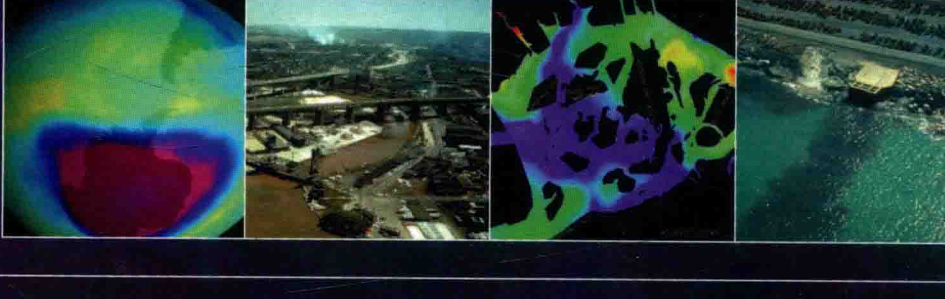
PARADIGMS LOST

Learning from Environmental Mistakes, Mishaps, and Misdeeds



DANIEL A. VALLERO

Paradigms Lost: Learning from Environmental Mistakes, Mishaps, and Misdeeds

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Paradigms Lost: Learning from Environmental Mistakes, Mishaps, and Misdeeds

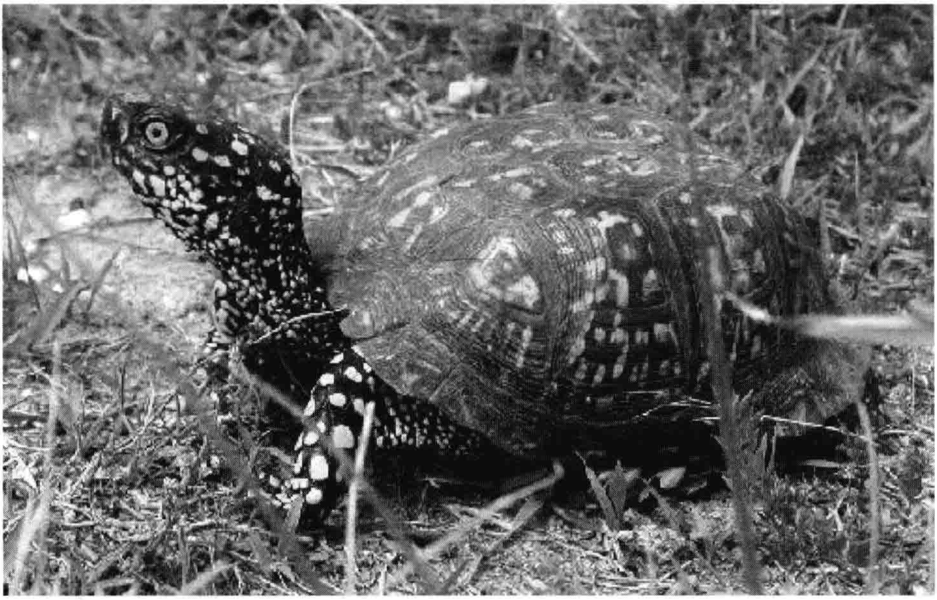
For

Amelia and Michael

and

Daniel and Elise,

in their shared pursuit of new paradigms.



Eastern Box Turtle—*Terrapene carolina Carolina.*
Photo credit: Brookhaven National Laboratory and U.S. Fish and Wildlife Service, Upton Ecological and Research Reserve: http://www.bnl.gov/esd/reserve/turtles.htm.

Preface and Introduction

Awake, arise, or be forever fallen!

