as scientists find motivation and self-esteem when faced with the challenge of carrying out authentic research projects and then reporting their results and exchanging constructive critiques with other students.

For more advanced science classes, *Invasion Ecology* provides opportunities to expand students' understanding of complex concepts related to ecology, invasive species, biological control, and the nature of conducting scientific research.

TABLE 1
National Science Education Standards Addressed through EI Research on Invasive Species Ecology

National Science Education Standards (NRC 1996)	Addressed in <i>Invasion Ecology</i>									
	Chapter 1 – Introduction	Chapter 2 – Population Ecology	Chapter 3 – Community Ecology	Chapter 4 – Ecosystem Ecology	Protocol 1 – Early Detection Surveys	Protocol 2 – Plot Sampling	Protocol 3 – Transect Surveys	Protocol 4 – Measuring Decomposition: Soda Lime	Protocol 5 – Measuring Decomposition: Titration	Interactive Research
Unifying Concepts and Processes in Science										
Systems, order, and organization	•	•	•	•	•	•	•	•		•
Evidence, models, and explanation	•	•	•	•	•	•	•	•	•	•
Change, constancy, and measurement	•	•	•	•	•	•	•	•	•	•
Evolution and equilibrium			•	•						
Science as Inquiry										
Abilities necessary to do scientific inquiry					•	•	•	•	•	•
Understandings about scientific inquiry	•	•	•	•	•	•	•	•	•	•
Physical Science										
Chemical reactions				•					•	
Life Science										
Biological evolution			•							
Interdependence of organisms	•	•	•	•	•	•	•	•	•	•
Matter, energy, and organization in living systems	•	•	•	•	•	•	•	•	•	•
Earth and Space Science										
Geochemical cycles				•						
Science and Technology										
Understandings about science and technology	•	•	•	•	•	•	•	•	•	•
Science in Personal and Social Perspectives										
Population growth	•	•								
Natural resources	•	•	•	•	•	•	•	•	•	•
Environmental quality	•	•	•	•	•	•	•	•	•	•
Natural and human-induced hazards	•	•	•	•	•	•	•	•	•	•
Science and technology in local, national, and global challenges	•	•	•	•	•	•	•	•	•	•
History and Nature of Science										
Science as a human endeavor	•	•	•	•	•	•	•	•	•	•
Nature of scientific knowledge	•	•	•	•	•	•	•	•	•	•
Historical perspectives	•	•	•							

WHY ECOLOGY OF INVASIVE SPECIES?

Ecology is a standard part of the life sciences curriculum. However, it is often only cursorily addressed. *Invasion Ecology* attempts to help students learn about this important scientific discipline in a rigorous manner and to apply ecological concepts to real-life environmental issues.

Your students may think of ecologists as people who pick up trash and protest for a cleaner environment. In this manual, we use the term ecologist to refer to scientists who study ecology—that is, the study of relationships among organisms and between organisms and their physical environment.

AUTHENTIC SCIENCE

Pick up any newspaper and you will be confronted with an array of environmental concerns ranging from global warming to local water supplies. Americans are concerned about the health of our environment, but we are uncertain how environmental issues should be taught in schools. Ecology, similarly to other sciences, sets forth fundamental principles that can be used to help us understand and manage our environment. Although no scientist can claim to be totally neutral, we can avoid more biased treatments of environmental issues by teaching students fundamental scientific principles and how to apply them toward solving environmental problems.

RELEVANCE

Invasive species constitute one of the most important threats to biodiversity in North America. Species are introduced, either accidentally or for a specific purpose, from every continent except Antarctica. About 1% of these species becomes invasive, outcompeting native plants and altering the habitat of native species. In agricultural lands, introduced invasive species cause millions of dollars in control measures and render some land unsuitable for cultivation. Along lake shores, zebra mussels can make it impossible to walk or swim in shallow areas. When species such as garlic mustard and purple loosestrife invade forests and wetlands, they outcompete native plant species, which in turn reduces the habitat and food available for wildlife. In cities, insects such as the Asian longhorned beetle kill ornamental trees treasured by communities, whereas the Norwegian rat, introduced several hundred years ago, may cause human health problems.

WHY ECOLOGY OF INVASIVE SPECIES?

In today's global economy, with cut flowers flown in daily from Europe and South America and people flying back and forth between continents, we are not able to close our borders entirely and prevent all new species from entering North America. We may be able to take some measures to limit the introduction of new species, such as treating ballast waters in ships and conducting awareness campaigns. For species that still enter accidentally or that are already established, we can use ecological science to develop effective means of control. Learning about ecology and invasive species allows students to address problems relevant to many different communities throughout North America.

