Chapter 21. TECHNOLOGY AND ENVIRONMENTAL DETERIORATION IN PRE-INDUSTRIAL SOCIETIES

> One assumption made by most... [is that] until about 5,000 years ago the earth retained its pristine form, and any modifications of its physiography, fauna or flora are ascribable to natural causes. This view is one with which I do not agree...
>
> Robert Heizer 1955

> More than one half [of the extent of the Roman Empire] is either deserted by civilized man and surrendered to hopeless desolation, or at least greatly reduced in both productiveness and population.
>
> George P. Marsh 1874

I. Introduction

A. What Impacts Have Non-Industrial Societies Had on Environment?

We tend to think that small, simple, technically unsophisticated societies have had less impact on the earth's environment than modern industrial societies. Relatively speaking this may turn out to be true, but it is not necessarily the case that the impacts of past societies were insignificant. In this chapter, we will review some of the important proposed impacts of hunting and gathering, horticultural, pastoral, and agrarian types of societies.

B. Three Theoretical Tools

Garrett Hardin, (1968) described the tendency of people to over exploit and damage their environment as the "Tragedy of the Commons." The situation he had in mind for illustrative purposes was the Medieval European Common Pasture. Suppose the pasture produced maximum meat and milk when stocked with 100 cows. Each cow over that cuts the yield per cow. Each of 50 peasant families in the village can keep 2 cows on the common without over exploiting it. But consider the motivation of a particular family to add a 3rd cow. They get all the benefits of the meat and milk from the 3rd beast, but the cost is borne equally by all 100 cows, 97 of which belong to others, from a selfish point of view it makes sense for each family to add a 3rd or 4th cow, even though that degrades the commons for everyone, and all become worse off. Hardin suggested that we can avoid the tragedy only by creating private property or making laws and enforcing them. Otherwise common property resources are very vulnerable to over exploitation. While this somewhat depressing picture of the use of common resources has come in for much attack from empiricists, it is an important theoretical model. Note its close links to the postulate of natural selection theory - the selfish individual.

R. A. Fisher first described the concept of "environmental deterioration." He pointed out that very generally the adaptive improvement of one species deteriorates the environment for other organisms that interact with it. For example, if predators become swifter or more cunning, the environment of the prey has deteriorated. This is "inter-specific environmental deterioration".

Another form of environmental deterioration is the impact that a population's own adaptations have on the environment, as they feed back on the population, mediated by effects on other species or the physical environment. If human impacts are serious, the environment will "deteriorate" with regard to prevailing technology (*intraspecific deterioration*[1]*)*. Dense populations can do serious physical and biological damage: they can overexploit prey species, damage resources by spreading onto marginal lands, shortening fallow cycles, or cause deliberate damage as a by-product of violent conflict, etc[2]. This may provide a selective or decision-making pressure for new technology, or it may merely result in lower human populations on a given deteriorated site. In other words one of the significant causes of human evolution might be that we have to continually adapt to our own environmental damage. We might have to adapt to our own poisons, in much the same way that we have to continually adapt as our prey get warier when our hunting skills and technology improve.

Evolutionary biologist Leigh van Valen proposed the "Red Queen" hypothesis in her discussion of evolution in deteriorating environments. The hypothesis is named after the part in Alice in Wonderland where the Red Queen tells Alice that she is running merely to stay in the same place. As prey get warier, evolutionary pressures force us to become better hunters, then the prey get warier still, and so (perhaps ad infinitum?). In this world, evolution continues, but populations do not really become any fitter. We will discuss this hypothesis in the evolutionary transformations section of the course beginning in Chapter 23. Suffice it to say here that humans coevolve with other species—prey, pests, diseases, competitors—and with the physical environment. This sort of evolution can lead to the most perverse conclusions, as we have already seen in the case of warfare. Improvement in the short run may mean no progress or sliding backward in the long run. But since even decision-making forces are often not very forward-looking, short-run adaptation may rule,

1. Note that current ecological thinking generally favors the idea that *intra*specific competition tends to be much more important in most environments than *inter*specific competition. In other words, we tend to experience much more competition from those who are most like us—because similar organisms exploit similar environmental niches.
2. For example, the Romans literally sowed the fields of conquered Carthage with salt to deny them the ability to produce food. More recently, we saw Iraq's Saddam Hussein torch Kuwaiti oil fields and open crude oil valves into the Persian Gulf.

whatever the long-term consequences.

