Controlling Environmental Pollution

An Introduction to the Technologies, History, and Ethics

P. Aarne Vesilind and Thomas D. DiStefano
Bucknell University

DES*tech* Publications, Inc.

Controlling Environmental Pollution

DEStech Publications, Inc.
439 North Duke Street
Lancaster, Pennsylvania 17602 U.S.A.

Printed in the United States of America
10 9 8 7 6 5 4 3

Main entry under title:
Controlling Environmental Pollution: An Introduction to the Technologies, History, and Ethics

A DEStech Publications book
Bibliography: p.
Includes index p. 409

ISBN No. 1-932078-39-8

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Preface

OVER the past decades we have seen some stunning victories in our fight against environmental pollution. Our lakes and rivers are cleaner than they have been in a century, and our air, even in the dirtiest cities, is breathable. The solid waste situation seems to be under control, and we have made a lot of progress in attacking the legacy of neglect in the management of hazardous waste.

But much work remains to be done, and we cannot revel complacently in our achievements. Sustained commitment of human and financial resources will be needed for the foreseeable future to address the management and cleanup of hazardous waste sites. An increasing population with an ever-growing demand for consumer goods will generate waste at record levels, not just in the United States but around the world. The free-market system continues to sell products that may either emit as-yet-unimagined pollutants or have unknown health effects.

The work of managing environmental pollutants will never cease. It will only change. But to understand where we are going, we need to know where we have been, and thus this book looks both forward and backward. The book describes state-of-the-art technology used in pollution control, and at the same time relates stories of environmental catastrophe, technological breakthroughs, and people who have been most influential in the development of this field.

This book is intended for a non-engineering audience. A knowledge of calculus, physics, or fluid mechanics is not required, whereas a high-school level chemistry course is necessary for full understanding. The text is based on a one-semester Bucknell University course designed for students in environmental studies. The course consists of three class hours plus a two-hour laboratory per week. Our experience in teaching the course has shown that students who have not had any training in technology are able to learn the concepts presented in this book. Even most BA candidates who have not taken college-level science do quite well.

As with any undertaking, the writing of a book requires the help and

assistance of many people. Most importantly, we want to acknowledge the assistance and participation of our colleague, Matthew Higgins, who wrote part of the chapter on water treatment, including the discussion on bottled vs. tap water and contributed his ideas and insights during the planning phase of this book.

Finally, we want to thank the many students who have been through the ENVR 211 course and have provided us with useful feedback on how the topics addressed in the following pages can best be presented.

P. Aarne Vesilind
Thomas D. DiStefano
Lewisburg, Pennsylvania
May, 2005

CHAPTER 1

The Pollution of the Environment

We begin this book on an optimistic note. We want you, the reader, to recognize that there have been tremendous achievements in controlling pollution and that our environmental quality is vastly improved from what it used to be only a few decades ago.

Pollution problems are as old as human history. Imagine the living conditions back in pre-historic times when smoke filled caves and huts, and human waste transmitted disease. And then fast-forward to the beginning of the Industrial Revolution in the 18th century. As bad as things might be today with human health and environmental quality, they were a far sight worse then.

One of the unsolved problems during the 19th century in industrial cities all over the world was the lack of toilet facilities for all but the wealthy, and the total absence of wastewater treatment for all. Sewage from those homes with water simply flowed into the nearest watercourse, while the less wealthy used toilets in outhouses that overhung rivers. The very poor often lived around crowded courtyards where the only means of relieving oneself was to make a pile in the courtyard. The worst part about all this was the diseases that were transmitted by such unsanitary conditions. In addition, the smell was overwhelming.

We know that sensitive gentlemen often stuffed cloves into a pomegranate and walked with this stuck under their nose in order to ward off the odors. The River Thames in London stank so badly that the Parliament had to stuff rags soaked with lye into the cracks in the windows to try to keep out the smell. Contemporary accounts claim that people chatting in the parlor would keel over in mid-sentence. The servants got the worst of human waste disposal because they so often lived in the basements. The waste from above would be stored in leaking tanks, and this would ooze through the walls into their rooms.

Air pollution in some cities was unimaginable by today's standards. The popular seaside resort Swansea, now a tourist mecca in Wales, was at one time one of the most polluted cities in the world. In the early part of the 19th century, iron and coal were discovered in the hills surrounding this old fishing community, and the discovery was followed in rapid succession by copper smelters and tinplate factories all along the shore. A travel writer described Swansea this way:

> Swansea in the 1860s, say when its metal exchange was the copper center of the whole world, seemed to have been visited by some horrific plague. Visitors approaching it by train from the east, seeing for the first time the green and sulfurous glow of its smelters, finding their carriages darkening by the black of its atmosphere, above all perhaps smelling its chemical fumes seeping and swirling all around, were sometime terrified by the experience, so absolutely of another world did the place seem, and so poisoned by its own exhalations.
>
> It was the works on the river bends that everyone remembered, for they cast a shroud-like spell. Everything was dead along that shore. All the grass was blistered off, all the water was fouled, not a tree lived, not a flower blossomed. A pall of vapour lay low over the valley: no bird flew through it, only the chimneys contributed to their filth, and the flicker of the furnaces was reflected eerily in its clouds. [Quote is courtesy of Richard Hummel, University of Toronto]

