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Impact of Pollution on Terrestrial Arthropods

John T. Trumble and Danel B. Vickerman

Pollution, the unwanted and undesirable presence of a chemical or compound, is unfortunately common. The problem is global, affecting all continents and nations, and frequently crossing natural and political boundaries. Specific occurrences may be quite localized (such as waste-water runoff from mining operations) or cover exceptionally broad geographic areas (like acidic precipitation in Northern Europe or the entire North Eastern U.S.A. plus adjacent regions of Canada).

Problems with pollution are not new; air and soil contamination have been reported for thousands of years. Over 2000 years ago, the Roman poet, Horace, complained about soot damaging the walls of temples. However, the problem has become substantially worse since the Industrial Revolution, with the large scale production and transport of many toxic materials. Most countries evolve through a period of intense industrialization, where the primary goal is to raise the standard of living for the population. During this period the environmental effects of pollutants are not considered a primary concern. As countries become more affluent, the desire for improving environmental quality increases, but nationalistic concerns, economic costs of less polluting technologies, and long standing patterns of industrial production work to impede changes that can reduce contaminants. Even in situations where pollution has been largely eliminated, a 'legacy' of contamination may still exist. Thus, the problem of pollution is likely to continue for the foreseeable future.

Solving our existing problems of environmental contamination and mitigating the effects of contaminants on living organisms are difficult because of the incredible variety of sources and forms of pollution. Even an abbreviated list of pollutants would include thousands of industrial by-products, pesticide residues from chemicals that have been banned from use, a variety of toxic metals and chemicals in mining waste, many compounds produced by burning fossil fuels, the by-products of warfare, chemicals used in electrical generation/transport machinery, fuel additives, as well as a host of other materials. Each pollutant has the potential to disrupt ecosystems. Some have minimal effects, others have contaminated soils so that plants or animals from these areas cannot be eaten. A few have created wastelands, where the ground has become too toxic to support even the most basic organisms in an ecosystem.

Terrestrial arthropods are critical to the functioning of ecosystems. Because they are at the base of the food web, changes in population densities of arthropods can have profound effects on higher level organisms that depend on them. Insects and their relatives are used as food by many birds and mammals. Many arthropods are beneficial, serving to keep pest populations under control, thereby preventing damaging outbreaks. Others pollinate plants, disseminate seeds, and produce structures used by countless other organisms. Disruption of any of these activities can have disastrous effects on an ecosystem. Thus, arthropods are often the first animals examined when ecosystems become polluted.

Interestingly, direct contact with most pollutants generally does not harm terrestrial arthropods. Populations of arthropods are more commonly affected when pollutants are ingested, or if the pollutants change the quality or quantity of their food. These effects can be either positive or negative. The following sections summarize the major types of pollutants and their effects on arthropods.

Air pollutants. Air pollution takes many forms. Some of the more common pollutants contain products resulting from fossil fuel combustion include ozone, carbon dioxide (CO_2) and carbon monoxide (CO), acidic precipitation (acidic fogs and acid rain), and many related compounds. In nearly all scientific studies, direct exposure to high concentrations of these contaminants does not physically harm arthropods. However, air pollution can alter plant chemistry, and thereby change the nutritional value of plants or their chemical defenses against arthropods. Examples are provided for ozone, acid fog, and CO_2.

Ozone is a remarkably active compound generated when combustion products from fuel are exposed to sunlight. Even moderate levels of ozone can damage plants and cause modifications in the form and content of plant nutrients. Exposure to ozone often increases availability of a key nutrient, nitrogen, which is critical for arthropod growth. This nutrient is very important, and frequently determines how fast an arthropod can grow, and if it will survive. Thus, insects such as the tomato pinworm, a key agricultural pest throughout the southern United States and Mexico, grow about 10% faster and survive at twice the rate if feeding on plants exposed to ozone. If ozone exposure is very high, then plants can become so damaged that arthropod populations can no longer survive. Like many toxic substances, the concentration of the contaminant, and the duration of exposure will determine if the pollutant is a benefit or detriment to arthropods.

The levels of CO_2 in the earth's atmosphere have been increasing dramatically since the industrial revolution. CO_2 concentration in the atmosphere has increased from 270-280 ppm to the current level of 355-360 ppm. This represents an increase of approximately 27% in a relatively short period of time. Scientists already have shown that increasing levels of atmospheric CO_2 can have substantial effects on plant suitability for arthropods. Because arthropods (like all animals) are mostly made of nitrogen, those feeding on plants have to separate the relatively small amounts of nitrogen from plant material consisting mostly of carbon. Plants grown in elevated concentrations of CO_2 have increased levels of carbon (from the carbon availability in the CO_2), and substantially reduced amounts of nitrogen. Most arthropods respond to this problem by simply eating more plant material. Some eat twice as much. Others cannot cope with the relative lack of nitrogen, and develop more slowly or even die. Changing CO_2 levels will therefore have significant effects on the plants that arthropods can eat, and how much damage is caused by their feeding.