Of course, not all impacts need be negative in terms of making it ever more difficult for humans to make a living in a particular environment. People may invest in the construction of long-lived capital facilities, such as roads, irrigation works, terraces, hedgerows, scientific knowledge, plant and animal domestication, and other things that make life easier for future generations. This we might call “positive deterioration”. Thus, Great Britain’s economic performance is so tattered these days that some of the advancing developing nations can equal her GNP per capita. However, life in Britain at the same level of per capita income is relatively more comfortable because of large past investments in roads, railroads, housing, cultural amenities, etc., compared to the newly industrialized nations. The Brits have paid their dues and can kick back!

C. Levels of Selection - A Reminder

The balance of positive and negative instances of environmental deterioration provides a clue about the level at which selection works. It also provides insight into the level at which different types of decision-making are effective. **Group selection**[3] leads to adapted societies and some measure of conservation of natural resources. **Individual selection**[4] tends to lead to over-exploitation of resources—the tragedy of the commons effect. Cooperation allows for mutual coersion, mutually agreed upon strategies can prevent ‘tragedies of the common’. Thus the kinds and degree of resource damage and improvement are indices of: (a) the degree of cooperation possible in a social system, (b) the organizational level at which such cooperation is most effective, and (c) the quality of decisions being made[5].

II. Environmental Relations of Hunters and Gatherers

A. Could Hunter-Gatherers Have a Substantial Impact on Their Environment?

Hunter gatherer societies typically have a relatively modest ability to affect their environments. This is because they have small populations and relatively low-powered technology. Consequently they are often portrayed as having harmonious, functional relationships with nature. However, we also have to remember that hunters and gatherers have an extensive life style (inefficient with respect to people supported per unit land area). Their per capita impact could be high just because they cover so much territory in their for-

3. or effective group decision-making evolved by other means
4. or individual rational choices, or selection or decision-making rational at the level of smaller as opposed to larger groups
5. Note that even the most cooperative people cannot make decisions about things of which they are ignorant, although natural selection can still be effective.

aging for the best resources. Also, perhaps, hunters and gatherers have relatively modest decision-making powers (no science, not even literacy) and very modest political institutions. If something does go wrong, they may have difficulty discovering the cause and effecting a correction.

B. Impacts of the Use Of Fire

Even the earliest hominids made extensive use of fire. Fire use is one way that even simple societies can release a lot of energy and cause a lot of destruction of vegetation. It is not entirely clear when humans started using fire, but the Zhoukuodian Cave in Northern China, with *Homo erectus* remains dating back to about 450,000 bp shows evidence of fire use. Human use of fire probably increased the frequency of wildfire due to accidental escapes of campfires and deliberately set fires. Historically, hunters and gatherers are known to have set fires to open dense vegetation for travel, to renew browse, to attract game, and to drive animals for hunts.

Major vegetation changes would often be caused by human set fires (Stewart 1956). The open savanna and prairie vegetation of many areas of the world may at least be expanded by this activity. His data came from the Wisconsin Prairie, where fire was controlled by Whites, soon after settlement began. They indicated that the prairie vegetation type shrank by 60% between the onset of agricultural development in 1829 and 1854 due to shrub and tree invasion of the grasslands. If you've ever lived in the Eastern Deciduous Forest, you may have gained an impression of just how fast trees will invade an abandoned field or a neglected lawn. In a extreme summer-dry climate like California, trees have a tough time and tend to need encouragement. In summer-wet climates, they are much more aggressive.

It is possible that other major grassland formations, such as the East African savanna and the Central Asian steppe are at least in part anthropogenic vegetations; the boundary of the forest and the grass may well have been pushed back by increases in fire frequency caused by human activity.

C. Direct Impacts of Hunting—

Were megafaunal[6] extinctions caused by humans? At various times and places in the relatively recent past, the earth's large mammal biota underwent a drastic reduction, known as the Pleistocene Megafaunal Extinction. Beginning in the Miocene Epoch 25 million years ago, the earth began drying and cooling. This led to the development of open plant communities that in turn favored the evolution of large grazing mammals and their predators. This trend reached its height during the Pleistocene Epoch, the epoch of cyclical gla-

6. literally "large animal"

ciations, the last 2 million years. Then, quite suddenly, in the last few tens of thousands of years, most of the large mammal assemblages were virtually wiped out. Only in Africa does a reasonable approximation of Pleistocene big game survive. As late as about 12,000 years ago the Central Valley of California had assemblage of game that were fully as spectacular as the game preserves at Amboseli or Ngorongoro in Africa do today.

