Case Study—Persistent Pesticides and Matter Flow

There is no better way to understand the flow of matter through an ecosystem than to study food webs. That is true of both natural organic matter and toxins (poisons) introduced by humans. In this case study, you will investigate the impact of pesticides on ecosystems.

Why use pesticide? The most common reason in Canada is to protect crops against losses due to pests. A second reason is to control populations of insects that cause disease. For example, in some regions of Canada, mosquitoes can carry the virus that causes West Nile disease. Many areas are sprayed with pesticide to reduce mosquito populations and thereby protect humans.

Worldwide, approximately 2.3 million tonnes of pesticides are used each year—about 0.4 kg for every person on Earth. About 75% of these chemicals are used in developed countries. As well as in agriculture and for disease control, pesticides may be found in shampoos, carpets, mattresses, and paints. More than 25% of pesticides are used in homes, gardens, and parks.

Table 1 shows the use of pesticides by different sectors in Alberta. Agriculture uses the highest amount by far. Herbicides make up about 77% of the total sold, while insecticides account for only 5.4% and plant fungicides approximately 3.6%.

Table 1 Pesticide Use in Alberta by Sector (from Pesticide Use in Alberta (1998) Factsheet, Alberta Environment)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Total use (T of active ingredient)</th>
<th>Estimated area (ha)</th>
<th>Use intensity (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural/commercial</td>
<td>7600</td>
<td>9 547 000</td>
<td>0.8</td>
</tr>
<tr>
<td>Home and garden</td>
<td>72</td>
<td>23 000</td>
<td>3.1</td>
</tr>
<tr>
<td>Edmonton parks</td>
<td>4.0</td>
<td>8 600</td>
<td>0.5</td>
</tr>
<tr>
<td>Calgary parks</td>
<td>3.6</td>
<td>7 400</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Pesticides can be grouped into four different categories (Table 2), according to the type of organism that they target. Within each of these categories, some pesticides will dissolve in fats (fat-soluble) and others will dissolve in water (water-soluble). Different pesticides also break down in the environment at different rates. This is called the persistence of the pesticide. Table 2 shows you the wide range of persistence. Pesticides that remain in the environment for long periods are called persistent pesticides.

Table 2 Classification of Pesticides

<table>
<thead>
<tr>
<th>Type of Pesticide</th>
<th>Target</th>
<th>Examples</th>
<th>Persistence</th>
</tr>
</thead>
<tbody>
<tr>
<td>insecticide</td>
<td>insects</td>
<td>DDT</td>
<td>high (2-15 years)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Malathion</td>
<td>moderate (1-2 weeks)</td>
</tr>
<tr>
<td>herbicide</td>
<td>weeds</td>
<td>2,4-D, Silvex, Roundup</td>
<td>mostly low (days to weeks)</td>
</tr>
<tr>
<td>fungicide</td>
<td>moulds and other fungi</td>
<td>Captan</td>
<td>low (days)</td>
</tr>
<tr>
<td>bacteriocide</td>
<td>bacteria</td>
<td>penicillin, vancomycin</td>
<td>mostly low</td>
</tr>
</tbody>
</table>
Bioamplification

Whenever a pesticide is used, organisms in the environment become contaminated by the pesticide to some degree. Imagine a canola field is sprayed with insecticide. Any organism that eats the canola would ingest some of the pesticide. If the organism is the target of the pesticide, it would likely die. However, some of the pesticide will land on plants other than the canola and some will land on the soil and water in the area. Wind might carry it away from the canola field. As they eat and drink, organisms in the environment that are not the intended target will also become contaminated. The chances that a non-target organism will become contaminated are higher for a persistent pesticide. Since persistent pesticides take a time to break down, they remain unchanged in the ecosystem for long periods. There is therefore more time and opportunity for non-target organisms to become contaminated by a persistent pesticide. If the pesticide enters the water supply, it can be carried great distances and non-target organisms can be exposed far from where the pesticide was applied.

Non-target organisms often are not killed by these low amounts of contamination. However, a contaminated organism will retain small amounts of a fat-soluble pesticide in the fat cells of its body if it cannot break it down. Over time, the amount of pesticide in its fat builds up. In contrast, a water-soluble pesticide will be excreted in sweat and urine and so will not build up in the body. Whenever an organism retains a toxin, such as a pesticide, in its body, all the organisms at higher trophic levels in the ecosystem will be affected. As you will see, as we move up to higher trophic levels, the concentration of the fat-soluble pesticide in each organism will increase. This process is called bioamplification.