But we cannot assume that the advances made in environmental pollution control over the last decades have solved the problem. Many of the grossest forms or pollution from the 19th century have been eliminated, but quite a few new ones—ones that are not nearly as obvious as a belching smokestack—have been substituted. Problems with endocrine disruptors, acid rain, global warming, pesticides, disinfection byproducts, heavy metals—the list can go on and on—are just now being identified, and these problems are a great deal more frightening than a stream polluted with paper mill waste or air contaminated with wood smoke. So not all of the problems in controlling environmental pollution have been solved, and new ones that threaten our health and well-being appear every day. Nevertheless, we have come a long way in the last centuries in making our world a cleaner place to live.

If factual evidence is presented that would lead one to conclude that certain forms of pollution are causing health effects or are creating conditions that will

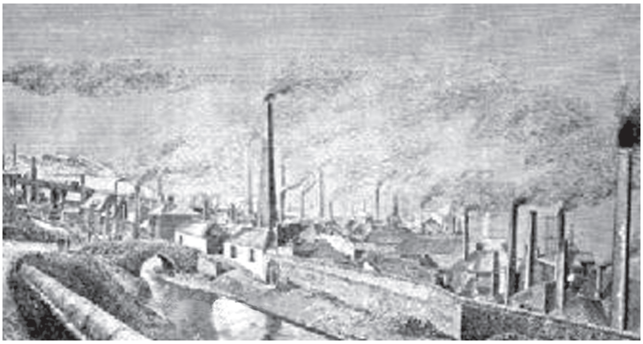


Figure 1.1. The Swansea copper smelter during the 19th century.

affect the welfare of distant or future populations, there generally are two responses. The first response is to agree with the data and analysis and strive to do something about the problem. The second response is to a) disagree with the data, or b) argue that there is no need to do anything about it. We see this latter approach most visibly in the debate on global warming. Many people simply will not believe the data, and insist that the whole thing is a conspiracy intended to destroy our economy and even our country. We can approach these people rationally, and we hope eventually to convince them that the data are accurate. A far more difficult group to convince are those who believe all the data, but simply do not care about what the pollution will do. These people argue it is the destiny of every generation to just take what we can for our own benefit, use up what is available, and throw away what we do not need. They believe that this approach will maximize our material happiness. To them the rest of the world is not of concern, and neither are future generations. Let them fend for themselves, they argue. Future generations are going to have many advantages we don't have, so we can take what we want right now and let these future people find their own way. Besides, how could we possibly know what the world would be like in the future? These people believe that the idea that one single individual can change the world is preposterous, so why not cruise along in a 25-foot powerboat, eat hamburgers, and throw aluminum beer cans into the lake? Life is good.

But fortunately, most people do not see the problems with environmental quality in that light. Most people *do* recognize our commitment to future generations, and they also understand that the actions of a single person *do* matter, when magnified by the thousands and millions of like-minded people. The Earth is worth saving, they argue, and it is the responsibility of all of us to do something to make this happen. If you are one of these caring optimists, then this book is for you!

1.1 WHAT ARE THE ROOT CAUSES OF ENVIRONMENTAL POLLUTION?

It can be argued that there was no environmental movement before the 1960s. Sure, there were activists like John Muir who went on to found the Sierra Club, President Teddy Roosevelt who oversaw the creation of the national park system, and Gifford Pinchot who advocated the wise use of our resources. Before them we had Henry David Thoreau and Ralph Waldo Emerson who eloquently praised the wonder of the natural world. But there was no welling of public opinion. Environmental quality simply was not a topic of conversation, and there were no activists marching or lobbying to support environmental legislation.

But small signs were there, and the willingness of the public to force action by the government was beginning to take hold, fueled in great part by other political issues, including the Vietnam War and civil rights. The situation was like a supersaturated solution, waiting for a single crystal that would cause it to solidify.

That crystal was the publication of Rachel Carson's book *Silent Spring*. While *Silent Spring* did not *cause* the environmental revolution any more than *Uncle Tom's Cabin* caused the Civil War, it nevertheless was hugely influential in promoting the cause of environmentalism. The vocal negative reaction from the chemical/agricultural industry had a lot to do with the success of the book. Many people, reading the reactions of the industry, wondered what nerve Carson had touched, and perhaps there was something to what she was talking about after all.

RACHEL CARSON

After graduating from the Pennsylvania College for Women (now Chatham College) in 1929 Rachel Carson (1907–1964) worked at Woods Hole Marine Biological Laboratory and continued her education with a master's degree in zoology from Johns Hopkins University in 1932. She was a writer, scientist, and in 1962 wrote perhaps the most influential book ever published in the environmental field, *Silent Spring*. The title comes from what she foresaw as the death and destruction of birds due to the extensive use at that time of chlorinated pesticides and she called for an end to their indiscriminate use. The reaction by the chemical industry to Carson's book was immediate and vitriolic. She was branded as everything from a flake to a Communist sympathizer. Here is a sample of the emotional tirades her book unleashed:

> The great fight in the world today is between Godless Communism on the one hand and Christian Democracy on the other. Two of the biggest battles in this war are the battle against starvation and the battle against disease. No two things make people more ripe for Communism. The most effective tool in the hands of the farmer and in the hands of the public health official as they fight these battles is pesticides. [Parke C. Brinkley, President of the National Agricultural Chemicals Association]

But in the end, it was clear that her cause was just, and as an increasing amount of evidence piled up on how the upper food chain was being affected by these non-biodegradable pesticides, she become a hero in the environmental movement. She did not, unfortunately, live to see her life and work honored by the world.