Extinctions in the terminal Pleistocene extinction in North America included many Genera[7]. Figure 21-4 (appended at the end of this chapter) provides some illustrations of the species lost in the North American and other megafaunal extinctions. Think of Yellowstone Park full of these things, instead of just a few elk, deer and bears! Here is a list of generic extinctions during the late Pleistocene (* indicates genera with living species in Eurasia or South America):

(1) Mastodons (2 genera), Mammoths
(2) Ground sloths (4 genera)
(3) Camels and llamas (2 genera)
(4) Peccaries (2 genera)
(5) Pronghorn antelopes (2 genera)
(6)* Horses
(7) Giant beavers
(8) Giant shortfaced bears
(9) Giant armadillos
(10) Sabertoothed cats (2 genera)
(11)* Capybaras (also an additional totally extinct genus)
(12) Shrub oxen (2 genera)
(13)* Tapirs
(14)* Spectacled bears
(15) Extinct bovids (2 genera)
(16)* Yaks
(17)* Saiga antelope
(18) Extinct moose
(19) Gylptodonts (2 genera)

Interestingly the timing of extinctions on various continents was quite variable. This

7. This term is used in the biological sense to mean extinctions of an entire Genus. Recall that organisms are classified in descending order by Kingdom, Phylum, Class, Order, Family, Genus, and Species. Generic extinctions therefore refer to the extinction of entire groups of species.

rules out simple climatic effects as causes of the extinctions because climate changes are roughly synchronous over the entire globe. However, the extinctions *do* appear to be closely related to the arrival of modern humans with more efficient hunting technology.

Geographic Region	Timing of Extinctions
Africa, Southern Asia	> 40,000 BP
Australia	13,000 BP
Europe, Northern Asia	11,000-13,000 BP (4 genera only)
North America	11,000 BP
South America	10,000 BP
New Zealand & Madagascar	800-700 BP

The sudden simultaneous demise of many genera, at least in North and South America, is consistent with the hypothesis that early humans were at least partially responsible for these extinctions. Mosiman and Martin’s mathematical models and illustrations of the wave-like nature of the spread (see below) indicate that rapid demise could be accomplished quite quickly by relatively few hunters.

Extinctions were least severe in Africa (30% of genera) and Europe. This is because these areas had had long, gradual exposure to evolving humans, and Red Queen - like evolutionary arms races had occurred over millennia.

Martin’s idea is that large, highly desirable game that have no experience with skilled Late Pleistocene hunters will be very vulnerable. In the Americas and on oceanic islands like New Zealand and Madagascar, human hunters arrived suddenly and very late. Where the extinction was less severe, as in Europe, the fauna had time to coevolve with human predators. The extinction was least severe in Africa, where human populations existed the longest and were longest held in check by disease.

Most of the extinct species were large herbivores and their predators (e.g., mammoths, ground sloths, big ungulates, saber-tooth tigers, giant condors). There was no sudden extinction of smaller mammals. Moreover, these were extinctions without replacements; in the earlier of the Pleistocene speciation kept up with extinction and no empty niches were left.

Since there is so little archaeological evidence critics have doubted that human pop-

ulations could have actually removed the mass of animals. Why don't we find a better fossil record in, especially, North America, which is well-explored archeologically? There are a few mammoth kill sites in the proper period, ca 11,000bp, but not many. Mosiman and Martin (1975) countered with a simulation model showing how a front-like wave of people could build up in Northern Canada, just south of the ice, and sweep to the Gulf of Mexico in roughly 300-1100 years, depending on details of the simulation. Figure 21-1 will give you some feeling for the simulation. The essential elements of it are exponential human population growth, and a considerable vulnerability of prey to human hunting. We did the essential arithmetic, less the wave-like spread and the complementary dynamics of the prey, in the chapter on demography (Chapter 8).

