1 Understanding pollution

"The very basis for life on earth is declining at an alarming rate."
Former UN Secretary, General Kofi Annan

Chapter 1 asks some basic questions: what is pollution and why is it important? What causes pollution? Is it always harmful? How do pollutants change once in the environment? Section I emphasizes the major impacts we humans exert on Earth's natural systems while reminding us of our profound dependence on the services provided by those systems. Section II asks why pollution happens. What substances pollute and where do they come from? We look at what happens to pollutants once released, and the effects exerted, sometimes at great distances from their point of release. Section III examines the catastrophic 1984 explosion in Bhopal, India. It also considers the opposite extreme: should we be concerned about very low levels of pollutants? We then move to impoverished parts of the world where pollution sometimes devastates human health. Section IV introduces root causes of pollution – growing human populations, growing consumption, and large-scale technology. Section V asks us to face ourselves, to see that our actions have environmental consequences, sometimes in ways we don't suspect.

SECTION I

Humans are massively changing the Earth

A 1997 article in the journal, *Science*, "Human domination of Earth's ecosystems", spoke of humanity's impact on the environment.[1] See Figure 1.1 from left to right. (1) Up to one half of Earth's land surface has been transformed by human action. (2) The percentage of the concentration of the atmospheric greenhouse gas, carbon dioxide, that results from human action. (3) The percentage of accessible surface fresh water on Earth being put to use by humanity. (4) The percentage of nitrogen fixation caused by humans is more than all natural terrestrial sources combined. (5) The percentage of plant species in Canada that humanity has introduced from elsewhere, i.e., invasive or exotic species. (6) The percentage of bird species on Earth that became extinct in the past two millennia (largely) from human activity. (7) The percentage of major marine fisheries that are fully exploited, overexploited, or depleted.

Ten years after the article, human domination has continued to increase. A 2007 report from the United Nation's Environmental Program (UNEP) stated: "The human population is

[1] Vitousek, P. M., Mooney, H. A., Lubchenco, J., and Melillo, J. M. Human domination of Earth's ecosystems. *Science*, **277**, July 25, 1997, 494–499, http://mk.geog.uu.nl/homepages/Peter/teaching/Themes/Vitousek.pdf.

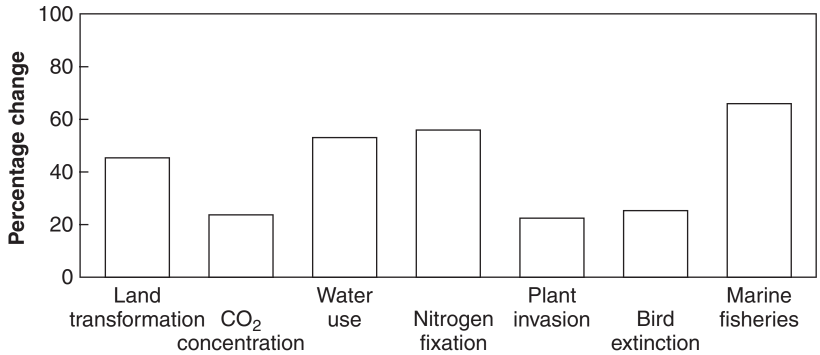

Figure 1.1 Human domination of Earth's ecosystems. Credit: Reprinted with permission from AAAS

living far beyond its means and inflicting damage on the environment that could pass points of no return."[2] One example: as much as one-third of ocean fisheries are in collapse, two-thirds may be so in 2025, and all major ocean fisheries may be gone by 2048. As the "Human Domination" article stated: "The rates, scales, kinds, and combinations of changes occurring now are fundamentally different from those at any other time in history; we are changing Earth more rapidly than we are understanding it. In a very real sense, the world is in our hands and how we handle it will determine its composition and dynamics, and our fate."

To the student: Chapter 1 describes major and discouraging problems. However, the chapter's purpose is to provide the background from which we can consider solutions. Solutions are assuredly difficult, but human willingness and energy can lead to surprising changes.

Nature's services

We may ignore pollution if its source is a local factory that provides employment. "That's the smell of money" we might say. Many of us still fail to recognize our total dependence on our environment or recognize that all human employment depends on nature's services. For a summary of nature's services, see Table 1.1.