Quote from: Graham, F. "The Mississippi River Kill" in *Environmental Problems*, W. Mason and G. Fokerts (ed) William C. Brown Co. 1973

The other two very important environmental personages in the 1970s as the environmental movement was gathering steam were Paul Ehrlich and Barry Commoner. Ehrlich was at the time a respected scientist at Stanford, and Commoner was at Washington University in St. Louis. They both spoke out eloquently for the movement and became its de facto leaders.

Unfortunately, they had a serious disagreement that eventually led to their professional falling out. Ehrlich claimed that the core problem we were facing was overpopulation, while Commoner blamed the sorry state of the environment on over-consumption and the unwise use of non-replenishable resources. The answer, of course, is that both were right, but at that time their egos would not allow them to accept this obvious conclusion. The root causes of our environmental pollution are twofold: overpopulation and unwise use of resources.

1.1.1 Human Population Growth

All species reproduce in larger numbers than is necessary for the preservation of the species. The rate at which a population or any species *could* increase is known as the *biotic potential,* which is influenced by the age at which reproduction begins, the percentage of the life span during which the organism is capable of reproducing, and the number of offspring produced during each reproductive cycle. Larger animals such as whales have a very low biotic potential, while bacteria can divide every 20 minutes. At this rate, a single bacterium can produce 1,000,000 bacteria in only 10 hours! This growth is called *exponential growth*, as illustrated by the J-curve in Figure 1.2.

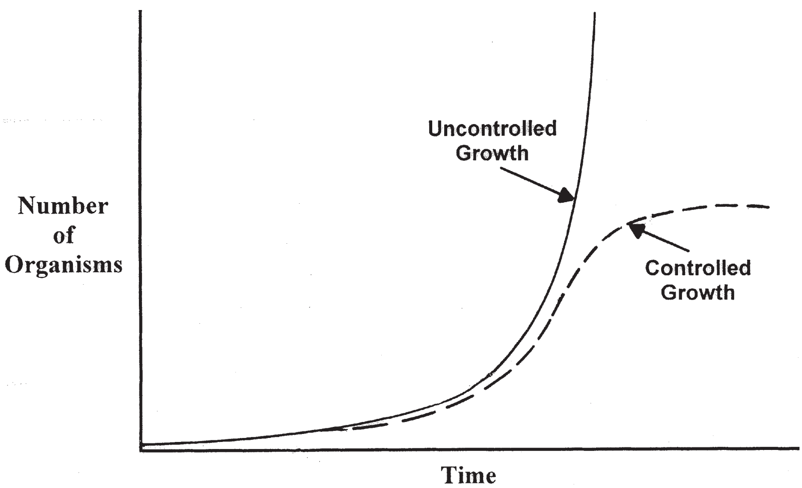


Figure 1.2. Growth curves for uncontrolled populations (the J curve) and populations that are controlled by environmental constraints (the S curve).

Exponential growth can best be illustrated by a story said to have originated in Persia. It tells of a clever courtier who presented a beautiful chess set to his king and in return asked only that the king give him one grain of rice for the first square, two grains, or double the amount, for the second square, four grains (or double again) for the third, and so forth. The king, being mathematically challenged, agreed and ordered the rice to be brought from storage. The eighth square required 128 grains, the 12th took more than one pound. Long before reaching the 64th square, every grain of rice in the kingdom had been used. Even today, the total world rice production would not be enough to meet the amount required for the final square of the chessboard. The secret to understanding the arithmetic is that the rate of growth (doubling for each square) applies to an ever-expanding amount of rice, so the number of grains added with each doubling increases.

Although some organisms can experience exponential growth for a short period of time, this rate of increase can not continue forever. What prevents the world from being overrun by various organisms is the *carrying capacity* of the environment, or the ability of the environment to support the population. At some point, as the population becomes overly large, there is *environmental resistance* to further growth due to predation, or lack of food and living space. The growth curve that occurs is thus more like the S-curve shown in Figure 1.2. At first the growth is exponential, but then various environmental resistance factors begin to limit the number of organisms and the number levels off to a constant number at the carrying capacity.

