Bioweapons, bioterrorism and biodiversity: potential impacts of biological weapons attacks on agricultural and biological diversity

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Summary

Diseases and biological toxins have been used as weapons of war throughout recorded history, from Biblical times through to the present day. Bioweapon uses have historically been directed primarily, although not exclusively, against human populations. Specialised technicians and state-of-the-art research facilities are no longer necessary for the production or deployment of many known bioweapon agents and commercially available technologies now permit the large-scale production of bioweapon agents in small-scale facilities at relatively low cost.

Failures in the detection and containment of bioweapon and emerging disease outbreaks among populations of wildlife and indigenous peoples in developing countries could result in severe erosion of genetic diversity in local and regional populations of both wild and domestic animals, the extinction of endangered species and the extirpation of indigenous peoples and their cultures.

Our ability to understand and control the spread of diseases within and among human and animal populations is increasing but is still insufficient to counter the threats presented by existing bioweapon diseases and the growing number of highly pathogenic emergent infections. Interdisciplinary and international efforts to increase the monitoring, surveillance, identification and reporting of disease agents and to better understand the potential dynamics of disease transmission within human and animal populations in both industrialised and developing country settings will greatly enhance our ability to combat the effects of bioweapons and emerging diseases on biological communities and biodiversity.

Keywords

Biodiversity – Bioterrorism – Bioweapons – Disease – Epizootics – Genetic diversity – Livestock – Wildlife.

'Many experts agree that it's just a matter of time until the United States or another country suffers a significant bioterrorist attack'

D.A. Henderson
Director, Johns Hopkins Center for Civilian Biodefense Studies
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Introduction

Cultivated or genetically engineered biological organisms are ranked by some analysts as the most potentially dangerous of all existing weapons technologies, nuclear weapons notwithstanding (25, 33, 48). Biological warfare and bioterrorism are defined as the intentional use of microorganisms or toxins derived from living organisms as an act of war or political violence with the intent to cause death or disease in humans, animals or plants. Diseases and biological toxins have been used as weapons of war throughout recorded history, from Biblical times through to the present day. Bioweapon uses have historically been directed primarily, although not exclusively, against human populations. Biowarfare agents known to have been employed historically include plant and fungal toxins (hellebore, ergot), animal carcasses, disease-infected human corpses, disease-contaminated clothing or blankets, and faecal contamination (31). The potential spectrum of bioterrorism ranges from isolated acts by individuals to international state-sponsored terrorism or military actions, resulting in mass casualties within or among human and/or animal populations (55).

Perhaps the oldest traditional application of bioweapons has been the contamination or poisoning of drinking water sources using animal carcasses, human cadavers, faeces or poisonous plants and their derivatives. This knowledge was exploited by British forces in East Africa during World War I, when antelopes were shot by British troops and carcasses placed around a remote water source in order to give the impression that the water had been poisoned, thus severely restricting the movements of the German East African forces while keeping the water available for emergency use by British forces (36). During the 14th Century, Tartar armies catapulted the infected corpses of plague victims over the walls into the besieged city of Kaffra, in what is now the Crimea, to force the surrender and subsequent extermination of the inhabitants of the city (1). During the 18th Century, the British colonial army used smallpox-contaminated blankets to spread disease among Native American tribes in the Mohawk Valley region of New York, precipitating an epidemic that proliferated widely and severely affected tribes of the Iroquois and Algonquin nations. During the early decades of the 20th Century, a number of countries began research programmes to develop more technologically sophisticated applications of biological warfare for use against humans, livestock and crops.

During World War I, Germany developed anthrax, glanders, cholera and a wheat fungus for use as biological weapons. German forces allegedly attempted to create outbreaks of anthrax among livestock in Romania and Argentina, precipitate an epidemic of bubonic plague among humans in St Petersburg, Russia, and to infect horses and mules (then still critically important for the transport of ordnance and supplies) in Mesopotamia, France, Argentina and the United States of America (USA) with glanders (*Burkholderia mallei*) (6, 14, 38). Japan is believed to have used biological weapons, including anthrax, in China between 1932 and 1945 (1, 24). During the 20th Century, many government biowarfare programmes included the culturing and testing of disease agents intended solely for use against livestock and crops (2). Newly developed genetic-engineering techniques to create vaccine-subverting and antibiotic-resistant disease strains have the potential for greatly increasing the virulence and effectiveness of bioweapon attacks (1, 3).

Military and terrorist applications of biotechnology are threats to more than just human lives and human societies; certain bioweapon diseases present a very real danger to agricultural ecosystems, wildlife faunas and wildlife habitats. Genetically modified zoonotic and epizootic diseases (plague, tularemia, anthrax) and cultivated diseases of livestock (foot and mouth disease [FMD], rinderpest, brucellosis) are potentially very serious threats to livestock, wildlife and endangered species populations. There are concerns that plant diseases developed for use against cereal crops, opium poppies (*Papaver somniferum*), and coca (*Erythroxylon* spp.) (e.g. *Fusarium* spp. and *Pleospora papaveraceae*) might infect and proliferate among non-target plant species (35). 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.