Examples of nature's services (ecosystem services[3,4])

Protecting drinking water

New York City spent hundreds of millions of dollars to buy ~70 000 acres (~28 000 hectares) of land along streams and rivers in the Catskill Mountains to the city's

[2] Kanter, J. UN issues "final wake-up call" on population and environment. *International Herald Tribune*, October 25, 2007, http://www.iht.com/articles/2007/10/25/europe/environ.php.

[3] Daily, G. C. *Nature's Services, Societal Dependence on Natural Ecosystems*. Washington DC: Island Press, 1997.

[4] *Ecosystem Services: A Primer*, Ecological Society of America, 2000–2005, http://www.actionbioscience.org/environment/esa.html [August 2008].

Table 1.1 What are nature's services?

Type	Examples
Provisioning	Food (plants and animals), water, fuel (such as wood and dung)
Regulating	Climate (including temperature and precipitation), water purification and waste treatment, pollination, preventing soil erosion (as with grasses and trees), storm protection (as with mangroves and coral reefs)
Supporting	Services necessary to produce other ecosystem services including soil formation, nutrient cycling, production of oxygen (from photosynthesis)
Cultural	Spiritual values, a "sense of place," recreation and ecotourism

Nature's services, also called "ecosystem services" are the benefits people obtain from the natural world. These services directly affect people and also support services needed to maintain the other services." (See Millennium Ecosystem Assessment, http://www.millenniumassessment.org/en/Framework.aspx.)

north – the watershed[5] that provides its drinking water.[6] It then restricted use of that land, forbidding activities such as the application of pesticides and fertilizers that would pollute watershed streams and rivers. ▪ The city also protected the land from development, leaving trees and grasses in place. Roots of grasses and trees hold the soil in which they grow, preventing it from eroding and running off into streams during rainstorms. Rooted vegetation also slows the rain falling through its foliage down into the soil. Leaf and other vegetation litter on the ground absorb and slow water too. These factors lessen the risk of flooding during heavy rains. And, as water seeps downward to groundwater, the soil traps pollutants contained in the rainwater. Because groundwater is in contact with surface water, keeping groundwater clean helps to provide clean surface water. The rainwater allowed to seep into groundwater replenishes it. ▪ By protecting the Catskills' from pollution and recognizing the natural water filtration capability of undeveloped land, the City avoided having to build a $6 billion treatment plant to purify its drinking water, plus the $300 million a year it would have cost to run the plant. The City saved billions of dollars by protecting natural services – also called ecosystem services. Other American cities are following New York City's example, e.g., Austin Texas has purchased 20 000 acres (~8000 hectares) of land around its Edwards Aquifer.

Preventing floods

China is taking similar action to help curb flooding there. Lester Brown described the major 1998 floods along the Yangtze River basin in China, floods continuing for many weeks, and causing many billions of dollars in damage.[7] Afterwards, the Chinese government traced part of the flooding to deforestation along the Yangtze River, so they banned tree cutting in the upper reaches of the basin. They calculated that the value of living trees is three times the value of cut trees.

[5] To get a sense of a watershed, see Figure 9.3.
[6] Carlton, J. Cities spending millions on land to protect water supplies. *The Wall Street Journal*, January 4, 2006.
[7] Brown, L. Eco-economy, building an economy for the earth. Chapter 8, *Protecting Forest Products and Services*. Earth Policy Institute, 2001, http://www.earth-policy.org/index.php?/books/eco/eech8_intro.

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Global climate change

In Chapter 7, we will see how important it is to limit atmospheric levels of carbon dioxide (CO_2), the major greenhouse gas. Human actions, especially burning fossil fuels, release large amounts of CO_2. Regulating the amount of CO_2 in the atmosphere requires the protection of trees and other vegetation that take up CO_2 from the atmosphere. Tropical forests are especially important. One scientist stated, "We'll never solve the climate challenge unless we address the loss of tropical forests, [a loss] which puts out as much carbon dioxide as all the planes, trains, and cars worldwide."[8]

Urban trees[9]