John Milton (1608–1674), *Paradise Lost.* Book 1, Line 330

Granted, Milton is a questionable choice to quote at the beginning of any scientific text, even one that considers mistakes, mishaps, and misdeeds. Having been engaged in the practice and the teaching of environmental science and engineering during their formative periods, I frequently have drawn upon the lessons learned from key cases. Certainly, the cases in this book are predominantly those with negative outcomes. But there is also much about which to be optimistic. Engineers and scientists have made great progress in advancing the understanding of the principles underlying environmental quality and public health. When asked, in fact, my students often have labeled me a technological optimist. However, our contemporary understanding has all too often come at a great cost. And, what makes this even more tragic is that society and the scientific community so often forget or do not learn the lessons that should have been learned. Paying attention to the past instructs us about the future.

Our experiences are collected into a set of shared values, which are incorporated into paradigms of acceptable norms (positive paradigms) and malevolent behavior (negative paradigms). Such paradigms instruct us on standards and laws, including those that instruct us on how to care for the environment and what happens when we fail to do so.

Societies become comfortable with their paradigms. Even slight shifts are met with resistance. The twentieth-century paradigm of almost unbridled avarice and the expectation that the air, water, and soil could absorb whatever manner of wastes we introduced had to be revisited and revised. We have slowly come to accept that the *paradise* of a diverse and sustainable life support system here on earth was in jeopardy. Our own ignorance of the vulnerability and delicate balances of our natural resources and environment was putting us at risk.

Thomas S. Kuhn (1922–1996), the noted physicist and philosopher of science, is recognized as having been among the first to show that scientists are reticent to change their ways of thinking.[1] It is probably fair to extend this reluctance more generally to human nature. But scientists and engineers are supposed to be, in fact are paid to be, objective! The modern concept of objective science grew out of the Renaissance, when Robert Boyle and other leading scientists of the Royal Society of London required that scientific investigation always include experimentation (*a posteriori* knowledge),[2] publication of methods and results (literary technology), and peer review (witnesses). Kuhn grew to see science as it is practiced in contemporary times often to be void of reason. This is ironic in light of the so-called scientific method, which is built upon objectivity and reason. Scientific ways of seeing the universe—paradigms—only change after incremental evidence forces us to change. This book highlights some of this evidence (i.e., cases) that pushes us toward a new environmental ethic and awareness.

Structure and Emphasis

This book blends the historical case perspective with credible and sound scientific explanations of key environmental disasters and problems. Scientific, engineering, technological, and managerial concepts are introduced using real-life incidents. Famous, infamous, and not-so-famous but important cases are explained using narrative, photographs, figures, and tables, as appropriate. In some instances, flowcharts and event trees show how the result came to be, as well as demonstrate alternative approaches, including preventive measures and contingency plans that could have ameliorated or even prevented the disaster.

If you were to ask my students to describe my pedagogical approach, they may tell you that it is Socratic. They may also describe it as anachronistic. Some may say it is eclectic. I would have to say that it is all those things. My approach to teaching has evolved into a journey of sorts. And, journeys require storytelling; storytelling requires real-world cases. The Socratic approach allows the class to relive events and along the way to learn through the students' own inquisitiveness. The questioning and doubt about certainties to elicit the truth are ideally suited to environmental science and engineering subject matter.

Environmental problems usually have no unique solution. Environmental consequences are the result of highly complex contingencies. The contingent probabilities of a particular outcome in a specific situation at a particular time, to use an engineering concept, are miniscule. But that specific outcome did in fact occur, so we need to discover why. Anachronisms are also valuable teaching devices. When considering problems of the industrial revolution, why not discuss contemporary lyrics or poetry? No single teaching device works in every situation, so an eclectic approach using group projects, case studies, lectures, seminar discussions, and any number of graphical and presentation techniques is more useful than force-fitting a favorite approach. I have blended the lessons learned from these approaches into this book. I do not shy away from highly technical and scientific discussions in my classes, nor do I in this book. Sometimes, the best way to introduce a very technical concept is to "sneak it" into a discussion that students would be having anyway. I am a true believer in teachable moments.[3] When they occurred, every one of the cases in this book provided such a teachable moment. The trick is to bring these teachable moments back to the present. The style and delivery of this book are quite similar to my pedagogy, so depending on the subject at hand the best approach will vary.

