SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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Student Materials

Learning Sequence Item:

953

Cycles and Ecosystems

March 1996
Adapted by: Linda W. Crow

Contents

This micro-unit was adapted by Linda W. Crow (Baylor College of Medicine, Houston)

Student Sheet

Science as Inquiry

How Does My Garden Grow?

In what forms does nitrogen exist in the environment and what role does it play in plant growth?

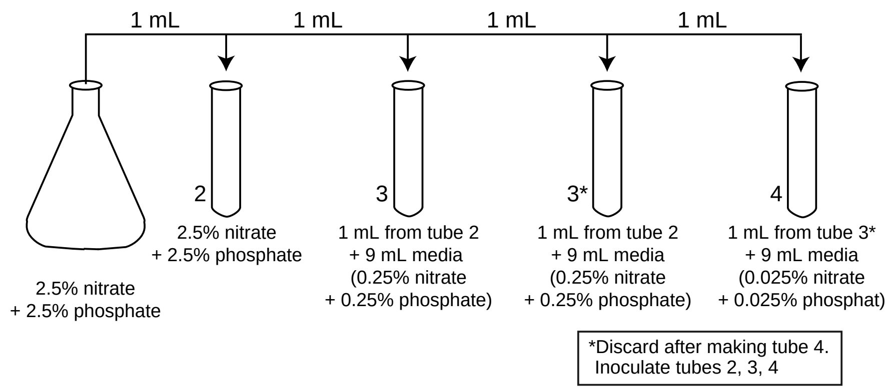
Overview:

What do plants need to grow? Algae will be your plant in this activity.

Procedure:

Seed germination. Your teacher will provide you with bacteria, seeds, and potting materials. Your task is to design an experiment to see how the bacteria affects seed germination. Plant the seeds and care for your garden as your teacher directs. Remember to set up a control!

Algae growth. In this experiment, you will determine how different concentrations of inorganic nutrients affect the growth of algae. First, create a dilution series using nitrate and phosphate as instructed by your teacher and according to the diagram below. Inoculate each test tube with an equal quantity of Chlorella, (algae) seal the tubes, and place them in a lighted location. Devise techniques for measuring the growth of algae in each container over several weeks.



Questions:

Seed germination.

1. Describe the conditions that you are holding constant in this experiment.

2. How does the presence or absence of bacteria affect seed germination?

3. Can you identify the bacteria? Think of ways to test your hypothesis.

Algae growth.

1. What does the dilution series allow you to test?

2. Describe the conditions that you are holding constant in this experiment.

3. Describe the growth of algae in each tube. Offer explanations for what you see.

4. What conditions or situations might cause these conditions to occur in nature?

Science as Inquiry

Plant Power

How do plants participate in the water cycle?

Overview:

Some people place celery in cold water so it does not wilt. Why do they do this?

Procedure:

Your goal is to explore the conditions that promote or hinder the movement of water in plants. Core the potatoes and prepare the sucrose solution dilution series. Weigh and measure the length of each potato core. Agree on a way to describe varying degrees of rigidity.

Place each core in a dish and pour the appropriate solution over the cores. After 30 minutes, remove each core from its solution, dry them, and check their rigidities. Return the cores to the solutions (make sure you place them in the right one!) and place the petri dishes in the refrigerator.

The next day, remove the dishes, dry the cores, and measure their weights, lengths, and rigidities. Record your results in the data table. Now construct a graph that shows change in length versus solution concentration.

Questions:

1. How did you determine the degree of rigidity?

2. Explain any initial differences in rigidity for the potato cores.

3. After 30 minutes, how did the cores vary in their rigidity?

4. How do the initial and final rigidities values compare to the initial and final lengths of the cores? How does rigidity compare to weight?

5. How can you explain any relationships?

History and Nature of Science

Rising Rates

How do plants participate in the water cycle?

Overview:

This procedure was used by a scientist to see how plants move water.

Procedure:

This activity uses a potometer. Assemble one using the diagram below.