The organization American Forests, using satellite and aerial imagery, showed that tree cover in 20 US cities had declined by 30% over three decades, a disturbing loss of shade, cooling, and aesthetic value. Fewer trees also means more runoff of storm water, which otherwise could seep into groundwater while also removing pollutants. Fewer trees also mean more air pollution because the stomata in tree leaves can help remove air pollutants, and sticky or hairy leaves filter particulates from air. ▪ Using a computer-based geographic information system, American Forests determined how much pollution urban trees remove, and then calculated the economic loss of cutting the trees down. In Washington, DC the cut trees would have removed ~354 000 pounds (over 160 000 kg) a year of major air pollutants including carbon monoxide, sulfur dioxide, and ozone. With fewer trees to trap storm water, storm water runoff increased by 34%. It costs Washington, DC about $226 million per year to trap and treat the additional runoff. Despite tree losses, the average city still has about 30% tree cover, and American Forests believes that this could reasonably increase to at least 40%.

Stabilizing soil depends on more than trees

Grass is also tremendously important for holding soil in place. Indeed, the greatest environmental catastrophe in American history, the "dust bowl", occurred in the Midwestern states after farmers cleared massive areas of native grasslands. They cleared the grassland to grow ever-increasing amounts of wheat. As long as rainfall was ample, catastrophe was averted, but as the region fell into a prolonged drought in the 1930s, wind whipped up the unprotected soil on 100 million acres (40.5 million hectares) and blew it, sometimes many hundreds of miles away (see Figure 1.2). Untold numbers of farms were destroyed as they were denuded of productive soil. Great numbers of animals, both domestic and wild, died. Humans suffered greatly too, many dying of "dust pneumonia." Many thousands left the land that could no longer be farmed. US President Franklin D. Roosevelt, in the late 1930s, asked: why did the Great Plains blow away? What made this land die? It was difficult for him to accept that human action was responsible. Beginning in the late 1930s, a major

[8] Source: Stephanie Meeks of The Nature Conservancy. She is working with the World Bank to provide incentives to people to preserve rain forests. Their effort is called Cool Earth.

[9] Fields, S. If a tree falls in the city (ecosystem services of urban trees). *Environmental Health Perspectives*, **110**(7), A390, July, 2002.

Figure 1.2 Dust storm approaching Stratford, Texas (April 18, 1935). Credit: NOAA George E. Marsh Album

effort began to restore the land, to plant windrows of trees, and to check erosion. However, it took many years for recovery, and some land was never restored. These Midwestern states now largely depend on irrigation to water their crops. The water comes from the Ogallala aquifer, another resource that is being depleted. A fascinating depiction of this tragedy is given by Timothy Egan in his book, The Worst Hard Time.[10]

▪ Undeveloped land provides a multitude of other natural services: home to wildlife, timber for careful lumbering operations, recreation, and aesthetic value. It is also cooler than cleared land. ▪ Undeveloped wetlands, whether located in forests or elsewhere trap eroded soil, preventing its runoff into streams and lakes. Wetland plants and microorganisms purify polluted runoff carried there. Wetlands provide flood protection as noted in the Yangtze example. They also provide habitat to multiple bird and other species.

Other ecosystem services

It is not possible to count the many services that nature provides, but Table 1.1 notes some major services, and other examples follow. ▪ Nature provides seafood, wild game, forage, timber, biomass fuels, and natural fibers. ▪ Trees and other vegetation take up the greenhouse gas carbon dioxide, while releasing the oxygen necessary to our lives. ▪ The atmosphere's ozone layer protects us from the sun's ultraviolet radiation. ▪ Worms and other organisms, and vegetation enhance soil fertility. ▪ Nature provides the insects, birds, and other animals that pollinate many food crops. Birds and some insects eat many agricultural pests. ▪ Many species of fungi and bacteria, insects, and worms degrade organic waste materials, a vital

[10] Egan, T. *The Worst Hard Time, the Great American Dust Bowl*. Boston: Houghton Mifflin Co., 2006.

function. Organic wastes include sewage, dead vegetation, and animal matter, and natural as well as anthropogenic organic pollutants. Some larger creatures eat wastes too – vultures are essential to scavenge dead animals in some places. Waste-degrading creatures could live without humans, but we cannot live without them.

