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# Ecology of Anthrax

Anthrax undergoes a propagation phase in soil before it infects livestock.

Glenn B. Van Ness

Anthrax, an infectious disease of herbivorous animals, has caused epidemics in livestock and in man since antiquity. In the acute form, the disease brings about little change in the tissues of dead animals except dark blood and swollen spleens. In man, a malignant carbuncle is suggestive of anthrax. Pulmonary anthrax, or "wool sorter's disease," is a serious and often fatal infection, resulting from the handling of contaminated hair and wool. Anthrax was linked with endemic soil environments long before *Bacillus anthracis* was identified as the causative organism. Livestock infections in new areas can be traced to areas of the world in which the disease is endemic in the soil. Spores of *B. anthracis* may contaminate bone meal, wool, hair, skins, and animal feeds—all products in world commerce. Outbreaks result from ingestion of or contact with these spores, but anthrax becomes a recurrent problem only when an animal-soil-animal cycle is established. The disease probably came to the New World with European colonists (*1*). We must know where the disease is likely to appear and where it is established in the soil before we can hope to control it.

Controlling an outbreak of anthrax may include vaccinating and treating the exposed herd. State laws and meat inspection regulations often influence the choice of programs. Since additional outbreaks may follow the first appearance of the disease, it is important to know where these are likely to occur. Livestock affected with anthrax must not be moved, but area quarantines have to be restricted, in order to avoid serious disturbances in the agricultural economy. If we understand the ecology of anthrax, we may be able to institute better regulatory programs.

The discovery (*2*) that anthrax organisms form spores was one of the significant events in the science of microbiology and disease. Discovery of the spore led to some erroneous and even pernicious conclusions. The spores will survive indefinitely in a dry environment, such as in dust, on string and swabs in a laboratory, and blood spots on clothing. From this observation, anthrax specialists advanced the concept that, once premises are contaminated with anthrax spores, the spores would persist and infect other animals.

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There is, however, good evidence that the theory of persistent spores is invalid. Spores vegetate when soil conditions are favorable, and organisms form spores when conditions are satisfactory. Soils and water that are not suitable, either because of acidity or biological competition, will eliminate both organisms and spores. This is true even when there is heavy contamination from improper disposal of livestock that died of anthrax. Epidemiological evidence indicates that suitable soils can maintain an organism-spore-organism cycle for years without infecting livestock. Laboratory studies on the relation of anthrax to the soil (*3*) are those of Whitworth (*4*) and Minett and Dhanda (*5*). From their work, and from my own studies of the epidemiology of anthrax in the United States, has come the hypothesis (*6*) that anthrax occurs in livestock that live upon a soil with a *p*H higher than 6.0, and in an ambient temperature above 15.5°C. In his important studies (*7*) of the role of temperature in sporulation, Minett considered the growth of organisms in animals only. Animals must develop anthrax from an infective soil before spore formation from a carcass becomes a concern. The repeated statement that anthrax spores survive indefinitely in the soil (*8*) is countered by evidence that biological factors such as the temperature of and the balance of moisture in the soil are prerequisites for outbreaks of the disease. These factors would have little influence on the static anthrax spore. Epidemiological evidence indicates that the disease occurs after livestock have been exposed to a soil in which the anthrax organism has survived ecological competition with other organisms. Animals become infected after biological conditions have favored the multiplication and then sporulation of the organism in the soil.

## Environment of Anthrax

Anthrax is associated with catastrophic changes in the microenvironment of the soil. An "incubator area" may form in a depression in which water has stood long enough to devitalize or kill grass. Recognizing *B. anthracis* in this environment is complicated by the presence of myriads of related spore-forming organisms, particularly *Bacillus cereus,* which must be carefully differentiated from *B. anthracis*. Livestock in daily contact with soil have a greater chance of coming in contact with anthrax organisms than an investigator studying a few grams of soil.

In the absence of incubator areas of dead grass, anthrax may occur in dried-up emphemeral watercourses or hillside seep areas. These hillside areas are calcareous or alkaline, and they accumulate organic material during the wet phase. These "rockland" environments may be the last areas to develop anthrax in an epidemic, while the water table returns to normal.