The global human population numbers over the past few thousand years

The Caribou on St. Matthew's Island, Alaska

St. Matthew's Island, located in the Bering Sea Wildlife Refuge, is roughly 128 square miles in area and supports a poorly developed land fauna. In 1944 a U. S. Coast Guard station was established on the island, and they decided to introduce a small herd of caribou to the island for recreational purposes. The Coast Guard station was abandoned shortly afterwards, and since that time the island has been uninhabited by humans. Because there were no predators on the island, and because there were no other large animals competing for the food supply, the small herd prospered. The herd's population increased exponentially from the original 29 to over 6,000 by 1963. This was far too many caribou than the vegetation of the island could support and the caribou overgrazed the island, nearly wiping out everything edible. Lichens, which were a staple of their winter diet, were completely eliminated, with predictable consequences. In the winter of 1964 nearly the entire herd of caribou starved, with only 8 females surviving to the spring. The caribou herd had experienced exponential, uncontrolled growth and exceeded the carrying capacity of the island. The only population control was death due to starvation.

eerily resemble the J-curve in Figure 1.2. The incredible increase in the number of humans has occurred because the controls that used to exists, such as famine, disease, and war, are being systematically eliminated.

Populations are governed by both birth rates and death rates. The growth of human populations is expressed as the difference between the births and deaths in a given population in a given time such as a year. In equation form,

$$R = B - D \tag{1.1}$$

where

R = annual population change
B = annual number of births
D = annual number of deaths

If population changes are to be compared, these numbers have to be normalized by dividing each term in the above equation by the population. The *birth rate* is then the number of births per year per capita, and the *death rate* is the number of deaths annually per capita. The rate of change, or the *growth rate*, is therefore the birth rate minus the death rate, or

$$r = (b - d) \tag{1.2}$$

where

r = the growth rate, or the rate of population change, number of people per year per capita (note that r can be negative if there is a net drop in population).
b = birth rate, number of births annually per capita
d = death rate, number of deaths annually per capita

To convert r to percent, multiply by 100.

Example 1.1

Ebolia has 150,000 people, and during the past year, there were 9,000 births and 3,000 deaths. What is the growth rate in Ebolia?

The birth rate, $b = 9{,}000/150{,}000 = 0.060$

The death rate, $d = 3{,}000/150{,}000 = 0.020$

The growth rate, $r = (0.060 - 0.020) = 0.040$, or $\times$ 100, 4%

That is, the population of Ebolia is increasing by 4% a year.

Another way of expressing the growth of populations is the *doubling time*, or the time it takes for a population to double. An approximation of doubling time is

$$t_d = 0.693/r \tag{1.3}$$

where

t_d = doubling time, years
r = growth rate, number of people per year per capita

Example 1.2

What is the doubling time for the population in Ebolia in the above example?

$$t_d = 0.693/0.04 = 17.3 \text{ years.}$$

At this rate of growth, the population of Ebolia will be roughly 300,000 people in 17.3 years.

Within a geographical area, there are two more ways the population can change: *immigration* and *emigration*, moving into the geographical area or out of it. The population growth rate for a certain geographical area is then expressed as

$$r = (b - d) + (i - e) \tag{1.4}$$

where

i = rate of immigration, number of people per year per capita
e = rate of emigration, number people per year per capita

Example 1.3

In the Ebolia situation in the above example, the rate of emigration from Ebolia is 8,000 people per year, whereas the rate of immigration is 500 people per year. What is the growth rate of the population in Ebolia?

Rate if immigration $i = (500/150{,}000) = 0.0035$ people per year per capita

Rate of emigration $e = (8000/150{,}000) = 0.0533$ people per year per capita

From Example 1.1, the birth rate is 0.060 and the death rate is 0.020 people per year per capita. Hence the Ebolian growth rate is

$$r = (0.060 - 0.020) + (0.0035 - 0.0533) = -0.0098 \text{ people per year per capita}$$

That is, the population in Ebolia is actually decreasing about 1% per year due to the high rate of emigration.

On a worldwide basis, both the birth and death rates are decreasing, as shown in Figure 1.3, but the world population continues to increase. Because the number of births has decreased slightly more rapidly than the number of deaths, the worldwide rate of increase has also declined. That is, the growth rate *r* is decreasing with time. But despite this decline in the global growth rate we will not see a stable population ($r = 0$) until about the year 2090, at which point the population will level off at about 10.5 billion, or about twice the present population. (Figure 1.4)

The growth of populations is uneven across the world, with the rate in more developed countries being much lower than in poorer countries. Almost all the population increase during the next half century will occur in the less developed countries in Africa, Asia, and Latin America, whose population growth rates are much higher than those in richer countries. The populations in the less developed regions will most likely experience the greatest growth, with Asia's share of world population stabilizing at about 55 percent of the world's population. Europe's portion has declined sharply and could drop even more during the 21st century. The more developed countries in Europe and North America, as well as Japan, Australia, and New Zealand, are growing by less than 1 percent annually. Population growth rates are negative in many European countries, including Russia (–0.6%), Estonia (–0.5%), Hungary (–0.4%), and Ukraine (–0.4%). If the growth rates in these countries continue to fall below zero, the populations will slowly decline (Figure 1.5).