The use of bioweapons for the purpose of economic sabotage against national agriculture or livestock industries is a potentially serious threat to biodiversity due to the potential for spill-over effects on non-target species of plants and animals. Although this review focuses primarily on the implications of bioweapon diseases for livestock and wildlife populations, much of what will be discussed also applies to potential effects of plant bioweapons on non-target species of plants.

Biological warfare and bioterrorism

Biowarfare actions in World War I and World War II expanded the scope of target organisms to include humans, livestock and crops (2). Government-sponsored bioweapons research programmes in the early decades of the 20th Century were directed initially towards:

– identifying the suitability of particular diseases for bioweapon applications

– isolating and cultivating exceptionally virulent and resilient disease strains

– perfecting novel systems and methods for the controlled delivery and dispersal of disease organisms (e.g. aerosol dispersion and subcutaneous pellet injection).

Zoonotic disease organisms known to have been cultivated and tested for bioweapon applications include anthrax (*Bacillus* *anthracis*), bubonic plague (*Yersinia pestis*), brucellosis (*Brucella abortus*), tularaemia (*Francisella tularensis*), *Clostridium botulinum*, *Coxiella burnetti*, *Burkholderia* spp., *Fusarium* spp., *Morbillivirus* spp., *Staphylococcus* spp., Venezuelan equine encephalomyelitis virus, and several haemorrhagic fever viruses (Ebola, Marburg, Lassa fever and Rift Valley fever) (7, 31, 37). The former Soviet Union sponsored extensive research on possible bioweapon applications of crop diseases (wheat stem rust and rice blast) and livestock viruses (rinderpest, Newcastle disease, African swine fever, sheep pox, fowl pox and malignant catarrhal fever) (4). During the 1980s and 1990s, scientists from the former Soviet Union used newly developed genetic-engineering techniques to create vaccine-subverting and antibiotic-resistant strains of anthrax, bubonic plague, tularemia, and smallpox (1, 4). Cultivated and potentially weaponised diseases identified by the Office International des Epizooties as possible major threats to livestock include FMD, rinderpest, Newcastle disease, African swine fever, sheep pox and Rift Valley fever (38).

At least twenty-two countries are believed to have had active biowarfare research programmes in recent years (11, 12). Several major international terrorist organisations, including, but not restricted to, the Osama Bin Ladin-associated al Qaeda network, are believed to have the financial resources and political contacts needed to access state-of-the-art bioweapon disease cultures and production technologies. Aum Shinriko, a Japanese terrorist group that used sarin gas for a terrorist attack on the Tokyo subway system, was also involved in developing terrorist bioweapons employing anthrax bacilli, botulinus toxin, Ebola virus and Q fever (*Coxiella burnetti*) (9).

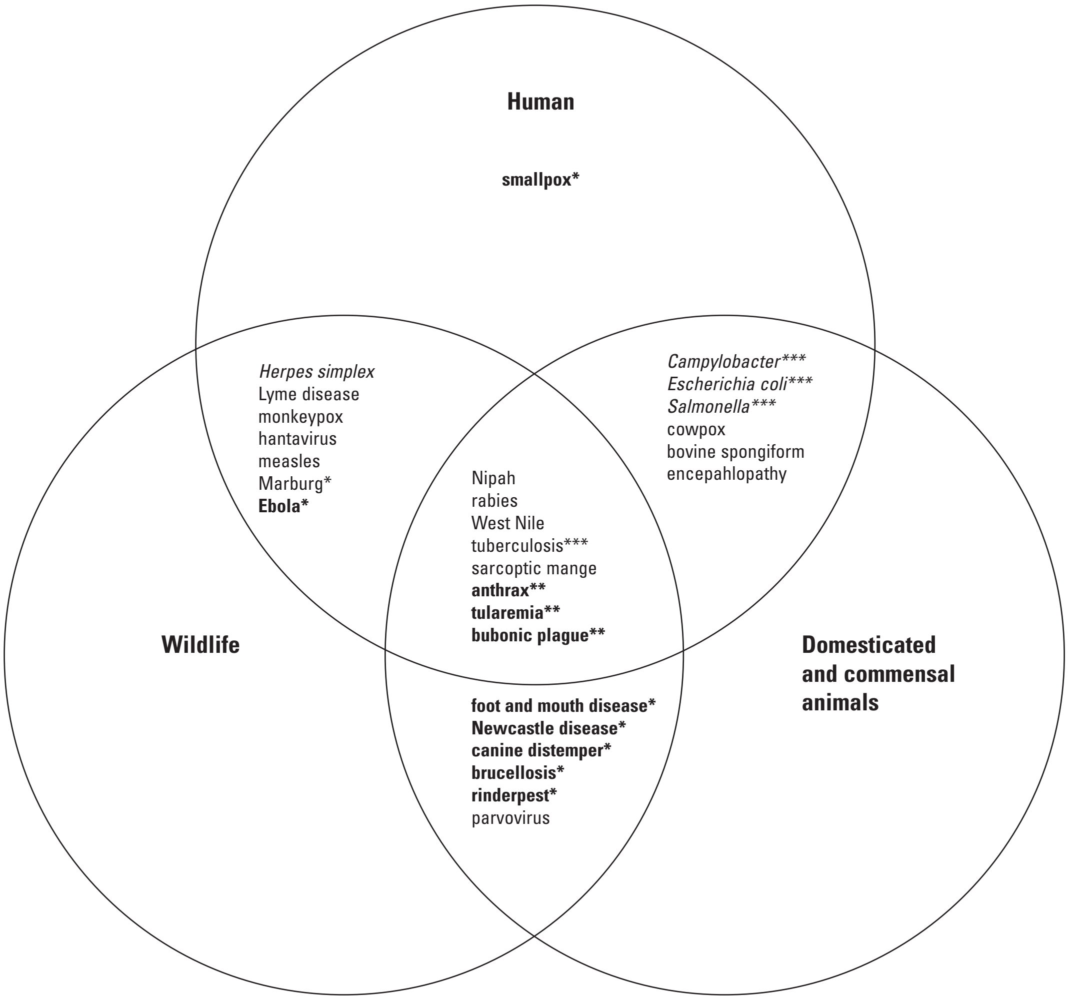
Of even greater concern is the fact that bioweapon attacks against agriculture do not require access to specialised knowledge, sophisticated technologies or laboratory disease cultures. The use of biological weapons for sabotage against livestock populations could have devastating effects on national livestock industries and national economies of developed and developing countries around the world, with potentially disastrous spill-over effects on susceptible wildlife and endangered species populations (5, 10). Many of the currently available bioweapons are broad-spectrum diseases capable of causing mass mortality among humans, domestic animals and wildlife (Fig. 1). Bubonic plague infects rodents as well as humans, and is transmitted by rat fleas. Efforts to contain epidemics from plague bioweapons even within urban areas will need to take into account the eradication of the animal reservoirs and flea vectors once the initial outbreak among human victims has been contained ('the rat factor') (K. Alibek, personal communication).

