Environmental Health and Bioterrorism☆

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Abbreviations

CDC Centers for Disease Control and Prevention
FMD Foot-and-mouth disease
GMO Genetically modified organism
MDR-TB Multidrug-resistant tuberculosis
SARS Severe acute respiratory syndrome
TBE Tick-borne encephalitis
WHO World Health Organization
WNV West Nile virus

Introduction

Biological warfare has complex and permanent relations with the environment in comparison to other war types (conventional, nuclear, and chemical). Changes of the environment interfere with many of the major determinants of biological warfare. Bioterrorism interfaces with the environment as a source of bioterrorism agents, as a means of bioterrorism and as a target. These three interfaces bioterrorism/environment allow us to prevent bioterrorism and protect environment. The most probable type and the key issue of biological war is bioterrorism. Bioterrorism itself is defined as a release of biological agents or toxins that affect human beings, animals, or plants with the intent to harm or intimidate. The essence of bioterrorism is a biological attack. Four components are required for a biological attack: perpetrators, agents, mediums/means of delivery, and targets.

To simplify the correlation and impact of the environment on bioterrorism, each component of biological attack, and its correlation to environmental health, has been analyzed. Biological weapons might act on many different targets; could easily be disseminated by food and water, by insect vectors, or by an aerosol; might have many means to penetrate targets; and might be used even by low-qualified terrorists. Considering these facts, it is practically impossible to have a unique doctrine for each eventual threat. The "global environment"—political, social, economic, and psychological environments—and the mass media distinguish themselves as very important, thus adding a new dimension to natural epidemics and biological attacks.

Discoveries that certain bioterrorist (emerging and reemerging) pathogens have their origin in environmental changes have given rise to an urgent need to understand how these environmental changes impact bioterrorism. An environmental change manifests itself through a complex web of ecologic and social factors that may ultimately affect bioterrorism activities.

Transmission dynamics of infectious pathogens mediate the effects that environmental changes have on bioterrorism activities. Bioterrorist occurrence could be the outcome of the interplay between environmental change and the transmission cycle of a pathogen.

Environmental changes include anthropogenic changes that affect landscape ecology, human ecology, and human-created environments as well as natural perturbations and natural disasters. Environmental characteristics are defined as directly measurable physical, chemical, biological, or social components of the environments including populations and traits of relevant organisms. Every environmental perturbation influences the ecological balance and context within populations, in which disease manifests itself. Many outbreaks are interrelated to global and local changes caused by climate change, human-induced landscape changes, or the direct impact of human activities. Landscape impacts such as de(re)forestation, human settlement sprawl, industrial development, road construction (e.g., linear disturbances), large water control projects (e.g., dams, canals, irrigation systems, and reservoirs), and climate change have been accompanied by the spread of pathogens into new areas. Changing environmental process might affect transmission cycles of infectious pathogens. These changes affect the hosts or vectors of disease and the pathogens and parasites that breed, develop, and transmit disease. Vector-borne zoonoses tend to be the most ecologically complex infectious diseases in which environmental change may have the greatest number and diversity of effects, some promoting transmission and others diminishing it. Habitat and species losses may reduce the normal buffering within ecosystems, leading to disease outbreaks. Finally, the juxtaposition of new vectors, hosts, and parasites within disturbed ecosystems provides a potential for the evolution of novel transmission pathways and thus new "emerging diseases." It is needed to learn more about the underlying complex causal relationships and apply this information to the prediction of future impacts, using more complete, better validated, integrated, models.

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Majority of human infectious diseases are of animal origin (zoonoses). For many emerging pathogens, wildlife and sometimes even domestic animals show no signs of infection and play the role of asymptomatic reservoirs (the most dangerous: Ebola virus, virus of Crimean-Congo Haemorrhagic Fever, etc.). OIE-World Organization for Animal Health estimates that 60% of existing human infectious diseases are zoonotic; at least 75% of emerging infectious diseases of humans (including Ebola, HIV, and Influenza) have an animal origin; five new human diseases appear every year and three of them are of animal origin; 80% of agents with potential bioterrorist use are zoonotic pathogens. Habitat fragmentation causes a reduction in biodiversity within the host communities, increasing disease risk through the increase in both the absolute and relative density of the primary reservoir. A relatively new and clear example of biological agent that could be extracted from the environment is given by the permafrost (an area of land that is permanently frozen below the surface) located in Siberia, Canada, and Alaska. Due to global warming some infected bodies appeared from the permafrost and intact biological agents re-emerged. Anthrax outbreak was described in 2016 in Siberia, after no outbreaks for 75 years. An exceptionally warm summer thawed out a reindeer carcass buried in a permafrost pit that was a source of spores. As human bodies infected by smallpox virus are frozen in the permafrost, the possibility of a re-emergence of this virus consequently of a permafrost thaw, and then its use for bioterrorism purpose, is a valid assumption made by several medical intelligence departments.

