Chapter 20. DISEASE EXCHANGES

> Soldiers have rarely won wars. They more often mop up after the barrages of epidemics. And typhus, with its brothers and sisters—plague, cholera, typhoid, dysentery—has decided more campaigns than Cæsar, Hannibal, Napoleon and all the generals of history.
>
> Hans Zinsser (1935)

I. Introduction

A. Disease as an Example of Links Between Environment, Technology, & Biology

We might say that disease is part of an "environment core," defined by analogy with the culture core as those features of the environment most closely connected with subsistence and technology. What diseases a population gets depends on the technology it employs in a given environment. This effect is mostly through population density, but other factors also play a role. At the same time, disease has effects on social organization. In the case of catastrophic epidemics, episodes of disease can completely disrupt a society. In the case of chronic diseases, population densities may be regulated at quite low levels compared to what we would otherwise expect from technology and environment. As we shall see, disease is also a result of population contact, and influences relationships between societies.

Disease organisms and their relations with human populations exemplify the coevolutionary and demographic interactions between humans and other species. In the past, interactions with predators might have been significant. We also have to cope with a host of weeds and pests that attack our domestic animals and crops. On the other hand, we also have more positive interactions with the domesticated plants and animals, with a suite of "friendly" gut bacteria, and so on. This chapter, and Chapter 25 on plant domestication, give examples of the coevolution of humans with other species.

B. Plagues and Peoples

Much of this chapter is based on the work of the ecologically oriented historian, William McNeill (1976) whose book ***Plagues and Peoples*** *was a pioneering discussion of the impact of disease on human history using an interdisciplinary approach*. McNeill imagines that the average person of history (a peasant in the case of recorded history) can be viewed as subject to two kinds of parasites, microparasites and macroparasites. Microparasites for McNeill are disease organisms, bacteria, viruses, parasitic worms, and the like, that live at humanity's expense. Macroparasites are lords, kings, soldiers, and priests, the burden of other humanity that lives at the expense of farmers. This is an interesting association of the

"highest" and "lowest" types of critters in the same general category, parasites on the primary producers of human societies! If you know any farmers, you may have caught them using the term "parasite" for all us city folk. They *do* put us in the same general category as plant pests and diseases!

Some other classics in this genre include Hans Zinsser's (1935) *Rats, Lice and History* and Rene Dubos (1965) *Man Adapting*. More recently, Gottfried's (1983) *Black Death,* Crosby's (1986) *Ecological Imperialism*, McKeown's (1988) *The Origins of Human Disease, and* Preston's (1994) *The Hot Zone* have added to this literature. There is also now an excellent summary of how evolutionary theory should apply to disease, Randolph Nesse and George Williams' (1994) *Why We Get Sick.* All of these books are "good reads;" they are not too technical and are written in lively fashion.

II. Theory of Disease

A. Dimensions of Variation in Communicable Diseases

The evolutionary ecology of disease has been the subject of an excellent body of work by Robert May and Roy Anderson. A few references to their papers are included in the references. May is an outspoken exponent of simple models by the way. His mathematics are usually quite trivial, and yet the conclusions quite powerful. He and Anderson have had a major impact on debates about many important disease problems, including AIDS.

We begin with basic terminology:

Virulent vs. avirulent diseases: Virulent disease rapidly kills a substantial fraction of those who are infected. Avirulent diseases don't kill, or kill very slowly or merely cause chronic illness. For example, smallpox was virulent, particularly in populations without a history of exposure, malaria is relatively avirulent in adapted populations.

Endemic vs. epidemic (and pandemic) disease: Endemic diseases are those that are always present in a population. Epidemic diseases appear, cause mortality and disappear from a population, at least temporarily. *Pandemics* are very large-scale epidemics involving large fractions of the world.

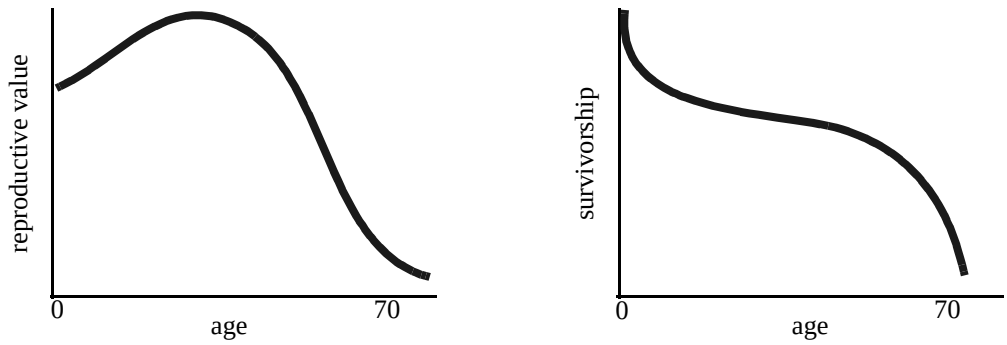
B. Evolution of Disease Systems

Selection on both the disease organism and the host very often seems to result in initially virulent diseases becoming less virulent with time. The essential idea is that host will be selected for ability to resist disease, while the disease will come under selection to remain infectious, but to do as little harm to the host as is consistent with being transmitted. From the diseases' point of view, the healthier the host the better, insofar as healthy hosts can make more new disease organisms and transport it further than sick ones. The trade-off

is that a parasite must rob a host of energy and resources to reproduce itself, and so usually cannot become completely harmless. Sometimes a former disease may evolve into a mutualist that actually helps its host. But vice versa too!