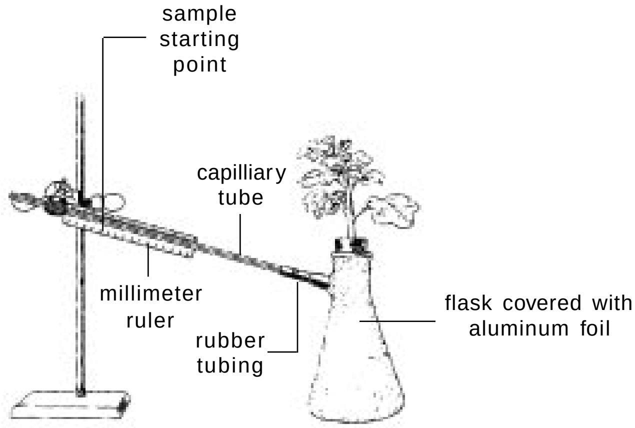
Fill the flask with distilled water and place the branch and stopper into the opening. If the water does not move into the capillary tube immediately, then use the syringe to add some water. Measure the rate of movement over a ten minute period.

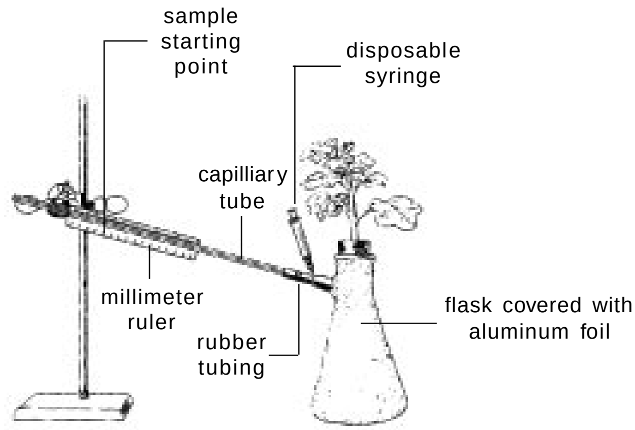
Questions:

1. Describe the rate of movement.

2. How do plants participate in the water cycle?

3. Try the experiment again and determine the effects of light intensity on water movement.





Student Sheet

Science as Inquiry

Tracking Down Carbon in Living Systems

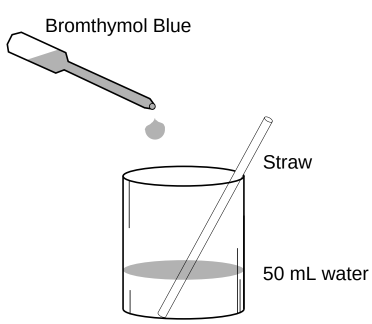
Does carbon cycle from animals to plants and the atmosphere?

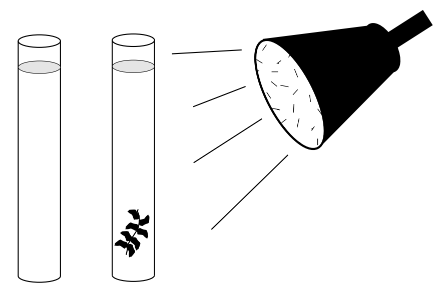
Overview:

Carbon is described as moving in a cycle. How do we know this?

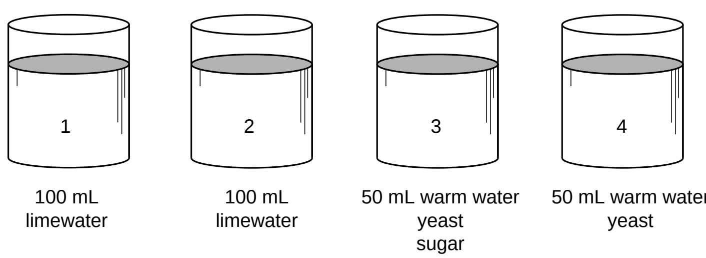
Procedure:

Part A. Add a few drops of bromthymol blue to 50 mL of limewater. Add a straw and exhale into the straw. What happens? Why?