Livestock are probably infected by spores, since the environment becomes dry and dusty before losses begin. Epidemiological evidence suggests that insect bites and skin abrasions are the most likely routes of infection. However, insects themselves, as vectors of anthrax, are epidemiologically insignificant, although they can transmit the disease from dead livestock to man (*1*). Livestock in pastures that do not have incubator areas do not develop anthrax, and the frequency with which only one death occurs in a herd further points up the insignificance of insects as vectors. In the Oklahoma outbreak of 1957 (*9*), 60 percent of the herds studied lost only one animal. Bloodsucking insects may gorge for several hours on cattle that have died of anthrax, since the blood coagulates poorly or not at all. Care must be taken that insects frightened off the carcass do not carry organisms to wounds or abrasions on persons who may be near.

The epidemiological studies and observations during the Oklahoma-Kansas anthrax outbreak showed that, for an understanding of the disease, the environment of anthrax must be studied in detail. A former cattle range had been divided into many fenced units, some of which contained a few acres. Earlier beliefs about the spread of anthrax were not compatible with the large number of disease-free premises that were found among the incubator areas in which the disease had developed.

## Geology of Anthrax

One of the most important factors in the occurrence of anthrax is the geology of the area involved. This was well illustrated during the 1957 pandemic in eastern Oklahoma and Kansas. The outbreak centered in Craig County, Oklahoma, which is mainly rolling prairie (*10, 11*) with rather narrow, wooded stream bottoms and smaller areas of wooded hills and broken escarpments. Anthrax occurred on soils that were developed from or influenced by limestone. It was absent from an irregular chain of sandstone and shale hills that crosses the county from the southwest to northeast. Since ground water was deficient, livestock were watered at small ponds. The region had suffered 3 years of drought prior to 1957, and grass grew in all but the deeper portions of these ponds. In 1957, a prolonged, wet spring had kept these ponds full, thus creating an unprecedented number of incubator areas for anthrax. In the valleys, grassy washout areas and ponds behind natural levees also created incubator areas; nevertheless, anthrax occurred less frequently in these areas than on well-drained pasturelands watered by ponds.

The outbreak began on high ground and spread to lower terrain, suggesting a dispersal by flood waters. However, the drainage patterns of contaminated premises were shown to be isolated from one another by topographic features that precluded dispersal by flood waters. This dispelled the fear that anthrax would be spread downstream by water. Some decrease in public hysteria followed the realization that anthrax was not developing everywhere. It did not occur on haylands and fields that were well drained or that were over shale and sandstone.

Anthrax in Craig County occurred primarily in incubator areas, but the drying up of ephemeral streams set off new epidemics in rockland environments near Pryor, Oklahoma, and Mount Valley, Kansas. At Pryor, vaccination was advocated for cattle on rockland pastures before any losses had occurred. Cattle owners were advised that the vaccine might not provide protection for the first 8 days following vaccination. Losses showed that selective vaccination was effective.

Craig County straddles what was once the Sedalia Trail, a cattle-drive route out of the anthrax areas of Texas and Louisiana. A fork to the east crossed the Grand River, skirting the Ozark uplift near Pea Ridge, Arkansas. Cattle were driven over both of these, but the Ozark route was located on more acid soils and was, therefore, unsuitable for anthrax perpetuation. The principal anthrax epidemic was centered along the western fork of the Sedalia

Trail, from Pryor, Oklahoma, to Baxter Springs, Kansas. When the anthrax organisms arrived in the area is not known, but the completion of the railroad there in 1871 closed the Sedalia Trail.

The Oklahoma-Kansas outbreak of 1957 occasioned a new era in anthrax study. One result was the differentiation between deaths caused by *B. anthracis* and deaths caused by anaerobic *Clostridium* species, leptospira, and anaplasma. The other was recognizing the need for identifying the specific location of an incubator area, rather than attaching significance to the point where the animal died. Probably because of the influence of the theory of persistent spores, little effort had been made to discover what environments are suitable for the survival of anthrax organisms. Perhaps this is because no hypothesis of the origin of the infection was available until after 1957, when it was suggested that outbreaks of anthrax follow growth of the organisms (*6*). This hypothesis made possible epidemiological studies that provided new insights into outbreaks of anthrax. One of the best reports was that of the 1959 outbreak in Wayne County, Illinois (*12*).