The concept of the "front" is an essential feature of Mosiman and Martin's paleolithic overkill model. As they describe the Figure 21:1:

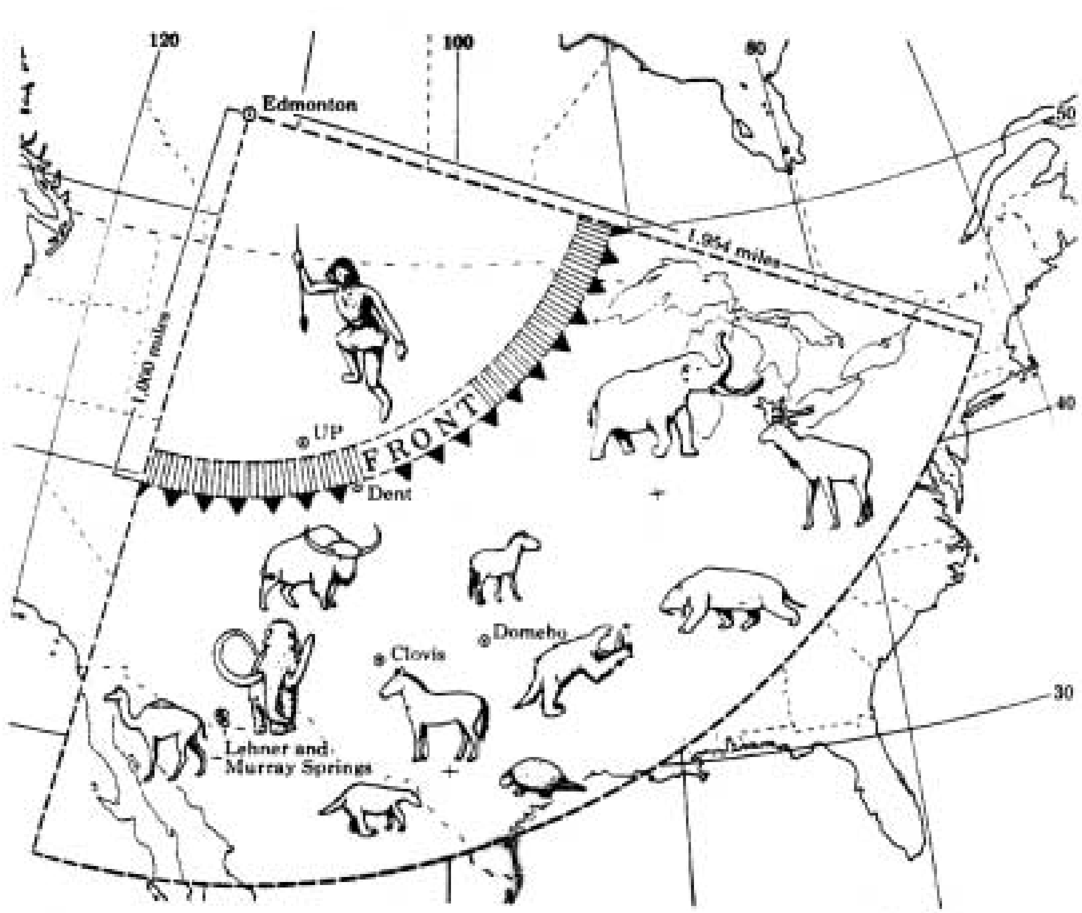
> Upon reaching a certain critical density, the population of hunters, newly arrived in the New World, expands southward in a quarter circle whose center is represented by Edmonton, Alberta. As long as some prey remains in the area of human occupation, the front advances smoothly. When the local herds are exhausted, it advances in a jump. The range available to the hunted is steadily reduced. The width of the front prevents survivors from "leaking" back into unoccupied areas behind the front. In the position shown, 1,000 miles from Edmonton, the front has begun to sweep through the region of radiocarbon-dated Paleoindian mammoth kill sites. Depending on the simulation strategy, these sites will be overrun in 40-170 years. By the time the front has reached the gulfs of Mexico and of California (radius of the circle = 1,954 mi) the herds of North America have been hunted to extinction (Mosiman and Martin, 1975:305).

Alternative hypotheses and challenges to the data have been raised. Krantz (1970) argues that direct human hunting pressure could not have been sufficient to cause extinctions. He makes a case for more subtle effects of human activities, suggesting that fire might heavily impact plant communities and indirectly the big game. Of course, the big game is adapted primarily to open grassland anyway, so more of it shouldn't hurt. (We don't buy this argument).