Since urban growth in many countries occurs without planned sanitation, water treatment, and sewerage, increased exposure to mosquitoes, rodents, and other vermin provides more opportunities for diseases such as tuberculosis and hantavirus. Mining, damming of rivers, and increased irrigation for agriculture also give mosquitoes more standing water to breed in. Man, in so doing, makes himself his major bioterrorist. Carefully controlled use of resources would gain great benefits to struggle against bioterrorism, and other threats of natural pathogens. In the context of bioterrorism, infectious diseases are not only the public health issue, but also the issue of national and international security.

Bioterrorism Related to Humans

Perpetrators

The first link in conducting biological attack is perpetrator. The most prevailing and dangerous bioterrorist is man through his numerous activities (auto-bioterrorism). Auto-bioterrorism could be performed through many environmental changes (**Table 1**).

Some changes affect disease only through a series of casual linkages. For example, a dam does not interfere with health directly. Instead, it causes changes in water flow, which affects mosquito habitats, and that, in turn, could affect transmission potential of biological agent. A new road may affect disease through major demographic shifts.

The real threats are terrorist/disaffected groups, making environment very important source of agents. Highly motivated perpetrators (mainly poor terrorists/fanatics with suicidal tendency, e.g., suicidal bio-bombers) are the most probable candidates for getting biological agents from the nature. At least 22 countries are believed to have had active biowarfare research programs. Several major international terrorist organizations, such as the Al Qaeda network, are believed to have the financial resources and political contacts needed to access state-of-the-art bio-weapon disease cultures and production technologies. Aum Shinriko was also involved in developing terrorist bioweapons employing anthrax bacilli, botulinum toxin, Ebola virus, and Q fever (*Coxiella burnetii*).

Table 1 Environmental changes caused by humans and bioterrorism-related diseases they may impact

Environmental change	*Description*	*Disease*
Urbanization	Increasing migration to and growth within towns	Influenza (pandemic), severe acute respiratory syndrome, plague, diseases caused by fecal-oral pathogens (*Entamoeba histolitica*, *Giardia lamblia*), multidrug-resistant tuberculosis
Agricultural intensification	Changing crop and animal management practices, fertilization, increased interplay between humans and domesticated animals	Avian fly, brucellosis, psittacosis, Q fever, salmonellosis, anthrax, Nipah virus infection
De(re)forestation	Loss of forest cover, large fires, changing water flow patterns, reforestation, and human encroachment along and into forested areas	Tick-borne hemorrhagic fevers, mosquito-borne encephalitis complex, hantavirus hemorrhagic fevers
Water projects	Water flow changes due to dam construction and irrigation networks	Infections caused by *Escherichia coli*, pathogenic vibrios, *Shigella* sp., *Cryptospridium parvum*, noroviruses infections, Hepatitis A
Climate changes	Change temperature and precipitation	Yellow fever West Nile fever and some other vector-borne diseases

Notes: Mosquito-borne encephalitis complex: Venezuelan equine encephalitis, Eastern equine encephalitis, and Western equine encephalitis, La Crosse and California encephalitis, Japanese encephalitis, West Nile encephalitis; tick-borne hemorrhagic fevers: Kyasanur Forest hemorrhagic fever, Crimean/Congo hemorrhagic fever, Omsk hemorrhagic fever, Alkhurma hemorrhagic fever.

