Activity 6

Examining the Effects of Pollution on Ecosystems

Duration	2 to 3 class periods
Grade Level	10-12
Key Terms/ Concepts	Acute Bioaccumulation Biomass Community Ecosystem Environment Population Relative abundances Species abundances
Suggested Subjects	Biology Chemistry Life Science Physical Sience

Purpose

This activity helps students recognize that hazardous waste may have far-reaching impacts on ecosystems and these impacts are not always easy to identify. Students become familiar with several types of tests used to measure the environmental effects of hazardous waste pollution. In the process, they learn that no single assessment procedure is applicable to all ecosystems and no single test is adequate to assess pollution impacts on an entire ecosystem. They examine a case study and discuss the limitations of current ecosystem assessment methods for establishing cause-and-effect relationships, especially for mixtures of chemicals in the environment.

Background

The impact of hazardous waste on the environment is thought to be widespread and in some areas severe. Establishing cause-and-effect relationships between exposure and ecosystem damage is a major challenge. An **ecosystem**—such as a marsh—is a highly complex structure, consisting of all living organisms in a given area and their interactions not only among themselves but also with the **environment**. Even a mature ecosystem—one that has achieved stability over time—is constantly adapting to changes. Some of these changes are due to natural influences such as animal migration patterns, weather, erosion, and sedimentation. Other changes, however, are the result of habitat encroachment and human pollution. This pollution is often in the form of complex mixtures of chemicals in widely varying concentrations.

Ecosystems are complex and dynamic (ever changing). This makes linking any one effect to a specific cause very difficult. Conditions cannot be controlled sufficiently to allow the effects of individual pollutants to be observed. Only recently have scientists begun to focus attention on finding ways to determine the major effects of hazardous waste on ecosystems.

Researchers have built laboratory models of ecosystems to study environmental pollution in controlled settings. But models can provide only simple representations of real ecosystems that contain thousands of living species. They cannot provide adequate measures of the diversity of species and the complexity of the relationships among all the living organisms that make ecosystems unique.

There is no single best strategy or design for assessing environmental pollution that is appropriate for every situation. The characteristics of the area and the specific objectives and issues of concern must be considered in determining how to proceed. Nevertheless, scientists generally use four major categories of tests to assess the impact of hazardous waste on ecosystems:

- **Chemical and physical tests** to measure contaminant levels, pH, oxygen levels, and other environmental conditions
- **Toxicity tests** to determine if the pollution can or is causing adverse biological effects in ecosystem species
- **Biomarkers** to indicate actual exposure
- **Field surveys.**

These ecological assessments are important tools in Federal and state government efforts to clean up hazardous waste contamination under the Superfund Program.

For additonal information on ecosystems and pollution, see the Suggested Reading list found at the end of the Haz-Ed materials. Other Haz-Ed materials related to this topic include *Fact Flash 2: The Superfund Cleanup Program*.

Preparation

1. Assemble the following materials:

   - Copies for each student of Student Handout 1, *Major Categories of Tests for Ecological Assessment,* found at the end of this activity
   - Copies for each student of Student Handout 2, *Case Study: Tidal Bay Ecological Assessment.*

2. Read the student handouts to prepare your lecture.

3. Distribute copies of Student Handout 2 and assign students to read the case study for homework.

NOTE: In this lesson, students will encounter a large number of scientific terms and phrases. Depending on the grade level in which you use the lesson and the skill level of your students, you may need to spend extra time introducing unfamiliar vocabulary and preparing your students for this lesson. Many terms are defined in the Glossary found at the end of the Haz-Ed materials, but a textbook may be helpful.

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Procedure

Class #1

1. Ask the class to define an **ecosystem**. Then ask the class to distinguish between an ecosystem and the environment. (An ecosystem is a specialized community, including all the component organisms, that forms an interacting system, for example, a marsh. An environment is the totality of conditions surrounding an organism.)

2. Organize the students in groups of 3 or 4 students each, and ask each group to write down how hazardous waste released into the environment can affect plants (flora) or animals (fauna) in an ecosystem. Ask them to list as many possibilities as they can think of in 10 minutes.