The lessons learned go beyond the typical environmental science and environmental engineering format. Indeed, these will be a part of the explanation of what occurred and what can be done to prevent the problems. In addition, process engineering, risk assessment and management, and practical solutions are considered, where appropriate.

Each case gives a platform to discuss larger, more widely applicable concepts that are important to engineers, planners, and decision makers. For example, Love Canal is an interesting and important case in its own right, but it also provides larger lessons about the importance of managers requiring contingency plans, the need to consider all possible effects from all options, and the need to coordinate public health responses and epidemiology once a problem begins to emerge. Such lessons apply to hazardous waste siting, landfill decisions, and health and public works services worldwide. Also, considering some of the nearly forgotten lessons learned from history provides insights into ways to address current problems. For example, were the deaths from the soot and smoke incidents of London and Pennsylvania in the 1950s all that different from those in developing countries now? The answer is open to debate, but at least some parallels and similarities seem apparent. And can we revisit steps taken and opportunities missed the past 50 years as lessons from which to advise those vulnerable populations today? The answer is clearly "yes."

The book is unabashedly technical, yet understandable to most readers. It is annotated with side bars and discussion boxes to keep the reader's interest and to help to extend the lessons beyond each case. As in my previous books, any technical term is introduced with a full explanation, including the generous use of examples. Each case is described in a way that it can stand on its own, alleviating the need for cross-referencing with other cases in the book or needing to refer to other sources. This makes for a better teaching device, as instructors may choose to begin with cases in a different order than that of the book.

There is much value in discussing the general lessons learned from the totality of the cases. So, each chapter ends with a litany of these lessons

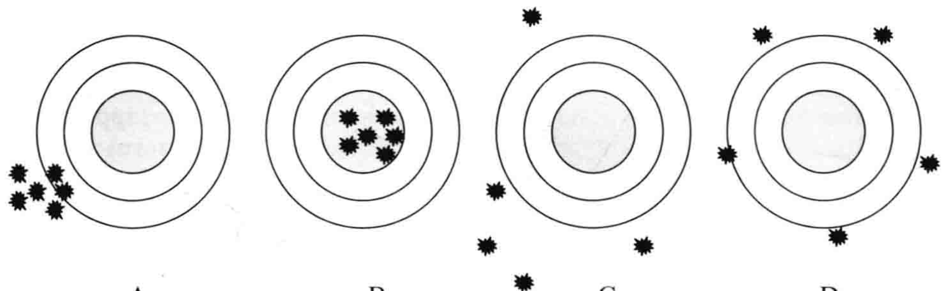


FIGURE P.1. Precision and accuracy. The bull's eye represents the true value. Targets A and B demonstrate data sets that are precise; Targets B and D, data sets that are accurate; and Targets C and D, data sets that are imprecise. Target B is the ideal data set, which is precise and accurate.

specific to that chapter, as well as insights as to the consequences of ignoring or adhering to these lessons. Environmental endeavors are always interconnected and integrated, so even though each case will be treated thoroughly, collective lessons from the myriad cases are considered.

Of course, like all things in the physical sciences and engineering, such predictions are always accompanied by uncertainties. Uncertainties are brought about both by variability and error.[4] Variability is ever-present in space and time. Every case has a unique set of factors, dependent variables, situations, and scenarios, so that what occurred will never be completely repeated again. Every cubic centimeter of soil is different from every other cubic centimeter. The same goes for a sample of water, sediment, air, and organic tissue. And these all change with time. Taking a sample in the winter is different from that in the summer. Conditions in 1975 are different in so many ways from conditions in 2005. And, of course, there are errors. Some are random in that the conditions that led to the cases in this book are partially explained by chance and things that are neither predictable nor correctable, although we can explain (or at least try to explain) them statistically, for example, with normal distributions.