Among services that you might not think of, consider glaciers, many of which are now melting as the climate warms. Glaciers provide water to many of the world's major rivers, which in turn provide drinking water, and water used for agriculture, hydroelectric dams, industry, and, of course, water for the countless other species that live on Earth. Or think about the soil that, in many places around the world is undergoing *desertification*, conversion into deserts. Desertification lessens the land available for human habitation, for agriculture, or habitat for our fellow species. Moreover, as land undergoes desertification we see increasing numbers of dust storms, often badly impacting people, plants, and animals living hundreds, even thousands of miles from those storms.

Vital species

We do not know which species are absolutely vital to life on Earth, but we know that a great many are needed to maintain the multitudes of ecosystem services (see Box 1.1). We also know that humanity is destroying and disrupting habitat, and producing pollution. In the process, species are going extinct at a rate perhaps 100 times greater than the natural rate. ▪ Coral is one example of a vital species. Coral reefs play an irreplaceable role in the marine environment. They provide habitat for marine species that are integral to the ocean's food chain. They provide a livelihood to a hundred million people in less-developed countries in jobs such as fishing and tourism. Beyond the marine environment, coral reefs protect the coastline from flooding and coastal erosion. But coral reefs are being lost through pollution from eroded soil carried in runoff along with chemical pollutants; global warming is also playing a deadly role.

Questions 1.1

1. In a paragraph, describe how protecting land from development, as New York City did, helps to provide clean water.
2. Coral reefs are a vital living resource that is being destroyed. What is another?
3. What did Harvard biologist, E. O. Wilson mean by saying "We need invertebrates but they don't need us"?
4. What natural services do the following provide? (a) Grasslands (b) Estuaries (c) Microorganisms.
5. When you think about vital species, what are two species (other than domestic animals) that come to mind? What services do these species provide?
6. How can pollution result from: (a) Deforestation? (b) Grassland loss? (c) Wetland loss?
7. Technology can mimic some natural services such as purifying water, albeit often at high cost. What technology – one that is already known or one that you can envision – can: (a) Provide clean drinking water at a reasonable cost? (b) Rebuild agricultural soil damaged by erosion? (c) Rebuild soil damaged by salt buildup? (c) Produce adequate food in the absence of fertile soil?

Box 1.1 "Less forgiving than our planet"

A facility known as *Biosphere 2* was designed to test a supposition often made by economists – that technology can substitute for natural life support systems. Biosphere 2 was to model a spacecraft that could allow humans to travel in space indefinitely. Within the structure, everything was to be sustainable. Built in the State of Arizona at a cost of $200 million, the 3.2 acres (1.3 hectares) of Biosphere 2 are a closed-off mini-Earth containing tiny *biomes* – a marsh from the Florida Everglades, an equatorial rain forest, a coastal desert, a savanna with a stream and grasses from three continents, an artificial mini-ocean with a coral reef, plus an orchard and intensive agricultural area. Its underbelly holds a maze of plumbing, generators, and tanks. In 1991, eight people started living in Biosphere 2 to test its ability to support life. They lived within the facility for two years. The first year went well, but in the second, crops failed, and people grew thin. They became dizzy as atmospheric oxygen levels fell from 21% to 14% – a level typical of a 14 000 feet (4270 m) elevation. This occurred because excessive organic matter in the soil absorbed oxygen from the air as did the type of concrete used. Atmospheric carbon dioxide "spiked erratically," while nitrous oxide rose to levels hazardous to brain function. Vines and algal mats overgrew other vegetation. Water became polluted. The Biosphere initially had 3800 plant and animal species. Among the 25 introduced vertebrate species 19 died out over the two years, and only a few birds survived. All the Biosphere's pollinators – essential to sustainable plant communities – became extinct. Excitable "crazy" ants destroyed most other insects. ▪In 1997, Columbia University took over Biosphere 2 for use as an educational facility designed to teach Earth stewardship, a place to "build planetary managers of the future." Its research efforts included studying the effects of various levels of the greenhouse gas carbon dioxide on plant communities. That effort ended and the University of Arizona is now in charge. ▪ Someone noted that Biosphere 2 is less forgiving than our planet. But Earth is a closed system too. History records many examples of civilizations that failed or grew weak after severely impacting their local environments.[11] But survivors often moved on to other environments. Today, many people still struggle to "move on," but there are fewer and fewer fresh locales into which Earth's huge population can move.