R. A. Fisher developed the theory of ***reproductive value*** *to explain some of the details about how hosts ought to respond to selection to resist diseases*. It explains why children and the old are especially susceptible to diseases. The sensitivity of social organization to disease outbreaks follows a similar logic, as we shall see. Figure 20-1 provides a sketch of Fisher's argument. Fisher characterized the reproductive value of the young as being low

Figure 20-1. Fisher explained the differential mortality of very young and very old humans in terms of their reproductive value. Reproductive value is an organism's expected future contribution to the size of the population, relative to its own present contribution to its size. Survivorship measures the proportion of an age cohort that is living at a particular age.



because they are small, subject to high mortality and not yet reproductively competent. Moreover, the young may die before they reproduce, and a family's investment in them is small. Similarly, the reproductive value of old individuals is low because the younger that an animal reproduces, the earlier its own offspring can begin to contribute to reproduction. Older individuals will have tended to have used themselves up[1] to reproduce when younger.

Because of trade-offs, selection will act to increase survival of organisms with high reproductive value and tolerate more mortality among the very young and very old. Selection falls hardest on individuals that have the biggest expected contribution to future generations, and thus emphasizes protection of adults near maximum reproductive value, at the expense of juvenile and old age mortality. If there is some trade-off between mortality at

1. Consider the applicability of this statement in the context of traditional human environments and pre-industrial cultural patterns.

different ages, all else being equal, selection will favor taking risks with the young and the old in order to let the reproductively valuable survive. For example, young children put practically everything they can find in their mouths. Selection might have favored this behavior because it is important for children to acquire immunities to many common bacteria before adulthood. If a child has an incompetent immune system, it is as well for this fact to be manifest at an early age. If the child dies young, parents will have wasted few resources, but if it dies at 20, they will have wasted much. The main tests of the immune system should occur while people are children. These reasons presumably explain why the mortality curves of humans are so steep during infancy, and again after about 50. Note also, the social value of young and middle-aged adults is high relative to the very old and very young. It is people 18-60 that provide the productive work force and leaders. Epidemics that kill people in this age group can be devastating to social organization as well as to population. Fisher's theory appears to give a good account of why there is excess juvenile mortality and for the existence of senescence (collapse of health in old age).

The existence of true senescence is a still-controversial prediction of Fisher's theory. To the extent that selection acts adaptively to crowd threats to death into old age, we should expect that many biological systems should break down more or less simultaneously. There should not be one cause or a few causes of old age infirmity, but a swarm of postponed debts all coming due together as selection loses its grip as reproductive value falls. Most but not all evolutionary biologists think Fisher was right, but much expensive biomedical research effort is predicated on the assumption that cures for old age can be found.

Virulent diseases tend to die out in a population, as all hosts either die, become genetically resistant or phenotypically immune. Therefore avirulent strains that kill slowly or not at all are more likely to persist, become a successful endemic disease (e.g. worm parasites, common cold virus, etc.). Diseases that remain relatively virulent, such as smallpox, may either have a strong trade-off between their own reproductive rate and the damage they do to their host for some biological reason, or they may have peculiar ecology that prevents the evolution of avirulence. Often selection favors intermediate virulence rather than completely avirulent strains of pathogen. The following example of myxomatosis illustrates this idea.

C. Evolution of Myxomatosis in Rabbits

This classic study demonstrated the decline in virulence of the virus, and an increase in resistance in the rabbit. The virus disease that was introduced into populations of European rabbits in Australia as a measure to control them. When rabbits were introduced to Australia, they lacked diseases or predators to control their populations and they became

serious pests. After it was introduced, the myxomatosis virus seemed to stabilize at intermediate virulence in several populations in Europe as well as Australia (see Table 20-1). At the same time, the rabbit populations evolved higher resistance to the disease. As a result, myxomatosis became endemic. This pattern is consistent with much evidence regarding the history and geographical distribution of humans and their diseases. However, as is discussed in section V.A.1 of this chapter, hard evidence is lacking for any human disease.

Table 20-1. Frequency of field-collected strains of myxoma virus of different grades of virulence, collected in different years from rabbits in Australia Grade I is highest virulence, Grade V the lowest. Adapted, from May and Anderson, 1983..

	Virulence Grade					
	I	II	IIIA	IIIB	IV	V
1950-51	100	--	--	--	--	--
1958-59	0	25	29	27	14	5
1963-64	0	<1	26	34	31	8

D. Influenza: A disease that remains virulent

Influenza is an example of a disease that retains its virulence. In this case, the tendency for virulent strains to arise from time to time (the “Spanish” flu of 1918 is a famous example) is apparently due to the rapid evolution of new strains of the disease from animal viruses. The ancestral viruses are fowl diseases that people acquire from pigs after pigs acquire them from ducks and chickens. (The biology of parasites is full of fascinating twists like this.) The strain is briefly virulent in humans before populations acquire immunities, then that strain just dies out in humans. There is no possibility of a stable long term evolutionary adjustment. The destructive diseases of the past, such as smallpox, plague, cholera, and so forth often had human or animal foci where they were endemic and avirulent. If human populations are infected from these foci at irregular intervals, the diseases similarly may never become endemic and avirulent in the populations into which they are “accidentally” introduced. Each time a major new disease adapts to attack humans, there is a chance that it will be briefly epidemic and virulent before the evolution of endemic, avirulent strains can take place. Influenza is an extreme example because the frequency with which new epidemic strains are acquired from pigs.

E. Dynamics of Classic Pandemic Outbreaks

The influenza pattern appears to be a common pattern for really destructive epidem-

ics. Pandemic diseases persisted in endemic foci in some population somewhere, often a nonhuman alternate host. In the case of the Black Death, the original focus was infected wild rodents some place in the Himalayan region. Other frequent alternate hosts are domesticated animals and wild animals such as rats or monkeys that live in close proximity to human settlements.

For some diseases, human populations were often too small to sustain the disease as an endemic infection, but large enough to carry epidemics. For example, in populations smaller than 300,000 measles cannot persist as an endemic disease. Too few non-immune children are born to sustain the disease population after an initial attack. There is a *threshold population size* below which a disease dies out in an isolated society. However, these societies may be dense enough to spread the disease *if it is introduced.* Once an epidemic passes through a population and dies out, the number of people with acquired immunities drops until there are once again enough susceptible individuals to carry an epidemic. Then the society is primed to explode if the disease is again introduced from the outside. Table 20-2 from Harrison et al. (1988) shows how, in a series of island populations, only Hawaii is large enough to sustain measles on its own. In the other cases, measles dies out and must be reintroduced by travelers. Note that percent of months with measles seems to be a function of both island size and frequency of visitation. Guam and Bermuda, with lots of visitors, have high rates for their size.