Other error is systematic, such as those of my own bias. I see things through a prism different from anyone else's. This prism, like yours, is the result of my own experiences and expertise. This prism is my perception of what is real and what is important. My bias is heavily weighted in sound science, or at least what I believe to be sound science (as opposed to "junk science").[5] Sound science requires sufficient precision and accuracy in presenting the facts. *Precision* describes how refined and repeatable an operation is, such as the exactness in the instruments and methods used to obtain a result. It is an indication of the uniformity or reproducibility of a result. This can be likened to shooting arrows,[6] with each arrow representing a data point. Targets A and B in Figure P.1 show equal precision. Assuming that the center of the target, the bull's eye, is the "true value," data set B is more accurate than A. If we are consistently missing the bull's eye in the same direction at the same distance, this is an example of bias or systematic error. The good news is that if we are aware that we are missing the bull's eye (e.g., by comparing our results to those of known standards when using our analytical equipment), we can calibrate and adjust the equipment. To stay with our archery analogy, the archer would move her sight up and to the right.

Thus, *accuracy* is an expression of how well a study conforms to some defined standard (the true value). So, accuracy expresses the quality of what we find, and precision expresses the quality of the operation by which we obtained our finding. So, the two other scenarios of data quality are shown in Targets C and D. Thus, the four possibilities are that our data is precise but inaccurate (Target A), precise and accurate (Target B), imprecise and inaccurate (Target C), and imprecise and accurate (Target D).

At first blush, Target D may seem unlikely, but it is really not all that uncommon. The difference between Targets B and D are simply that D has more "spread" in the data. For example, the variance and standard deviation of D is much larger than that of B. However, their measures of central tendency, the means, are nearly the same. So, both data sets are giving us the right answer, but almost all the data points in B are near the true value. None of the data points in D are near the true value, but the mean (average location) is near the center of the bull's eye, so it has the same accuracy as Target B, but with much less precision. The key is that precision and accuracy of the facts surrounding a case must be known.

I recognize that science is a crucial part of any case analysis, but so are other factors. To wit, philosophers tell us that the only way to make a valid argument is to follow the structure of the syllogism:

1. Factual Premise
2. Connecting Premise (i.e., factual to evaluative)
3. Evaluative Premise
4. Moral Conclusion

For example, the facts may show that exposing people to a chemical at a certain dosage (e.g., one part per million) leads to cancer in one in every ten thousand people. We also know that, from a public health perspective, allowing people to contract cancer as a result of some human activity is morally wrong. Thus, the syllogism would be:

1. Factual Premise: Exposure to chemical X at 1 ppm leads to cancer.
2. Connecting Premise: Release of 10 kg per day of chemical X leads to 1 ppm exposure to people living near an industrial plant.

3. Evaluative Premise: Decisions that allow industrial releases that lead to cancer are morally wrong.
4. Moral Conclusion: Therefore, corporate executives who decide to release 10 or more kilograms of chemical X from their plants are morally wrong.

Upon examination, the syllogism is not as straightforward as it may first appear. In fact, the exact meanings of the premises and moral conclusions have led to very vigorous debates (and lawsuits). For example, all parties may agree with the evaluative premise, that releases should not lead to cancer, but they strongly disagree on the facts, such as whether the data really show that these dosages "cause" cancer or whether they are just coincidental associations. Or, they may agree that they cause cancer, but not at the rate estimated by scientists. Or, they may disagree with the measurements and models that project the concentrations of chemical X to which people would be exposed (e.g., a conservative model may show high exposures and another model, with less protective algorithms, such as faster deposition rates, may show very low exposures). Or, they may argue that measurements are not representative of real exposures. There are even arguments about the level of protection. For example, should public health be protected so that only one additional cancer would be expected in a population of a million or one in ten thousand? If the former (10^{-6} cancer risk) were required, the plant would have to lower emissions of chemical X far below the levels that would be required for the latter (10^{-4} cancer risk). This is actually an argument about the value of life. Believe it or not, there are "price tags" placed quite frequently on a prototypical human life, or even expected remaining lifetimes. These are commonly addressed in actuarial and legal circles. For example, Paul Schlosser in his discussion paper, "Risk Assessment: The Two-Edged Sword" states:

