12

Effects on Vegetation and Animals

I. INJURY VERSUS DAMAGE

The US Department of Agriculture makes a distinction between air pollution damage and air pollution injury. *Injury* is considered to be any observable alteration in the plant when exposed to air pollution. *Damage* is defined as an economic or aesthetic loss due to interference with the intended use of a plant. This distinction indicates that injury by air pollution does not necessarily result in damage because any given injury may not prevent the plant from being used as intended, e.g., marketed. Thus, damage is a value-laden concept.

Vegetation reacts with air pollution over a wide range of pollutant concentrations and environmental conditions. Many factors influence the outcome, including plant species, age, nutrient balance, soil conditions, temperature, humidity, and sunlight [1]. Any type of observable effect due to exposure can be termed plant injury. A schematic diagram of the potential levels of injury with increasing exposure to air pollution is presented in Fig. 12.1. At low levels of exposure for a given species and pollutant, no significant effects may be observed. However, as the exposure level increases, a series of potential injuries may occur, including biochemical alterations, physiological response, visible symptoms, and eventual death.

Air pollutants may enter plant systems by either a primary or a secondary pathway. The primary pathway is analogous to human inhalation. Figure 12.2

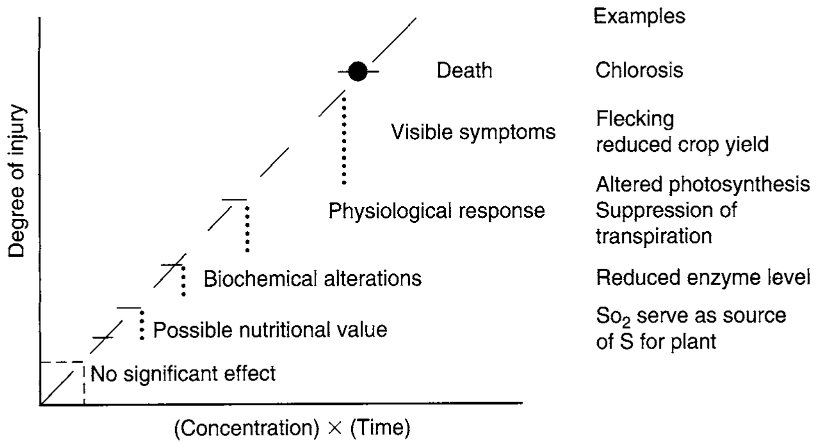

Fig. 12.1. Biological response spectrum for plants and air pollution. Note the similarities to the dose–response curves discussed in Chapter 11.

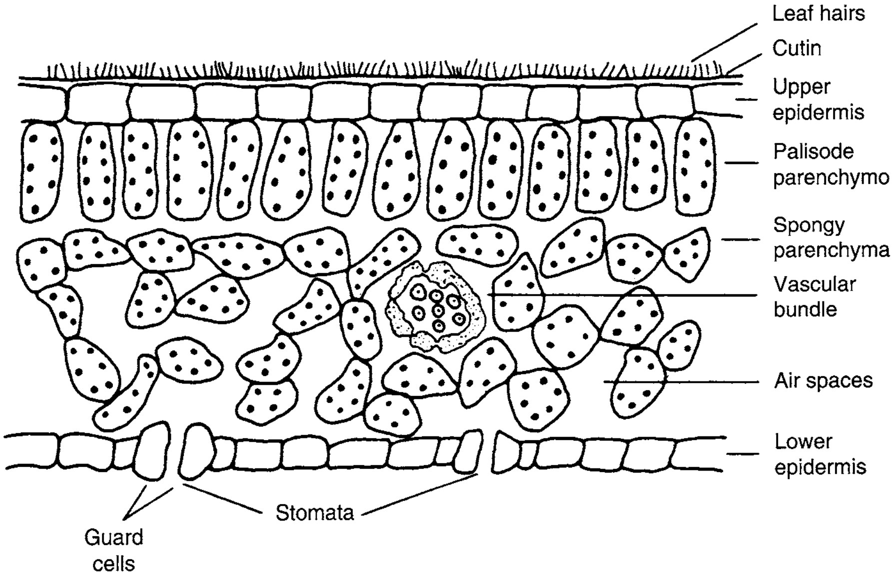

Fig. 12.2. Cross section of leaf showing various components.

shows the cross section of a leaf. Both of the outer surfaces are covered by a layer of epidermal cells, which help in moisture retention. Between the epidermal layers are the mesophyll cells–the spongy and palisade parenchyma. The leaf has a vascular bundle which carries water, minerals, and carbohydrates throughout the plant. Two important features shown in Fig. 12.2 are the openings in the epidermal layers called *stomates*, which are controlled by guard cells which can open and close, and air spaces in the interior of the leaf.