Animal diseases cultivated and tested specifically for use against livestock, such as rinderpest, could have particularly devastating spill-over effects on susceptible wildlife species. The rinderpest epizootic which occurred in Africa a century ago provides a useful model for predicting the effects of the proliferation of highly virulent and contagious bioweapon diseases – such as rinderpest and FMD – on susceptible wildlife and livestock species. Rinderpest virus was accidentally introduced into Africa in 1889 through Eurasian cattle imported to Abyssinia (now Ethiopia) to supply an invading colonial army. The resulting rinderpest epizootic left a swath of death stretching over 7,000 km, sweeping southwards from the Horn of Africa to the southern Cape in less than a decade. This represents an effective rate of travel of about 3 km/day in a pre-automobile and pre-aircraft era. Naïve, susceptible populations of cattle and wild ungulates throughout most of East and Southern Africa suffered mortality rates as high as 95% during the early stages of the rinderpest outbreak (10). Rinderpest killed 95% of the Cape buffalo (*Syncerus caffer*), wildebeest (*Connochaetes taurinus*) and domestic cattle in British East Africa within two years of its first appearance, and caused the extirpation of Cape buffalo from large parts of its range in Southern and East Africa. Despite intensive control efforts, rinderpest is still enzootic within East Africa, with periodic outbreaks among livestock and the presence of susceptible wildlife populations throughout the region (16, 30).

The recent emergence and ongoing proliferation of West Nile virus in eastern North America illustrates the immense difficulties entailed in identifying and controlling novel or newly introduced diseases within and among human and wildlife populations. West Nile virus is a mosquito-transmitted disease of birds and mammals that causes high rates of mortality in some host species, including humans (41). Although West Nile virus is primarily a disease of birds, mammals are common secondary hosts and infections have been reported among numerous species of mammals (e.g. humans, horses, cats, bats, chipmunks, skunks, squirrels, domestic rabbits and raccoons) (8). Current indications are that West Nile virus has become firmly established in eastern North America and is proliferating (8). It now appears probable that migrating birds will spread the disease into many other areas of the Western Hemisphere, including the Caribbean, Central and South America.

There is a growing but still insufficient recognition of the importance of disease control for the conservation of biodiversity and endangered species populations (10). Disease outbreaks caused by the release and proliferation 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.

The release and proliferation of weapons-grade rinderpest or anthrax strains could have potentially 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 recognised rapidly and may be difficult or impossible to eradicate. In the



* Natural disease organisms selected, cultured and tested for bioweapon applications
** Agents reported as genetically modified, vaccine-subverting, antibiotic-resistant bioweapon diseases (1)
*** Emerging, highly pathogenic and in some cases antibiotic-resistant natural diseases

Fig. 1
Aetiology of bioweapon and emerging diseases
(adapted from 10)

case of anthrax, the risk of subsequent outbreaks, even following the eradication of host animals, may continue for decades and even centuries in suitable soils. Viable, infectious anthrax bacilli have been cultured from animal bones recovered from archeological sites dating back 150-250 years (13, 15). The history of rinderpest in Africa and brucellosis in North America (diseases that have persisted despite concerted efforts at eradication over the past century), clearly demonstrates the seriousness of potential long-term threats of bioweapon releases for wildlife populations.