Agents

The World Health Organization (WHO) defines a biological agent as an agent that produces its effect through multiplication within a target host intended for use in war to cause disease or death in human beings, animals, or plants. Biological agents also include protein biotoxins produced by microorganisms, poisonous animals, and plants. Some plants are known to naturally produce highly toxic compounds (cyano-genic molecules, cardiotoxic alkaloids, ricin, etc.). When ingested or inoculated, small amounts of these toxic compounds have potential to cause severe damage to health of human beings or animals even up to death, including cardiotoxicity, neurotoxicity, cytotoxicity, metabolic disorders and inhibition of cell division. For example, ricin can be extracted from castor bean. Al Qaeda in Yemen tried that in 2011, without success. It shows however the interest those terrorists bring to the possibility to extract bioagent from the environment.

The Centers for Disease Control and Prevention (CDC) has classified critical biological agents into three major categories (A, B, and C).

The category A agents include *Variola major* (smallpox), *Bacillus anthracis* (anthrax), *Yersinia pestis* (plague), *Clostridium botulinum* toxin (botulism), *Francisella tularensis* (tularemia), and viruses related to Ebola and Marburg hemorrhagic fevers, Lassa fever, and Argentine hemorrhagic fever.

The category B agents contain approximately 30 potential weapons of bioterrorism (the majority of them are ubiquitous agents), including a wide variety of bacteria, viruses, protozoa, and toxins.

The category C agents include Nipah virus, Hantavirus, tick-borne hemorrhagic fever viruses, tick-borne encephalitis (TBE) virus complex, yellow fever virus, and multidrug-resistant tuberculosis (MDR-TB).

Additionally, there are several *emerging pathogens* with the potential for bioterrorism: severe acute respiratory syndrome virus (SARS virus), pandemic and avian influenza virus, West Nile virus (WNV), and monkeypox virus. Since more than approximately 80% of potential bioweapons are zoonoses, animals are likely to be at high risk and thus the surveillance of animals may provide early warning of a bioterrorist attack.

Traditional biological weapons include naturally occurring organisms or toxins, characterized by easy production, high toxicity, stability, and abundance of modes of transmission. Dangers associated with conventional agents can be enhanced by genetic modification (increased virulence, antibiotic resistance, toxin production, enhanced aerosol stability, and improved survival in the environment). Many infectious microorganisms considered suitable for bioterrorism could be obtained from natural sources, such as infected animals, patients, or even contaminated soil (anthrax spores). SARS-CoV-like viruses were isolated from Himalayan palm civets and a raccoon dog in an animal market in southern China, which suggests that SARS-CoV may originate from these or other wild animals. Since 2003, the highly pathogenic H5N1 strain of avian influenza A has spread to poultry in 17 countries in Asia and Eastern Europe and now is considered endemic in some of these countries. It is noted that pig's trachea contains receptors for avian and human influenza viruses and supports the growth of viruses of human and avian origin. Genetic reassortment between human and avian influenza viruses may occur in pigs leading to a novel strain against which there would be little or no population immunity and that would be highly pathogenic, capable of human-to-human transmission and having pandemic potential. In 2003, monkeypox virus emerged for the first time in the Western Hemisphere when an outbreak of human monkeypox occurred in the Midwestern United States. Most of the patients got sick by having direct contact with pet prairie dogs already infected by being housed with rodents imported from Ghana to Western Africa. In August 1999, West Nile virus was detected for the first time in North America by causing an outbreak in New York City. It is possible that the virus was imported to North America by infected birds, infected mosquitoes, or viremic humans. Natural pathogens widely vary in virulence; many strains isolated from nature may have low virulence. Micro-biologists have catalogued more than 77 different strains of *B. anthracis*, only a minority of them being highly virulent. Considering this, a terrorist should almost certainly have to isolate many different strains before finding one sufficiently potent to be used as a weapon. Since obtaining virulent microorganisms from nature is technically difficult, it would probably be easier for a terrorist to steal well-characterized strains from any research laboratory or to purchase the known pathogenic strains from a national culture collection or a commercial supplier, claiming to be engaged in a legitimate bio-medical research. From 1985 to 1989, Iraqi government ordered virulent strains of anthrax and other lethal pathogens from culture collections in France and the United States, ostensibly for public health research—a purpose that was legal at the time, and indeed approved by the Department of Commerce.