> The processes of risk assessment, risk management, and the setting of environmental policy have tended to carefully avoid any direct consideration of the value of human life. A criticism is that if we allow some level of risk to persist in return for economic benefits, this is putting a value on human life (or at least health) and that this is inappropriate because a human life is invaluable—its value is infinite. The criticism is indeed valid; these processes sometimes do implicitly put a finite, if unstated, value on human life.
>
> A bit of reflection, however, reveals that in fact we put a finite value on human life in many aspects of our society. One example is the automobile. Each year, hundreds or thousands of U.S. citizens are killed in car accidents. This is a significant risk. Yet we allow the risk to continue, although it could be substantially reduced or eliminated by banning cars or through strict, nation-wide speed limits of 15 or 20 mph. But we do not ban cars and allow speeds of

TABLE P.1
Regulation cost of saving one life (in U.S. dollars).

Activity	*Cost ($ US)*
Auto passive restraint/seat belt standards	100,000.00
Aircraft seat cushion flammability standard	400,000.00
Alcohol and drug control standards	400,000.00
Auto side door support standards	800,000.00
Trenching and excavation standards	1,500,000.00
Asbestos occupational exposure limit	8,300,000.00
Hazardous waste listing for petroleum refining sludge	27,600,000.00
Cover/remove uranium mill tailings (inactive sites)	31,7000,000.00
Asbestos ban	110,700,000.00
Diethylstilbestrol (DES) cattle feed ban	124,800,000.00
Municipal solid waste landfill standards (proposed)	19,107,000,000.00
Atrazine/Alachlor drinking water standard	92,069,700,000.00
Hazardous waste listing for wood preserving chemicals	5,700,000,000,000.00 (This is not a typo.)

Source: P.M. Schlosser, 1997. "Risk Assessment: The Two-Edged Sword": http://pw2.netcom.com/~drpauls/just.html; accessed April 12, 2005.

65 mph on major highways because we derive benefits, largely economic, from doing so. Hence, our car "policy" sets a finite value on human life.

You can take issue with my car analogy because, when it comes to cars, it is the driver who is taking the risk for his or her own benefit, while in the case of chemical exposure, risk is imposed on some people for the benefit of others. This position, however, is different from saying that a human life has infinite value. This position says that a finite value is acceptable if the individual in question derives a direct benefit from that valuation. In other words, the question is then one of equity in the risk-benefit trade-off, and the fact that we do place a finite value on life is not of issue.

Another way to address this question is to ask, "How much are we willing to spend to save a human life?" Table P.1 provides one group's estimates of the costs to save one human life. From what I can gather from the group that maintains the Web site sharing this information, they are opposed to much of the environmentalist agenda, and their bias colors these data. However, their method of calculating the amount of money is fairly straightforward. If nothing else, the amounts engender discussions about possible risk trade-offs since the money may otherwise be put to more productive use.

Schlosser asks "How much is realistic?" He argues that a line must be drawn between realistic and absurd expenditures. He states:

> In some cases, risk assessment is not used for a risk-benefit analysis, but for comparative risk analysis. For example, in the case of water treatment one can ask: is the risk of cancer from chlorination by-products greater than the risk of death by cholera if we do not chlorinate? Similar, if a government agency has only enough funds to clean up one of two toxic waste sites in the near future, it would be prudent to clean up the site which poses the greatest risk. In both of these cases, one is seeking the course of action which will save the greatest number of lives, so this does not implicitly place a finite value on human life. (In the second example, the allocation of finite funds to the government agency does represent a finite valuation, but the use of risk assessment on how to use those funds does not.)[7]