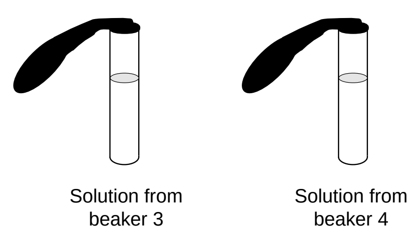


When a change has occurred, add 0.1 gram of baking soda and pour the solution into two test tubes. Place a sprig of Anacharis (Elodea) in one tube, stopper them, and place the tubes in front of a light. Make observations every 10 minutes for 45 minutes.



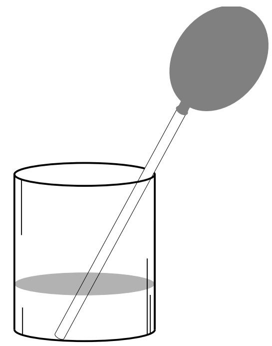
Part B. Pour 100 mL of lime water into two beakers. Then mix 50 mL of warm water with 1 package of dry yeast and 1 teaspoon of sugar in a third beaker. Finally, mix 50 mL of warm water and the other package of yeast in a fourth beaker.

Fill a test tube half full with the solution of yeast-sugar-water and another test tube half full with the solution of just yeast-water. Stretch a balloon over the opening of each test tube to capture any gas that is produced.



If a gas is produced carefully transfer the filled balloon to a straw and stick in one of the beakers of limewater. What happens?

After the students have completed both parts of this experiment, have them draw a diagram of how carbon is cycled from plants to animals and to the atmosphere.e.



Beaker with limewater

Questions:

1. From this experiment, what materials is the sprig of Anarcharis using? How do you know?

2. From this experiment, what materials is the sprig of Anarcharis producing? How do you know?

3. Create a diagram tracing the pathway of carbon dioxide in this experiment?

4. It would seem that we need plants and the plants need us. What evidence supports this statement.

Student Sheet

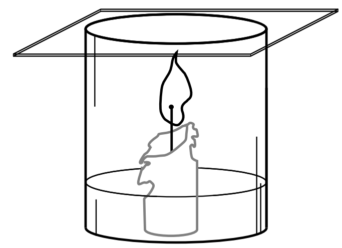
Science as Inquiry

Tracking Down Carbon in Nonliving Systems

How does carbon cycle in nonliving materials such as rocks and ocean sediments?

Overview:

Carbon in a cycle can be found in nonliving things. How can we find this carbon cycle?



Procedure:

Place 15 mL of limewater in a beaker and cover it with a glass plate. Shake for 10–15 seconds and quickly pour it into a test tube. Next place a candle in the beaker and add 15 mL of limewater to it. Light the candle and cover the beaker with a glass plate.

When the candle has gone out, shake the beaker as you did before, for about 10–15 seconds. Compare this shaken limewater to the first test tube of shaken limewater. Using different soil samples, determine the acidity of the soil. Finally, exhale into the limewater until it is as milky as possible. Filter it and let it dry overnight. What does it look like?

Questions:

1. Create a diagram that traces the carbon in this series of experiments.

2. If large amounts of material are burned in the atmosphere, what are the results?

Science as Inquiry

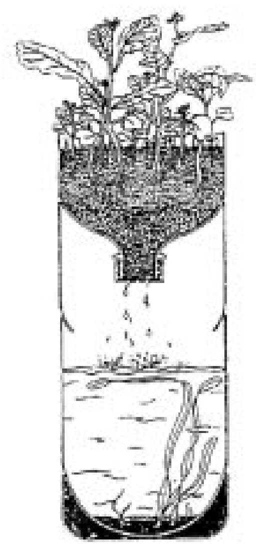
Life in a Bottle

How do ecosystems interconnect?

Overview:

Create your own ecosystem using plastic bottles.

Procedure:



Your goal in this experiment is to devise a system to study the interaction between a terrestrial and an aquatic environment. Your teacher will provide you with a variety of materials, along with a column constructed from 2-liter plastic bottles (you may be asked to construct this column yourself). The upper portion of the column will house a terrestrial environment. You can fill this portion with different types of soil, nutrients, and fertilizers, and observes the growth of seeds or plants in this environment. The lower portion of the column houses an aquatic environment. You can fill this portion with pond water, plant life, algae, or other aquatic organisms.