Mediums/Means of Delivery

The medium of delivery could be *air* (airborne pathogens), and dissemination of an agent through ventilation/air conditioning systems is a very powerful way of attacking by terrorists. Aerosolized release of 100 kg of anthrax spores upwind of Washington, DC, could result in approximately 130,000–3 million deaths, a weapon as deadly as a hydrogen bomb. Other means of delivery could be *food* and *water* (food-borne and water-borne pathogens) when human exposure to waterborne infections occurs by contact with contaminated drinking water, recreational water, or food. This may result from human action, such as improper disposal of sewage wastes, or be due to weather events. Heavy rainfall and runoff influence the transport of other microbial and toxic agents from agricultural fields, human septic systems, and toxic dumpsites. Rainfall can alter the transport and dissemination of microbial pathogens (such as cryptosporidium and giardia), and temperature may affect their survival and growth. This group includes infectious diseases for which the environment (e.g., food and water) plays a significant role in a pathogen's transmission cycle. Transmission occurs between humans and the environment directly (cholera, hepatitis

A, entero-viruses, noroviruses, shigellosis). These pathogens survive in the environment for long periods of time. *Fomites* with personal infiltration of suicidal bio-bombers in the targets or by different facilities like mail might be a mean of delivery. Even animals, like birds infected with avian influenza, might serve as *vectors* for infectious diseases. In vector-borne diseases, transmission occurs through contact between humans and vectors (defined here as arthropods that take pathogens from one host to another). Transmission cycles share common attributes: namely, all are affected by the population level and vector, and all are driven by a transmission potential governed by a number of biological and environmental characteristics. Environmental changes can affect population levels of the host, vector (vector survival and reproduction), or environmental stage of the pathogen (pathogen's incubation rate within the vector organism) as well as the transmission rate (vector's biting rate) at which pathogens move between hosts, vectors, and environment. Vectors, pathogens, and hosts each survive and reproduce within a range of optimal climatic conditions: temperature and precipitation are the most important, although wind and daylight duration are also important. The crossover to humans of the Nipah virus is related to a host of changes that create more favorable conditions for their spread. Often fatal Nipah virus, normally found in Asian fruit bats, is believed to have passed over to humans when bats lost their habitats due to forest fires at Sumatra and the clearance of land for palm plantations. Trying to find new food, bats came into contact with pigs, which, in turn, passed the disease to their human handlers in the late 1990s. Nipah infection causes severe encephalitis in humans, with a 40% mortality rate recorded among infected patients in Malaysia and Singapore. At least 109 people died as a result of the epidemic, and more than 1 million pigs were destroyed in an effort to control the disease. *Soil* can also be the medium of transmission *(B. anthracis, Giardia lamblia, Burkholderia mallei*, and *pseudomallei, C. burnetii)*.

Environmental change impacts these diseases caused by pathogens within some transmission group via mechanisms that are primarily mediated by social processes. The initial spread of SARS or other respiratory diseases depended mainly on the social connectivity of the first (index) case in a community. As public health moves more toward examining how both ecological and social processes affect disease transmission, and more specifically toward examining the fundamental role of environmental change in creating the landscape of human disease, a systems theory framework is needed to integrate data from disparate fields.

Targets

There are two types of targets: direct (biological) and indirect (political/economical). Biological/direct targets could be "hard" and "soft" targets. The US anthrax attack in 2001 comprised both types of attack: the Hart Senate Building in Washington was "hard" and the US Postal Offices were "soft" targets. The estimated cost of decontaminating parts of the Hart Senate building in Washington, DC, was $23 million, the economic impact involving potential exposure to anthrax was estimated at $26.2 billion/100,000 persons exposed (indirect/economic target), and the cost and resources needed to decontaminate the environment should be added to this. Health damage could be both somatic and psychological. Therefore, biological attacks cause two types of epidemics: epidemic of infectious disease and epidemic/pandemic of fear and panic. Epidemic/pandemic of fear and panic multiplies economic damage (losses in tourism, investment, and export). The main objective of bioterrorists is to propagate fear, anxiety, uncertainty, and depression within the population, induce mistrust of authorities/government, inflict economic damage, and disrupt travel and commerce. The cause of physical disease is the second important objective. Even the use of biological weapons for small-scale attack on "soft" targets (airports, railway stations, food production industries) can bring about devastating losses with strategic dimensions. At least one case of SARS or avian influenza is enough to cause catastrophic economic consequences. The world airline industry lost $10 billion in 2003 due to SARS. The developed, Western countries have an intensive food production and centralized food industry. It means that only one successful bioterrorist action can contaminate huge amounts of food and threaten lives of thousands or hundreds of thousands inhabitants. Preharvest threats target livestock and crops, carrying the risk of economic devastation compounded by direct costs (international trade restrictions, slaughter of animals, loss of production) and indirect costs throughout related communities (tourism). Postharvest threats affect the food industries (processing, transportation, delivery) and public health (possible human illness and death). Detrimental social, political, diplomatic and even military consequences could follow an agroterrorist attack.