Relationships between bioweapons and emerging diseases

Our technical capabilities for countering the impact of disease threats from bioweapons and emerging infectious diseases may be handicapped by the ongoing proliferation of drug-resistant disease strains (e.g. *Mycobacterium tuberculosis*, *Plasmodium* spp.

and *Campylobacter* spp.). Improper and inappropriate uses of antibiotics to suppress diseases and infections in both humans and animals are contributing to the emergence of drug-resistant strains of many important pathogens (23).

Genetic disease resistance can pass between and among bacteria of different types through the transfer of 'resistance' plasmids, and there are clear links between sub-therapeutic uses of antibiotics and the prevalence of resistant bacteria (52). The current widespread use of antibiotics in livestock feeds, now banned in countries of the European Union but not in the USA and elsewhere, is a potentially dangerous practice that may have serious epidemiological consequences for both animals and humans (34, 44).

Newly identified diseases and known, but formerly uncommon, diseases are emerging as major threats to human, livestock, and wildlife populations as the result of progressive human-mediated changes in the ecology of host-pathogen and human-wildlife interactions (10). The emergence of new or formerly obscure diseases, such as Ebola and Marburg fever, and the proliferation of drug-resistant strains of important diseases, such as tuberculosis, that were once thought to be under effective control and susceptible to global eradication, are of considerable importance to this discussion because of their potential use as:

– experimental models for evaluating and testing the probable responses of populations, social institutions and veterinary medical facilities to bioweapon releases

– new bioweapon disease organisms.

Conflict and contagion

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 (29, 32). The Iran/Iraq War and the Arabian Gulf War precipitated rinderpest epizootics among livestock populations in the region, which may have been caused or aggravated by war-related displacements of pastoralists and their flocks (21, 42). Recent outbreaks of several lethal zoonotic diseases in human populations have been linked to disruptive effects of war and civil strife (monkeypox, Marburg fever, Ebola and bubonic plague) (19, 49).

Disruption of Government Veterinary Services during the Rhodesia-Zimbabwe civil war may have contributed to epizootic outbreaks of anthrax and rabies among wild and domesticated animals in Zimbabwe. Anthrax mortality among humans and livestock reached epidemic proportions in 1979-1980 and continued to proliferate for more than four years after the end of the war (29, 32). Anthrax ultimately spread through six of the eight provinces of Zimbabwe, with >10,000 recorded human cases before effective control of the disease was finally re-established in 1987 (26, 40).

However, there seems to be little, if any, hard evidence to confirm the alleged use of weaponised anthrax against human populations in Zimbabwe, since the vast majority of reported cases involved secondary cutaneous infections resulting from apparent contact with diseased cattle (29, 40). This interpretation appears to be supported by the recent resurgence of human anthrax in Zimbabwe, with nearly 1,000 reported human cases, including at least 11 reported human deaths, during 2000 and 2001. In what appears to be a similar enabling environment to that which precipitated the previous wartime outbreak of anthrax, the disruption of anthrax vaccination programmes and Veterinary Services as a result of internal political turmoil has permitted a resurgence of the disease in cattle populations in several areas of the country. Meanwhile, deteriorating economic conditions and food shortages are promoting the butchering of carcasses of cattle killed by anthrax. Villagers are apparently willing to take the risk of disease and death when skinning and butchering anthrax carcasses in order to obtain meat for sale or personal consumption.

Technologies and threats

Recent advances in biotechnology have simultaneously increased the potential economic value of genetic diversity of organisms by making possible the transfer of genes between even unrelated species (39), while increasing the threat of their elimination by bioweapon uses of genetically modified disease organisms. The threat of biological weapon attacks has increased greatly since the ratification of the Biological and Toxin Weapons Convention in 1975.

Specialised technicians and state-of-the-art research facilities are not necessary for the production or deployment of many commonly known bioweapons agents. Biotechnology techniques and equipment now available on the open commercial market permit the large-scale production of bioweapons in small-scale facilities, at relatively low cost (37). The basic techniques for culturing many bioweapon organisms are relatively simple, and microbrewery and pharmaceutical equipment easily adaptable for bioweapons production are readily available through the domestic and international commercial markets. The cost of developing smaller-scale bioweapons facilities and arsenals is within the range of US$10,000-US$100,000, easily affordable for technologically sophisticated terrorist groups (12, 50). Bioweapon cultures, diseased animals, or infectious materials could be easily introduced into international cargo transportation networks for shipment elsewhere, with virtually no risk of identification or interception (20).

The greatest threats from bioterrorism to biodiversity may well come from accidental releases of virulent broad-spectrum disease agents in countries, as the result of:

– inadequate containment within production and/or storage facilities

– accidental premature deployment of terrorist devices while in transit

– inadvertent releases resulting from offensive strikes against production or storage facilities.

The threat of catastrophic impacts from disease epidemics resulting from agricultural bioweapon releases is proportionally higher in developing countries, due to severe limitations on the availability of doctors, veterinarians, medicines, and medical facilities for treatment and quarantine. However, even countries with well-organised and efficient Veterinary Services are susceptible to deliberate or inadvertent introductions of highly infectious pathogenic disease agents into their livestock populations (12). Disease outbreaks in livestock populations resulting from bioweapon attacks could result in severe economic damage to both industrialised and developing countries. The spill-over of weaponised livestock diseases into susceptible wildlife populations 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 (10).