The leaf structure has several important functions, three of which are photosynthesis, transpiration, and respiration [2]. Photosynthesis is accomplished by chloroplasts in the leaf, which combine water and CO_2 in the presence of sunlight to form sugars and release O_2. A simplification of this process is:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \tag{12.1}$$

Transpiration is the physical movement of water from the root system up to the leaves and its subsequent evaporation to the atmosphere. This process moves nutrients throughout the plant and cools the plant. Respiration is a heat-producing process resulting from the oxidation of carbohydrates by O_2 to form CO_2 and H_2O:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \tag{12.2}$$

These three functions involve the movement of O_2, CO_2, and H_2O through the epidermal layers of the leaf. The analogy to human inhalation is obvious. With the diffusion of gases into and out of the leaf, pollutant gases have a direct pathway to the cellular system of the leaf structure. Direct deposition of particulate matter also occurs on the outer surfaces of the leaves.

The indirect pathway by which air pollutants interact with plants is through the root system. Deposition of air pollutants on soils and surface waters can cause alteration of the nutrient content of the soil in the vicinity of the plant. This change in soil condition can lead to indirect or secondary effects of air pollutants on vegetation and plants.

Injury to plants and vegetation is caused by a variety of factors of which air pollution is only one. Drought, too much water, heat and cold, hail, insects, animals, disease, and poor soil conditions are some of the other causes of plant injury and possible plant damage [3]. Estimates suggest that less than 5% of total crop losses are related to air pollution. Air pollution has a much greater impact on some geographic areas and crops than others. Crop failure can be caused by fumigation from a local air pollution source or by more widespread and more frequent exposure to adverse levels of pollution.

The subtle interaction of air pollutants with these other stressors to plants and vegetation is the subject of ongoing research. For some plant systems, exposure to air pollutants may induce biochemical modifications which interfere with the water balance in plants, thereby reducing their ability to tolerate drought conditions.

II. EFFECTS ON VEGETATION AND CROPS

The effects of air pollution on plants range from subtle to catastrophic, as shown in Fig. 12.1. Historically, these effects have been classified as visible symptoms and non-visual or subtle effects [4]. Visible symptoms are deviations from the normal healthy appearance of the leaves. For broadleaf plants, a healthy leaf has good color, with a normal cell structure in the various layers. Deviations from this healthy appearance include tissue collapse and various degrees of loss of color. Extensive tissue collapse or necrosis results from injury to the spongy or palisade cells in the interior of the leaf. The leaf is severely discolored and loses structural integrity. Dead tissue may fall out of the leaf, leaving holes in the structure. Less dramatic discolorations are caused by a reduction in the number of chloroplasts, a symptom referred to as *chlorosis*. Injury to the outer or epidermal layer is referred to as *glazing* or *silvering* of the leaf surface. When the pattern is spotty, the terms *flecking* and *stippling* are used to describe the injury.

Other forms of visible injury are related to various physiological alterations. Air pollution injury can cause early senescence or leaf drop. Stems and leaf structure may be elongated or misshapen. Ornamentals and fruit trees can also show visible injury to the blooms of the fruit, which can result in decreased yield.

The nonvisual or subtle effects of air pollutants involve reduced plant growth and alteration of physiological and biochemical processes, as well as changes in the reproductive cycle. Reduction in crop yield can occur without the presence of visible symptoms. This type of injury is often related to low-level, long-term chronic exposure to air pollution. Studies have shown that field plantings exposed to filtered and unfiltered ambient air have produced different yields when no visible symptoms were present [5]. Reduction in total biomass can lead to economic loss for forage crops or hay.

Physiological or biochemical changes have been observed in plants exposed to air pollutants, including alterations in net photosynthesis, stomate response, and metabolic activity. Such exposure studies have been conducted under controlled laboratory conditions. An understanding of the processes involved will help to identify the cause of reduction in yield.

Laboratory studies have also investigated the interaction of air pollutants and the reproductive cycle of certain plants. Subtle changes in reproduction in a few susceptible species can render them unable to survive and prosper in a given ecosystem.

The major air pollutants which are phytotoxic to plants are ozone, sulfur dioxide, nitrogen dioxide, fluorides, and peroxyacetyl nitrate (PAN) [2]. Table 12.1 lists some of the types of plants injured by exposure to these pollutants. The effects range from slight reduction in yield to extensive visible injury, depending on the level and duration of exposure. Examples of the distinction between air pollution injury and damage are also given in Table 12.1. Visible markings on plants or crops such as lettuce, tobacco, and orchids caused by air pollution translate into direct economic loss (i.e. damage). In contrast, visible markings on the leaves of grapes, potatoes, or corn caused by air pollution will not result in a determination of damage if there is no loss in yield. Individual circumstances determine whether air pollution damage has occurred.