The technical problems of Biosphere 2 could probably be solved. But for the whole Earth, or major parts of it, can we substitute technology for nature's services, for breathable air, or for fertile clean soil?

What is happening to Earth's ecosystems?

Keeping in mind our absolute dependence on Earth's ecosystems and the major stresses on them, how well are they still providing their natural goods and services? The first systematic examination of this question was a four-year $20 million study, the Millennium Ecosystem Assessment (MEA).[12] Carried out by 1400 scientists worldwide under the aegis of the UN

[11] Diamond, J. *Collapse, How Societies Choose to Fail or Succeed*. New York City: Viking, 2004.
[12] (1) Stokstad, E. Taking the pulse of Earth's life-support systems. *Science*, **308** (5718), April 1, 2005, 41–43. (2) *Global Economic Growth Continues at Expense of Ecological Systems*. Worldwatch Institute, January, 2008, http://www.worldwatch.org/node/5456.

Environment Program's (UNEP), the MEA evaluated the health of the planet's forests, coastlines, inland waters, shrub lands, dry lands, deserts, agricultural lands, and other ecosystems vital to human and natural welfare. Helping investigators to envision what was happening were 16 000 photographs donated by the US National Aeronautics and Space Administration (NASA). Taken from space by satellite, these showed changes occurring in the 1990s in biomes such as coastlines, mountains, and agricultural land.

In 2005 MEA provided some answers as to what is happening to ecosystem services. Their report revealed that *at least 60% of services supporting life on Earth* including fresh water, fisheries, and many other services are being used unsustainably. The report, *Living Beyond Our Means: Natural Assets and Human Well-being*,[13] has shown that we are using about 1.25 Earths' worth of resources, even while human population and consumption continues to increase. Consequences of environmental degradation could become more obvious in coming years. Although results were extremely worrisome, the study pointed toward means by which we can improve ecosystem management, a topic that we will examine throughout this text.

SECTION II

Pollution

When pollution is obvious

If you read that a *pollutant* is "any substance introduced into the environment that adversely affects the usefulness of a resource" you may yawn. But pollution literally hits you if you live in a city where emissions from cars, trucks, and motorbikes sting your eyes, congest your nose, cause your head to ache, or tighten your breathing. ▪ In the 1960s and '70s, pollution in the United States, a wealthy country, was often blatant. Some rivers were obviously polluted by industries operating on their banks. Oil floating on the surface of Ohio's Cuyahoga River caught on fire more than once. One fire in 1959 burned for 8 days. ▪ Air pollution was obvious too. In industrial cities soot drifted onto streets and clothing, and into homes. Severe air pollution episodes increased hospital admissions killing sensitive people. Trash burned in open dumps. ▪ Heavy pesticide use killed fish, birds, and other animals. ▪ The new century finds the environment in industrialized countries improved. But continuing population growth in the United States, and unremitting, indeed accelerated, land development may be reversing some of that progress. And the United States, once an environmental leader, abandoned that role in the first decade of the twenty-first century.

Just as a weed is "a plant out of place," a pollutant is "a chemical out of place." Oil enclosed within a tanker is not a pollutant. Spilled into the environment, it is. However, doing harm often involves more than being out of place. A small oil spill may go unnoticed,

[13] See http://millenniumassessment.org/en/index.aspx, home page of the MEA, which links to the report's summary and other reports including *Living Beyond Our Means*. Also see the World Resources Institute's *EarthTrends* at http://earthtrends.wri.org/ for more useful information on Earth's ecosystems.

Table 1.2 Terms used to describe pollutant concentration

ppm = parts per million[a]
ppb = parts per billion (one thousand times smaller than ppm)
ppt = parts per trillion (1 million times smaller than ppm)
ppq = parts per quadrillion (1 billion times smaller than ppm)
To grasp these concentrations, consider the following:
1 ppm = 1 pound contaminant in 500 tons (1 million pounds)
1 ppb = 1 pound of contaminant in 500 000 tons
1 ppt = 1 pound of contaminant in 500 000 000 tons
1 ppq = 1 pound of contaminant in 500 000 000 000 tons.
For a different perspective, think about periods of time:
1 ppm is equivalent to 1 second in 11.6 days
1 ppb is equivalent to 1 second in 32 years
1 ppt is equivalent to 1 second in 32 000 years
1 ppq is equivalent to 1 second in 32 000 000 years.