Climate-related hypotheses have also been suggested as alternatives to Mosiman and Martin's hypothesis. The climate argument goes like this. If people were not responsible, then some potent natural force must have been involved. The simplest possibility is environmental change resulting from the fluctuating Pleistocene climate[8]. Some researchers have questioned Martin's dates and the direct association of extinction with humans. Others have also noted that there is some evidence of a wave of bird extinctions in North America.

8. See several of the papers in Martin (1984) for a thorough discussion of this hypothesis.

Figure 21-1. An illustration from Mosiman and Martin's (1975:305) Paleolithic Overkill model.



Climate stress hypotheses are viable. The best data are from North America, where extinctions, humans, and major climatic change all came at the same time. Humans may have been only *part* of the cause (Butzer, 1971). However, the problem with this hypothesis is explaining differential extinction on different continents. Also, it is hard to see why extinctions due to climatic effects should have been so extreme at the end of the last glacial episode when the same fauna had either survived many previous glaciations and deglaciations or at least had been replaced by other, similar species.

What conclusions can we draw about environmental degradation in hunter-gatherers? If Martin's case holds, as we think it very well might, food foragers of the Pleistocene probably were not natural conservationists. Selfishness ruled. Individuals and small groups (bands) were the operational decision-making units and killed megafauna whenever they were hungry. Especially with respect to migratory big game, where herds must have been accessible to many bands, we might well expect that the tragedy of the commons problem would remain unsolved[9].

The actual extent of food forager conservation practices is controversial (Heizer, 1955). The sudden reduction of big game may have led to specialized food foraging, which rapidly led in turn to agriculture. This idea provides a possible model of the origins of agriculture—environmental deterioration!

III. Environmental Relations of Agricultural Societies

A. Substantial Increases in Potential Impacts

The environmental relations of agricultural societies were first studied in the classic book by George Perkins Marsh (l874), *The Earth as Modified by Human Action*. Essentially, these societies are characterized by more dense populations that were more efficient[10] food producers per unit land than hunter-gatherers. Agricultural technology also required more resources per capita (e.g., ore, fuel, forage). This makes more potent impacts possible since there are tools for clearing forests, civil engineering projects, etc.

B. Classic Environmental Degradation Problems of Agriculturalists

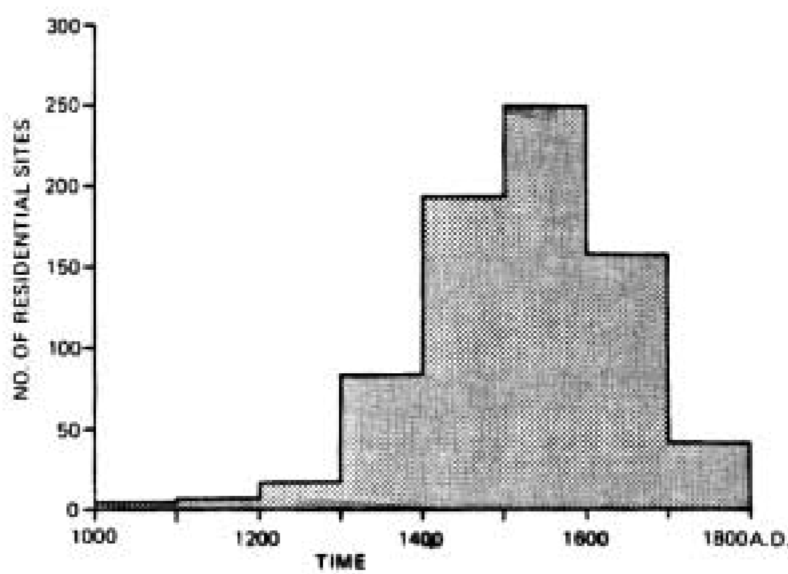
The classic effects of farming in habitats that are the least bit sensitive are deforestation, soil erosion, and (in the tropics) soil laterization[11]. Marsh noted these effects in the Mediterranean Basin by comparing ancient Greek and Roman sources with 19th century conditions as he observed them. Where the ancient texts described forests of oak, pine, and other trees, only barren, rocky hills with a bit of goat-chewed scrub were visible.