The column set-up provides many options for a research study. Take care to design your experiment carefully, controlling as many variables as possible to ensure that your are testing what you think you are testing.

Questions:

1. Describe your experimental design. What is your hypothesis? What variables are involved? How do you plan to control them?

2. Describe how your system responds over time. How were terrestrial changes reproduced in the aquatic environment?

3. How might the changes that you are studying appear in nature? What would be some causes for the situation you are modeling to occur in nature? Can you propose some ways to alleviate the effects?

Science as Inquiry

It's a Small World . . .

How do abiotic factors and relationships between organisms affect ecosystems?

Overview:

Use ordinary snails and Elodea to create different worlds in this activity.

Procedure:

Your goal in this experiment is to explore the effects of biotic and abiotic factors on a miniature ecosystem. Collect the materials from your teacher and set-up four different environments, consisting of the following components:

Bottle 1. pond water, snail, 3–4 drops bromthymol blue
Bottle 2. pond water, snail, Elodea, 3–4 drops bromthymol blue
Bottle 3. pond water, Elodea, 3–4 drops bromthymol blue
Bottle 4. pond water, 3–4 drops bromthymol blue

Seal the bottles with paraffin, and place them in a lighted or dark location as instructed by your teacher. Over the next four days, observe the bottles, noting color changes, snail activity, and Elodea growth. Compare your findings with those of the other groups.

Questions:

1. Describe what happened in each bottle. Explain any color changes you observed. What do these changes tell you about conditions in the bottles?

2. How did biotic factors influence conditions in each bottle?

3. What abiotic factors were involved in this experiment? How did these factors influence conditions in each bottle?

4. Which conditions were most conducive to the snail population? Explain your answer.

5. What would happen if you introduced more snails to Bottle 2? More Elodea? Explain your answer.

Student Sheet

Science as Inquiry

Heat Sensitivity

How do abiotic factors affect ecosystems?

Overview:

How can you tell if an organism likes a particular environment? Use Daphnia in this activity and find out.

Procedure:

In this experiment you will explore the effects of heat on two different organisms: Daphnia and yeast. Your teacher will set-up two stations where you will perform tests on these specimens.

Station 1: Daphnia. Several different Daphnia cultures in water baths of varying temperatures have been set-up. Remove one Daphnia from each culture to a slide and observe the heart rate of each organism, recording the number of beats per minute in a table. Graph the results with respect to temperature.

Station 2: Yeast. Your teacher will set-up fermentation tubes, along with a concentrated yeast solution and a glucose solution. Place a predetermined amount of each solution in one of the fermentation tubes, filling the side-arm completely, but leaving the bulb partially empty. Plug the opening with cotton. Then place the tubes in a water bath, and measure the length of the gas column that accumulates in the side-arm. Perform this procedure for the rest of the water baths. When finished, graph the length of the column as a function of temperature.

Questions:

1. What types of responses did you observe in each organism?

2. How did the organisms respond to increases in temperature? Did any seem more comfortable with the changes than others? What do you think would have happened to each organism if you had continued to increase the temperature?

3. List some environmental factors that could cause temperature to rise? Given what you have seen in this laboratory, what impact do you think temperature changes have on ecosystems?

Science as Inquiry

Daphnia Farming

How do environmental condictions affect populations?

Overview:

Old MacDonald had a farm—but he had only Daphnia. There are some environmental problems, so help this farmer out!

Procedure:

In this experiment, you will explore how different environmental factors affect Daphnia populations. Design your experiment around a specific hypothesis. Consider, for example, how temperature might affect the colony. Harden or soften the water and see how the colony responds. You should test for a specific variation in the environment, and hold all other conditions in the colony as constant as possible. Other students in the class will investigate how other conditions affect the colony. Remember to compare your observations to the control, and to offer explanations for what you observe.

Questions:

1. State your hypothesis and outline your experimental design. What factors will you hold constant? Which will you vary? How will you collect data to support your hypothesis?