Prevention

Basic prevention of biological attack includes impeding the access of bioterrorists and of the biological agents to the target territory. These activities could be improved by better international cooperation and control, and by better border control. From the environmental point of view, basic prevention should also improve the ability to understand and control potential dynamics of disease transmission within human and animal population, as well as plant diseases, in both industrialized and developing country settings. This should enhance the capacity to combat the effects of biological weapons and emerging diseases in biological communities and biodiversity.

The primary prevention of biological attack comprises monitoring and surveillance of potential internal/indigenous sources of biological agents and bioterrorists. Animals in many habitats may be studied to monitor health hazards in the environment. Chickens have been used for the surveillance of arboviruses like: West Nile Virus (WNV), western equine encephalomyelitis (WEE), and St. Louis encephalitis (SLE) viruses, making them excellent sentinel animals of arboviruses. Mussels, clams and oysters are particularly suitable as surveillance tools, because they are able to concentrate microbial organisms and pathogens to concentrations in excess of 1000-fold. In Sverdlovsk outbreak in 1979, livestock 60 km away from the plant died, whereas human cases occurred within 4 km downwind of the facility. The ideal case regarding environmental health is the eradication of the diseases (by minimal environmental changes destroyed reservoirs), then the elimination of the diseases (not affected people).

The outbreak of a disease could occur due to accidental infection during a test and research of biological weapons. A Soviet field test of weaponized smallpox killed three people (two of them children) and involved the disinfection of homes, quarantine of hundreds of people, and administration of 50,000 vaccine units. Subtle differences between usual and unusual occurrence of diseases must be recognized (detection of unusual diseases, spread in unusual ways). A developed network of data collecting, rapid data transmission to the relevant public health decision-makers, and their careful analysis are the priorities. Early detection could save many lives by triggering an effective containment strategy such as vaccination, treatment, and, if necessary, isolation and quarantine. Also, active monitoring of domestic or wild animals for biomarkers could be very useful. The choice of surveillance type depends on the characteristics of a pathogen and the objective of the program. Passive surveillance is best employed when the objective of the program is targeted toward early detection of outbreaks or monitoring the extent of disease for making decisions on control strategies. Active surveillance is best employed when a disease is targeted for elimination. A sentinel is a naïve animal which is intentionally placed in an environment of potential infection that is monitored at short time intervals to detect infection. There are three fundamental components of the sentinel framework: the pathogen under surveillance, the target population and the sentinel population.

The nature of a particular biological weapon could also have a consequential impact on recovery efforts. For example, anthrax spores can persist in the environment for decades; this could make decontamination efforts problematic and lead to persistent health concerns. Viable, infectious anthrax bacilli were cultured from animal bones recovered from archeological sites dating back to 150–250 years. For example, after the destruction of the community by a biological attack, people are being displaced, and they experience additional stress, loss of dignity by being forced into public shelters, and the feeling of anxiety and fear because of strange environments and the disruption of former social networks. Unexplained epidemic illness occurs (also known as mass sociogenic illness, mass psychogenic illness, or mass hysteria), involving the rapid spread of medically unexplained signs and symptoms, and is often misinterpreted as a sign of a serious physical illness. The potential for new, larger, and more sophisticated attacks has created a sense of vulnerability. Biological weapons induce loss of confidence in authorities. People have to learn to live with the threat of bioterrorism.