Table 20-2. "Endemicity of measles in islands with populations of 500,000 or less, all of which had at least four exposures to measles during 1949-1964 (from Harrison et al., 1988:520)."

Islands	Population	Annual Population Input	% Months With Measles
Hawaii	550,000	16,700	100
Fiji	346,000	13,400	64
Samoa	118,000	4,440	28
Solomon	110,000	4,060	32
French Polynesia	75,000	2,690	8
Guam	63,000	2,200	80
Bermuda	41,000	1130	51
Falkland	2500	43	0

Thus, the most virulent epidemics occur in situations where the disease spreads from an endemic focus to poorly adapted populations, who suffer great mortality, but do not sus-

tain the disease. The disease may recur at irregular intervals due to chance contact with the endemic focus. The intermediate-sized population will carry an *epidemic*, but will not sustain the disease as an *endemic* infection.

If the population is larger still, the disease becomes endemic, strikes mostly children and old people, and is much less of a burden on the population than one that strikes people near maximum reproductive and social value. From the point of view of the disease, the important variable is the rate of generation of new susceptible people relative to the rate at which people die or are cured of the disease. For the most serious infectious diseases, such as smallpox, people die or recover fairly quickly. In small populations, such diseases tend to die out pretty quickly after an epidemic is introduced because so many people are cured or become immune that the chain of infections is broken. These diseases can be sustained in larger populations because enough new children lacking immunity are born to continue the train of infections within the population. As diseases become endemic in this fashion, the coevolution of disease and host populations will ensue, inherited immunities will build up, and the disease may become less virulent. Thus, populations with intermediate densities are most vulnerable because infectious diseases do not become endemic. Instead, these diseases attack *irregularly* after a large enough number of susceptibles has built up to carry the disease, and some chance event reintroduces the microbe.

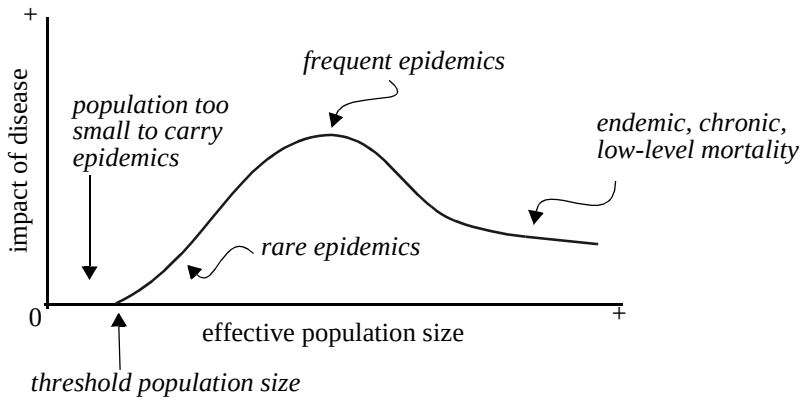
Effective population size is population size measured in terms of probability of contact of one sick person with another. It is therefore a function of **both** density *and* mobility.

Effective population size is a function of _both_ density and mobility. This means that the rate of contact between people and sub-populations is important, not so much the population's actual size and density.

The literal population size and density important, but mainly operates by affecting the rate of contact between potentially infected subpopulations and individuals. Frequent, long-distance travel increases effective population size, sedentarism reduces it. The impact of disease on the demography and sociology of a population is of course low when it is too small to suffer the disease at all. It is usually tolerable when the disease is endemic. The worst impacts occur at intermediate effective population sizes that are large enough to carry the epidemic, frequently make contact with endemic foci, but are too small to allow the evolution of endemism and avirulence. Figure 21-2 illustrates the biology behind this idea.

The evolution of resistance to infectious disease amounts to reducing the effective population size of susceptibles. In the case of viruses, histocompatibility antigens are the first line of defense. Each human genetic variant at such loci is resistant to some diseases and disease strains, but not others. There is a coevolutionary merry-go-round between selection increasing the frequency of disease genotypes that can attack currently common antigen types, and the human population response of increasing frequencies of those antigen genotypes that are most difficult to attack. In human populations exposed to repeated attack by many viruses, there are many genotypes. Each disease strain can attack only a minority of the population. For example, it is estimated that in African populations, the effective population size is only 1/200th the raw numbers due to antigen diversity, at least for a virus that can attack only one genotype. In contrast, isolated island populations are as large as 1/3 of their raw numbers. As we will see below, the consequences of low antigen diversity are dramatic when isolated populations are exposed to the full spectrum of disease variants..:

Figure 20-2. Impact of disease on population growth rate or size according to McNeill's (1976) hypothesis.



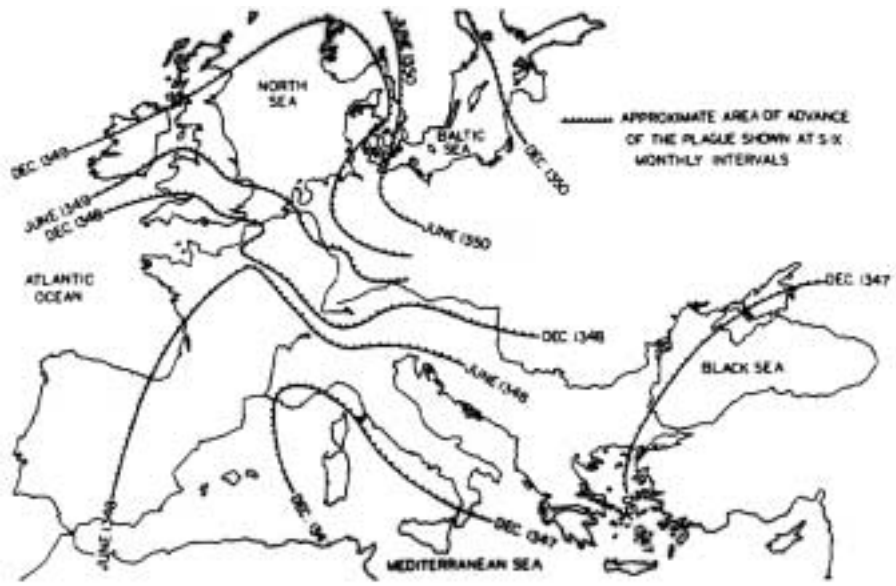
III. Disease, Technology, and Technical Change