2. How did individual organisms respond to the initial environmental changes? Did the population as a whole change significantly

3. Discuss how prolonged exposure to the conditions affected your colony. Did the population benefit, or was it harmed by the changes? Did the colony adapt? Was reproduction affected? How did younger Daphnia respond compared to the starter population?

4. How might the conditions that you tested in laboratory be reproduced in nature? Would natural Daphnia respond the same as your population? How would a change in Daphnia population affect other organisms in the ecosystem?

Science in Personal and Social Perspectives

Mystery Matters

The fish were dying, by the tens, hundreds, thousands. No one knew why. Experts at the Wisconsin Department of Natural Resources (DNR) were scratching their heads, unable to explain why the dead sturgeon, white bass, walleye, and other fish were floating on a three-mile stretch of the Fox River that flows through the city of Oshkosh. This stretch of river links Lake Winnebago and Lake Butte des Morts.

Solving the mystery would mean countless hours of tracking down, and finally discarding, all the plausible explanations and eventually settling on an explanation that the scientific literature seemed to rule out.

According to Joe Ball, a DNR water resources specialist, there had been fish kills on that stretch of river for about 30 years. One or two major kills had occurred annually. Ball explained that fish kills are not terribly unusual. They're often the result of natural causes, such as the stress of spawning or a lack of dissolved oxygen in the water; the. latter can be caused by an overabundance of algae or decaying plants. But in 1986 the frequency and severity of the die-offs increased so noticeably that the DNR began to investigate.

'People were starting to think •i there was something going on here besides natural factors,' Ball said.

The kills would typically go on for between one and three days, then stop. The largest kill occurred just after Memorial Day weekend in 1988, when an estimated 30,000 white bass and sheepshead died.

A kill that size meant something unnatural was going on, explained Ball. "There shouldn't be that many fish dying in this section of the river, especially since monitoring hadn't indicated any problem with dissolved oxygen, which is commonly found as a cause of a fish kill.'"

Usually low levels of dissolved oxygen can be recognized just before sunrise. "The reason is," said Bail, "there is plenty of dissolved oxygen during the day, when algae are busy using sunlight in photosynthesis. At night the plants are taking back the oxygen (emitted during photosynthesis), and threatening the fish with suffocation." But the scientific sleuths discovered no lack of dissolved oxygen in the water.

"We had no idea what to look for," said Ball. "Any of a thousand things might be doing it."

Dead wrong

Could it be pesticides and herbicides washing into the river from a nearby golf course? The section of the city bordering the river is a filled-in wetland. Could some long-forgotten toxic material, used as part of the fill, now be leaking into the river? Were there barrels rusting on the river bottom, 20 or so feet below the surface, with poisons oozing into the water? In fact, Ball said, recently a barrel containing chemical residue had been found floating in the river.

A number of storm sewers discharge into the river. Had a "midnight dumper" been illegally pouring toxic materials into them? What about bioaccumulation? Were insect larvae feasting on contaminated sediments and becoming poisoned food for the fish? Were the fish infected with some harmful bacteria or virus? Like a mystery novel, there were a number of plausible explanations. Ball checked them all.

"We were testing the water. We were testing the sediment. We were taking numerous water samples and analyzing for toxic organic compounds and toxic metals. We were also testing the fish," Ball explained.

The intensive work continued through the summers of 1986, 1987, .and the spring of 1988. And, as in a good mystery novel, the plausible leads, one by one, turned into blind alleys. The tests were all negative.