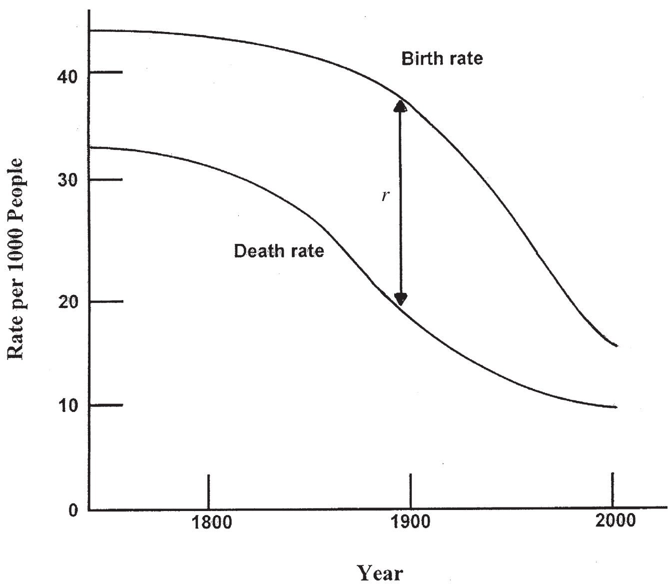


Figure 1.3. The decrease in both global birth rate and death rate. The difference is the growth rate, *r*.

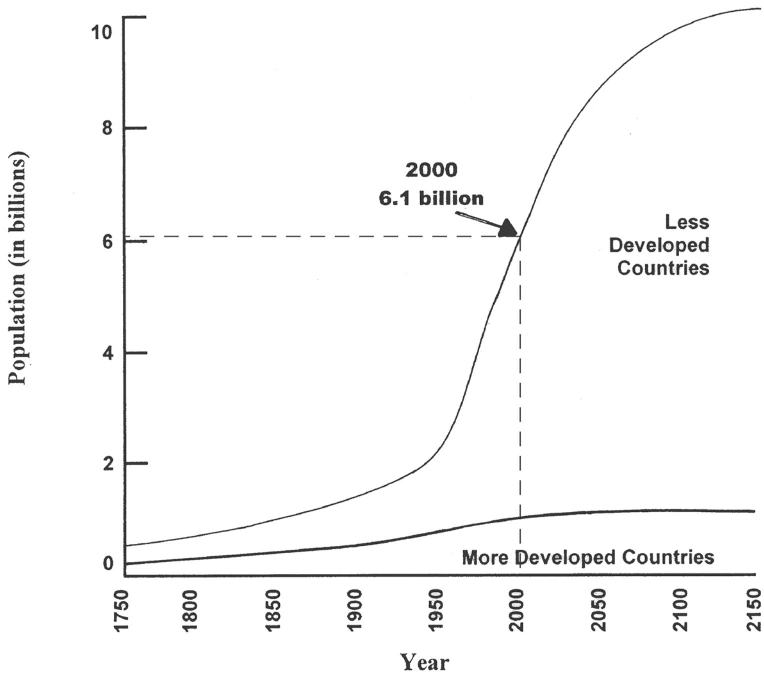


Figure 1.4. Global population prediction.

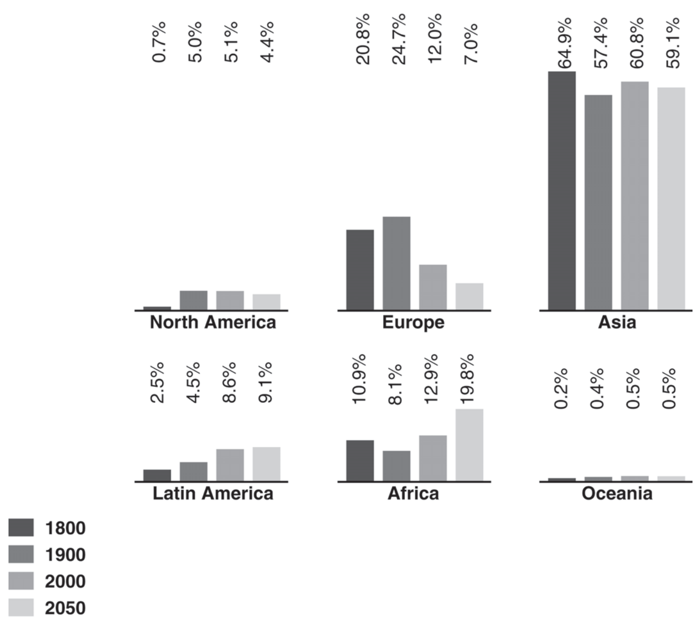


Figure 1.5. Populations for the six continents. The graphic shows the percent of the world's population. (*Source:* The United Nations Population Division, 1998).

Making such predictions presumes there will be no catastrophic changes to the population such as new viruses that defy treatment. We also do not know what the carrying capacity of the earth is and when this will be reached. It is possible that the carrying capacity is considerably less than 10.5 billion people, and that at some point there will occur a catastrophic population decline due to lack of food or the prevalence of disease. Given the past population growth, and the apparent inability of humans to understand the "tragedy of the commons," the Earth might well be another St. Matthew's Island.