A. Importance of transport, technology, and the like:

Changes in technology sharply affect the diseases humans get because they lead to changes in the effective size and density of our populations. Technological progress over the last 10,000 years has tended to move populations from below threshold to the endemic size for a large spectrum of diseases. McNeill (1976) argues that the classical period from 500 B.C. to 1500 AD brought densities and travel rates up to the point that effective popu-

lation sizes were around the peak of severity for disease impacts for many classic epidemic diseases like smallpox and plague. This was the Era of the Plagues. The Black Plague struck Europe at least twice 542-3 AD, and again in 1347-50 (see figure 20-3). Other lesser outbreaks occurred and other severe outbreaks that might have been Black Plague occurred at earlier times. It seems that open trade routes across Central Asia, such as the Mongols supervised in the 14th century, linked Europe to the Black Plague focus in Central Asia at irregular intervals, initiating the outbreaks. Mortality over wide areas could reach 50%. Many other diseases of great severity swept Europe as each society acquired a tenuous contact with the disease pools of the others.

Figure 21-3. Spread of the Black Plague in fourteenth-century Europe (modified by Harrison et al. (1988:524) from McNeill (1976).



After 1500, contact by ship became so regular that the whole civilized world essentially became a single population for many purposes. Now, for most diseases, the world population began to move down the right shoulder of the curve, and most diseases became endemic and less virulent childhood diseases. Mortality was still high until the advent of scientific public health, but was concentrated among those who were reproductively less valuable and/or less advantaged socially.

The AIDS epidemic is testimony to how cultural changes can still expose human populations to new diseases. The current AIDS pandemic reminds us that we may still be vulnerable to new plagues, despite scientific public health. Relaxed sexual mores, alas, are still dangerous. Another example is polio, which was a dreaded disease in the 1950s. The polio

virus had apparently long been common, but few people had the disease, because most children were infected very young when the course of the disease was normally mild. As sanitation *improved* in the 20th Century many children got the disease at later ages when infection caused severe paralysis or death. More generally, a new technology may alter the habitat so as to favor a disease (e.g. irrigation favors waterborne and mosquito-born diseases). Similarly, technology may determine which habitats can be occupied, and different habitats may have different disease profiles. For example, the introduction of the American sweet potato to New Guinea allowed people to push cultivation to higher altitudes, and thus to escape malaria; population densities are much higher in the healthier highlands.

B. Historically small importance of medical technology

Curing was an early occupational specialization; people have always tried to find technical solutions to disease. Even hunting and gathering societies have people who specialize in curing the sick. Even in the absence of proper specialists, all human societies have some curative techniques. The so-called "secondary compounds" of plants are a rich source of drugs. These compounds are usually chemical defenses against herbivores and parasites, but sometimes have useful pharmacological properties for humans. Quinine, morphine, digitalis, and cocaine are examples of drugs discovered by folk healers and later brought into scientific medicine. Also, people often have customs regarding disposal of feces and other traditions that have sanitary implications. Finally, unlike most other animals, humans nurse the sick. This is a tremendous help in surviving seriously debilitating illnesses such as many epidemic diseases. In really severe epidemics, significant mortality is thought to occur just because so many people are sick there are not enough left healthy to nurse them.

However, prescientific doctoring seems to have depended largely on the placebo effect. The placebo effect is the psychological effect that treatment has even if treatment is nothing but a sugar pill. All good medical experiments control carefully for the placebo effect, because for many diseases, it is actually quite effective. People really do get better faster if they take a cure they believe in, even if the non-psychological effects of the treatment are nil. Not until the development of scientific medicine does medical treatment seem to have been generally efficacious. Although folk pharmacopoeia have yielded many important drugs, the vast bulk of folk cures appear to be "medically" ineffective. Not a few treatments are plainly magical and aimed at improving the patient's morale. In many cultures people go both to traditional practitioners and to modern doctors. This is presumably the best approach in practice, getting the maximum placebo effect as well as whatever real cures the proper doctor can provide! Of course, it may be hard to optimize this strategy. The witch doctor's treatment only works if you believe in it, but if you believe in the witch doc-

tor, you may not make proper use of the scientific practitioner.

C. Generalized Result

Long-stabilized conditions seem to result in genetic and cultural adaptations to disease. Sudden changes often lead to increased burdens of micro-parasitism, as human populations come into contact with new organisms for which neither genetic nor cultural means of adaptation exist. New or insufficiently regular contact with foreign populations is a troublesome source of exposure to diseases for which populations are ill-adapted. Because technology plays such an important role in regulating human population density and mobility, each of the technological types of society we have studied in this class tends to have a characteristic disease profile. However, environmental variation also plays an important role. The following sections document these generalizations. Table 21-3 summarizes the relationship between cultural characteristics and population size.

Table 21-3. "Cultural characteristics in relation to the number of human generations and population aggregation (modified from Harrison et al., 1988:515)."