We, as fallible human beings, are not the best assessors or predictors of value. We can rationalize the elimination of a "problem." Humans are very good at that. So, how do moral arguments about where to place value and the arguments made by Schlosser and others (such as the concept of willingness to pay) fit with moral theories, such as duty-based ethics (i.e., deontology), consequence-based ethics (teleology), or social contract theory (contractarianism)? Where do concepts like John Stuart Mill's harm principle, John Rawls' veil of ignorance, and Immanuel Kant's categorical imperative come into play? How do such concepts fit with the code in one's chosen profession? How do teleological, deontological, contractarian, and rational models hold up this scrutiny?

One method for testing our ethics is to try to look back from a hundred years hence, such as we can do now with slavery, women's rights, and so forth. What would you expect the future societies to think of what we are doing with those in our society with the weakest voices? As I mentioned, even though I continue to be strongly utilitarian in my support for animal testing, I fear that through the prism of future perspective, I may be found lacking. . . . I have seen every one of these arguments in environmental situations. Some are valid, some are not.

Syllogisms are not specifically drawn in most of the cases, but they are there just the same. Whenever we draw a moral conclusion—that the behavior of certain groups was improper, unacceptable, or downright immoral—we have intuitively drawn a syllogism. Intuitive syllogisms are present every time we give credit or place blame. The best we can hope for is that we have thoroughly addressed the most important variables and with wisdom may prevent similar problems in the future.

I have learned that syllogisms can easily be inverted to fit the perception and needs of those applying them. That is, people already have a conclusion in mind and go searching for facts to support it. The general public expects that its professionals understand the science and that any arguments being made are based in first principles. We must be careful that this "advocacy science" or, as some might call it, "junk science" does not find its way into environmental engineering. There is a canon that is common in most engineering codes that tells us we need to be "faithful agents." This, coupled with an expectation of competency, requires us to be faithful to the first principles of science. In a way, I fear that because of pressures from clients and political or ideological correctness, the next generation of engineers will be tempted to "repeal Newton's laws" in the interest of certain influential groups! This is not to say that engineers will have the luxury to ignore the wishes of such groups, but since we are the ones with our careers riding on these decisions, we must clearly state when an approach is scientifically unjustifiable. We must be good listeners, but honest arbiters.

Unfortunately, many scientific bases for decisions are not nearly as clear as Newton's laws. They are far removed from first principles. For example, we know how fluids move through conduits (with thanks to Bernoulli *et al.*), but other factors come into play when we estimate how a contaminant moves through very small vessels (e.g., intercellular transport). The combination of synergies and antagonisms at the molecular and cellular scales make for uncertainty. Combine this with uncertainties about the effects of enzymes and other catalysts in the cell, and we propagate even greater uncertainties. So, the engineer operating at the meso-scale (e.g., a wastewater treatment plant) can be fairly confident about the application of first principles of contaminant transport, but the biomechanical engineer looking at the same contaminant at the nano-scale is not so confident. That is where junk science sometimes is able to raise its ugly head. In the void of certainty, for example at the molecular scale, some crazy arguments are made about what does or does not happen. This is the stuff of infomercials! The new engineer had better be prepared for some off-the-wall ideas of how the world works. New hypotheses for causes of cancer, or even etiologies of cancer cells, will be put forward. Most of these will be completely unjustifiable by physical and biological principles, but they will sound sufficiently plausible to the unscientific. The challenge of the new engineer will be to sort through this morass without becoming closed-minded. After all, many scientific breakthroughs have been considered crazy when first proposed (recalling Copernicus, Einstein, Bohr, and Hawking, to name a few). But even more really were wrong and unsupportable upon scientific scrutiny.