The costs of air pollution damage are difficult to estimate. However, estimates indicate crop losses of \$1–\$5 billion for the United States [6]. When compared to the crop losses due to all causes, this percentage is small. However, for particular crops in specific locations, the economic loss can be very high. Certain portions of the Los Angeles, California, basin are no longer suitable for lettuce crops because they are subject to photochemical smog. This forces producers either to move to other locations or to plant other crops that are less

TABLE 12.1

Examples of Types of Leaf Injury and Air Pollution

				Injury threshold		
Pollutant	Symptoms	Maturity of leaf affected	Part of leaf affected	ppm (vol)	$\mu g\ m^{-3}$	Sustained exposure
Sulfur dioxide	Bleached spots, bleached areas between veins, chlorosis; insect injury, winter and drought conditions may cause similar markings	Middle-aged leaves most sensitive; oldest least sensitive	Mesophyll cells	0.3	785	8 h
Ozone	Flecking, stippling, bleached spotting, pigmentation; conifer needle tips become brown and necrotic	Oldest leaves most sensitive; youngest least sensitive	Palisade or spongy parenchyma in leaves with no palisade	0.03	59	4 h
Peroxyacetyl nitrate (PAN)	Glazing, silvering, or bronzing on lower surface of leaves	Youngest leaves most sensitive	Spongy cells	0.01	50	6 h
Nitrogen dioxide	Irregular, white or brown collapsed lesions on intercostal tissue and near leaf margin	Middle-aged leaves most sensitive	Mesophyll cells	2.5	4700	4 h
Hydrogen fluoride	Tip and margin burns, dwarfing, leaf abscission; narrow brown-red band separates necrotic from green tissue; fungal disease, cold and high temperatures, drought, and wind may produce similar markings; suture red spot on peach fruit	Youngest leaves most sensitive	Epidermis and mesophyll cells	0.1 (ppb)	0.08	5 weeks
Ethylene	Sepal withering, leaf abnormalities; flower dropping, and failure of leaf to open properly; abscission; water stress may produce similar markings	Young leaves recover; older leaves do not recover fully	All	0.05	58	6 h
Chlorine	Bleaching between veins, tip and margin burn, leaf abscission; marking often similar to that of ozone	Mature leaves most sensitive	Epidermis and mesophyll cells	0.10	290	2 h

(*continued*)

TABLE 12.1 (*Continued*)

Examples of Types of Leaf Injury and Air Pollution

				Injury threshold		
Pollutant	Symptoms	Maturity of leaf affected	Part of leaf affected	ppm (vol)	μg m^{-3}	Sustained exposure
Ammonia	"Cooked" green appearance becoming brown or green on drying; overall blackening on some species	Mature leaves most sensitive	Complete tissue	~20	~14 000	4 h
Hydrogen chloride	Acid-type necrotic lesion; tip burn on fir needles; leaf margin necrosis on broad leaves	Oldest leaves most sensitive	Epidermis and mesophyll cells	~5–10	~11 200	2 h
Mercury	Chlorosis and abscission; brown spotting; yellowing of veins	Oldest leaves most sensitive	Epidermis and mesophyll cells	<1	<8200	1–2 days
Hydrogen sulfide	Basal and marginal scorching	Youngest leaves most affected		20	28 000	5 h
2,4-Dichlorophenoxyacetic acid (2–4D)	Scalloped margins, swollen stems, yellow-green mottling or stippling, suture red spot (2,4,5–T); epinasty	Youngest leaves most affected	Epidermis	<1	<9050	2 h
Sulfuric acid	Necrotic spots on upper surface similar to those caused by caustic or acidic compounds; high humidity needed	All	All	—	—	—

susceptible to air pollution damage. Concern has been expressed regarding the future impact of air pollution on the much larger Imperial Valley of California, which produces up to 50% of certain vegetables for the entire United States.

III. EFFECTS ON FORESTS

Approximately 1.95×10^{10} km^2 of the earth's surface has at least 20% or more crown tree cover, representing about one-third of the total land area [7]. Several different types of forest ecosystems can be defined based on their location and the species present. The largest in area are tropical forest systems, followed by temperate forests, rain forests, and tidal zone systems. The temperate forest systems are located in the latitudes where the greatest industrialization is occurring and have the most opportunity to interact with pollutants in the atmosphere. The impact of air pollution on forest ecosystems ranges from beneficial to detrimental. Smith [8, 9] classified the relationship of air pollutants with forests into three categories: low dose (I), intermediate dose (II), and high dose (III). With this classification scheme, seemingly contradictory statements on the impact of air pollution on forests can be understood.