Years bp	Generations	Cultural Type	Community Size & Type
1,000,000	50,000	Hunter Gatherer	nomadic bands <100
10,000	500	Early Agriculture	relatively settled villages <300
5,500	220	Irrigated Agriculture	few cities ~100,000, mostly villages <300
250	10	Industrial & Commercial	some cities 500,000+, many cities ~100,000, many villages ~1,000
130	6	(introduction of sanitary reforms)	—
0	—	—	some cities 5,000,000+, many cities 500,000, fewer villages ~1,000

IV. Diseases of Hunter Gatherer Societies[2]

A. Ecological Circumstances and Types of Diseases

Hunter gatherers had a far different disease profile than we experience. They have low population densities and are intimately involved in local ecological processes. These circumstances make them particularly vulnerable to diseases with alternate hosts such as malaria[3] and intestinal parasites (e.g., tapeworms, round worms, etc.). Most of the diseases

2. Taken largely from Dunn (1968).
3. See The end of this chapter for a recent article about contemporary problems with a new strain of malaria.

suffered by hunter gatherers are relatively mild and are passed by intimate contact (e.g., T.B. & herpes). Population sizes are far too low to carry virulent epidemics or to support endemic infections of moderate virulence. Food foragers probably lacked most microbial diseases that are either virulent or cause only a short infectious period, or survive a short time outside the host (e.g. everything from smallpox to colds, to intestinal bacterial diseases).

B. Great Geographical Differences

There are high micro-parasite loads in the Old World tropics where humans have a long history, primate relatives are present, and disease organisms tend to survive for a long time outside hosts[4]. Micro-parasite loads are generally lower in temperate and arid zones. There, cold seasons and/or dry conditions limit populations of insect vectors and reduce lifetimes of disease organisms outside the body. There are also fewer primate relatives of humans or other animals to act as reservoirs and evolutionary sources of infections.

In rain forests in Malaysia and Africa, hunters and gatherers carry ~20 worm and protozoa parasites, in the African and Australian deserts from 1 to 9 (Dunn, 1968). Dunn argues that this range is in rough proportion to biotic diversity generally, implying that places with many species of animals have many alternate hosts, many species to enable them to complete complex life cycles, and many species to act as the evolutionary sources for human infestations.

Micro-parasite loads are lowest in New World because of the Arctic barrier and the fact that humans have no close New World relatives, even in tropics. The diseases that the original migrants brought to America must have been only those that small groups of sub-arctic hunters and gatherers could carry. Once across, Americans were almost completely isolated from any possibility of acquiring Old World diseases, except perhaps infections that were filtered through sub-Arctic hunters like the Eskimo. Australia and the Oceanic Islands were similarly isolated and nearly disease free (Crosby, 1986).

The main form of human adaptation to disease is via biological resistance. However, some cultural customs and curative practices are also important. For example, as we discussed previously, simple nursing is quite effective for saving the seriously, but not catastrophically, ill.

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4. because conditions more closely approximate the warm moist environment within the human body

V. Diseases of Simple Horticultural Societies

A. Ecological Circumstances and Types of Diseases

Use of domestic plants and animals usually greatly increases population densities and substantially modifies environments. Virulent endemic childhood disease such as smallpox were probably first experienced in these types of societies. Higher rates of infestation of specialized parasites (e.g. bilharzia from irrigation water, *Anopheles,* the malarial mosquito) are found around settlements because of higher population density and poor sanitation. Until the last few hundred years, there was still a great deal of geographical variation in the amount and type of disease suffered by horticulturists.

B. Biological and Cultural Adaptations

Increased densities and expansion into new habitats exposed horticultural people to new diseases and set in train evolutionary responses, most importantly genetic responses. Diseases were, until the last few decades, features of the environment to which people adapted very substantially genetically as well as culturally. Human populations vary considerably in their abilities to resist various diseases.

Classic, well-studied examples include the various hemoglobin variants, e.g. sickling trait for malaria[5] *resistance in West Africa*. Sickle cell anemia is a disease caused by being homozygous for a particular gene coding for a non-standard hemoglobin. When one is heterozygous for this gene, the anemia is very mild, and the individual is protected from malaria. The heterozygous sickling person's red blood cells are prone to become distorted and leak nutrients when stressed by the malaria parasite, which multiplies inside red blood cells. The multiplication rate of malaria in the host is thus reduced. With a double, homozygous dose, the blood cells distort and leak in such high frequency as to cause anemia and usually premature death of the carrier. Selection favored a fairly high frequency of this gene in the more malarial parts of West Africa, despite high mortality among homozygotes. At the same time, individuals homozygous for the normal gene are unprotected from malaria.

Malarial parasites evade the immune system better than bacteria and viruses, and other means of resisting them have to be run up. The costly sickle cell system is a result. In some African populations heavily exposed to malaria, the proportion of the sickling gene reaches around 15%. This will provide malaria protection for about 26% of the population (the heterozygotes), leave 72% unprotected (homozygous normals), and sacrifice about 2% of the homozygous sicklers. Protected heterozygotes have about a 20% fitness advantage homozygote normals, and the homozygous state causes a fitness reduction of 80% relative

5. Malaria is a human disease caused by parasitic protozoans in the red blood cells. It is transmitted by the bite of *Anopheles* mosquitoes, and is characterized by periodic attacks of chills and fever.

to the protected heterozygotes. The crudity of this anemia producing mechanisms betrays a recent evolution; selection may not yet have "discovered" the appropriate adjusting modifier genes to permit the anemia genes to go to fixation without causing fatal anemias. There is some suspicion that people avoided the most malarial parts of Africa until the advent of horticulture there ca. 3,000 BP. DNA sequencing data suggests that the sickling gene evolved independently 3 times, a remarkable example of convergent evolution.

Even more remarkably, other functionally equivalent systems for malaria resistance have evolved. One of these, G-6-P-D deficiency, has an interesting coevolution with a cultural mechanism for malaria resistance, fava bean consumption. Genes for G-6-P-D deficiency confer resistance to malaria, but based on a different biochemical mechanism from sickling. The gene is in high frequency in the Mediterranean region where the disease was common in the past, for example in Sardinia. These genes also have the effect of making red blood cells less good places for malaria plasmodia to live, at the cost of making them somewhat less good at carrying oxygen and having other problems.