An excellent example of this is the recent inadvertent introductions into the UK of FMD and classical swine fever (CSF) virus. Classical swine fever, or hog cholera, is a highly infectious disease of pigs that is enzootic in the wild boars of many continental European countries. A recent CSF outbreak in England is alleged to have resulted from a tourist feeding a ham sandwich containing pig meat imported from the European mainland to a free-ranging pig on a farm in East Anglia. The resulting CSF epidemic caused great economic hardship. Pig farmers in the area were obliged to slaughter their pigs as a preventive measure and the export of pig products from the UK was suspended. There is a small but CSF-free population of wild boars in Great Britain that has escaped from captivity and established wild populations. Had the free-living wild boar population become infected by CSF during this outbreak, the disease would have been very difficult if not impossible to eradicate, with severe and perhaps permanent damage to swine production and export industries in the UK.

Recent outbreaks of FMD in Taipei China (1997) and the UK (2001) demonstrate the potentially catastrophic impacts of bioterrorist attacks against national livestock industries. The FMD virus is extremely contagious and infects most wild and domesticated ungulate species (sheep, goats, cattle, deer, pigs, etc.), but not humans. Although FMD is typically a debilitating rather than a fatal disease among healthy adult animals of most livestock species, the disease can be extremely damaging to commercial dairy and livestock industries by causing severe losses in meat and dairy production due to mortality among new-born animals, and sickness and debility among adults. The FMD virus begins to be shed before clinical signs appear, and the incubation period ranges from 2 to 21 days. Rates of infection can reach 100% within susceptible populations, and mortality can range from 5% to 75% among infected animals, depending on species, age and condition. Eradication is extremely difficult, as asymptomatic and recovered cattle may remain active carriers of FMD for as long as 18 to 24 months, FMD may be spread over long distances by wind-borne virus, and FMD virus survives well within various kinds of processed but uncooked meat products (frozen, salted, dried and cured meats).

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 parts of the UK. These include the native red deer (*Cervus elaphus*), the formerly indigenous but reintroduced roe deer (*Capreolus capreolus*) and introduced populations of four other deer species, Chinese water deer (*Hydropotes inermis*), muntjac (*Muntiacus reevesi*), sika deer (*Cervus nippon*) and fallow deer (*Dama dama*). It is believed, however, that there was no spread of FMD infection into the wild and feral populations in the UK during the recent epizootic.

News reports in March 2001 indicated that at least one of the relict endemic sheep breeds of England may have been destined for extinction through sanitary slaughter as a consequence of the FMD outbreak. The Government of the UK has initiated a permit system for exempting rare pig breeds from precautionary sanitary slaughter, in view of the probable economic importance of maintaining genetic diversity within the national swine herd.

The above examples of the devastating economic effects of the inadvertent introduction of serious diseases of livestock and their potential impact on often sympatric wildlife populations, demonstrate the critical importance of the early detection and reporting of disease outbreaks. The international reporting system for wildlife diseases initiated by the 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.

Impacts on agricultural infrastructure and national economies

Modern high-density industrial livestock facilities, centralised feed supply systems and transportation methods, increase the susceptibility of livestock populations to disease outbreaks and the vulnerability of national economies to disruption as the result of disease epidemics in livestock. An FMD outbreak in the domestic pig population of Taipei China in March 1997 revealed the extreme vulnerability of the modern pig industry to the transmission of contagious diseases. More than 6,150 outbreaks have resulted in the almost total depopulation of domestic pigs on the island, with huge economic costs including the loss of an estimated 50,000 jobs and US$6.9 billion in revenue. Three years later, the disease has still not been eradicated and the direct and indirect costs of containment and eradication of the FMD outbreak are expected to approach US$15 billion (38). Similarly, a three-month outbreak of Nipah virus among domestic pig populations in South-East Asia during 1999 led to the wholesale slaughter of pigs in parts of the region, with devastating effects on livestock industries and local economies. Nipah is a zoonotic virus transmitted to domestic swine from the faeces of free-ranging fruit bats or 'flying foxes' (*Pteropus* spp.), and thence from swine to humans. Nipah infection causes severe encephalitis in humans, with a 40% mortality rate recorded among infected patients in Malaysia and Singapore (18). At least 109 people died as the result of the epidemic, and more than one million pigs were destroyed in an effort to control the disease.

The susceptibility of food-processing and livestock feed industries to the accidental and/or deliberate introduction of disease contaminants is further illustrated by recent experiences in the USA involving the illegal processing of genetically modified maize and soy beans into foods manufactured for human consumption, and the spread of bovine spongiform encephalopathy (BSE, or 'mad cow disease') among cattle populations in the UK and Europe through the processing of meat-and-bone meal from infected carcasses into commercial livestock feeds. The UK, which banned the use of livestock feed containing carcass residues for cattle within national borders in 1986, continued to export such feed to Europe, Indonesia, Thailand, Taipei China, Japan and Sri Lanka long after domestic consumption was banned, before the practice was finally terminated nearly a decade later.