ENGAGING STUDENTS

Some ecology courses teach ecological principles and then give a variety of examples. We have taken a slightly different approach—starting with real-life examples of the history and impact of invasive species and then using the examples to teach ecological concepts and principles. In addition, we present opportunities for students to engage in hands-on research, modeled after that conducted by scientists studying invasive species and other ecological problems. Thus, students learn about one discipline and one major environmental issue in depth, as well as principles and methods that can be applied to studying other ecological problems. By presenting the information in this way, we hope to engage students more fully in studying ecological science.

In sum, through the readings, exercises, protocols, and research projects in *Invasion Ecology*, students will learn not only about important ecological concepts, but also about how ecologists conduct research. Furthermore, they will learn how ecological science and research can be applied to solving a real-life environmental problem—the control of invasive species.

INQUIRY AND ECOLOGY

LEVELS OF INQUIRY

Environmental science is organized into two levels of inquiry modeled after research activities conducted by professional scientists. In general, when novice scientists first enter a lab, they learn a series of techniques from the more experienced scientists. Once they have mastered these techniques, they are encouraged to develop their own, open-ended research projects. Throughout this process, they interact with their peer scientists, who help them sharpen their research skills.

Similarly, in Environmental Inquiry (EI), students first learn standard research methods, or *protocols*. EI protocols introduce students to laboratory and field methods adapted from university research so they are feasible and safe for use by high school students. The protocols are inexpensive to carry out, yet are authentic techniques used by professional scientists. Experience with the protocols helps students develop basic skills and understandings they will be able to use in designing and carrying out more open-ended scientific investigations.

Having mastered one or more protocols, students are likely to come up with questions that could be addressed through open-ended, or interactive, research. This level is called *interactive research* rather than simply research because it emphasizes working collaboratively, similar to the way scientists work with their peers in laboratories and field settings.

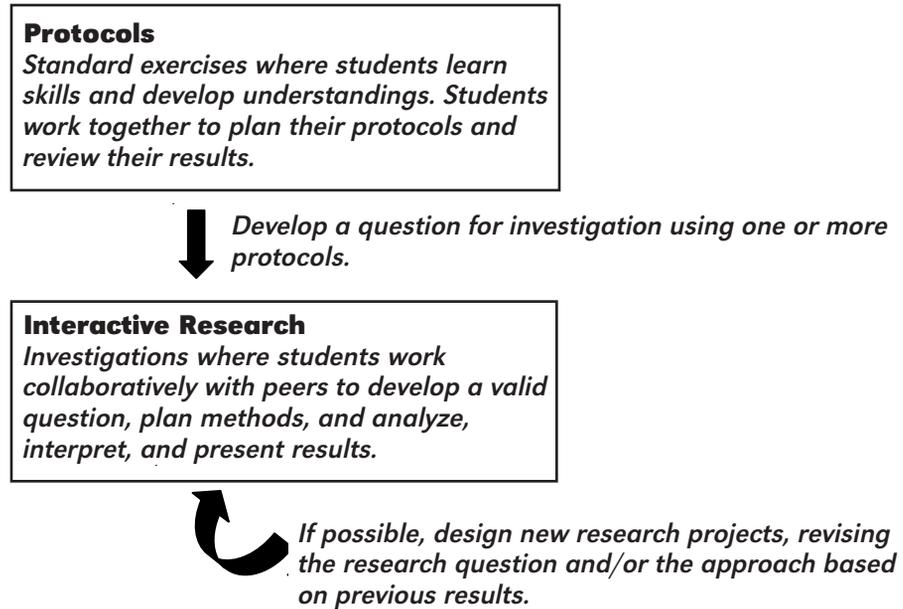
Interactive research is designed for students to follow the steps scientists normally conduct, including

- ▶ Narrowing down an interesting research question
- ▶ Using appropriate protocols to answer their question
- ▶ Sharing observations and advice with students conducting similar studies
- ▶ Discussing various possible interpretations of research results
- ▶ Presenting findings in oral or written form
- ▶ Participating in peer review of research presentations
- ▶ Recommending ideas and approaches for future research

INQUIRY AND ECOLOGY

As EI students move from protocols to interactive research, they accept increasing levels of responsibility for the design of their investigations. Similarly, there is a progression in interaction among students as they work with peers to define questions, analyze their results, argue among alternative interpretations, and communicate their findings to fellow student scientists and community members (see Figure 1).

FIGURE 1
Levels of Inquiry in EI



COOPERATION AND PEER REVIEW IN SCIENCE

A common misconception among students is that scientists are social loners who work in isolation with little connection to each other or society. In fact, research is a cumulative process, with each scientist learning from the work of preceding and contemporary researchers. Before embarking on a research endeavor, scientists typically begin by talking with colleagues, listening to presentations at conferences, and reading publications to learn what has already been accomplished and what questions remain unanswered.

Although much of the interaction among scientists is informal, researchers also have devised a formal process, called peer review, to help them separate fact from falsehood and good science from bad. Peer review, in which scientists critically review the research of another scientist working in the same field, plays a key role in determining which research endeavors receive funding, which conference papers get accepted, and which articles get published in journals. Just as importantly, the constructive comments provided by peer reviewers help scientists improve their research projects.