Garrett Hardin

Garrett Hardin (1915–2003) received a BS in zoology from the University of Chicago and then went to Stanford University where he received his Ph.D. in microbiology. He is best remembered as a curmudgeon—a person who is not afraid to speak the truth, however unpopular the truth may be. In 1968 he wrote a hugely influential article entitled "The Tragedy of the Commons" which as become a must-read in every ecology course. In this article Hardin imagines an English village with a common area where everyone's cow may graze. The common is able to sustain the cows and village life is stable, until one of the villagers figures out that if he gets two cows instead of one, the cost of the extra cow will be shared by everyone, while the profit will be his alone. So he gets two cows and prospers, but others see this and similarly want two cows. If two, why not three—and so on—until the village common is no longer able to support the large number of cows, and everyone suffers. Harding applies this to the problem of birth control, arguing that the environmental cost of a child born today (air, water, and other resources) is shared by everyone, while the benefit is only to the parents. Hence every family will want more children, until the ability of the earth to support these populations is exceeded, resulting in global disaster.

A similar argument can be made for the use of non-renewable resources. If we treat diminishing resources such as oil and minerals as capital gains we will soon find ourselves in the "common" predicament of having too many people and not enough resources.

A thread running all through Hardin's books is that ethics has to be based on rational argument and not on emotion. He argues that for ethics to be useful people have to be literate, they must use words correctly, and they must appreciate the power of numbers. His most interesting book is *Stalking the Wild Taboo* in which he takes on any number of social misconceptions that demand rational reasoning.

1.1.2 Unwise Use of Resources

The resources necessary to allow humans to survive on this planet include air to breathe, water to drink, food to eat, and materials with which to build civilization. The objective is to use such resources in a manner that the Earth will be able to sustain the human population. This objective has been given the name *sustainability*.

Without doubt, human use of resources as presently practiced is unsustainable. That is, our present generations are using resources and polluting the earth at a rate that should make life more difficult (if not impossible) for future generations.

The *precautionary principle* states that if a problem is sufficiently severe and the consequences sufficiently serious, one would not need *proof* before action is taken to alleviate the potential damage. This recognition led the World Commission on Environment and Development, sponsored by the United Nations, to conduct a study of the world's resources. Also known as the Brundtland Commission, their 1987 report, *Our Common Future*, introduced the term *sustainable development* and defines it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The United Nations Conference on Environment and Development, i.e., the Earth Summit held in Rio de Janeiro in 1992 communicated the idea that sustainable development is both a scientific concept and a philosophical ideal. The document, *Agenda 21*, was endorsed by 178 governments and hailed as a blueprint for sustainable development. The administration of the first President Bush objected to some of the provisions that would require the United States to voluntarily cooperate with the rest of the world and refused to sign the document. Fortunately, the intransigence of the United States government has not prevented most other countries from adopting the central principles of this accord.

The underlying purpose of sustainable development is to help developing nations manage their resources such as rain forests without depleting these resources and making them unusable for future generations, and to prevent the collapse of global ecosystems. The Brundtland report presumes that we have a core ethic of intergenerational equity, and that future generations should have an equal opportunity to achieve a high quality of life. (The report is silent, however, on just *why* we should embrace the ideal of intergenerational equity, or why one should be concerned with the survival of the human species.)

One of the central problems with achieving sustainability is that consumption of resources is highly uneven. People in less developed countries consume considerably less resources than people in wealthier countries. Figure 1.6 is a dramatic illustration of the unevenness of the consumption of energy on a per capita basis. If the unwise consumption of resources is the root cause of

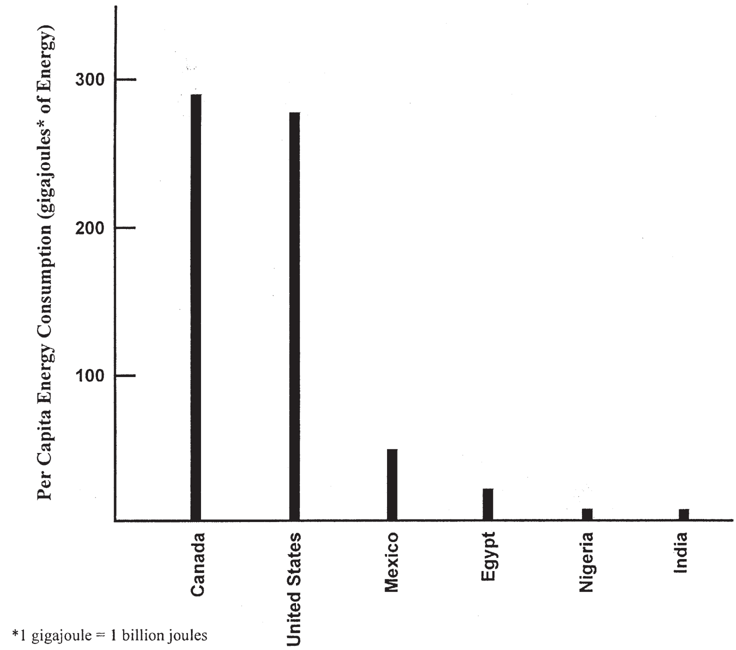


Figure 1.6. The uneven use of energy resources in six countries. (*Source:* P. H. Raven, L. R. Berg, and G. B. Johnson, *Environment* Saunders College Publishing, 1993).

our environmental problems, then certainly the rich countries have to take the vast majority of the blame.