The minimum infective dose for BSE is very small, of the order of 1/10th of a gram of nervous tissue. The impacts of the BSE outbreak in the UK spread and escalated with the subsequent appearance of the disease in 18 European countries and Japan. The identification of a single BSE-infected cow in Japan resulted in a reported 70% decrease in beef consumption by Japanese consumers (R. Casagrande, personal communication). Sanitary slaughter costs associated with the BSE outbreak in Great Britain have been estimated at US$4.2 billion.

The economic costs of the subsequent outbreaks of FMD in the UK and the European Union may ultimately far surpass those associated with identification and control of the BSE threat. The incremental costs of the recent outbreak of FMD in Great Britain in lost meat and livestock exports were estimated at US$2 million per day. By 15 October 2001 more than 3,900,000 animals had been condemned and destroyed within FMD-affected areas of the UK as the result of the epidemic, with direct costs of slaughter and disposal of condemned livestock estimated at approximately US$7.5 billion. A previous five-month long outbreak of FMD in the UK during 1967 resulted in the destruction of 442,000 animals, with direct costs totalling approximately US$260 million. 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 non-agricultural sectors of the economy. Estimated losses to the tourism industry because of restrictions on travel in affected areas were estimated as of 14 March 2001 at US$350 million per week, or 25 times higher (2,500%) than concurrent direct losses in the agriculture sector (US$14 million per week). The cancellations and losses of international tourist bookings as a result of negative publicity associated with FMD hysteria and the highly publicised slaughter and burning of animal carcasses (the 'CNN factor') severely impacted the entire industry in the UK, with economic losses to the national tourism industry at the peak of the epidemic in March 2001 estimated at more than US$4 billion and rising.

Potential bioterrorist uses of livestock diseases

Bioterrorist uses of enzootic livestock diseases and emerging diseases that may infect human and animal populations represent a serious threat to livestock and wildlife populations that have never been exposed to these diseases. Many formerly ubiquitous diseases that have been eradicated from livestock populations in the USA and Western Europe are still common in other areas of the globe, and are readily accessible to political fringe groups and terrorist organisations. Vaccines for many diseases still common in 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.

Many of the bioweapon agents developed for use against animals and humans during the early decades of the 20th Century were not highly contagious organisms. However, new biological weapons include many diseases that are highly infectious and contagious, potential zoonoses, easy to produce, antibiotic-resistant, vaccine subverting, and able to cause severe morbidity or mortality. Organisms of particular concern in this regard are tularemia and plague and the viruses of Newcastle disease, FMD, CSF, avian influenza, African swine fever, Rift Valley fever, African horse sickness, rinderpest and Venezuelan equine encephalomyelitis (7, 31, 37).

Parasites have the potential for use as either bioweapons or delivery systems for infectious diseases, and the Soviet Bioweapons Programme experimented with the use of ticks and insects for the transmission of weaponised animal and plant diseases (2). When the New World screwworm fly (*Cochliomyia hominivorax*) was introduced into Libya (probably inadvertently along with a consignment of small livestock from Central America), it took three years work by veterinarians of the Food and Agriculture Organization (FAO) and more than US$80 million to eradicate this voracious parasite of all warmblooded animals, including humans. Had the screwworm not been rapidly eliminated from Libya by an intensive international control effort involving the release of millions of sterile male flies artificially reared in Mexico, the animal and human populations of the Mediterranean Basin and ultimately of the rest of continental Africa would have been at serious risk from this parasite (53).

Bioweapons attacks using non-contagious respirable aerosol agents (the major threat for attacks against human populations) would probably not be the method of choice for targeting animal populations. Disease organisms could be introduced effectively and clandestinely, with little chance of detection, through the simple expedient of randomly or selectively introducing pre-infected animals or feeds into feedlot operations. The simple act of dropping a contaminated apple into a feeder trough or holding pen at a major livestock auction facility could have devastating consequences for entire regional livestock industries, since 78% of the beef cattle marketed in the USA pass through just 2% of the commercial feedlots of that country (2).

No elaborate delivery technology or methods would be necessary under such a clandestine, economically targeted bioweapons assault scenario: a willing conspirator, a little careful planning, and access to an appropriate disease agent are all that would be required (37). It is important to emphasise that bioterrorist attacks against livestock do not require access to weaponised disease strains or laboratory cultures of disease organisms; samples of infectious materials obtained or cultured from infected animals or carcasses are all that is required (5). Natural highly virulent diseases of livestock that are easily acquired and transported, and are capable of causing catastrophic epidemics in countries with industrialised livestock production methods, are common and widely distributed in many countries around the world. Virulent contagious diseases of livestock, such as anthrax, rinderpest and FMD, are still enzootic and even common within a number of countries.