A. Low-Dose Levels

Under low-dose conditions, forest ecosystems act as sinks for atmospheric pollutants and in some instances as sources. As indicated in Chapter 11, the atmosphere, lithosphere, and oceans are involved in cycling carbon, nitrogen, oxygen, sulfur, and other elements through each subsystem with different timescales. Under low-dose conditions, forest and other biomass systems have been utilizing chemical compounds present in the atmosphere and releasing others to the atmosphere for thousands of years. Industrialization has increased the concentrations of NO_2, SO_2, and CO_2 in the "clean background" atmosphere, and certain types of interactions with forest systems can be defined.

Forests can act as sources of some of the trace gases in the atmosphere, such as hydrocarbons, hydrogen sulfide, NO_x, and NH_3. Forests have been identified as emitters of terpene hydrocarbons, which are a component of the photochemistry that leads to the formation of ozone.[1] In 1960, Went [10] estimated that hydrocarbon releases to the atmosphere were on the order of 108 tons per year. Later work by Rasmussen [11] suggested that the release of terpenes from forest systems is 2×10^8 tons of reactive materials per year on a global basis. This is several times the anthropogenic input. Yet, it is important to remember that forest emissions are much more widely dispersed and less concentrated than anthropogenic emissions. Table 12.2 shows terpene emissions from different types of forest systems in the United States.

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[1] This harkens back to the 1980s when President Reagan postulated that trees accounted for much pollution, which spawned the phrase, "killer trees." This led to some hilarious running gags and skits on the show, Saturday Night Live, where such a tree (played by the late John Belushi) would attempt entry into homes with obvious mal intent. What made the skits so funny was, like most humor, they were based on some element of truth.

TABLE 12.2

Composition of US Forest-Type Groups by Foliar Terpene Emissions

	Percent of total US forest area	Percent α pinene emitters	Percent of isoprene emitters
Eastern type group			
Softwood types			
Loblolly-shortleaf pine	11	~100	Some from oak and sweetgum associates
Longleaf-slash pine	5	~100	Some from oak and sweetgum associates
Spruce-fir	4	~75	25% from spruce, which also emits (pinene
White-red-jack pine	2	~90	10% from aspen trees
Subtotal	22%	~91%	~9%
Hardwood types			
Oak-hickory	23	~10	70%, diluted by hickory, maple and black walnut
Oak-gum cypress	7	~50	50% from plurality of oak, cottonwood and willow
Oak-pine	5	~30	60%, diluted by black gum and hickory associates
Maple-beech-birch	6	~15	Terpene foliates are hemlock and white pine
Aspen-birch	5	~20	60%, diluted by birch, α pinene source balsam fir and balsam poplar
Elm-ash-cottonwood	4	–	30% from cottonwood, sycamore, and willow
	–	–	–
Subtotal	50%	~21%	~45%
Total	72%	–	–
Western type groups			
Softwoods			
Douglas fir	7	~100	–
Ponderosa pine	7	~100	5% from aspen associates
Lodgepole pine	3	~90	10% from Engelmann spruce and aspen
Fir-spruce	3	~100	40% from spruce trees
Hemlock-Sitka spruce	2	~100	25% from Sitka spruce
White pine	1	~100	5% from Engelmann spruce
Larch	1	~100	–
Redwood	0.5	~100	–
Subtotal	24.5%	~98%	~12%
Hardwoods	2	–	~100% from aspen trees
Total	26.5%		

Source: Rasmussen, R. A., *J. Air Pollut. Contrl. Assoc.* **22**, 537–543 (1972).

Forest systems also act as sources of CO_2 when controlled or uncontrolled burning and decay of litter occur. In addition, release of ethylene occurs during the flowering of various species. Thus, although trees are an important part of strategies to control global warming by storing (sequestering) carbon, especially in large root systems, they are also sources of CO_2. One additional form of emission to the atmosphere is the release of pollen grains. Pollen is essential to the reproductive cycle of most forest systems but becomes a human health hazard for individuals susceptible to hay fever. The contribution of sulfur from forests in the form of dimethyl sulfide is considered to be about 10–25% of the total amount released by soils and vegetation [12].

Trees and soils of forests act as sources of NH_3 and oxides of nitrogen. Ammonia is formed in the soil by several types of bacteria and fungi. The volatilization of ammonia and its subsequent release to the atmosphere are dependent on temperature and the pH of the soil. Fertilizers are used as a tool in forest management. The volatilization of applied fertilizers may become a source of ammonia to the atmosphere, especially from the use of urea.