Agroterrorism

Agroterrorism implies deliberate attack against commercial crops or livestock population. It can be made using a variety of viruses, bacteria, and fungi either as targets in their own right or as vehicles to attack humans or animals. Agroterrorism is a multidimensional threat, involving a wide range of motives and perpetrators, and encompassing a wide range of actions from single act of sabotage to strategic wartime programs with potentially disastrous "spillover" effects on susceptible wildlife and endangered species population. Traditional governmental responses to deliberate attack with foreign livestock pathogens—sweeping quarantines, mass slaughter, and burning or burial of millions of carcasses under the ceaseless eye of television, together with staggering financial losses triggered by international trade embargoes are exactly what terrorists want to see. Consequences of such an attack would be lasting damage to the rural economy and public confidence in government and enormous costs for taxpayers. And should the foreign disease infect humans as well as livestock, families would also be at risk, all of which would greatly embolden and encourage terrorists.

Through history, outbreaks of crop diseases were associated with famine. Agriculture of any country is particularly vulnerable to foreign diseases, to which domestic animals and plants have not built up a natural resistance. In addition, with crops and animals concentrated in fewer production facilities, and with the frequent transportation of animals among these facilities, a single pathogen introduction could cause very widespread infection. Capabilities of a country to detect a disease and respond to it might be overwhelmed by a deliberate attack, especially if an attack involves a foreign disease or several simultaneous outbreaks. The public reaction to an agroterrorist attack might further amplify these financial losses, if food safety concerns prompt voluntary boycotts of domestic agricultural products. So, agroterrorism remains an attractive option because:

1. Animal or plant biological pathogens are easy to acquire. Due to the endemic nature of many of these disease agents in large geographic regions worldwide, samples of agents are readily available;
2. In general these agents can easily be disseminated. Animals and plants provide the primary means of transmission. Sophisticated weaponization is not required;
3. Many animal or plant diseases are not zoonotic. Therefore, they are not harmful for the perpetrator and there are no requirements for elaborating personal protective equipment and containment procedures.

Bio-weapons and emerging disease outbreaks could result in severe erosion of genetic diversity in populations of wild and domestic animals and plants, leading to the extinction of endangered species. The threat lies in the release and proliferation of a broad spectrum of diseases of domesticated livestock and crops among naive, susceptible populations of wildlife and plants.

The threat of an agroterrorist attack depends on motivations and technical requirements of agroterrorism.

Technical Requirements of Agroterrorism

Technical barriers to agroterrorism are lower than those to human-targeted bioterrorism. Bioweapon attacks against agriculture do not require any specialized knowledge, sophisticated technologies, or laboratory disease cultures. A perpetrator with a basic understanding of microbiology could simply visit an area where foot-and-mouth disease (FMD) occurs naturally, obtain diseased tissue, culture an infectious substance, and clandestinely infect the herd. Even a larger program of sabotage could use this method for multiple, simultaneous attacks.

Certain livestock and poultry viruses can travel great distances on their own. In 1981, 3 days after an outbreak of FMD in Britain and France, single cases appeared across the English Channel on the Isle of Wight. Prevailing wind patterns corroborated the hypothesis that the virus had traveled a distance of 175 miles as an airborne aerosol. Biotechnology techniques and equipment available at the open commercial market permit the large-scale production of bioweapons in small-scale facilities, at a relatively low cost. The cost of developing smaller-scale bioweapons facilities and arsenals befall within the range of $10,000–100,000.

Motivations for Agroterrorism

Terrorists' motives vary widely. The two most common are the profit motive and the anti-GMO (genetically modified organism) motive. Handling human pathogens is extremely dangerous; a terrorist puts himself in danger when developing or dispersing bioweapons against humans. However, animal and plant pathogens do not usually affect humans. The psychological barrier against human casualties is lower when targeting animals or plants. Killing plants and animals is not generally ethically objectionable as killing people. Agricultural targets are "soft targets," or ones that maintain such a low level of security that a terrorist could carry out an attack unobserved. A terrorist may choose to use bioweapons against agriculture simply because it is the easiest and cheapest way to cause large-scale damage.