Figure 1 shows a simplified example of bioamplification. The contaminated primary consumers (the grasshoppers) are prey to secondary consumers (the shrews) in the food chain. The secondary consumers eat many of these prey animals. As a result, although the body of each prey animal contains only a small amount of the pesticide, a much larger amount of the pesticide will be in the secondary consumer’s body. At the next trophic level, the secondary consumers (shrews) are eaten by the third-level consumer (an owl). The body of the own contains all the pesticide in each shrew it eats.
Consequences of a Persistent Pesticide: DDT in Alberta

The first widely used synthetic pesticide was developed in 1939, when Paul Mueller found that dichlorodiphenyltrichloroethane (DDT), a chemical known since 1874, was a potent insecticide. This chemical was quickly adopted in Western Canada, to address a devastating problem with grasshoppers. In some years, giant clouds of grasshoppers blackened the sky. Each adult grasshopper is capable of eating its own body weight in crops every 16 h. By the late 1940s and 1950s, DDT was used by nearly everyone as the technological fix to this problem.

However, DDT persists in the environment for 2 to 15 years. The ecological impact of DDT was not felt until much later, when DDT began showing up in other forms of life. The peregrine falcon, once found throughout the grasslands, began to die rapidly. DDT was passed from grasshopper to insect-eating birds and mammals to falcons and hawks. The pesticide collected in the fatty tissues of the birds, sometimes leading to sterility. Fertile females passed high levels of the pesticides to their eggs. Here, DDT caused developmental problems in the young, such as shortened wings or poor vision, which decreased the likelihood of survival. DDT also interfered with the female’s calcium metabolism during egg formation. The eggshells became thinner, causing the developing embryos to dehydrate and die before they were able to hatch.

Like other top predators, humans are subject to bioamplification. Evidence that DDT was beginning to accumulate in humans was collected in the 1950s and 1960s. DDT levels became especially high in humans who lived where the persistent pesticide DDT was sprayed on crops. However, anyone who ate crops from these areas or ate animals that had fed on the crops was exposed to DDT.

Concern about this growing threat was so great that use of DDT was banned in Canada in 1971 and in the United States in 1972. The ban has not totally eliminated the problem. Since DDT persists in the environment so long, it continues to affect ecosystems long after a ban is called. Migratory birds like the mallard duck, Canada goose, and peregrine falcon winter in Central America and Mexico, where DDT is still used. Fish living in the Atlantic and Pacific Oceans also migrate up and down the coasts. This DDT then remains in Canadian ecosystems for years.

Although pesticides are closely regulated in Canada, they are used widely in Latin America where peregrine falcons winter. Restoration management projects in Alberta have begun a slow recovery. Each year since 1992, wildlife agencies have released 45 captive-bred falcons. Once the birds are 30 days old, they are placed in boxes, called hacks, located on steep cliffs or even office towers. An attendant provides food through a tube until the bird begins to fly a few weeks later. However, life expectancy after flight isn’t promising. Without parental support, about 60% of the inexperienced hunters will not see the following spring.

Modern Chemical Pesticides

Based on the experience of DDT, modern pesticides are usually not persistent. Unlike DDT, these pesticides are water-soluble, not fat-soluble. Animals can break them down in their livers and excrete them, so they don’t build up in their bodies. They can also be broken down within the soil, so they don’t persist.

Although somewhat safer than the older chemicals, the newer pesticides are not without their problems. Since they break down quickly in the soil, they must be applied to crops more often. Second, many of these new chemicals will also affect non-target organism, either killing them or weakening them so that they are more susceptible to disease or predation. As a result, they may cause unintended changes to the food web. Third, animals that have died or been weakened by the toxin put any other animal that eats them at risk through bioamplification.
Questions

1. Which animals normally help control grasshoppers? Predict how these animals might be affected by pesticides.

2. How would a decrease in peregrine falcon populations affect the population of ground squirrels? Explain.

3. It is often said that technology works as a double-edged sword solving some problems, but at the same time creating others. Do you agree or disagree with this statement? Justify your answer.

4. In Atlantic Canada, a group of synthetic pesticides, called pyrethoids, were used to control the winter moth and tentiform leafminers in apple orchards. Unfortunately, the chemical killed other species of insects as well, including predators of red mites and apple mites. The mite population rose quickly, damaging the trees and reducing the yield of apples. Describe the recommendations you would make to anyone considering using pyrethoids. Explain.

5. Among others the ideal pesticide should have the following characteristics. It should:
   • selectively kill only the intended pest.
   • disappear into something harmless after it works on the pest.
   • be cheap to produce.

   For each of these three characteristics,
   • explain why the characteristic is important.
   • describe the consequences should a pesticide lack the characteristic.

6. Many land-based contaminants end up in the marine ecosystem. A 1991 report by Environment Canada showed that some valuable shellfish, crustaceans, and fish were contaminated with DDT and other pesticides. Chemical pesticides have also been found in shore birds and marine mammals, particularly along the Bay of Fundy and the coast of Newfoundland. Although the levels of pesticides are declining in most marine animals, there is still some reason for concern. The porpoises in the lower Bay of Fundy still have unacceptably high levels of DDT: 500 ppm (parts per million).

   (a) How would DDT enter a marine ecosystem?
   (b) If DDT was banned in Canada in the early 1970s, why do animals still carry residues of this toxin?
   (c) Why might the levels of DDT fall more slowly in porpoises than in other animals in the food chain?