Nitrogen oxides are formed at various stages of the biological denitrification process. This process starts with nitrate; as the nitrate is reduced through various steps, NO_2, NO, N_2O, and N_2 can be formed and, depending on the conditions, released to the atmosphere.

The interactions of air pollutants with forests at low-dose concentrations result in imperceptible effects on the natural biological cycles of these species. In some instances, these interactions may be beneficial to the forest ecosystem. Forests, as well as other natural systems, act as sinks for the removal of trace gases from the atmosphere.

B. Intermediate-Dose Levels

The second level of interaction, the intermediate-dose level, can result in measurable effects on forest ecosystems. These effects consist of a reduction in forest growth, change in forest species, and susceptibility to forest pests. Both laboratory investigations and field studies show SO_2 to be an inhibitor of forest growth. When various saplings have been exposed to SO_2 in the laboratory, they show reduction in growth compared with unexposed saplings [13]. Various field investigations of forest systems in the vicinity of large point sources show the effects of elevated SO_2 levels on the trees closer to the source. For example, Linzon [14] found that SO_2 from the Sudbury, Ontario (Canada), smelter caused a reduction in forest growth over a very large area, with the closer-in trees severely defoliated, damaged, and killed.

The effect of photochemical oxidants, mainly O_3 and PAN, on the forests located in the San Bernardino Mountains northeast of Los Angeles, California, has been to change the forest composition and to alter the susceptibility of forest species to pests. This area has been subjected to increasing levels of oxidant since the 1950s (Fig. 12.3). During the late 1960s and early 1970s, changes in the composition and aesthetic quality of the forest were observed [15].

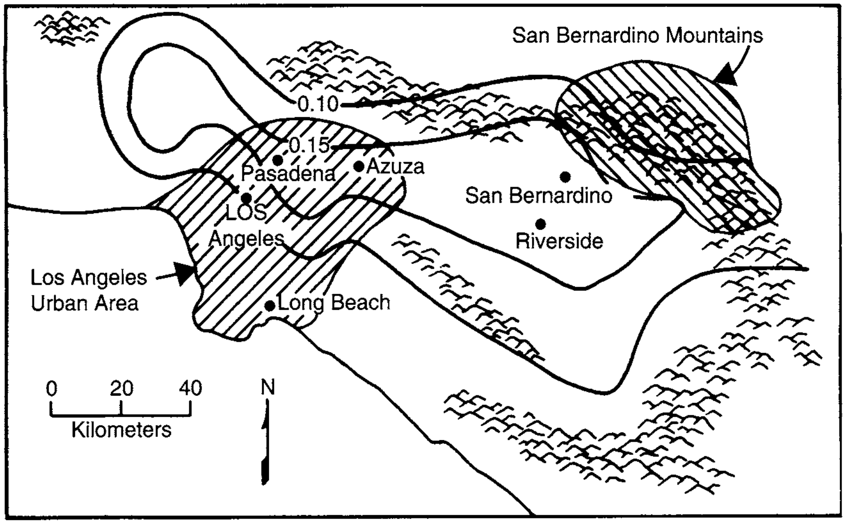

Fig. 12.3. Relationship between Los Angeles Basin's urban sources of photochemical smog and the San Bernardino Mountains, where ozone damage has occurred to the ponderosa pines. The solid lines are the average daily 1-h maximum does of ozone (ppm), July–September 1975–1977. *Source*: Adapted from Davidson, A., Ozone trends in the south coast air basin of California, in *Ozone/Oxidants: Interaction with the Total Environment*, pp. 433–450. Air Pollution Control Association, Pittsburgh, PA, 1979.

During this period, the photochemical problem was expanding to a wider geographical region; and photochemical oxidant was transported to the San Bernardino Mountains with increasing frequency and at higher concentrations. The receptor forest system has been described as a mixed conifer system containing ponderosa pine, Jeffrey pine, white fir, and cedar, along with deciduous black oak. The damage to the ponderosa pine ranged from no visible injury to death. As the trees came under increased stress due to exposure to oxidant, they became more susceptible to pine beetle, which ultimately caused their death. The ponderosa pine appears to be more susceptible than the other members of this forest system, and continued exposure to photochemical oxidant may very well shift it from the dominant species to a minor one.

The interactions in the intermediate-dose category may result in effects on the reproduction cycle of species, the utilization of nutrients, the production of biomass, and the susceptibility to disease.

C. High-Dose Levels

The third category for interactions is high dose (III). The effects produced by this level of interaction can be seen by the casual observer. The result of high-dose exposure is destruction or severe injury of the forest system. High-dose conditions are almost always associated with point source emissions. The pollutants most often involved are SO_2 and hydrogen fluoride. Historically, the most harmful sources of pollution for surrounding forest ecosystems have been smelters and aluminum reduction plants.