1.1.3 Population vs. Resources

So who is right? Ehrlich or Commoner? Is our problem one of overpopulation, or is it a problem of the unwise use of resources? Of course, they are both right. A country or geographic area is overpopulated if it has more people that consume more resources than it can supply, and a country can be overpopulated in two ways:

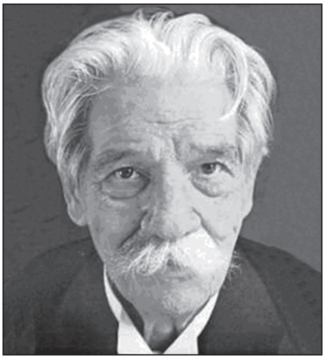
1. If there are too many people and the environment is being damaged because of the sheer number of people, even though their consumption is at a minimal level then this is called *people overpopulation*.
2. Even though there are few people, if their consumption is so high that they are not able to attain sustainability, then this is called *consumption overpopulation*.

It is the congruence of unwise use and consumption of resources by too many people that results in environmental pollution.

Epilogue

FOLLOWING the destructive hurricane Isabella that brought devastation to the North Carolina shore, the Reverend Tom Fairley offered this prayer at the releasing of sea turtles from the turtle hospital in Topsail Beach NC.

> God of all creatures, both great and small, if Isabel was a tiny demonstration of your power and might, then we stand dutifully in awe. But frankly, such demonstrations are getting very boring. If You truly hear our prayers, then we pray for You to re-evaluate Your own priorities. Unleash your fury on polluters who poison Your Oceans instead of Your lovely coastlines. Visit your wrath on profiteers who would make a buck by any means possible, even to the detriment of this tiny dust speck we call home. Strike down politicians bought by the highest bidder whose vote to clean the environment is silenced by big money.
>
> In a similar manner, O God, infuse into us a mighty dose of Your indignation and courage. As we ask you to get Your priorities straight, so, too, do we pray that you will help us to get our priorities in order. Give us the might and the fury of Isabel to attack polluters, profiteers, and crooked politicians at every opportunity. Let them know that because of us, by comparison, Isabel was nothing but a puff. Let them learn to fear us more than they fear a hurricane, and give us the courage of our resolve to act as Your agents. Help us to be your hurricanes for good.
>
> Once again, we ask You to pay attention to a handful of Your sea turtles. Keep them out of polluted waters, and away from all of our gadgets that cut them or drown them. But most importantly, keep them away from our kind who attacks them for money or sport. And may the calm that follows a hurricane become the peace we have in our hearts because we have done Your work, and have done it well. Amen.



ALBERT SCHWEITZER

Albert Schweitzer was born in Alsace, and following in the footsteps of his father and grandfather, entered into theological studies in 1893 at the University of Strasbourg where he obtained a doctorate in philosophy in 1899, with a dissertation on religious philosophy. He began preaching at St. Nicholas Church in Strasbourg in 1899 and served in various high ranking administrative posts. In 1906 he published *The Quest of the Historical Jesus,* a book on which much of his fame as a theological scholar rests.

Schweitzer had a parallel career as an organist. He had begun his studies in music at an early age and performed in his father's church when he was nine years old. He eventually became an internationally known interpreter of the organ works of Johann Sebastian Bach. From his professional engagements he earned funds for his education, particularly his later medical schooling.

He decided to embark on a third career, as a physician, and to go to Africa as a medical missionary. After obtaining his MD at Strasbourg in 1913 he founded his hospital at Lambaréné in French Equatorial Africa. In 1917, however, the war intervened and he and his wife spent 1917 in a French internment camp as prisoners of war. Returning to Europe after the war, Schweitzer spent the next six years preaching in his old church, and giving lectures and concerts to raise money for the hospital.

Schweitzer returned to Lambaréné in 1924 and except for relatively short periods of time, spent the remainder of his life there. With the funds earned from his own royalties and personal appearance fees and with those donated from all parts of the world, he expanded the hospital to seventy buildings which by the early 1960's could take care of over 500 patients in residence at any one time.

On one of his trips up the Congo to his hospital Schweitzer saw a group of hippopotamuses along the shore, and had a sudden inspiration for a new philosophical concept that he called "reverence for life" which has had wide influence in Western environmental thought.

He was awarded the Nobel Peace Prize in 1953.

Appendix

Mutiply	by	to obtain
acres	0.404	ha
acres	43,560	ft^2
acres	4047	m^2
acres	4840	yd^2
acre ft	1233	m^3
atmospheres	14.7	lb/in^2
atmospheres	29.95	in mercury
atmospheres	33.9	ft of water
atmospheres	10,330	kg/m^2
Btu	252	cal
Btu	1.053	kJ
Btu	1,053	J
Btu/ft^3	8,905	cal/m^3
Btu/lb	2.32	kJ/kg
Btu/lb	0.555	cal/g
Btu/s	1.05	kW
Btu/ton	278	cal/tonne
Btu/ton	0.00116	kJ/kg
calories	4.18	J
calories	0.0039	Btu
calories/g	1.80	Btu/lb
$calories/m^3$	0.000112	Btu/ft^3
calories/tonne	0.00360	Btu/ton
centimeters	0.393	in
cubic ft	1728	in^3
cubic ft	7.48	gal
cubic ft	0.0283	m^3
cubic ft	28.3	L
cubic ft/lb	0.0623	m^3/kg
cubic ft/s	0.646	million gal/day