3. Ask each group how many ideas they wrote down.

4. Ask the group with the fewest ideas to lead off by naming one effect of pollution. Ask the rest of the class if they agree that the named effect can result from pollution. Ask those who agree to explain why they agree. Ask those who do not agree to explain their reasons.

   Continue the discussion by asking each group in turn to add to the list. Have a student write the ideas on the chalkboard as they are mentioned. Some possible effects that could be listed include:

   - Gaps in vital food chains or nutrient cycles
   - Reproductive problems (such as eggshell thinning or loss of nesting materials)
   - Developmental effects (such as malformed chick beaks)
   - Tumors (such as fish tumors)
   - Critical organ damage (such as liver, kidney, or skin lesions)
   - Immune system dysfunction (leading to, for example, viral infections in dolphins)
   - Altered individual or population growth rates
   - Changes in population and community organization
   - Loss of total **biomass** (flora and fauna)

- Relative loss of **taxa** or **species abundance** in defined areas (such as fish kills, amphibian mortality, **macroinvertebrate** depletion)
- Loss of species diversity.

Some of the students' ideas may overlap because one adverse ecosystem effect can impact another since life in ecosystems is interdependent. For example, reproductive and developmental problems in birds may ultimately cause a decrease in species abundance and diversity, which in turn may alter community organization.

Students may not come up with many ideas. In a way this reflects the current state-of-the-science in ecological assessment. It can be difficult to determine what is occurring or could occur in an ecosystem as a result of pollution; effects are often very subtle unlike those of habitat loss, which usually tend to be very obvious.

Leave the list on the chalkboard.

5. Distribute the Student Handout, *Major Categories of Tests for Ecological Assessment.* You may wish to have students discuss the various types of tests in more depth before proceeding.

6. Ask the students which category or categories of tests could be used to study each of the adverse effects listed on the chalkboard. Have students explain the choices they make. Encourage the rest of the class to comment on various answers.

Class #2

1. Give each student a copy of the Student Handout, *Case Study: Tidal Bay Ecological Assessment*. Give them about 30 minutes to read it in class or as homework. Questions and guidelines are in the text to assist them in their review. Ask them to answer as many of the questions as possible.

2. For the remainder of the class period, discuss the case study and the students' answers to the questions. An *Instructor's Answer Key* is included at the end of this lesson for your use.

Extensions (Optional)

- After allowing each group to add to the list of ideas about how hazardous waste can adversely effect ecosystems, ask students to rank the items according to their importance. Have them discuss their choices.

- Point out during the discussion that sometimes investigators limit ecological components of concern to commercially important species (e.g., blue crabs in the Chesapeake Bay). Have students discuss how this might influence public attitudes with respect to proposed environmental regulations or legislation.

Instructor's Answer Key – Handout 1

Case Study: Tidal Bay Ecological Assessment

1. *What are the benefits of comparing contaminant concentrations and biological impacts in Tidal Bay sediments with those of a reference area?*

   By expressing all chemical and biological measures as changes (increases or decreases) relative to a "normal" ecosystem (Shipshape), comparisons can be made that provide a sound basis for identifying and quantifying effects. Comparing results with a reference area allows investigators to determine not only what is not "normal" in the study area, but also how much weight to place on the changes.

2. *What are some of the limitations (problems) associated with the use of a reference area and with the choice of Shipshape Inlet as this area?*

   Shipshape Inlet differs in sediment type from Tidal Bay, and although it may be the least polluted area of those studied in the basin, it is hardly a pristine environment unaltered by urbanization and industrialization. Furthermore, comparing a complex biological response such as benthic macroinvertebrate community change with a reference site requires reducing the data to a single value(s), which results in a substantial loss of data.

3. *Can you think of another approach that would work?*

   If Tidal Bay contained only one or possibly two specific wastes, the contaminant concentrations and biological measures of their impact on the ecosystem could be compared with toxicity and risk levels published in the literature or in government databases. It is not known, however, how complex chemical mixtures interact to possibly increase or decrease the effects of individual chemicals. Further, the exact combination of chemicals in Tidal Bay may be unique. So, under these circumstances, the use of a reference area is probably the best choice.