Acid deposition in the form of 'acid rain' or acidic fogs is common in North America. Although terrestrial arthropods are not typically affected by direct exposure, their food plants are often damaged. Typical damage symptoms include lesion development, weathering of leaf surface waxes, foliar leaching, premature leaf fall, changes in plant nitrogen form and content, or even plant death. All of these can impact arthropod populations. Encounters with lesions can change arthropod feeding patterns. Leaf waxes are important cues used by some arthropods to identify a particular plant as a food source, and changes in waxes can make normally acceptable plants unrecognizable. Early leaf loss shortens the time available for leaf-feeding arthropods to develop. Changes in plant nitrogen form and content and plant defensive chemistry generally have profound impacts on arthropods. Some acidic fogs contain high levels of nitrogen, and may act as a fertilizer. In some instances this provides the arthropod with a more nutritious food source, allowing populations to increase. In other cases, the plants use the additional nitrogen to produce defensive chemicals that can suppress insect populations. The death of large areas of trees caused by acid rain and acidic fogs in eastern North America and some parts of Europe have dramatic effects on abundance of many arthropod species that survive on the affected tree species.

Pollutants that transfer from water to soil. Many common water pollutants are readily transferred from water to soil or directly from water to plants. Terrestrial arthropods are then exposed to these materials. Some of the more common water-borne pollutants include hexavalent chromium, MTBE (methyl tertiary butyl ether), and selenium. Each of these widespread contaminants has different effects on insects.

Hexavalent chromium is one of the most common contact sensitizers in industrialized countries and is associated with numerous materials and processes, including chrome plating baths, chrome colors and dyes, cement, tanning agents, wood preservatives, anticorrosive agents, welding fumes, lubricating oils and greases, cleaning materials, and textile production. Due to the past and present use of chromium in so many industries it is a widespread pollutant. When ingested, this material has been shown to cause a decrease in growth and fecundity in arthropods.

MTBE is a gasoline additive used to elevate the oxygenate level in gasoline. This helps the gasoline burn more completely, reducing the production of some contaminants associated with automobile exhaust. Unfortunately, this chemical has leaked into the groundwater at over 385,000 sites nationwide due to poorly sealed underground fuel storage tanks. MTBE has now been detected in 21% of 480 wells in regions using MTBE as a gasoline additive. In addition, findings from the National Water Quality Assessment Program indicate that MTBE is the second most frequently detected volatile organic compound in ground water and urban streams. Preliminary data suggest that this material can slow development of some arthropod species.

Selenium is found in contaminated soils throughout western North America. Soil accumulation is associated with agricultural irrigation, geochemical processes, mining, and a variety of other industrial sources and frequently results in significant effects on animal and human health. Although selenium is an essential trace nutrient important to humans and most other animals, toxicity occurs at high concentrations due to replacement of sulfur with Se in amino acids resulting in incorrect folding of the protein and consequently malformed, nonfunctional proteins and enzymes. Remediation strategies include removal of soil selenium by plant accumulation, harvest, and removal. Use of plants in soil remediation programs results in the availability of selenium to plant eating arthropods. Ingestion of selenium in plants by arthropods generally results in slowed growth, reduced egg production, and higher mortality.

Pollutants that transfer from water to the soil are likely to be long term problems for arthropods. Contaminated aquifers will be used for irrigation, and plant feeding organisms will be exposed to these pollutants throughout their lives. The long term effects of such exposures, and the possible interactions between the various water-borne contaminants, is not yet known.

The special case of metals. Eighty-seven of the elements on the periodic table are considered metals or metalloids (elements which act like metals). These metals are toxic at relatively low levels to terrestrial arthropods and many other organisms. Although natural mineral deposits containing metals occur around the world, and the erosion of rocks and volcanoes release metals into the atmosphere, contamination of soils by metals is most often associated with human activity. In our industrial society, metals are one of the most commonly used raw materials. Consequently, waste-water runoff from mining, metal refining, sewage sludge, and other anthropogenic sources contain high levels of metals that pollute water and soil. Additionally, gas exhaust, energy and fuel production, smelters, and foundries emit metals as airborne particulates. Sources of contamination often contain mixtures of several metals or metalloids making analysis of the effects of any one element difficult to determine in a field setting.

Airborne particulates containing metals may land on the surface of food plants of arthropods, damaging plant photosynthetic systems and resulting in altered plant chemistry and nutrition for herbivores. Contamination of soils also allows for plant uptake of many metals making these metals available to herbivores. Additionally, decaying plant materials containing metals are consumed by soil and leaf litter dwelling arthropods. Metals have been shown to accumulate in the tissues of some arthropods making them more available to predatory and parasitic arthropods, as well as higher animals that eat arthropods. This can lead to biomagnification, where pollutants accumulate in the tissues of animals as they consume the contaminated arthropods.

Toxicity of metals to terrestrial arthropods has been demonstrated in the field as well as in the laboratory. Because metals are such a large and diverse group of elements it is not surprising that the mode of action and concentrations resulting in toxicity to terrestrial arthropods are variable. Additionally, arthropods themselves differ in their ability to tolerate environments containing metals. Some arthropods are able to excrete small amounts of metals and thereby avoid toxic effects at low levels of pollution. However, at slightly higher concentrations the presence of metals may result in their incorporation into proteins and enzymes, altering their ability to function properly in the arthropod system. Some metals interfere with metabolic pathways in arthropods resulting in reduced total body protein. Additionally, metals can affect the energy source of insects, the fat body. Collectively, these effects often result in impaired growth and development and the disruption of reproduction. Therefore, not surprisingly, arthropod abundance and species diversity are usually diminished in areas where metal pollution is present.

Conclusion. All of these pollutants, whether airborne, carried by water, or present in contaminated soil, can affect population development and survival of terrestrial arthropods. Because of this, all of these contaminants can influence how communities of arthropods, and the higher animals that feed on them, will function within ecosystems. Scientists are just beginning to understand the long term effects of these pollutants on terrestrial organisms.

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