One example of high-dose interaction is the impact of a smelter on the surrounding area in Wawa, Ontario, Canada. This smelter began operating about 1940. Gordon and Gorham [16] documented the damage in the prevailing downwind northeast sector for a distance of 60 km. They analyzed vegetative plots and established four zones of impact in the downwind direction: Within 8 km of the plant, damage was classified as "very severe" where no trees or shrubs survived; "severe damage" occurred at ~17 km, where no tree canopy existed; "considerable damage" existed at ~25 km, where some tree canopy remained, but with high tree mortality; and "moderate damage" was found at ~35 km, where a tree canopy existed but was put under stress and where the number of ground flora species was still reduced.

This type of severe air pollution damage has occurred several times in the past. If care is not taken, additional examples will be documented in the future.

D. Acid Deposition

Acid deposition refers to the transport of acid constituents from the atmosphere to the earth's surface. This process includes dry deposition of SO_2, NO_2, HNO_3, and particulate sulfate matter and wet deposition ("acid rain") to surfaces. This process is widespread and alters distribution of plant and aquatic species, soil composition, pH of water, and nutrient content, depending on the circumstances.

The impact of acid deposition on forests depends on the quantity of acidic components received by the forest system, the species present, and the soil composition (notably ionic strength and depth). Numerous studies have shown that widespread areas in the eastern portion of North America and parts of Europe are being altered by acid deposition. Decreased pH in some lakes and streams in the affected areas was observed in the 1960s [17] and further evidence shows this trend.

When a forest system is subjected to acid deposition, the foliar canopy can initially provide some neutralizing capacity. If the quantity of acid components is too high, this limited neutralizing capacity is overcome. As the acid components reach the forest floor, the soil composition determines their impact. The soil composition may have sufficient buffering capacity to neutralize the acid components. However, alternation of soil pH can result in mobilization or leaching of important minerals in the soil. In some instances, trace metals such as calcium or magnesium may be removed from the soil, altering the aluminum tolerance for trees.

This interaction between airborne acid components and the tree-soil system may alter the ability of the trees to tolerate other environmental stressors such as drought, insects, and other air pollutants like ozone. In Germany, considerable attention is focused on the role of ozone and acid deposition as a cause of forest damage. Forest damage is a complex problem involving the interaction of acid deposition, other air pollutants, forestry practices, and naturally occurring soil conditions. As in all ecosystems, forests must always be understood as complex, integrated systems with myriad interrelationships that can be affected by air pollutants.

IV. EFFECTS ON ANIMALS

Acid deposition and the alteration of the pH of aquatic systems has led to the acidification of lakes and ponds in various locations in the world. Low-pH conditions result in lakes which contain no fish species.

Heavy metals on or in vegetation and water have been and continue to be toxic to animals and fish. Arsenic and lead from smelters, molybdenum from steel plants, and mercury from chlorine-caustic plants are major offenders. Poisoning of aquatic life by mercury is relatively new, whereas the toxic effects of the other metals have been largely eliminated by proper control of industrial emissions. Gaseous (and particulate) fluorides have caused injury and damage to a wide variety of animals-domestic and wild-as well as to fish. Accidental effects resulting from insecticides and nerve gas have been reported.

Autopsies of animals in the Meuse Valley, Donora, and London episodes described in Chapter 19, Section III, revealed evidence of pulmonary edema. Breathing toxic pollutants is not, however, the major form of pollutant intake for cattle; ingestion of pollution-contaminated feeds is the primary mode.

In the case of animals we are concerned primarily with a two-step process: accumulation of airborne contaminants on or in vegetation or forage that serves as their feed and subsequent effects of the ingested herbage on animals. In addition to pollution-affected vegetation, carnivores (humans included) consume small animals that may have ingested exotic chemicals including pesticides, herbicides, fungicides, and antibiotics. As in humans, the principal route of exposure to air pollutants can be indirect. After deposition, the animal ingests the contaminant. This reminds us that not every exposure to air pollution is by inhalation. Increasing environmental concern has pointed out the importance of the complete food chain for the physical and mental well-being of human beings.

A. Heavy Metal Effects

One of the earliest cattle problems involved widespread poisoning of cattle by arsenic at the turn of the century. Abnormal intake of arsenic results in severe colic (salivation, thirst, and vomiting), diarrhea, bloody feces, and a garlic-like odor on the breath; cirrhosis of the liver and spleen as well as reproductive effects may be noted. Arsenic trioxide in the feed must be approximately 10 mg kg^{-1} body weight for these effects to occur.

Cattle feeding on herbage containing 25–50 mg kg^{-1} (ppm wt.) lead develop excitable jerking of muscles, frothing at the mouth, grinding of teeth, and paralysis of the larynx muscles; a "roaring" noise is caused by the paralysis of the muscles in the throat and neck.