Bioweapon threats to biological and genetic diversity

There appears to be little possibility over the long-term for preventing bioweapon attacks against agriculture and livestock populations, or for preventing the subsequent spill-over of weaponised livestock diseases into wildlife populations. The threat to biological diversity from bioweapons lies in the release and proliferation of broad spectrum diseases of domesticated livestock and crops among naïve, susceptible populations of wildlife and plants. Notable among these are zoonotic and epizootic diseases of both wild and domesticated animals such as rabies, anthrax, plague, tularemia, glanders, meilioidosis, FMD, CSF, rinderpest, psittacosis, canine distemper and Venezuelan equine encephalomyelitis (31). Wild species that are naturally rare, and species that have been severely depleted in numbers due to over-harvesting or habitat degradation, are particularly at risk of extinction from introduced diseases of domesticated animals. More than 60 wildlife species are known to be susceptible to FMD (38), but the total number of susceptible wildlife species around the globe is probably much higher. The traditional livestock breeds and varieties that constitute our most critical reservoirs of genetic diversity for domesticated animal species are also highly susceptible to severe losses or extinction from even highly localised disease outbreaks (47).

Wildlife and endangered species

The extinction of local populations of the North American black-footed ferret (*Mustela nigripes*) and African wild dog (*Lycaon pictus*) by canine distemper are excellent examples. Habitat loss and persecution, combined with the concurrent effects of sylvatic plague and canine distemper on ferrets and their prey populations, caused the decline and ultimate extinction of black-footed ferrets from most of their range in North America. Similarly, persecution and predator-control operations have reduced the African wild dog to a few small and scattered populations, now gravely threatened by spill-over infections of rabies and canine distemper from sympatric domestic dog populations (22, 54). Canine distemper is a common viral disease of domestic dogs that can spill over into wildlife, with devastating results on some wild carnivore populations. Cheetah (*Acinonyx jubatus*) might have been driven to the verge of extinction in the Serengeti had this species experienced a rate of mortality comparable to that observed for lions (*Panthera leo*) in the same environment, where approximately two-thirds of the resident lion population died as a result of the Serengeti distemper epidemic (28). There needs to be wider recognition of the potential impact of diseases of domesticated animals and humans on wildlife and particularly endangered species populations, and the pivotal role of human interventions in promoting the introduction and establishment of exotic diseases in new areas (10, 17).

Control measures for zoonotic diseases may result in efforts to eradicate certain wildlife species that are potential reservoirs, intermediate hosts, or vectors for disease transmission to humans or domesticated animals. Containment of bubonic plague outbreaks necessitates the control or eradication of rodent populations within affected areas, in order to prevent the transmission of the disease from rodents to humans. Populations of many wildlife species are 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 or efficacy of such efforts. In the USA, the control of brucellosis in cattle has resulted in the culling or attempted eradication of populations of bison (*Bison bison*), wapiti (*Cervus canadensis*) and white-tailed deer (*Odocoileus virginianus*) (45).

Rabies control programmes target populations of red fox (*Vulpes vulpes*) in Europe and North America, jackals (*Canis mesomelas*) in eastern and southern Africa, and raccoons (*Procyon lotor*) in southern and eastern North America. In Central and South America, vampire bats and other sympatric but insectivorous bat species are killed in large numbers in an attempt to reduce rabies infections among humans and livestock. Nonetheless, efforts for the control of populations of some wildlife species may be constrained or curtailed as the result of strong public opposition. For example, efforts currently underway to reduce the incidence of human Lyme disease in suburban areas of the eastern USA by the culling of whitetail deer populations are faltering or failing outright in many localities due to lobbying and legal challenges by animal-rights organisations.

Livestock populations and endemic livestock breeds

Livestock breed conservation is important for the retention of the genetic raw material for morphological and physiological adaptations that provide special resistance to insects, parasites, disease, climate, altitude and other environmental factors (27). The once great array of breeds of most important livestock species has been drastically reduced over the past century in many countries (43). World-wide, there are approximately 4,000 recognised breeds and breed varieties of the principal domesticated livestock species (ass, cattle, water buffalo, pig, horse, sheep and goats), some of which have critically small population sizes and highly localised distributions that are restricted in some instances to only one or two nearby farms located within a single village or township (43). At least 700 of the surviving local and traditional breeds of these seven livestock species, including 350 breeds in Europe alone, are in imminent danger of extinction due to the global emphasis on the commercial exploitation of a few highly cosmopolitan modern breeds (46). These important reservoirs of livestock genetic diversity are highly susceptible to extinction from even extremely localised disease outbreaks (43, 47).

Conclusions

There appears to be little possibility for preventing bioweapon attacks against domesticated animals, and for preventing the subsequent spill-over of weaponised livestock diseases into wildlife populations. Bioterrorist attacks against livestock do not require access to weaponised disease strains or laboratory cultures. Natural diseases that can cause catastrophic epizootics, and are easily acquired and transported, are common and widely distributed within many countries around the world. The current ease and rapidity of international transport of potential human and animal vectors, coupled with the increasing virulence and variety of human-selected and genetically engineered disease organisms, are setting the stage for plague scenarios that may well equal and surpass those of any known precedents within recorded human history. While it is one of the missions of the OIE to inform national governments of the occurrence and course of economically important animal diseases throughout the world and of ways to control them, the capability for early detection and prompt reporting of diseased animals, both wild and domestic, needs to be further developed.

This is the reason why the OIE is implementing a new animal disease information system which includes an active approach in the search for information on the occurrence of diseases and a new electronic warning system for the international community (51).