4. *What impact do you think the presence of multiple types of hazardous waste will have on the ability of investigators to establish a cause-and-effect relationship between specific chemicals and adverse biological changes in Tidal Bay?*

   Ideally, characterization of ecological impacts from hazardous waste is supported by definitive cause-and-effect relationships between specific chemicals and biological endpoints. Almost no information is available for establishing cause and effect for chemical mixtures, however, so they will not be able to determine specific cause and effect relationships. In lieu of a standardized approach for assessing ecological impacts of complex chemical mixtures, the Tidal Bay investigators developed relative measures of effect based on the reference area.

5. *Do you feel these measurements are relevant to this aquatic ecosystem?*

A number of biological measures are used to quantify the pollution impact on Tidal Bay. These include several toxicity tests, benthic community composition, and fish histopathology. All of these measures can be justified on ecological grounds. For example, amphipods are crustaceans that reside in Tidal Bay and are important prey for higher trophic-level species like fish. Also, they are relatively sensitive to toxic chemicals and are highly likely to be exposed to contaminants because they burrow in and feed on sediment material.

Oysters also are considered useful indicators of ecological effects because they are very sensitive to toxic chemicals. The oyster test is a standardized test of developmental effects, which provides a broader view of adverse effects than lethality tests alone.

Benthic macroinvertebrate species also are valuable indicators of toxicity because they live in direct contact with sediments, are relatively stationary, and are important components of aquatic food chains. Many fish and crab that live near the sediment feed on benthic organisms and are exposed to contaminants through the food chain.

<u>Note</u>: Although the investigators avoided limiting ecological components of concern to commercially important species or to those selected for the sake of political expediency, the ecological significance of the effects observed in the bioassay tests is not explained in terms of the entire ecosystem of Tidal Bay.

6. *Are these measurements likely to furnish the kind of data required to fulfill the purpose of the assessment? If not, how would you change the approach?*

The use of multiple chemical and biological tests (such as sediment chemistry, sediment toxicity, benthic macroinvertebrate assemblages, tissue residues resulting from bioaccumulation, and fish liver histopathology) provides a powerful weight-of-evidence approach to identify pollution problems in an ecosystem. They also provide the kind of data needed to define the extent of hazardous waste contamination in estuarine sediments and the magnitude of damage to benthic organisms and fish.

7. *Investigators characterized degradation of benthic macroinvertebrate communities in terms of a decrease in the abundance of total amphipods, molluscs, polychaetes, or total macrofauna. Many conditions can influence the overall abundance of benthic macroinvertebrates, including an algae bloom that depletes oxygen in the water. Did the investigators' report consider all factors that could have altered macroinvertebrate numbers?*

   While some species may decrease in abundance due to chemical pollutants, other, more pollution-tolerant species are likely to increase. This makes changes in abundance at a major taxon level or at the total macrofauna level an unreliable indicator of ecosystem health. Generally speaking, a chemical pollution problem is the only condition that will render a waterway totally devoid of macroinvertebrates. However, the investigators did not study the levels of macroinvertebrate species in detail, possibly because of the extra costs involved. Precise and careful analyses of macroinvertebrate samples is time consuming and expensive. Also, they did not report looking at other possible causes for macroinvertebrate depletion.

8. *Could apparent effects thresholds be determined for bioaccumulation and histopathology in fish? Why do you suppose investigators did not do this?*

   Apparent effects thresholds could have been established for bioaccumulation and histopathology in fish, but the purpose of the apparent effects thresholds was to rank specific problem areas within the bay. The fish indicators reflect a wide area of conditions. Also, there is a lot of uncertainty associated with how much hazardous waste the fish have been exposed to in the water and food chain and for how long. Thus, it is difficult to link the bioaccumulation and histopathology data directly to chemical concentrations in specific sediment samples.

9. *What are some major strengths of the apparent effects thresholds and what are some limitations?*

   The apparent effects thresholds method is a plausible approach for dealing with problems created by contamination and uncertain cause-and-effect relationships. It uses empirical relationships to get around difficulties like bioavailability and synergistic and antagonistic relationships among chemical mixtures. The approach is limited for several reasons: it does not describe cause-and-effect relationships, it is site-specific (specific to certain areas), does not take into account data on bioavailability of chemicals in organ tissues, and lacks independent validation.