FMD has long been considered the most dangerous foreign disease that might be inadvertently introduced into each country, and it is also the most likely terrorist threat. Because of its high level of virulence, FMD is particularly expensive to eradicate, and it triggers immediate export restrictions. In Canadian outbreak of FMD from 1951 to 1953, 2000 animals had to be destroyed, at the cost of approximately $2 million. Trade restrictions, however, decreased the value of Canadian livestock by $650 million, and the total economic impact due to international embargoes was about $2 billion. An outbreak of FMD in Italy in 1993 produced 10 times higher costs in market disruption than in its eradication. In 1996, an FMD outbreak among swine in Taiwan caused the killing of 4 million hogs, and the long-term losses to swine-related industries were projected to reach $7 billion. Direct costs of containing the 2001 FMD epizootic appear to have been far less than the indirect costs associated with consequent lost income and investment in nonagricultural sectors of the economy. Losses to the tourism industry because of restrictions in traveling in the affected areas were estimated at $350 million per week, or 25 times higher (2500%) than the concurrent direct losses in the agricultural sector ($14 million per week). The FMD hysteria and the highly publicized slaughter and burning of animal carcasses (the "CNN factor") severely impacted the entire industry of the United Kingdom, with economic losses estimated to be more than $4 billion. Vaccines can keep animals from acquiring diseases, but in most cases, they do not keep animals from being carriers. A cow vaccinated against FMD can carry the pathogen in her throat tissues for two and a half year after the exposure. To eradicate a pathogen completely, both infected and vaccinated animals have to be destroyed.

Agents

Zoonotic disease organisms known to have been cultivated and tested for bioweapon applications include anthrax (*B. anthracis*), bubonic plague (*Y. pestis*), brucellosis (*Brucella abortus*), tularemia (*F. tularensis*), *Clostridium botulinum*, *C. burnetii*, *Burkholderia* spp., *Fusarium* spp., *Morbillivirus* spp., *Staphylococcus* spp., Venezuelan equine encephalomyelitis virus, and several hemorrhagic fever viruses (Ebola, Marburg, Lassa fever, and Rift Valley fever).

Genetically modified zoonotic and epizootic diseases (plague, tularemia, and anthrax) and cultivated diseases of livestock (FMD, rinderpest, brucellosis) are potentially very serious threats to livestock, wildlife, and endangered species population. New biological weapons include many diseases that are highly infectious and contagious, zoonoses that are easy to produce, antibiotic-resistant, vaccine subverting, and able to cause severe morbidity or mortality. Organisms of particular concern in this regard are the viruses of Newcastle disease, CSF, avian influenza, African swine fever, and African horse sickness.

There are concerns that plant diseases developed for use against cereal crops, opium poppies (*Papaver somni-ferum*), and coca (*Erythroxylon* spp., e.g., *Fusarium* spp. and *Pleospora papaveraceae*) might infect and proliferate among nontarget plant species. The genetic diversity of local crop varieties and traditional livestock breeds is a critically important asset of global agriculture that may be subject to severe damage from deliberate or accidental bioweapon releases.

There is a growing but still insufficient recognition of the importance of disease control for the conservation of biodiversity and endangered species population. Disease outbreaks caused by the release of weapons-grade rinderpest virus or anthrax bacilli could have an even greater impact than historical examples might indicate, given the enhanced virulence and resilience of cultivated disease strains, and accelerated rates of dispersal of disease vectors and infectious materials by motor vehicles and aircraft. They could have disastrous consequences for endemic and endangered populations of wild and domestic ungulates within many areas of the globe. Once established in a new locality, introduced diseases may not be recognized rapidly and may be difficult or impossible to eradicate. Known, but formerly uncommon, diseases (Ebola and Marburg fever) are emerging as major threats to human, livestock, and wildlife population as the result of progressive human-mediated changes in the ecology of host-pathogen and human-wildlife interactions. Breakdowns in medical and veterinary support systems during wars and civil conflicts have resulted in epidemic outbreaks of diseases within and among human, livestock, and wildlife populations (monkeypox, Marburg fever, Ebola, and bubonic plague). The Iran/Iraq War and the Arabian Gulf War precipitated rinderpest among livestock population in the region, probably caused or aggravated by war-related displacements of pastoralists and their flocks. Disruption of Government Veterinary Services during the Rhodesia-Zimbabwe civil war had contributed to epizootic outbreaks of anthrax and rabies among wild and domestic animals in Zimbabwe. Anthrax mortality among humans and livestock reached epidemic proportions in 1979–80 and continued to proliferate for more than 4 years after the end of the war. Anthrax ultimately spread through six of the eight provinces of Zimbabwe, with many recorded human cases before effective control of the disease was finally reestablished in 1987. The threat of catastrophic impacts from disease epidemics resulting from agricultural bioweapon releases is proportionally higher in developing countries, due to severe limitations in the availability of doctors, veterinarians, and medical facilities for treatment and quarantine.