Mutiply	by	to obtain
cubic ft/s	0.0283	m^3/s
cubic ft/s	449	gal/min
cubic ft of water	61.7	lb
cubic in of water	0.0361	lb
cubic m	35.3	ft^3
cubic m	264	gal
cubic m	1.31	yd^3
cubic m/day	264	gal/day
cubic m/hr	4.4	gal/min
cubic m/hr	0.00638	million gal/day
cubic m/s	1	cumec
cubic m/s	35.31	ft^3/s
cubic m/s	15,850	gal/min
cubic m/s	22.8	mil gal/day
cumec	1	m^3/s
cubic yards	0.765	m^3
cubic yards	202	gal
C-ration	100	rations
decacards	52	cards
feet	0.305	m
feet/min	0.00508	m/s
feet/s	0.305	m/s
feet/s	720	in/min
fish	10^{-6}	microfiche
foot lb (force)	1.357	J
foot lb (force)	1.357	Nm
gallon of water	8.34	lb
gallons	0.00378	m^3
gallons	3.78	L
gallons/day	43.8×10^{-6}	L/s
gallons/day/ft^2	0.0407	$m^3/day/m^2$
gallons/min	0.00223	ft^3/s
gallons/min	0.0631	L/s
gallons/min	0.227	m^3/hr
gallons/min	6.31×10^{-5}	m^3/s
gallons/min/ft^2	2.42	$m^3/hr/m^2$
gallons of water	8.34	lb water
grams	0.0022	lb
grams/cm^3	1,000	kg/m^3
hectares	2.47	acre
hectares	1.076×10^5	ft^2
horsepower	0.745	kW
horsepower	33,000	ft lb/min
inches	2.54	cm
inches/min	0.043	cm/s
inches of mercury	0.49	lb/in^2

Mutiply	by	to obtain
inches of mercury	0.0038	N/m^2
inches of water	249	N/m^2
joules	0.239	cal
joules	9.48×10^{-4}	Bru
joules	0.738	ft lb
joules	2.78×10^{-7}	kWh
joules	1	Nm
joules/g	0.430	Btu/lb
joules/g	1	W
kilocalories	3.968	Btu
kilocalories/kg	1.80	Btu/lb
kilograms	2.20	lb
kilograms	0.0011	tons
kilograms/ha	0.893	lb/acre
kilograms/hr	2.2	lb/hr
$kilograms/m^3$	0.0624	lb/ft^3
$kilograms/m^3$	1.68	lb/yd^3
$kilograms/m^3$	1.69	lb/yd^3
kilograms/tonne	2.0	lb/ton
kilojules	9.49	Btu
kilojules/kg	0.431	Btu/lb
kilometers	0.622	mile
kilometer/hr	0.622	miles/hr
kilowatts	1.341	horsepower
kilowatt-hr	3600	kJ
kilowatt-hr	3.410	Btu
liters	0.0353	ft^3
liters	0.264	gal
liters/s	15.8	gal/min
liters/s	0.0228	million gal/day
meters	3.28	ft
meters	1.094	yd
meters/s	3.28	ft/s
meters/s	196.8	ft/min
microscope	10^{-6}	mouthwash
miles	1.61	km
miles/hr	0.447	m/s
miles/hr	88	ft/min
miles/hr	1.609	km/hr
milligrams/L	0.001	kg/m^3
million gal	3,785	m^3
million gal/day	43.8	L/s
million gal/day	3785	m^3/day
million gal/day	157	m^3/hr
million gal/day	0.0438	m^3/s
million gal/day	0.0438	m^3/s
million gal/day	1.547	ft^3/s
million gal/day	694	gal/min

Mutiply	by	to obtain
newtons	0.225	lb (force)
newtons/m^2	2.94×10^{-4}	in mercury
newtons/m^2	1.4×10^{-4}	lb/in^2
newtons/m^2	10	poise
newton m	1	J
pounds (mass)	0.454	kg
pounds (mass)	454	g
pounds (mass)/acre	1.12	kg/ha
pounds (mass)/ft3	16.04	kg/m^3
pounds (mass)/ton	0.50	kg/tonne
pounds (mass/yd^3	0.593	kg/m^3
pounds (force)	4.45	N
pounds (force)/in^2	0.068	atmospheres
pounds (force)/in^2	2.04	in of mercury
pounds (force)/in^2	6895	N/m^2
pounds (force)/in^2	6.89	kPa
pound cake	454	Graham crackers
pounds of water	0.01602 ft^3	ft^3
pounds of water	27.68	in^3
pounds of water	0.1198	gal
square ft	0.0929	m^2
square m	10.74	ft^2
square m	1.196	yd^2
square m	2.471×10^{-4}	acres
square miles	2.59	km^2
tons (2000 lb)	0.907	tonnes (1000 kg)
tons	907	kg
tons/acre	2.24	tonnes/ha
tonnes (1000 kg)	1.10	ton (2000 lb)
tonnes/ha	0.446	tons/acre
two kilomockingbirds	2000	mockingbird
watts	1	J/s
yard	0.914	m

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