Major Categories of Tests for Ecological Assessment

There are 4 major categories of tests scientists use to study the effects of pollution on ecosystems:

1. **Chemical and Physical Tests** provide information on the total concentration of specific chemical compounds in the ecosystem and information on pH, temperature, moisture, and other measures. Samples of soil, sediment, or water are collected and usually taken to a laboratory for testing using several standard laboratory methods.

2. **Toxicity Tests** measure the number and severity of biological effects of contamination on the survival, growth, and reproduction of plants and animals. Most toxicity tests are conducted in the laboratory using laboratory-raised species or organisms collected in the field (from the ecosystem). Examples include:

   - **Acute** test (number of animal deaths) using field-collected specimens or test species such as earthworms or fathead minnows
   - Chronic growth, tumor, and functional tests of selected species (usually the most sensitive species)
   - Multigenerational reproduction and developmental tests of specific species
   - Gene and chromosome tests
   - Plant mutation tests such as stamen hair
   - Photosynthesis rates (usually tested in field)
   - Seed germination
   - Root elongation

3. **Biomarkers of Exposure** are sensitive indicators of a physiological, anatomical, or biochemical response to pollution exposure such as abnormal blood changes. They can be used as sensitive monitoring tools for detecting exposure. Individual organisms usually are obtained from the ecosystem and their blood and body tissues are examined. (Biomarkers are not considered adequate measures of biological effects at the population, community, and total ecosystem levels of organization.) Examples include:

   - **Bioaccumulation** tests indicate the level of chemical pollution that has gathered in an individual animal or plant and the availability of those pollutants to vulnerable tissues inside the body.

   - Blood enzyme levels are used to assess exposure to certain pesticides.

   - Histopathologic tests using light microscopy, electron microscopy, and chemistry involve examinations of specific tissues and organs like the liver and kidney to detect chemical damage. *(Histologic exams often are used in long-term and chronic toxicity tests to confirm findings.)*

4. **Field Surveys** involve observations in the ecosystem and tests on field-collected samples. Field surveys require many sampling excursions to avoid over- or underestimating. Examples include:

   - Abundances of native species and numbers of individuals within those species

   - **Relative abundances** of major taxa to determine community-level effects

   - Number of individuals with offspring

   - Estimates of total biomass (mass of tissue present in an individual, population, or community at a given time) or biomass of certain communities such as phytoplankton

   - Guild structure (functional feeding groups such as collector-gatherers or predators based on how organisms obtain their food) may change as a result of exposure to contamination. This can alter levels of competition for common resources.

Case Study:
Tidal Bay Ecological Assessment

This case study is an example of how one scientific group attempted to document the impact of a mixture of organic compounds and metals on an estuary, fictitiously named Tidal Bay. Although there is no single best strategy or design for ecological assessments that is appropriate for every ecosystem, the assessment techniques and lessons learned in this case study have implications for measuring the impact of pollutants in other ecosystems where water—fresh, tidal, or marine—is contaminated or threatened.

Directions:

1. *Critique this case study using the questions provided. <u>You may not understand all of the detail provided; for example, you probably will not be familiar with all the animal species and chemicals</u>. This should not limit your ability to see the logic underlying the investigation and the strengths and weaknesses of the approach. In the process, you will discover a lot about environmental science.*

2. *Read through the entire case study first, and then in a sentence or two answer each question.*

Approach

Purpose

This ecological assessment was conducted for the purpose of defining the extent of hazardous waste contamination in the tidal sediments (soil, stones, or other materials deposited by tidal waters) of Tidal Bay and to measure the magnitude of existing biological damage to **benthic** (bottom-dwelling) organisms and fish. It was not intended to be a risk assessment since it did not investigate the future of the ecosystem.