The spillover of weaponized livestock diseases into susceptible wildlife population could amplify and exacerbate the effects of initial attacks and create situations in which disease containment and control could become extremely difficult, and total eradication nearly impossible. Rinderpest could have particularly devastating spillover effects on susceptible wildlife species. Should FMD become established within wildlife populations, control efforts currently underway might include the attempted extirpation of some of the large wild and feral deer populations in some areas.

Many formerly ubiquitous diseases that have been eradicated from livestock population in the United States and Western Europe are still common in other areas of the globe (anthrax, rinderpest, and FMD), and are readily accessible to political fringe groups and terrorist organizations. Vaccines for many diseases still common in the Third World countries have been phased out in Europe and North America, and these, along with drugs for treatment, may not be readily available in sufficient quantities to suppress large-scale disease outbreaks.

Prevention

The above-mentioned examples demonstrate the critical importance of early detection and reporting of disease outbreaks. The international reporting system for wildlife diseases initiated by OIE Working Group on Wildlife Diseases has thus been of great importance for alerting national veterinary services to the necessity for the monitoring and reporting of specified wildlife diseases. Environment can provide useful signals and indicators for early warning and health monitoring (birds for West Nile Virus and other viral encephalitis agents, pets for anthrax and plague, cattle for anthrax, and Rift Valley fever, etc.).

The threat of an agroterrorist attack can be countered at four levels:

1. at the organism level, through animal or plant disease resistance;
2. at the farm level, through facility management techniques designed to prevent disease introduction or transmission;
3. at the agricultural sector level, through disease detection and response procedures;
4. at the national level, through policies designed to minimize the social and economic costs of a catastrophic disease outbreak.

These four levels are not independent from each other. The threat of agroterrorism cannot be fully countered at any one level. A disease that is introduced deliberately may be indistinguishable from the one that is introduced inadvertently, or from the one that arises naturally. The questions are: who would carry out such an attack and for what reasons; who has developed antiagriculture bio-weapons in the past; who has actually used bioweapons against agriculture; and the technical requirements of an agroterrorist attack. To control the spread of disease, the exposed animals must also be destroyed.

Control measures for zoonotic diseases result in efforts to eradicate certain wildlife species that are potential reservoirs, intermediate hosts, or vectors for disease transmission to humans or domestic animals. Wild species that are naturally rare, and species that have been severely depleted in numbers due to overharvesting or habitat degradation, are particularly at the risk of extinction from introduced diseases of domestic animals.

The traditional livestock breeds and varieties that constitute the most critical reservoirs of genetic diversity for domesticated animal species are also highly susceptible to severe losses or extinction from even highly localized disease outbreaks. Containment of bubonic plague outbreaks necessitates the control or eradication of rodent population within affected areas, to prevent the transmission of the disease from rodents to humans. Population of many wildlife species is already routinely subject to stringent control or local extirpation in attempts to control the transmission of diseases to domestic animals, in some instances without adequate data to validate the actual need for efficacy of such efforts. In the United States, the control of brucellosis in cattle has resulted in culling or attempted eradication of populations of bison (*Bison bison*), wapiti (*Cervus canadensis*), and white-tailed deer (*Odocoileus virginianus*). These important reservoirs of livestock genetic diversity are highly susceptible to extinction from even extremely localized disease outbreaks.

There appears to be little possibility of preventing bioweapon attacks against domesticated animals, and of preventing the subsequent spillover of weaponized livestock diseases into wildlife populations. People's ability to understand and control the spread of diseases within human and animal populations is increasing. However, it is still insufficient to counter the existing threats presented by bioweapons and a growing number of newly recognized and highly virulent infectious diseases, such as Ebola and Marburg fever, as well as less devastating but potentially fatal human and animal diseases, such as the West Nile virus. Interdisciplinary and international efforts to increase the surveillance, identification, and reporting of disease pathogens, and to better understand the dynamics of disease transmission within and among human and animal populations will enhance the ability to combat the effects of bioweapons and emerging diseases on biota and biodiversity.

See also: Biological Agents and Infectious Diseases in War and Terrorism; Political and Social Violence: Health Effects.

Further Reading

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