Symptoms of molybdenum poisoning in cattle include emaciation, diarrhea, anemia, stiffness, and fading of hair color. Vegetation containing 230 mg kg^{-1} of this substance affects cattle.

Mercury in fish has been found in waters in the United States and Canada. Mercury in the waters is converted into methyl mercury by aquatic vegetation and other processes. Small fish consume such vegetation and in turn are eaten by larger fish and eventually by humans; food with more than 0.5 ppm of mercury (0.5 mg kg^{-1}) cannot be sold in the United States for human consumption. The US Food and Drug Administration recommends that pregnant women and women of childbearing age should not exceed consuming 14 ounces of fish with 0.5 ppm mercury per week.

Mercury has a very complicated chemistry. It forms numerous chemical species with very different properties and behaviors in the environment. Three major types of mercury are important in air pollution: elemental mercury [Hg(0)], which is the uncombined chemical element; divalent mercury [Hg(II)], which is chemically reactive and under most environmental conditions is found to be combined with other substances into mercury salts (e.g. $HgCl_2$); and particulate-phase mercury [Hg(p)], most of which is actually the chemical species Hg(II) but is only slightly reactive because it is mixed with solid-phase material in the atmosphere. These three species have very different affinities for compartments and organisms (see Fig. 12.4). Thus, the mercury that is released from a stack can have a tortuous journey to and through the food chain.

B. Gaseous and Particulate Effects

Periodically, accidental emissions of a dangerous chemical affect animal well-being. During nerve gas experimentation in a desolate area in Utah, a high-speed airplane accidentally dropped several hundred gallons of nerve gas. As a result of the discharge, 6200 sheep were killed. Considering the

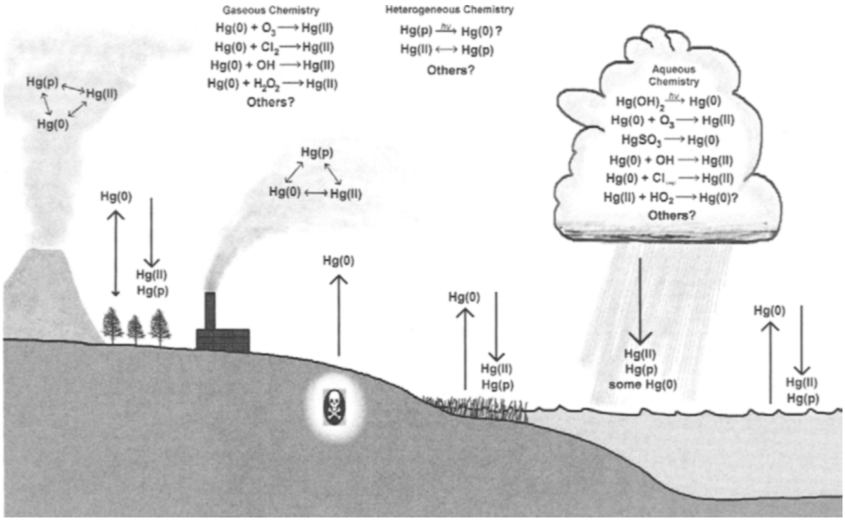

Fig. 12.4. Chemical speciation of mercury after it is released into the environment. Hg(0) is elemental, zero valence mercury; Hg(II) is divalent mercury (also known as reactive Hg); and Hg(p) is particulate-bound mercury. Drawing by Russell Bullock, National Oceanic and Atmospheric Administration, Research Triangle Park, North Carolina.