Concept

Concerns about the potential ecological and human health effects of hazardous waste in Tidal Bay focus on exposure of aquatic organisms to contaminated marine sediments. The sediments support a variety of benthic organisms that can be directly influenced by sediment contamination. Benthic macroinvertebrate species, such as shrimp, are valuable indicators of toxicity because they live in direct contact with sediments, stay close to their homes, and are important parts of aquatic food chains. Many fish and crabs that live in or near the sediment feed on benthic organisms and are exposed to contaminants through the food chain. Therefore, if tests on these benthic macroinvertebrates do not reveal negative effects caused by polluted tidal; sediments, it is unlikely that other biological groups, such as fish or plankton, are affected by these pollutants. For example, if the shrimp that live in the sediment are tested and have nothing wrong with them, the crabs and fish will probably be fine too, since they eat the shrimp.

Description of Area

The study area is a bay formed by a river delta made up of seven minor waterways, associated shorelines, and water at depths less than 60 feet below low tide. Tidal Bay is in a heavily industrialized area at the south end of a large basin. Industrial and municipal sources, such as a pulp mill, petroleum refineries, chemical manufacturers, aluminum processors, and a shipbuilding and repair yard are located on filled-in tideflats. A municipal sewage treatment plant discharges into the river upstream of the bay.

Selection of Reference Area

A reference area, Shipshape Inlet, was selected to compare against the contaminated sites in Tidal Bay. Chemical and biological measures taken in Tidal Bay are compared to this reference site. Shipshape Inlet was chosen because it is associated with the same large basin that includes Tidal Bay and has some of the lowest levels of the contaminants of concern in the basin. Also, an extensive amount of chemical and biological data are already available on Shipshape Inlet. The range of sediment types in Shipshape Inlet, however, does not include the fine-grained sediments characteristic of the Tidal Bay waterways.

Chemical Pollutants

Routine chemical tests for about 150 chemicals were completed on over 190 samples of surface and subsurface sediments collected from areas of the bay. Chemicals detected in more than two-thirds of the surface sediments include phenol, 4-methylphenol, polycyclic aromatic hydrocarbons (PAHs), 1,4-dichlorobenzene, polychlorinated biphenyls (PCBs), dibenzofuran, and metals.

The chemicals present in Tidal Bay at higher concentrations than those in Shipshape Inlet are causing the greatest concern. Twelve chemicals or chemical groups were at concentrations greater than 100 times and less than 1,000 times those in Shipshape Inlet. Nine chemicals or chemical groups were at concentrations greater than 1,000 times those in Shipshape Inlet.

1. *What are the benefits of comparing contaminant concentrations and biological impacts in Tidal Bay sediments with those of a reference area?*

2. *What are some of the limitations (problems) associated with the use of a reference area and with the choice of Shipshape Inlet as this area?*

3. *Can you think of another approach that would work?*

4. *What impact do you think the presence of multiple types of hazardous waste will have on the ability of investigators to establish a cause-and-effect relationship between specific chemicals and adverse (negative) biological changes in Tidal Bay?*

Measurement

To assess the health and condition of the selected animals (benthic macroinvertebrates and fish), several measurement endpoints were evaluated. These included:

1) toxicity tests using sediment species, population abundances, and community indicators (species richness and community similarity)
2) biomarkers for tissue residues of contaminants and fish histopathology (microscopic examinations of specific tissues and organs to detect chemical injury)
3) chemical tests of contaminants in the sediments.

The sediment toxicity tests were conducted in the laboratory using amphipods, oysters, or bacteria, and field-collected sediment samples with known chemical concentrations. Bioassays were repeated using the same sediment samples that were diluted to lesser contaminant levels.

The amphipod toxicity test measures death rates in a crustacean that resides in Tidal Bay and is an important prey for higher species like fish. Amphipods are relatively sensitive to toxic chemicals and are likely to be exposed to contaminants because they burrow in and feed on sediment material.

Although oysters do not live in Tidal Bay, they reside in other areas of the basin, and oyster embryos and larvae are very sensitive to toxic chemicals. The oyster toxicity test measures the occurrence of developmental abnormalities in larvae (and embryos) exposed to Tidal Bay sediments for 48 hours.