Fava beans have been widely cultivated around the Mediterranean Region for centuries in spite of the fact that they cause a deadly disease called favism in people who are G-6-P-D deficient. In such susceptible people, eating the beans causes red blood cells to break, and the victims die as the capacity of their blood to carry oxygen collapses. Fava beans (also called broad beans) are large flat beans about the size of the end of your thumb. They are very similar to a number of other legume crops in terms of ease of cultivation and nutritional value. Solomon Katz et al. (1979), who studied fava consumption in this region originally hypothesized that populations with the highest proportions of this gene would exhibit the lowest use of fava beans. However, what they found was that fava bean consumption was actually *highest* in those populations with the highest proportions of the gene.

According to Katz and his colleagues, fava consumption is adaptive in malarial regions because some of the compounds in the bean confer malarial resistance in individuals who do not have the favism gene. Unfortunately, having G-6-P-D and eating fava beans is analogous to being a sickling homozygote.

This example may provide a good example of natural selection acting on a cultural—rather than biological—trait. A great variety of cultural beliefs have developed regarding fava beans during the long period of their use in this region. Despite some recognition that they can have harmful effects, fava beans continue to be eaten. There is no evidence that those who eat fava beans understand the biological complexities involved or have specific genetic biases (e.g. a distaste for the beans among individuals genetically vulnerable to favism). Using cultural evolutionary concepts, we can construct a plausible hypothesis that

natural selection is acting on a *cultural trait* (eating fava beans) much as it is acting on the *gene* that causes favism. Individuals characterized by beliefs that lead them to consume fava beans had a higher probability of surviving to adulthood and becoming cultural parents for the next generation that individuals who did not consume fava beans. Selection would also favor the spread of folk medical beliefs that helped G-6-P-D deficienct people avoid fava beans. The use of plant foods high in secondary compounds of presently unknown or poorly understood effects is widespread in human cuisines. Natural selection for such preferences could be an important phenomenon.

Many other cultural practices have been hypothesized to have evolved to protect human populations from disease. Hill tribes of North Vietnam live in raised huts to avoid malaria mosquitoes. The nocturnal mosquitoes that carry malaria in this habitat apparently fly close to the ground, and prefer to bite cattle rather than people. By stabling cattle on the ground floor and living above them, one can largely avoid bites. To give another example, Mongols living in areas with endemic Plague avoid rodents, especially sick ones. Since rodents are reservoirs of Plague, this is probably an effective means of avoiding outbreaks of this dreaded disease. Adjustments such as these, supplementing biological resistance, were apparently relatively successful in converting most of the new virulent diseases into the relatively harmless endemic ones, so long as sufficient time, perhaps a few thousand years, were available to evolve the appropriate mechanisms. In the case of the crude sickling resistance gene and the dangers of combining G-6-P-D deficiency with fava bean consumption, it would seem that 3,000 years is too short to *perfect* an adaptation to malaria.

V. Diseases of Classic and Renaissance Agrarian Societies

A. Ecological Circumstances and Types of Diseases

Agrarian societies tended to be around the maximum impact part of the effective population size curve for many diseases, according to McNeill's hypothesis. As table 21-2 showed, early agricultural societies brought about increases in population and settlement density (cities). Trade was greatly expanded due to political consolidation, improved transportation, and expanded warfare. By about 500 B.C. the stage was set for the various urban civilizations to start exchanging diseases all over the Old World as noted above. During this era, local epidemic diseases spread with trade and military adventures due to a confluence of disease pools.

A variety of diseases, many of which cannot be reliably identified, swept through the ancient Old World civilizations. Most probably became avirulent or died out after initial attacks. Note that historical epidemiology is a difficult business. Only a few diseases leave

traces on skeletons for the archaeologist to find. Mummies make the best material for paleopathology (Armelagos, 1969), but are relatively uncommon. Diseases tend to evolve, and old chroniclers were not always the most acute observers. Hence, there is a great deal of uncertainty about the identity of many ancient diseases.

The demographic and political consequences of disease epidemics were very important. For instance, the spread of invaders into India and Southern China may have been slowed by diseases. Similarly, bubonic plague is associated with the fall of the Roman Empire. Plague was renewed in Europe with the Mongolian invasions and led to major political upsets in Western Europe in the 14th century. The demographic collapse of Europe due to the 14th Century bubonic plague raised wages for a century or more due to labor shortages (see Chapters 7 and 15).

B. Colombian Catastrophe

The most catastrophic disease epidemics in human history were associated with the voyages of discovery ca 1500 AD which ended of the isolation of the Americas. Every other demographic holocaust we know of pales by comparison. According to the summary of evidence by Henry Dobyns (1993), roughly 80-95% of the precontact populations of the Americas was killed as wave after wave of new diseases decimated New World natives for 50-125 years after contact. Native Americans have much less variability at the key histocompatibility antigen loci that protect against virus infections. Epidemic diseases that reach such unprotected populations are called *virgin soil* diseases. Unlike endemic diseases among well-adapted peoples, these epidemics struck people in the prime of life, as well as children. Social disorganization was extreme, even in comparison with the plague in classical Old World civilizations, where the analogous situation was horrifying enough. The following series of passages from historical sources quoted by Crosby (1972) provide a graphic example:

> Thomas Hariot [a member of the 1587 English colony at Roanoke Island in what is now Virginia] wrote that there was no Indian village where hostility, open or hidden, had been shown,
>
> > but that within a few dayes after our departure from everies such townes, that people began to die very fast, and many in short space; in some townes about twentie, in some fourtie, in some sixtie, & in one sixe score, which in trueth was very manie in respect to their numbers…. The disease also was so strange that they neither knew what it was, nor how to cure it; the like by report of the oldest men in the countrey never happened before, time out of mind (Crosby, 1972:41).
>
> Similarly, French settlers in what is now Canada in 1616 reported that the Indians:
>
> > are astonished and often complain that, since the French mingle

> with and carry on trade with them, they are dying fast and the population is thinning out. For they assert that, before this association and intercourse, all their countries were very populous and they tell how one by one [different areas] have been more reduced by disease (Crosby 1972:41).