Kirch (1984) provides clear documentation for several examples of marked environmental deterioration due to impacts of human horticulture in Polynesia. Typically, Polynesian populations greatly reduced fish and game populations in the first centuries after contact, on the overkill model. The first signs of impact are declines in the sizes of shells of exploited mollusks, and the vanishing of flightless bird-bones (many species of vulnerable birds disappeared from the islands a few centuries after humans arrived). Population expansions a few centuries after colonization often caused people to expand cultivation onto sensitive upland soils, where erosion and nutrient loss converted them to degraded fernland savanna. In some cases, there is clear evidence of population decline; the number

9. i.e. they hunted the herds to extinction
10. in terms of per capita productivity
11. a hardening and mineralization of the soil that leaves it hard and unsuitable as a medium for growing most food crops

of house sites falls after a peak in what looks like an overshoot-and-crash population trajectory. Figure 21-2 shows data from leeward (dry) Kaho'olawe, one of the smaller Hawaiian islands. In other areas, the accumulation of eroded sediment along river flats apparently compensated for loss of upland fields to erosion. Thus, deterioration caused by farmers is less than expected from theory. The Polynesian chiefly system did serve as an effective decision-making system for many purposes, including resource use and conservation. For example, chiefs on many islands supervised the storage of staples against the hazard of typhoons and droughts. Perhaps the degradation of uplands was too slow for the chiefs to understand what was happening, or perhaps the intense competition between chiefs forced them to take a short-run view.

Figure 21-2. Site frequency histogram for Kaho'olawe Island (copied from Kirch, 1984:109).



Did the depletion of England's wood lead to coal use, and in turn to the industrial revolution? It has been argued that this form of "environmental deterioration" was the key to many of the initial industrial innovations (Wilkinson, 1973). This argument is reminiscent of the data from Polynesia. Environmental deterioration provides an impulse to develop new technology to prevent living standards from declining as old resources are exhausted. Usually this results in the running-to-stay-in-place of the Red Queen hypothesis. However, occasionally, there may be a lucky breakthrough that allows a burst of real getting ahead. The shift from wood to coal as a fuel may have set off the industrial revolution as one of these lucky accidents.

Grazing animals kept by horticulturalists and pastoralists can also cause severe environmental damage. The loss of vegetation from overgrazing decreases recycling of water via evapotranspiration[12] and increases the reflectivity of the ground, leading to less total heat absorbed by the ground. Both of these effects may contribute to less thundershower activity in marginal semiarid areas. In this manner, overgrazed dry grass and shrublands may be converted to actual desert, although this mechanism is still a bit controversial.

Under horticultural, pastoral and agricultural subsistence modes, pressures on huntable animals continue to increase, often becoming extreme. Hunting pressure on game animals increases as human populations become larger and more dense. When, as is often the case, humans and game compete for similar habitats, games are also squeezed into more marginal environments. As a result, game populations often decline dramatically—as the Kaho'olawe case illustrates.

C. The Special Case of Hydraulic Societies

Despite their strong governments, hydraulic societies were unable to effectively solve soil salinization and food control. Large-scale "hydraulic" societies based on flood control and irrigation such as arose in around the Tigris and Euphrates Rivers in Classical Mesopotamia tend to have strong central administrations. Under this type of political system we might expect centralized decision-making and planning to lead to effective conservation, at least if decision-makers have the right motives and reasonable information. However, there are two problems that hydraulic societies almost never solve effectively: soil salinization and flood control.

Soil salinization is particularly problematic in arid irrigated areas. This is because plants transpire about 2/3 of the water that is applied to them and concentrate salts in the remainder. These salts must be leached[13] from below the root zone with extra water if they are not to poison the plants. As water percolates through the soil salts build up in the ground water. Consequently if a water catchment basin is not drained, the water table rises, carrying salty water to surface and large areas are therefore gradually lost to production due to soil salinization.

Classical Mesopotamian civilization suffered this problem beginning 2,500 B.C. (Jacobsen and Adams, 1958). The expensive drainage projects required to avoid salinization are often postponed by governments until it is too late. The present situation in California's Southern San Joaquin Valley is extremely serious. The selenium problem you have read

12. loss of water from the soil both by evaporation and by transpiration from the plants growing thereon
13. washed away by repeated application of water

about in the last few years is only one manifestation of the salt balance problem in this area.