Abundances of benthic macroinvertebrates were determined from field-collected samples. Community indicators involved counting species richness and the amount of major taxa such as crustaceans and molluscs. Only decreases in abundances of major taxa in Shipshape Inlet were used to identify and rank problem areas in the bay. Bioaccumulation (contaminant concentrations in muscle tissue) of English sole (fish) and Dungeness crab were measured as biomarkers of exposure. Because contaminants were detected infrequently in the crab muscle tissue, only the English sole data were used to identify and rank exposure levels. Histopathological tests were conducted on the livers of English sole.

The magnitude of exposure was determined by the chemical concentrations of contaminants in sediments. Because sediments represent a sink for pollution (that is, pollutants tend to accumulate in sediments), organisms that live in it or on it are continuously exposed.

A number of measurements were used to quantify contaminant impact on the ecosystem. These include several bioassay species, benthic community composition, bioaccumulation, and fish histopathology.

5. *Do you feel these measurements are relevant to this aquatic ecosystem?*

6. *Are these measurements likely to give the kind of data required to fulfill the purpose of the assessment? If not, how would you change the approach?*

7. *Investigators characterized degradation of benthic macroinvertebrate communities in terms of a decrease in the abundance of total amphipods, molluscs, polychaetes, or total macrofauna. However, many conditions can influence the overall abundance of benthic macroinvertebrates including an algae bloom that depletes oxygen in the water. Did the investigators consider all factors that could have altered macroinvertebrate numbers?*

Analysis

The analysis of the ecological effects and exposure data involved mainly statistical comparisons of test results from Tidal Bay and the reference area. For example, Tidal Bay sediments from 18 of 52 tested areas induced significant, acute lethality in amphipods as compared with the reference area sediments. Significant elevations in oyster larvae abnormalities occurred in sediments from 15 of 52 areas tested compared with sediments from the reference area. Significant decreases in the abundance of total taxa and the abundance of polychaetes, molluscs, and crustaceans occurred in 18 of 50 areas tested in Tidal Bay compared to the reference area.

Concentrations of most metals in the muscle tissue of English sole were less than 2 times the average reference concentrations, but concentrations of copper in the Tidal Bay fish tissue were 3 to 9 times higher than average reference concentrations. Polychlorinated biphenyls (PCBs) were detected in all fish and crab sampled. Lead and mercury were elevated in Dungeness crab with maximum concentrations about 5 times the reference concentrations.

Histopathological analyses revealed the presence of liver abnormalities that were significant in terms of number in Tidal Bay compared to the reference area. The incidence of liver lesions was greatest in fish from areas with the highest concentrations of sediment-associated contamination.

Characterizing and Ranking Problem Areas

The original data from the toxicity tests, abundances, and biomarkers were used to evaluate the increases in contamination or negative effects to determine if these changes were statistically significant. They were also used to evaluate quantitative relationships among these variables. However, because single-chemical relationships between exposure and effects could not be established (that is, a one-to-one relationship could not be proved), two methods were used to characterize and express the ecological impacts:

1. **Biological Indicators**. Using both exposure (chemical concentration) and effects data (from toxicity tests, macroinvertebrate abundances, and biomarkers), investigators developed ratios between the effects in Tidal Bay and those found at the reference site, Shipshape Inlet. The ratios, or biological indicators, were used in describing the overall impact of contamination on the ecosystem.

2. **Apparent Effects Thresholds**. Because biological effects data were not available for all portions of the study area, a method was developed to estimate thresholds of chemical concentrations above which biological effects would be expected. These are called apparent effects thresholds. Threshold concentrations of contaminants were estimated using data generated from the amphipod mortality toxicity test, oyster larvae abnormality toxicity test, and macroinvertebrate abundances. These measurements were selected because of their sensitivity to sediment contamination, availability of standard test protocols, and ecological relevance. The apparent effects thresholds were compared with measured concentrations of sediment contaminants. The apparent effects thresholds indicate the potential for adverse ecological effects in Tidal Bay.

8. *Could apparent effects thresholds be determined for bioaccumulation and histopathology in fish? Why do you suppose investigators did not do this?*

9. *What are some major strengths of the apparent effects thresholds and what are some limitations?*

10. *Name one point you learned that you feel is most interesting.*