Anthrax is endemic in a limited portion of Wayne County. Losses due to anthrax had occurred in 1953 and 1954, and it is a reasonable conclusion that many other anthrax infections have been diagnosed as bloat, lightning kill, heart cases, or poisoning from water in oil-well ponds. Denial of the existence of anthrax is not uncommon, particularly when the shipping of livestock or the sale of milk is stopped as part of a control program. Only during pandemic situations is the general distribution of anthrax likely to be reported. However, it should not be concluded that outbreaks of anthrax can be expected yearly in endemic areas. For example, the weather is an important factor. Incubator areas do not form when there is intermittent rainfall through the warm months, or during prolonged dry periods.

The Wayne County pandemic in 1959 encouraged reliable reporting, with most interesting results. Anthrax broke out in Wayne County on 8 July 1959, with the loss of eight cattle on a farm that had lost nine cattle in 1953. The farm was divided by a road, and all losses were on the south pasture. Soils in this pasture (*13*) were calcareous Hickory eroded gravelly loam, overlaid by fertile Bluford yellow-gray silt loam on compact medium plastic clay. Hickory and Bluford soils were both present on seven other farms, which had a total of 24 cattle killed by anthrax. In addition, calcareous Hickory soils were present as a significant soil on an additional seven farms which had lost 15 cattle. Gray silt loam over tight clay, of the Cisne and Hoyleston series and characterized by alkaline slick spots, was involved in single losses on each of two farms. These two farms were far from other outbreaks, and the losses occurred a month after the first losses.

In the Wayne County outbreak, only one farm of the 23 studied was located exclusively on bottomland. Three cases of anthrax occurred on that farm on 20 August, over a month after the first loss. Anthrax was not reported upstream of this farm. In the 1957 Oklahoma outbreak, a similar delay was seen (*11*) on bottomlands of the Neosho River. Bottomlands, drying out last, are the last to experience the disease.

The anthrax potential of Wayne County is associated with a glacial till plain, dissected by Elm Creek. The Hickory soils are found on contours. Since they do not hold water well enough to be cultivated, these soils are used primarily for pasture and timber. Their relation to anthrax more closely resembles that of the rockland environment than that of the incubator area, which is formed in grasslands.

The remainder of the anthrax environments were associated with gray silt loams and poor subdrainage. The Bluford soils normally have good drainage, but excessive rainfall can flood the soil profile, thus creating incubator areas for anthrax by prolonged surface runoff. In the area in which anthrax is endemic, this soil may be found between the flat prairie upland and the steep, gullied land along streams.

## Anthrax Distribution in the United States

In the northeastern states, anthrax has been associated with the tanning of imported hides. Anthrax in human beings has been a serious problem (*1*, *14*) in the industries that use imported wool and goat hair. Anthrax in livestock can often be attributed to the tanning of imported hides in the past. Tanneries were in remote locations, usually near hemlock tanbark, and scraps and trimmings were dumped into nearby streams and rivers. This practice may have been the cause of anthrax in pastures downstream. When not dumped in streams and rivers, the wastes were often taken to farms, presumably for fertilizer. Studies of specific farms showed that land conducive to incubator areas existed wherever livestock had contracted anthrax from tannery wastes. Not all anthrax can be attributed to tanneries—anthrax organisms in the bone meal phosphates that are used on intensively farmed soils or dairy pastures must also be considered. Either glaciated calcareous soils or alkaline groundwater can provide a suitable environment for the soil phase of anthrax. Some of the anthrax pastures are at relatively high elevations, quite remote from streams or drainage from other areas.

In the Middle and South Atlantic states, anthrax occurs in sporadic outbreaks, since the circumstances favoring repeated outbreaks are usually lacking. It is likely that more cases of anthrax would be diagnosed if all of the cattle that died suddenly, under unusual circumstances, were studied bacteriologically. On at least three occasions since 1957, carcasses during outbreaks of anthrax were salvaged for human consumption.

The calcareous soils of southern Florida provide both the incubator area and the rockland environment, and anthrax may be a yearly problem in this area. Cattle that die in remote sections of large pastures may be destroyed by scavengers and decomposition. No interstate problems arise as a consequence of such deaths, nor is the disease of epidemic proportions. A carcass that has lain 3 days in a tropical environment may create no problem from the standpoint of anthrax, and little interest otherwise.