A European who lived in [the Boston Bay] area in 1622 wrote that the Indians had

> died on heapes, as they lay in their houses; and the living, that were able to shift for themselves, would runne away and let them dy, and let there Carkases ly above the ground without burial….. And the bones and skulls upon the severall places of their habitations made such a spectacle after my coming into those partes, that, as I travailed in the Forrest nere the Massachusetts, it seemed to be a new found Golgotha (Crosby, 1972:42).

…The Cakchiquel Mayas [of South America]… kept a chronicle of the tragedy for their posterity…. Their words speak for all the Indians touched by Old World disease in the sixteenth century:

> Great was the stench of the dead. After our fathers and grandfathers succumbed, half of the people fled to the fields. The dogs and vultures devoured the bodies. The mortality was terrible. Your grandfathers died, and with them died the son of the king and his brothers and kinsmen. So it was that we became orphans, oh, my sons! So we became when we were young. All of us were thus. We were born to die! (Crosby, 1972:58)

C. Disease and Imperialism

Patterns of disease appear to have strongly channeled European colonial practices from 1500 to about 1850 (Crosby, 1986). European conquest of places like the Americas and New Zealand was comparatively swift because diseases were flowing from Europeans to the Natives. In Africa, which was so convenient to Europe, white presence was very thin until the advent of antimalarial drugs in the mid-19th century. Then Europeans were able to effectively colonize Africa. Throughout most of the Old World, disease flows were more or less balanced, and Europeans remained a small minority. Even today, whites are scarce in tropical countries, and in cases like Brazil tend to be restricted to the temperate end of the country. Crosby attributes this pattern to diseases and subsistence techniques. Europeans are biologically and culturally temperate-zone animals and cannot compete with other populations nearer the equator. Nor were they able to really displace native populations anywhere without the aid of a sharp disease gradient in their favor.

D. The Confluence of Disease Pools

In the European Era, long-distance travel became so routine that many human populations passed to sizes that maintained formerly epidemic diseases in the endemic state. Thus smallpox tended towards a routine childhood disease, which perhaps favored the evolution of less virulent strains and host resistance. And at any rate, young people were dis-

proportionately victims, compared to the more valuable adults. Thus the Era of Plagues (big pandemics) was essentially ended by most formerly epidemic diseases becoming endemic. The catastrophes in the New World were the last of the truly horrific epidemics. Native Americans turned the corner of exposure to Old World diseases, and began to increase again.

VI. Diseases of Industrial Society

A. Ecological Circumstances and Types of Diseases

Industrialization brought about further increases in population size, density, and rates of communication. Effective population size took another dramatic jump. This meant more people were exposed to old virulent infections. It also meant that more people were exposed to old urban sanitary diseases such as cholera and typhoid. Even if immunities from the late agrarian confluence of the disease pools was high, chronic mortality was probably an increasing problem in early industrial cities as densities increased. (See Knauft's 1987 article on pre-industrial cities for a vivid description.) Transportation improvements probably were responsible for influenza becoming pandemic during that time. Even in the best 19th century cities, disease problems were severe due to massive exposure to poor nutrition, environmental pollutants, and noninfectious diseases such as scurvy, beri-beri, etc.

B. Adaptations

Biological adaptations to disease were rather slow compared to the variety and rate of spread of infectious disease during the 19th century. The most effective adaptations were *cultural*. Scientific medical technology, primarily public health adaptations, were especially effective. Vaccines were developed for smallpox; chemotherapies were developed to treat venereal diseases and the like; insecticides were developed to combat insect borne diseases like malaria and yellow fever; and nutritional supplements (e.g. citrus, vitamin C, for scurvy) began to be used. Moreover, the development of sewer systems began to improve both the health and general appearance of the cities. Pedestrians no longer had to divide their attention between where they were stepping and the 'night soil' being thrown out of upper-story windows.

Modern industrial life absolutely requires high quality public health measures. Quite grim new diseases, like AIDS, and old ones like malaria, continue to threaten modern societies. Public health organizations, such as County Mosquito Abatement Districts and the U.S. Communicable Disease Center in Atlanta probably save more lives in this country every year than all the work of all the practicing physicians.

Let us give credit to a couple of the relatively uncelebrated public health pioneers to

whom we owe so much:

> (a) John Snow and the Broad Street Pump organization, working on a London cholera outbreak, developed methods of tracing the source of polluted water by appropriate statistical studies.
>
> (b) Thomas Crapper and Edwin Chadwick developed the flush toilet[6] and sanitary sewers. The very deadly water-transmitted diseases of industrial cities (e.g. typhoid, cholera) were almost eliminated by piped and treated pressurized[7] water, an efficient buried sewer system, and flush toilets. Pressurization is important; otherwise pollutants and disease organisms can enter the water supply through cracks. In many water-short 3rd World cities, the water is still dangerous because the supply system is frequently shut down, allowing contamination.

In industrial societies, the epidemic disease situation would probably have been intolerable without these public health innovations. In the event, scientific innovations have protected us despite the awesome run-up of effective population size. It is hard for us to even imagine how bad it must have been.

It is interesting to note that most classic diseases of the early industrial period began to decline well before modern medical advances came up with "cures." Figure 20-4 McKeown's shows such an example for tuberculosis. Such declines are not well understood. Improved nutrition, larger, cleaner dwellings, improved sanitation—all a result of increased prosperity—are the leading candidate explanations.