Flood control is also a very difficult problem for hydraulic societies to solve. The problem is that flood waters carry silt which builds up in water channels. The best solution is to dig deep narrow channels so that water flows fast and carries the silt away. A second best, but cheap solution is to build wide floodways with shallow dikes. The problem with wide floodways, however, is that they silt up. This causes the river to gradually rise above its flood plain on its own silt. Eventually, catastrophic floods result when the river overflows into the flood plain. The silt-laden Yellow River of China is especially prone to this problem. A catastrophic flood in 1194 caused the Yellow River to switch its mouth about 300 km south, so that it flowed on the opposite side of the Shantung Peninsula. Then in 1852 it switched back. All of this switching took place in one of the most densely settled parts of China and was responsible for many thousands of deaths[14]. Figure 22-3 illustrates these phenomena.

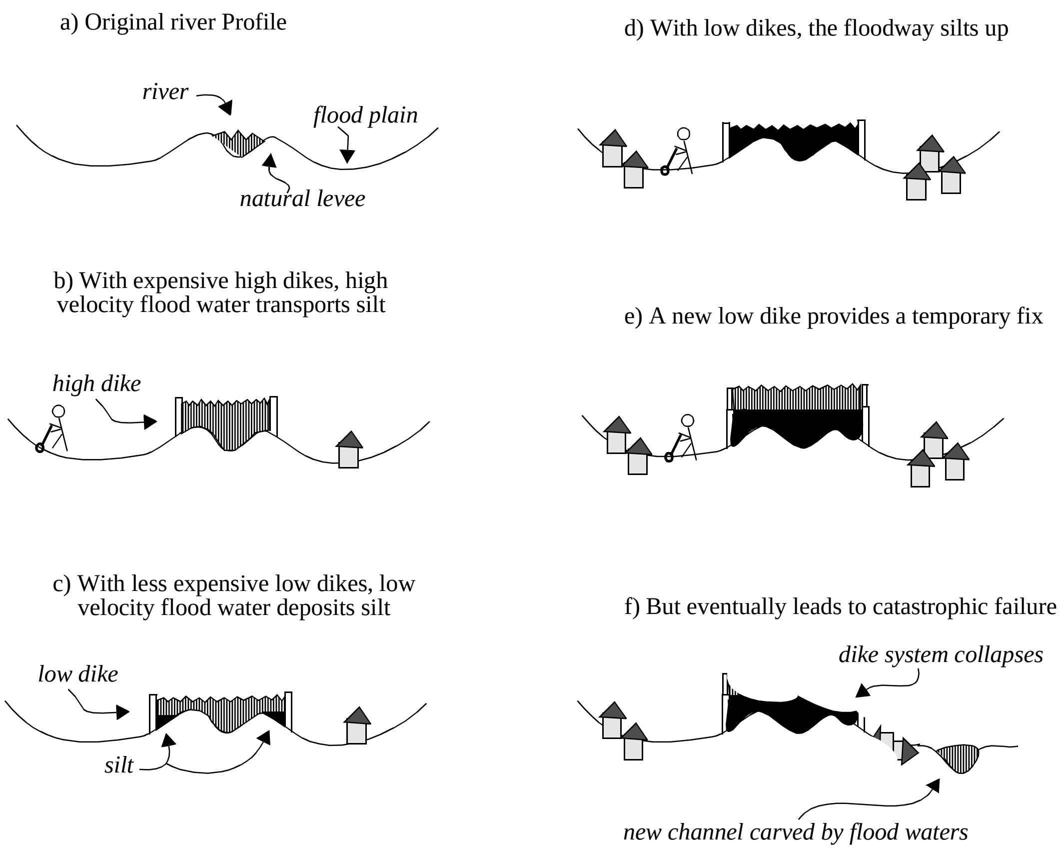
IV. Conclusion

Modern hominids are something of a pest from the perspective of the rest of the Earth's biota. The environmental movement has made us all aware of the problems caused by modern human populations. However, it is quite common to romanticize food foragers and village agriculturalists by assuming that they interacted more harmoniously with nature. If Martin's hypothesis is correct, this assumption is wrong; the first hunters in the Americas and on oceanic islands were perhaps responsible for an even more spectacular wave of mammalian extinctions than even industrial societies have accomplished—thus far at least. Even in the Old World, their impact on game was apparently dramatic. Of course, some human societies presumably cause much less environmental impact than others, and modern industrial societies are certainly unprecedented in the rate they can cause damage, and the exotic forms of damage of which they are capable. On the other hand we have an unprecedented knowledge of environmental matters and sophisticated institutions to reach collective decisions. It seems that ancient hunters might hold the dubious record of most species driven to extinction. Let's hope we don't beat it!