[a] ppm, ppb, etc. refer to parts by weight in soil, water, or food. In air, they refer to parts per volume.

but a large one can be disastrous. Circumstances are important too. If the oil is of a type easily degraded, or one that evaporates easily, or if wind blows the spill quickly away from a shoreline, there may be little harm. But, coming ashore, oil may devastate animals, birds, and other shore-dwelling organisms.

Almost any substance, synthetic or natural, can pollute. However, it is synthetic and other industrial chemicals that are emphasized here. If we learn that industrial chemicals in a water body are obviously impairing the ability of birds to reproduce, or are associated with fish tumors we all agree that the water is polluted. But what if only tiny amounts of industrial chemicals are present and living creatures are apparently unaffected? Is the water polluted? Some would say "yes," arguing that chronic effects could result, i.e., adverse effects resulting from long-term exposure to even very low concentrations of a substance. ▪ The word *waste* differs from *pollutant*, although a waste can be a pollutant too. Waste refers to material such as garbage, trash, construction debris: materials that have reached the end of their useful life. ▪ See Table 1.2 for a description of how pollutant concentrations are described.

Pollution is often less obvious if you live in a wealthy country where the twentieth century brought cleaner air and drinking water, sewage treatment, safe food laws, and food refrigeration. But it took many years and many billions of dollars to reach those results. And wealth does not guarantee an unspoiled environment. For example, parts of the American Appalachian Mountains suffer destruction and pollution resulting from mountaintop-removal mining (described later). Or think about wealthy Hong Kong. In the 1990s, the beaches of this island were too polluted for swimming. High concentrations of hazardous industrial metals, livestock waste, and human waste polluted its rivers, and large amounts of trash polluted the harbor. However, between 1993 and 2000, hazardous metal discharges were reduced from 15 432 lb/day (7000 kg/day) to 4409 lb/day (2000 kg/day). And, Hong Kong increasingly collects and treats sewage before releasing it into the harbor. However, air pollution remains critical. In the mid-1990s, exhausts from motor vehicles resulted in 25% of the population suffering from respiratory problems. Today, despite better air pollution controls, heavy smog often blankets Hong Kong. Up to half of this enters Hong Kong from nearby Chinese cities in Guangdong Province. But part of the imported pollution comes from facilities owned by Hong Kong companies – operating on the mainland with poor pollution controls.

Why does pollution happen?

Unless you assume that people and industry deliberately pollute, why does pollution occur? It happens because no process is 100% efficient. Consider your own body – it cannot use 100% of the food you eat. ▪ The gastrointestinal (GI) tract does not break down the fiber in the food you eat, and this is excreted from the body as solid waste. ▪ Enzymes in the gut do break down other foods into molecules that can cross the GI wall into the bloodstream, which carries the nutrition throughout your body. But the body cannot use 100% of the nutrient value, and a portion is excreted into urine as water-soluble waste. ▪ Also, your body cannot convert all the potential energy in food into useful energy – part becomes waste energy.

As with your body, no other process, natural or human, such as manufacturing or fuel burning, is 100% efficient: each produces pollution and waste, and waste energy. See Box 1.2. Lack of prevention, carelessness, unwillingness to invest in good technology, or lack of appropriate technology aggravates the waste and pollution produced. Architect William McDonough and chemist Michael Braungart observe, “Pollution is a symbol of design failure.” In other words, wastes need not be wastes and pollutants need not be pollutants. We should be able to return these to the manufacturing process, or else make sure the wastes involved are able to biodegrade harmlessly in the environment. We will return to this later.

What substances pollute?

Almost any chemical or material from either human or natural sources can pollute. See Table 1.3. Also see Pollutant Sources below.

Natural pollutants

This text emphasizes anthropogenic pollutants (i.e., pollutants produced by human activity), but natural chemicals can also pollute. This happens dramatically when an erupting volcano spews out huge quantities of rocks, ash, chlorine, sulfur dioxide, and other chemicals. Other natural chemicals can pollute too, but sometimes human actions allow natural substances to reach dangerous levels as in the following illustrations: 1. *Radon* is a naturally radioactive chemical, a gas that arises from transformations occurring in underlying rocks and soil