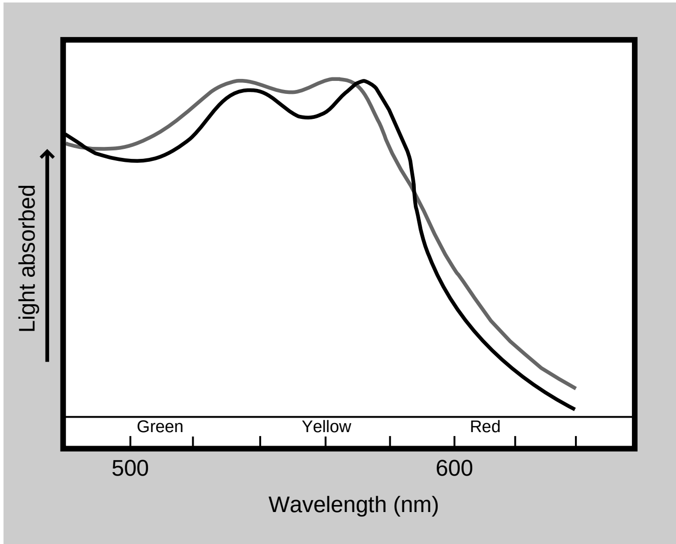


Fig. 1. When light is passed through blood, some of it is absorbed. The amount absorbed depends on the color of the light and the chemical condition of the blood. The black line on the graph shows the absorbance spectrum of blood that is saturated with oxygen; the gray line is blood saturated with carbon monoxide.

But this wasn't a novel. There was something harmful in the environment, and the DNR had to find it. Attention focused on the Oshkosh sewage treatment plant, which discharges its waste into this section of the river, because large numbers of dead fish appeared just downstream from the plant. Furthermore, according to Ball, low levels of chlorine used to treat the waste can be toxic to fish.

"We were able to detect concentrations of chlorine in the water that were borderline," Ball continued. To check out this possibility, cages of live fish were hung directly in the path of the plant's discharge. "The fish survived. We totally eliminated the sewage treatment plant as having anything to do with the fish kills," said Ball. The plant's operators could breathe easier but not the people who lived near the river. The dead fish stank and they weren't pretty to look at. The public wanted an end to the mess.

Last chance

With just about every explanation examined and rejected, the scientists turned their attention to the testing facility of a major outboard motor corporation. It is located across the river from the sewage treatment plant, a few hundred yards downstream.

"It was a process of elimination," said Ball. "After doing a lot of analysis, taking a lot of samples, and coming up with zeros for everything, we finally started looking at that plant."

According to Ball, the firm tests as many as a dozen prototype motors at a time. Mounted on boats that are tethered along the shore, they can collectively burn as much as 4,000 gallons of gas a day and generate up to 3,000 horsepower.

Focusing on the testing facility raised a new set of questions. What could the motors be putting in the water? What kind of tests were needed to examine these compounds? According to Ball, researchers had examined the effects of outboard motors on the environment, but both industry and independent findings showed no reason to be concerned.

Nevertheless, officials at the DNR examined the scientific literature to see what was coming out of the exhaust pipes of the motors. Volatile organic compounds were one product. But Ball said they "were nowhere near lethal levels for fish."

Cold-blooded victims

Eventually the search narrowed the possible culprit to carbon monoxide. A product of incomplete combustion, CO is a colorless, odorless gas. And it can be lethal. If inhaled, it attaches itself to the hemoglobin molecule in the blood, preventing this molecule from doing its job of carrying lifegiving oxygen to the tissues. Carbon monoxide not only takes the place of oxygen but also forms a much tighter bond to hemoglobin than does oxygen. The result is suffocation (see "Pumping Oxygen," Chem Matters, February 1984).

As a possible culprit, carbon monoxide brought along its own share of problems. For one thing, Ball said, there is no convenient way to test for it in water. Second, it's not very soluble in water and disperses rapidly into the air, so it appears unlikely that fish would take it up.

"We had looked at everything" explained Ball.

"We got a call from Joe Ball," remembered Tom Ecker, a chemist at the Wisconsin State Laboratory of Hygiene, "and he had this weird request. He wanted me to take a stab at ruling out carbon monoxide poisoning in fish."

Ecker said he had never heard of the possibility that fish could suffer from carbon monoxide poisoning. When Ball told Ecker of another fish kill, the chemist got ready to test the fish blood for carbon monoxide. In a sense Ecker was flying blind. The instrument he used was a CO

Oximeter, a standard instrument used to test for CO in human blood. The CO-Oximeter measures the transmission of light wavelengths through blood, allowing investigators to determine the percent of oxyhemoglobin, carboxyhemoglobin, total hemoglobin, and oxygen content (Fig. 1). But Ecker said no one had tested fish blood for this compound before, so there were no standards of judgment.