Human (or anthropogenic) modifications of environments are also interesting from a theoretical perspective. Environmental deterioration (and improvement) affects future evolutionary forces on a population by putting new pressures on other individuals, popula-

14. Note that the PRC government is currently planning to build one of the largest hydroelectric dams in the world in this area to provide electricity and flood control. Unfortunately, however, it will also put some of the most striking terrain in East Asia under water.

Figure 21-3. Dynamics of the flood control problem faced by hydraulic societies.



tions and species (the Red Queen again). Also, to the extent that environmental effects are public goods (or 'bads'), their incidence is indicative of human societies' abilities (and limitations) in solving such problems. We will return to this topic in the next chapter.

VI. Bibliographic Notes

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15. There is also an Arno Press Reprint edition; this book is a classic of the environmental impact genre. Marsh was a New England congressman and later US ambassador to Turkey and Italy. He was able to compare old, careworn Europe with relatively pristine America.
16. This book is a classic; it contains 30-40 papers summarizing various impacts. Many of the historical chapters are still useful.

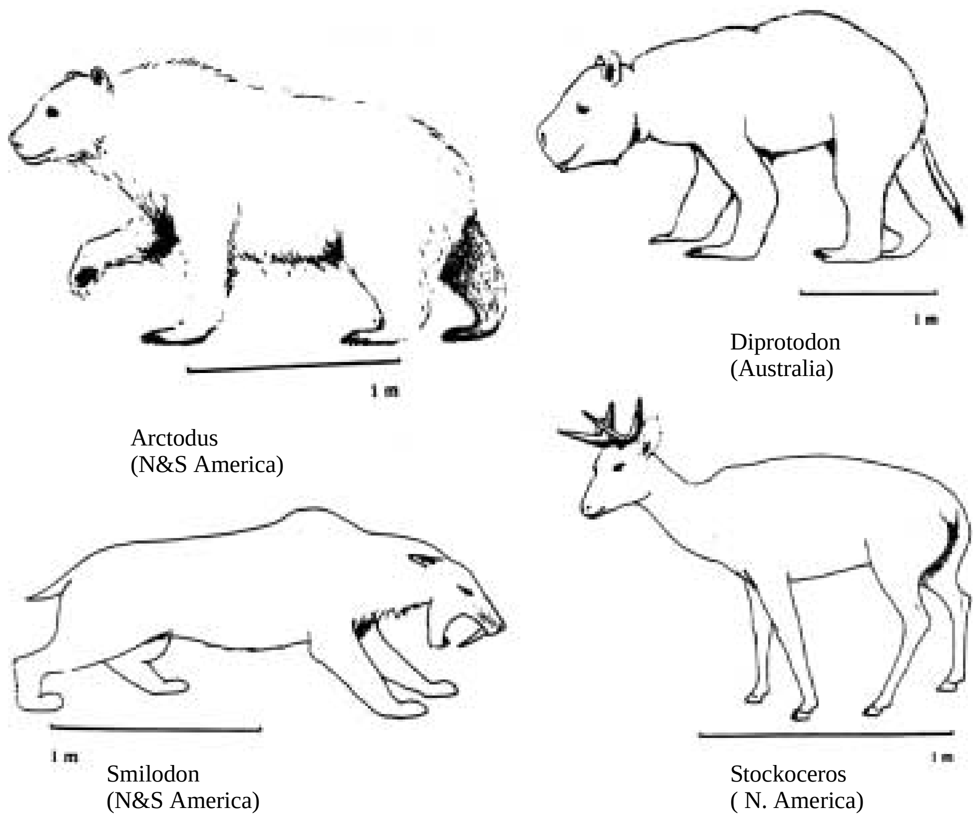

Figure 21-4. Some of the species lost during megafaunal extinctions in North America and elsewhere. (Illustrations copied from Martin and Wright 1967)

Figure 21-4. (continued)

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Figure 22-4. (continued)