The Appalachian Plateau and Southern Piedmont are remarkably free of anthrax. Some areas of calcareous soils in the Valley and Ridge provinces, particularly in northern portions, are sites of sporadic anthrax outbreaks. This area is attracting industries that use imported wool and goat hair, with the attendant contamination by anthrax. As long as acid soil conditions predominate, there is little threat of agricultural anthrax. On the other hand, these industries become suspect when anthrax does occur, as it did in Virginia in 1963. The regulatory program for this outbreak made good use of a knowledge of the soil $p$H and the concept of the incubator area, beginning with the demonstration that the outbreak was confined to one pasture that had a suitable environment, and that it was not a water-borne infection.

Anthrax in the lower Mississippi Valley has long been of interest, and pandemics occur when conditions are suitable for anthrax propagation. Notable epidemics occurred in 1954, below New Orleans, and in 1958, east of the Ouchita River in Louisiana. Most of the livestock lost in 1958, a total of over 1439, were remote from the flood plains of the larger rivers. The disease can be a serious problem on the rich alluvial soils flooded periodically by the Mississippi River, but it is no longer a problem in the well-managed delta soils behind the levees. It is inaccurate to speak generally of anthrax on the Mississippi Delta, since much of the disease occurs on the landforms whose geology is only remotely related to the flood plain of the Mississippi River itself. This became apparent when anthrax developed along the Natchez Trace of Mississippi. In 1961, numerous outbreaks, with losses of more than 350 cattle, as well as other livestock, developed on this area of high ground northwest of the Pearl River. Epidemiological studies in 1959 of the anthrax potential of central Mississippi showed that calcareous areas are essential for anthrax.

Anthrax has long been in existence in the coastal areas of Louisiana and Texas, where the livestock of Spanish and French settlers may have introduced the organism. In contrast to the sandy soils east of the Mississippi River Delta, the Louisiana and Texas soils are rich in both minerals and organic matter. It is not surprising that anthrax can perpetuate itself in this soil. Geologically, the Texas coast is significant in that the alkaline rivers of the southern Great Plains water the area, and local accumulations of alkaline salts more than compensate for the rainfall that would otherwise leech the soil of its bases. Inland, where the sandy, acid soils are covered by pine woods, anthrax is not a problem, despite the opportunity this area has had to become contaminated.

Anthrax on the Great Plains is of continued interest. Following the Civil War, large numbers of cattle in Texas, huge expanses of grass on the Great Plains, and the progressive westward push of the railroads provided a base for a new livestock industry. These factors also provided an opportunity for anthrax to spread from the Gulf Coast to geological and climatological environments similar to those in which anthrax occurred in the Old World. The expansion of contaminated areas will be a matter of concern for future generations only if they create suitable conditions for the organism to perpetuate itself in a dynamic biological environment. The introduction of the level bench system into Great Plains agriculture may provide such an environment.

At present, anthrax occurs sporadically on the Great Plains. It is endemic on the dendritic drainage of the Niobrara and White rivers, and the playa areas and valleys of small streams near the Missouri River in Nebraska and South Dakota. It occurs in Colorado, Montana, New Mexico, and Wyoming. These areas appear to have been concentration points for livestock trail drives from Texas to Montana. In eastern Montana, anthrax was diagnosed near east and west Charlie Creek in 1957, with 24 deaths and seven treated cases in cattle. According to the theory of persistent spores, land should have been contaminated in sequence as spores were washed down the creek from previous outbreaks. Instead, each outbreak was isolated by hills and occurred at about the same geological level on the branches of the creek. The anthrax occurred on terrains in which a mature stream valley had created incubator areas.

One of the more interesting outbreaks occurred in 1956 on the Green River Drift, a trail near Pinedale, Wyoming, that connects summer and winter cattle ranges. In this area, cattle are managed as they were in a bygone era. Livestock leave the summer range when they are driven off by snowfall, although cattle may be brought out in an old-fashioned roundup. Anthrax occurred on pasturage at an elevation of approximately 8000 feet, in an area where abandoned beaver ponds had created the rich, organic soil deposits needed for an anthrax incubator area. In high altitudes, rapid heating of the soil is important to the biology of anthrax organisms. In June 1962, the temperature 5 centimeters below the surface of the ground had reached 27.5°C by midmorning. Thus soil temperature, rather than ambient air temperature, satisfies the requirements for anthrax.

Beyond the Great Plains, the principal endemic areas for anthrax are in California and Nevada. Anthrax may have been introduced as the result of commerce with the Mediterranean countries, where anthrax is also endemic. The nature of the California environment and soil is such that it is unlikely that anthrax will disappear with time.