Ball brought the samples of fish blood to the lab. Ecker tested control samples-—fish not exposed to carbon monoxide. He compared those results with tests of blood from fish killed in the infamous stretch of the Fox River.

"I got significant differences," said Ecker. The blood of the fish that were killed showed a 60–70% saturation of carbon monoxide, which means that 60–70% of the hemoglobin molecules that would normally carry oxygen were bound up with carbon monoxide instead. The control fish showed less than 10%. Ecker thought the results showed the carbon monoxide hypothesis was "on to something.'

'I usually look at human blood, where we see fatalities at anywhere from 30% to 90% (CO concentration)," he said.

Because of the newness of these findings, Ecker was not satisfied with one test. He used the palladium reduction method to confirm the results (see Chem Matters, December 1984). This involves using acid to decompose the carbon monoxide-hemoglobin bond. The released carbon monoxide is trapped in a solution containing a palladium compound. The palladium, as a result, changes from its ionic state to its metallic form.

"A mirror tends to form," explained Ecker. "You have metal formed at the surface of the liquid that looks like a mirror. The more carbon monoxide, the more of this is formed."

There were other tests. Ball said carbon monoxide was injected into a tank of live fish. The fish died quickly. Caged live fish were placed at a site near the outboard motor tests in the Fox River. A similar cage was placed at a control site. In eight hours the fish near the test site were either dead or dying. Their blood carbon monoxide saturation was between 50% and 80%. The control fish were healthy.

"As scientists, we were sure, as sure as you can possibly, get that carbon monoxide was responsible for killing the fish," asserted Ball.

Finding that carbon monoxide was responsible for the fish kills meant more than solving a mystery. It helped teach a valuable lesson: Use caution in interpreting the scientific literature. As both Ecker and Ball said, previous experiments had shown that carbon monoxide was not a threat to fish.

"Scientists are taught you shouldn't have to reinvent the wheel," said Ecker. "We're told to go to the literature."

But it's important to be alert to the limitations of past experiments and note how the phenomenon being investigated differs from the published experiments.

As both Ecker and Ball pointed out, the Fox River situation differed from published reports because in the Fox River immense amounts of carbon monoxide were being forced into the water by powerful propellers (outboard motors vent their exhaust underwater because the water muffles the noise). When this was combined with higher water temperatures in the summer, the fish were more susceptible to the CO's lethal effects.

Ball said that when water temperature increases, the metabolism of fish does also, but the amount of oxygen in the water decreases. Consequently, the fish pump more water-—in this instance laden with carbon monoxide—through their gills.

But why did the fish kills suddenly increase in the last few years? The company's test facility has been there for nearly 30 years. Ball said that the company recently had started running more powerful motors, meaning more carbon monoxide was being injected into the water.

When the DNR presented its findings to the firm, its environmental and safety director said he was surprised at the results. He declined to discuss the matter further because of lawsuits over the cost of the fish kills. But a company-hired consultant verified the findings, though he said, "When I first heard the suspicion (that the CO was responsible for the fish kills), I laughed. It was so far out...." He, too, declined further comment because of the lawsuits.

In light of the findings, the company installed an exhaust venting system. Now the outboard motors are attached to a system of pipes, which prevents the carbon monoxide from getting into the water. The pipes carry exhaust gases directly from the motors to a stack, where they are dispersed into the air high above the city.

With the installation of that system in the spring of 1989, the problem appears solved. No fish kills were reported in the summer of 1989 in that once-deadly stretch of the Fox River. In July 1990, the company paid the state of Wisconsin $40,000 in penalties for the fish kill. They also paid $20,000 to finance a study of fish in the Fox River.

If you're worried about outboard motors on lakes threatening fish with carbon monoxide poisoning, you can relax. Both Ball and Ecker say the testing facility is unique in the force with which it injected large amounts of gas into a small stretch of the river. The amount put into lakes by normal outboard motors is generally so small and the lakes are so large that there is little to be concerned about. ▲