Quality Control

The case-based approach to environmental problems does have the disadvantages of uncertainty and representativeness. We often are not sure of the physical scientific facts fundamental to a case, let alone the social science, humanities, and political subtleties. For example, I have attempted to choose cases that reflect the environmental paradigm shifts. This means that some important cases have been omitted, probably more than a few that you would have expected to see. As part of my quality control in this matter, after completing my manuscript, I inquired of a number of experts in various environmental disciplines such as science, engineering, and policy, as to what they considered to be important cases. The good news is that most of the cases they expected have been included. The not-so-good news is that some important cases are not directly addressed. Those identified that are either not covered or only mentioned in reference to other cases are:

1. The near meltdown of the nuclear reactor core at the Three Mile Island power facility near Harrisburg, Pennsylvania.
2. The Kuwaiti oil fires and eco-terrorism at the end of the first Gulf War.
3. The eco-disaster in the Danube basin resulting from the Iron Gates Dam project.
4. Rainforest destruction.
5. The ecosystem destruction wrought by introduced plant species.
6. The cadmium poisoning of miners in Japan.
7. Recent concerns about mercury, especially from fossil fuel combustion.
8. Exposure to asbestos, especially vermiculite and the Libby, Montana, mine.

To assuage my guilt for not directly addressing these eight issues as individual cases, allow me to discuss them briefly here. I also address them, with links to Web resources in the companion Web site to this book (http://books.elsevier.com/companions/0750678887).

I chose to address the Chernobyl nuclear disaster as a "sword of Damocles" in Chapter 7 rather than Three Mile Island because the consequences of the Ukrainian meltdown demonstrated failure at so many levels—design, implementation, oversight, regulatory, and emergency response. The 1979 accident at Three Mile Island did release radiation, especially the radioactive isotope iodine-131, which is formed after uranium undergoes fission. More importantly, the accident was an omen of what *could* happen and in fact did happen at Chernobyl. Our failure to heed the lessons of both nuclear disasters would be folly.

The 1991 Kuwait oil spills and fires do represent an important case in terms of intentional environmental destruction. I chose to discuss terrorism and environmental vulnerability, especially following the attacks on the Pentagon and the World Trade Center towers. However, every war and international conflict extracts an ecological and public health toll. There is no question that Iraq committed ecological terrorism in Kuwait by deliberately spilling millions of barrels of oil into the Persian Gulf and igniting, via sabotage, 500 Kuwaiti oil wells, storage tanks, and refineries. In fact, the oil spill was the largest ever: an estimated six million barrels of oil, 25 times larger than the 250,000 barrels from the *Exxon Valdez* in Alaska's Prince William Sound. The oil fires started in mid-February were the worst the world has ever suffered, releasing as much as six million barrels of oil residue in the plume per day at their peak. The thick, black clouds reached thousands of meters, eclipsing the sunlight, so that Kuwait City and Saudi Arabian cities just south of the border experienced almost constant night. The EPA Administrator at the time, William K. Reilly, said "If Hell had a national park, it would be those burning oil fires," and "I have never seen any one place before where there was so much compressed environmental degradation."[8] Indeed, it does represent an important case.