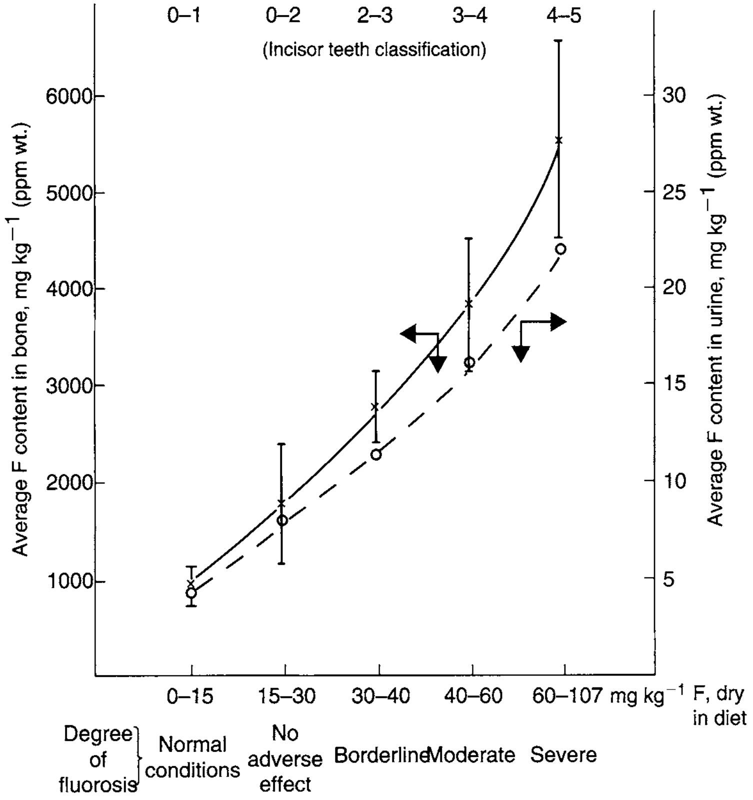

Fig. 12.5. Effects of fluoride on 4-year-old dairy cattle.

large number of exotic chemicals being manufactured, such unfortunate accidents may be anticipated in the future.

Fluoride emissions from industries producing phosphate fertilizers or phosphate derivatives have caused damage to cattle throughout the world; phosphate rock, the raw material, can contain up to 4% fluoride, part of which is discharged to air (and waters) during processing. In Polk and Hillsborough counties of Florida, the cattle population decreased by 30 000 between 1953 and 1960 as a result of fluoride emissions. Since 1950, research has greatly increased our knowledge of the effect of fluorides on animals; standards and guides for diagnosing and evaluating fluorosis in cattle have been compiled.

Chronic fluoride toxicity (fluorosis) is the type most frequently observed in cattle. The primary effects of fluorides in cattle are seen in the teeth and bones. Excessive intake weakens the enamel of developing teeth; the initially dulled erupted teeth can develop into soft teeth, with uneven wearing of molar teeth. Characteristic osteofluorotic bone lesions develop, causing intermittent lameness and stiffness in the animal. Fluoride content of the bone increases with dosage despite excretion in urine and feces. Secondary symptoms include reduced lactation, nonpliable skin, and dry, rough hair coat. As shown in Fig. 12.5, the fluoride ingestion level correlates with the fluoride content of bones and urine as well as incisor teeth classification [18].

TABLE 12.3

Fluoride Tolerance of Animals (ppm wt. in Ration, Dry)[a]

Species	Breeding or lactating animals (ppm)[b]	Finishing animals to be sold for slaughter with average feeding period (ppm)[b]
Dairy, beef heifers	30	100
Dairy cows	30	100
Beef cows	40	100
Steers	–	100
Sheep	50	160
Horse	60	–
Swine	70	–
Turkeys	–	100
Chickens	–	150

[a] Data based on soluble fluoride; increased values for insoluble fluoride compounds.
[b] 1 ppm wt. = 1 mg kg^{-1}.

Tolerance of animals for fluorides varies, dairy cattle being most sensitive and poultry least (Table 12.3). Fluorosis of animals in contaminated areas can be avoided by keeping the intake levels below those listed by incorporating clean feeds with those high in fluorides. It has also been determined that increased consumption of aluminum and calcium salts can reduce the toxicity of fluorides in animals. In addition, high-dose exposures can completely alter an ecosystem. For example, if the population of a species of animals or plants that is sensitive to an air pollutant falls dramatically, then the entire predator–prey interactions can change. Thus, non-human species are indicators of environmental quality.

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QUESTIONS

1. Distinguish between air pollution damage and injury.
2. Why is it difficult to prove that effects on plants in the field observed visually were cause by exposure to air pollution?
3. What functions do the stomates serve in gas exchange with the atmosphere?
4. Why is air pollution damage important when estimates suggest that it accounts for less than 5% of total crop losses in the United States?
5. List examples of air pollution effects on plants that cannot be detected by visual symptoms.
6. What types of trace gases are released to the atmosphere by forest ecosystems?
7. How have ozone and insects interacted to damage trees in the San Bernardino Mountain National Forest of California?
8. Why are animals used in research on air pollution effects?
9. Calculate the daily fluoride intake of a dairy animal from (a) air and (b) food and water, based on the conditions below and assuming 100% retention of the fluoride:
   - Animal breathing rate: 30 kg air per day containing 6 μg fluoride per cubic meter of air (STP).
   - Animal food and water intake:

     Herbage 10 kg containing 200 mg kg^{-1} of fluoride.
     Water 5 kg containing 1 mg kg^{-1} of fluoride.
10. If you were a forest manager for a woody grove in Atlanta, Georgia, how might you use the information in Table 12.2? What if our were doing the same in Los Angeles, California? What differences, if any, would come into play?