Thus, scientists depend on discussions with their peers to help them narrow down research questions, determine which methods are most appropriate to address those questions, and make sure the interpretations of their results are valid. In EI, we have attempted to reproduce such collaborations for students, both face-to-face and electronically with their peers in other classes and schools. Through modeling collaborative

processes that are integral to professional scientific communities, EI students improve their own work and enhance their critical-thinking skills. In addition, we have found that by participating in science as a social rather than an individualistic endeavor, students who tend to shy away from science may find it fun and so become engaged.

ECOLOGICAL RESEARCH

Although many people may think research always involves a controlled experiment, ecological research takes on a variety of forms. Nearly all ecological research involves careful fieldwork (work outdoors). Ecologists working in a new area may start by making an inventory of the plant and animal species. Once they have an idea of what is present, they often monitor changes in populations of organisms and in physical factors without imposing any experimental treatment. They may establish permanent plots so they can monitor species over a period of time. In fact, many ecological questions can be answered only by long-term studies (e.g., the response of a forest to clear-cutting or fire).

Once they are familiar with the species and physical factors at their research sites, ecologists may conduct a “natural” experiment in which they compare species in two or more habitats. For example, after observing that frog populations were declining in agricultural areas, scientists measured pollution levels and the health of frog populations in a series of lakes varying in exposure to agricultural chemicals. They then tried to correlate frog health to pollution levels. Although such a natural experiment may provide important evidence, it is not a true controlled experiment because the lakes vary in a number of ways, in addition to their exposure to agricultural chemicals. Furthermore, it is difficult to determine whether any differences in frog populations are due to differences in pollution in the lakes or to some other factor such as disease or the ability of certain types of frogs to colonize the different lakes.

In fact, scientists only rarely are able to conduct a true controlled experiment in the field, because study sites generally differ (e.g., in soil nutrients, slope, plant species), and thus they cannot find good controls. Nevertheless, some ecologists do impose treatments and compare treatment sites to reference sites, which are as similar as possible to the treatment sites. A famous example of such a “field experiment” in ecology occurred at the Hubbard Brook Experimental Forest in New Hampshire, where scientists clear-cut an entire watershed and compared the regrowth of plants there to growth in a watershed that had not been cut.

Laboratory studies offer ecologists a chance to study processes that occur in the field under more controlled conditions. For example, Cornell scientists measured methane production in outdoor wetlands. In a related laboratory study, they used measured methane production in quart mason jars of various soils gathered from the wetlands. In the laboratory study, the scientists were able to vary temperature while controlling for other factors such as soil type. Thus, such a laboratory study can determine the relationship of temperature to methane production under controlled conditions. However, ecologists still need to conduct fieldwork to determine whether what happens in the laboratory really represents what occurs under natural conditions, where many factors in addition to temperature interact.

In short, it generally is not possible to conduct one study to definitively answer an ecological question. Rather, ecologists answer questions by using a variety of approaches at different scales, ranging from broad field surveys to controlled laboratory studies. They

INQUIRY AND ECOLOGY

then piece together the evidence from these different investigations to determine the best possible answer to their question.

TABLE 2
Intended Learning Outcomes

Skills: Students will be able to
<ul style="list-style-type: none">▶ Conduct scientific research, starting with well-defined protocols and progressing to open-ended research projects▶ Work collaboratively to design research projects, interpret results, and critically analyze ideas and conclusions▶ Define a research question, then plan and carry out a study to address this question using surveys or other types of studies▶ Analyze data and draw conclusions about invasive species▶ Write a concise and accurate summary of methods, results, and conclusions▶ Use commentary from fellow students to revise or justify research reports and presentations▶ Critically analyze summaries of other students' research to determine whether each study was based on good research design▶ Provide constructive criticism of fellow students' data analyses, interpretations, and conclusions
Concepts: Students will understand that
<ul style="list-style-type: none">▶ Ecology is the study of living things and their interactions with each other and the physical environment▶ Population ecology is the study of how populations of organisms change in size and location▶ Community ecology is the study of how organisms interact with each other and how groups of organisms change over time▶ Ecosystem ecology is the study of how organisms interact with the physical environment▶ Invasive species are an important threat to biodiversity in North America▶ Biological control is one of several alternatives to controlling invasive species▶ Monitoring, laboratory, and field studies all contribute to our understanding of ecological systems▶ Scientists work both individually and collaboratively, reviewing each other's work to provide feedback on experimental design and interpretation of results; these "peer reviews" are used to make decisions about what research gets funded and what results get published in scientific journals▶ Scientific understandings are tentative, subject to change with new discoveries; peer review among scientists helps sort genuine discoveries from incomplete or faulty work