The Iron Gate Dam illustrates the importance of small things and a systematic approach. As such, it would fit nicely into the discussions in Chapter 12. It clearly represents the huge ecological price that must be paid when biodiversity is destroyed. The case is very interesting in that something that we do not ordinarily consider to be a limiting factor, silicates, led to major problems. The Black Sea is the largest enclosed catchment basin, receiving freshwater and sediment inputs from rivers draining half of Europe and parts of Asia. As such, the sea is highly sensitive to eutrophication (see Chapter 4) and has changed numerous times in recent decades. The Danube River receives effluents from eight European countries, flows into the Black Sea, and is the largest source of stream-borne nutrients. In less than a decade, the system changed from an extremely biodiverse one to a system dominated by jellyfish (*Aurelia* and the combjelly *Mnemiopsi*).[9] These invaders were unintentionally introduced in the mid-1980s, culminating in the fisheries almost completely vanishing by the early 1990s. This collapse was first attributed to unpalatable carnivores that fed on plankton, roe, and larvae. Subsequently, however, the jellyfish takeover was found to result from human perturbations in the coastal ecosystems and in the drainage basins of the rivers, including changing the hydrologic character of out-flowing rivers. The biggest of these was the damming of the Danube in 1972 by the Iron Gates, approximately 1,000 km upstream from the Black Sea. In addition, urban and industrial development, heavy use of commercial fertilizers, over-fishing, and the introduction of exotic, invasive organisms (e.g., *Mnemiopsi*) contributed to the problem. After 1970, this change in nutrient concentrations induced phytoplankton blooms during the warm months and changed the dominance to nonsiliceous species that were not a first choice as food for meso-zooplankton. The decreased fish stocks further increased the dominance of the jellyfish, since they competed better than the game fish for the same food. Ironically, since the mid-1990s, the ecosystems have begun to improve, mainly due to increased nutrient (phosphorus and nitrogen) loading. In most situations, we are looking to decrease this loading, to prevent eutrophication. But in this system, the added nutrients have allowed certain plankton and benthic (bottom dwelling) organisms to recolonize. The abundance of jellyfish has also stabilized, with a concomitant increase in anchovy eggs and larvae.

Nutrient limitation occurs when the presence of a chemical, such as phosphorus or nitrogen, is insufficient to sustain the growth of community or species. Usually, marine systems are nitrogen limited whereas freshwater plankton systems are phosphorus limited. Numerous freshwater organisms can "fix" atmospheric nitrogen but, with minor exceptions, the nitrogen is impeded in marine water. The nutrient requirements differ by species. A disturbance in the ratio of nitrogen, phosphorus, silica, and even iron changes the biotic composition of a particular plankton community. Often, all four nutrients can be considered as limiting. For instance, the lack of silica limits diatoms. This was observed first in natural blooms off Cape Mendocino in the United States and subsequently observed in the northwest part of the Black Sea, after closing the Iron Gates dam. The case also demonstrates that economics is crucial, since the marine ecosystem improvement directly corresponds to the decline of the economies of Central and Eastern European nations in the 1990s.

Rainforest destruction is certainly an important problem for numerous reasons, including the loss of irreplaceable habitat and the endangerment of species, the loss of "oxygen factories" as photosynthesis is reduced, and the loss of sinks to store carbon in both its oxidized forms (carbon dioxide) and reduced forms (methane). Both carbon dioxide and methane are principal greenhouse gases. This is touched on briefly in Chapter 9 when the major greenhouse gases are described and in the brief discussions on forestlands. In a sense, rainforest destruction is probably most akin to the coral reef destruction discussed in Chapter 9, since it is an example of resources that are almost impossible to recover. Public concern is increased in situations where the consequences are irreversible. The potential irreversibility means that what we are doing now will adversely affect future generations and is also evidence that we lack control and are uncertain about what the damage means. People want to prevent catastrophes or at least to catch problems before they become large and irreversible. The rates of rainforest losses are staggering; some estimates put the losses at 1 hectare per hour or about 31 million hectares per year, which is about the area of the country of Poland![10] Along with the sheer land numbers, about 50,000 rainforest species are becoming extinct each year.[11] Indeed, the problem is large and, given geopolitical realities, seemingly intractable.

Introduced plant species is a widespread problem. In fact, Table 6.1 includes a number of plants. The two species addressed in Chapter 6 (shore crab and zebra mussel), both aquatic, allow for comparisons and contrasts in the ways that the species are introduced and how they colonize. However, plants are certainly important. For example, numerous invasive plants have been introduced intentionally with good intentions; they represent an all-too-common problem of doing the wrong thing for the right reasons. This brings back memories of my father and Uncle Louie vigorously digging up the tough little multiflora rose (*Rosa multiflora* (Thunb.