Anthrax in Nevada was probably introduced from California. During the period of wagon transportation, hay cut in California was sold at rest stops in the Carson River Valley. Later, most of the cattle that grazed in Nevada valleys were from California. Homesteaders near Wellington, Nevada, posted armed guards to keep California cattle out of the Smith Valley. Anthrax has occurred where the California cattle grazed, but has not yet occurred in the homesteaded area. The Meadows area at Fallon, Nevada, which was a rest area on the Humboldt Trail, now has a problem with anthrax, but the disease can be controlled by vaccinating the animals yearly.

## Discussion

Studies of the ecology of anthrax reveal a relationship among parasite, environment, and host. They also indicate that anthrax is an infectious disease that may multiply outside the affected host. At a time when the emotional impact of ecological concepts has polarized the scientific community, if not the whole country, the study of the ecology of anthrax could open a new and practical approach to the biology of infectious diseases. When the laboratory approach considers only the host and the parasite, it misses the factors that identify infectious diseases with some environments and not with others.

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# International Environmental Problems—A Taxonomy

Clifford S. Russell and Hans H. Landsberg

The last few years have seen an explosion of interest in environmental problems among citizens of the developed countries, both East and West. Most of this interest has focused on domestic situations and on possible changes in domestic policies designed to provide remedies. Increasingly, however, the focus has widened to embrace environmental concerns that transcend national borders. A high point may be reached in June 1972, when the United Nations Conference on the Human Environment will be held in Stockholm. Wide-ranging discussions and the signing of international treaties on specific international environmental issues are on the agenda. Even though it will not be the first conference on these subjects (*1*), both the auspices of the United Nations and the publicity that it is bound to receive will give it special importance.

The growth of interest and enthusiasm, however, is not matched by accomplishments. That little action has been taken is perhaps easily explained, since sovereign states are involved in these issues, which are old as a class but essentially novel in degree. So far, it has even proved difficult for concerned parties to discuss the problems (*2*).

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A major reason for the lack of communication has been the general failure to look beyond the label, "international environmental problems," to the disparate elements it covers and to limit, in advance, the number of such elements that can be discussed at any one time and in any given group. A second reason may be that environmentalists have sometimes couched their arguments in terms that impugn the morality and intelligence of the parties concerned, thus guaranteeing defensive, hostile reactions (*3*).

A third reason may be that management of international environmental problems is most often thought of in terms of "police actions" and regulatory authorities rather than as a component of growth and development. It should be realized that this component of growth and development, neglected by the now developed countries (and being paid for dearly by them), can still be built into the development of emerging countries, probably with long-lasting benefits. Finally, political problems, in terms of a lack of new institutions and mechanisms, have played a role. For example, the growing pollution of the Baltic Sea involves eight countries, three of which are in the Soviet orbit, and one of which (East Germany) has a sufficiently undefined international status to make any international agreement difficult, at best, to achieve (*4*).

Many environmental problems involve citizens of two or more countries and hence are "international." Confusion and controversy arise easily: an individual or a government is usually concerned with (or even aware of) only one or two specific problems and incorrectly assumes that other individuals or governments are talking about the same problem when they use the same general label. Consider, for example, the prospects for agreement when one group's mind is on the long-term buildup of carbon dioxide in the atmosphere and particulates in the lower stratosphere; another worries over the dangers associated with increasing storage of radioactive wastes; a third focuses on the ecological implications of large-scale hydroelectric developments in the tropics; a fourth is concerned with the effect of domestic air pollution controls on export prices and hence trade patterns; yet another is concerned about a specific regional problem in which one nation's pollution, or attempt at protection against pollution, imposes costs on another nation; and, finally, a group of developing nations views matters through the prism of its overwhelming interest in increasing per capita income.

Some of these situations affect all the world's people, though significant contributors may number only a handful. Others are problems of a particular region and do not concern nations outside that region. To developing nations, all environmental problems may appear to be potential threats to their domestic development. At the least, they seem to be concerns of those nations that have incomes sufficiently high to permit concern with esthetics and that have health standards high enough to permit detection of the effects on morbidity and mortality of concentrations of sulfur dioxide. To lay the basis for more successful discussion, this article suggests a first cut at a taxonomy of international environmental problems and solutions, as well as areas in which further research can