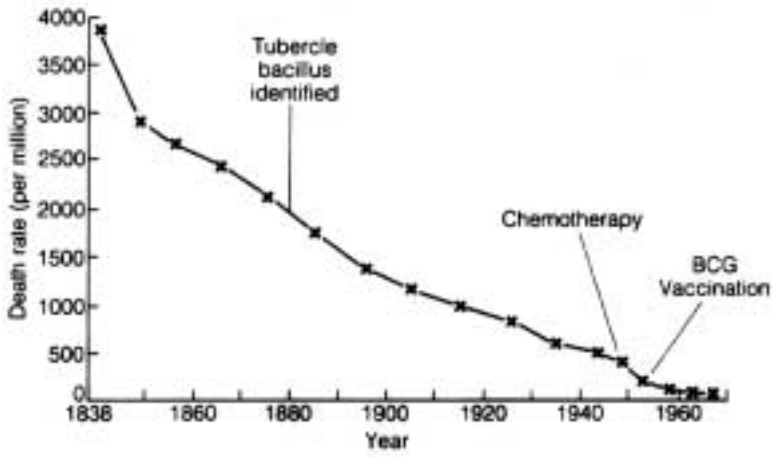
Complacency is unwarranted. The AIDs epidemic is on everyone's mind, and could turn out to be a major "virgin soil" epidemic, as it seems from experience in some parts of Africa. Other old diseases, such as tuberculosis and malaria, have evolved resistances to drugs and insecticides used to control vectors, and are on the rise. The coevolutionary race between disease and host tips back and forth, and permanent, total victory is not on the horizon.

VI. Conclusion

Infectious disease might seem mainly like an interaction between a human population and a non-human one. *In this chapter, we've emphasized the extent to which disease depends on the way populations interact with each other, as well as the way disease populations interact with any given human population*. If hypotheses like those developed by McNeill and Crosby and others are correct, disease and disease exchanges have been important determinants of the expansion and contraction of societies. Note that until the ad-

6. Honest!
7. .

Figure 20-4. Decline of tuberculosis in Western Europe. Mean annual death rates from respiratory tuberculosis in England and Wales from 1838 to 1969 standardized to 1901 population. (Copied from McKeown, 1988:79.)



vent of scientific medicine, disease-ridden societies may have had an advantage in intersocietal competition. Crosby's case that Africa resisted European domination until the development of effective antimalarial drugs in 19th century, whereas the Americas fell quickly beginning in the 15th century seems reasonably compelling.

This chapter also serves as an example of biological adaptations to environmental variation. We stressed the importance of culture in human adaptations in this course, but the case of disease illustrates that genetic adaptations *still* play a quite significant role. Until recently, medical technology was too primitive to be very effective, and the evolution of immunities seems to have played an important role in human abilities to cope with parasite burdens. Physical anthropologists believe that some other genetic variations between human populations have adaptive significance, for example body build differences and skin color, and disease serves as our example of the wider importance of genetic adaptations.

Note also how cultural and genetic adaptations have interacted in intimate ways in the case of disease. This too is presumed to be a general phenomenon. We have stressed the importance of gene-culture coevolution in this class, and disease-genetics-culture interactions furnish some nice, albeit specialized, examples.

VII. Summary

A. *Concepts*: reproductive value, virulence vs. avirulence, endemic vs. epidemic

B. *Discoveries*: placebo effect, patterns of disease as a function of technology

C. *Models*: Evolution of avirulence

D. *Hypothesis*: McNeill's ideas about the relation of epidemic disease to effective population density

VII. Bibliographic notes

References:

Black, F.L. 1975. Infectious diseases in primitive societies. *Science* 187: 515-518.

Crosby, A.W. 1986. *Ecological Imperialism: the Biological Expansion of Europe 900-1900*. Cambridge: Cambridge University Press.

Dubos, R. 1965. *Man Adapting*. New Haven: Yale Univ. Press.

Dobyns, H.F. 1993. Disease transfer at contact. *Ann. Rev. Ecol. Syst*. 22:273-91.

Dunn, F.L. 1968. Epidemiological factors: health and disease in hunter-gatherers. In R.B. Lee and I. DeVore (eds). *Man the Hunter*. Chicago: Aldine.

Gottfried, R.S. 1983. *The Black Death: Natural and Human DIsaster in Medieval Europe*. New York: Free Press.

Harrison, G. A., J. M. Tanner, D. R. Pilbeam, and P. T. Baker. 1988. *Human Biology: An Introduction to Human Evolution, Variation, Growth, and Adaptability*. Oxford: Oxford University Press.

Katz, Solomon H. and J. Schall. 1979. Fava bean consumption and biocultural evolution. *Medical Anthropology* 3:459-476.

Katz, Solomon H., M. L. Hediger, and L. A. Valleroy. 1974. Traditional maize processing techniques in the New World. *Science* 184:765-773.

Knauft, Bruce. 1987. Divergence between Cultural Success and Reproductive Fitness in Preindustrial Cities. *Cultural Anthropology* 2:1:94-114.

McKeown, T. 1988. *The Origins of Human Disease*. Oxford: Basil Blackwell.

McNeill, W.H. 1976. *Plagues and Peoples*. New York: Anchor Doubleday.

May, R.M. 1983. Parasitic infections as regulators of animal populations. *Amer Scient*. 71: 36-45.

May, R.M. and R.M. Anderson. 1983. Parasite-host Coevolution. In D.J. Futuyma and M. Slatkin (eds) *Coevolution*. Sunderland Mass.: Sinauer.

Nesse, R.M. and G.C. Williams. 1994. *Why We Get Sick: The New Science of Darwinian Medicine.* New York: Random House.

Preston, Richard. 1994. *The Hot Zone.* New York: Anchor-Doubleday.

[8]Zinsser, H. 1935. *Rats, Lice, and History*. New York: Little, Brown.

8. This is a classic of science writing for the general public. It is a "study in biography, which after twelve preliminary chapters indispensable for the preparation of the lay reader, deals with the life history of TYPHUS FEVER." You get the idea; it has been extensively reprinted as late as the early 70s at least.

Deadly Malaria Comes Back With a Vengeance[1]

Do we want to do these or no?

[1] Drogan, Bob. 1992. Los Angeles Times 7/28:H2.