Our ability to understand and control the spread of diseases within and among human and animal populations is increasing, but is still insufficient to counter the existing threats presented by bioweapons and a growing number of newly recognised and highly virulent emerging infectious diseases, such as Ebola and Marburg fever, as well as less devastating but nonetheless still potentially fatal diseases of both humans and animals 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 in both industrialised- and developing-country settings, will greatly enhance our ability to combat the effects of bioweapons and emerging diseases on biotas and biodiversity. Improved mechanisms for interagency and intergovernmental communication, co-operation and collaboration will be necessary to effectively combat and control the threats of bioweapon disease outbreaks. Failures in the prevention, reporting, detection, control and containment of bioweapon disease outbreaks could result in the erosion of genetic diversity in wild and domestic animal species, the extinction of endangered wildlife populations, the extirpation of indigenous peoples and the destruction of traditional human livelihoods and cultures.

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Armes biologiques, bio-terrorisme et biodiversité : impacts potentiels d'attaques à l'arme biologique sur la diversité agricole et biologique

J.P. Dudley & M.H. Woodford

Résumé

L'histoire écrite de l'humanité fait état de l'utilisation d'agents pathogènes et de toxines à des fins militaires, et ce depuis les temps bibliques jusqu'à nos jours. Par le passé, les armes biologiques visaient en priorité, quoique non exclusivement, les populations humaines. De nos jours, la fabrication d'armes biologiques à partir des nombreux agents pathogènes connus ne nécessite plus le concours de techniciens spécialisés ni d'installations de recherche ultramodernes, et désormais, des technologies facilement accessibles permettent de produire à grande échelle des armes biologiques dans des installations modestes et à un coût relativement réduit.

Les insuffisances dans la détection et le confinement de foyers dus à l'utilisation d'armes biologiques ou à l'apparition de maladies émergentes, et frappant les animaux sauvages et les peuples autochtones des pays en développement, pourraient se traduire par un grave appauvrissement de la diversité génétique des espèces animales sauvages et domestiques à l'échelle locale ou régionale, par l'extinction des espèces menacées, ainsi que par la destruction des populations autochtones et de leurs cultures.

Des progrès réels ont été accomplis dans nos connaissances et notre capacité à prévenir la propagation des maladies au sein des populations humaines et animales et entre ces populations, mais ils restent insuffisants face aux menaces que représentent les maladies liées aux armes biologiques et au nombre croissant d'infections émergentes hautement pathogènes. Les actions internationales interdisciplinaires visant à améliorer le suivi, la surveillance, l'identification et la déclaration des agents pathogènes, et à mieux comprendre la dynamique potentielle de la transmission des maladies au sein des populations humaines et animales, aussi bien dans les pays industrialisés qu'en développement, devraient améliorer considérablement notre aptitude à combattre les effets des armes biologiques et des maladies émergentes sur les communautés biologiques et sur la biodiversité.

Mots-clés

Animaux d'élevage – Armes biologiques – Biodiversité – Bio-terrorisme – Diversité génétique – Épizootie – Faune sauvage – Maladie.

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Armamento biológico, bioterrorismo y biodiversidad: eventuales repercusiones en la diversidad agrícola y biológica de un ataque con armas biológicas

J.P. Dudley & M.H. Woodford

Resumen

La historia escrita de la humanidad ofrece testimonios varios de la utilización de agentes patógenos y toxinas como armas de guerra, desde los tiempos bíblicos hasta nuestros días. En el pasado, las poblaciones humanas han sido las víctimas principales, aunque no exclusivas, del uso de armas biológicas. Hoy en día ya no es necesario disponer de técnicos especializados y modernas instalaciones de investigación para elaborar o difundir muchos de los agentes de armas biológicas conocidos, y es ahora posible adquirir en el mercado las técnicas necesarias para fabricar esos agentes a gran escala en instalaciones reducidas y a un costo relativamente bajo.

La detección y contención insuficientes de brotes de enfermedades emergentes o derivadas de la guerra biológica en poblaciones de animales salvajes y pueblos indígenas de países en desarrollo podrían conducir a una sensible merma de la diversidad genética de poblaciones locales y regionales de animales salvajes o domésticos, a la extinción de especies amenazadas o a la desaparición de pueblos indígenas y sus culturas.

A pesar de los progresos realizados en ese campo, nuestra capacidad de entender y controlar la propagación de enfermedades dentro de poblaciones humanas y animales, así como entre ellas, no es suficiente todavía para hacer frente a la amenaza de enfermedades ligadas a la guerra biológica y al creciente número de infecciones emergentes altamente patógenas. El objetivo de mejorar substancialmente la capacidad de lucha contra los efectos que puedan tener las armas biológicas y las enfermedades emergentes sobre las comunidades biológicas y la diversidad biológica pasa por un trabajo interdisciplinar a escala internacional, que sirva para perfeccionar el seguimiento, la vigilancia, la detección y la declaración de agentes patógenos y entender con más precisión la posible dinámica de la transmisión de enfermedades en poblaciones humanas y animales tanto en los países desarrollados como en vías de desarrollo.

Palabras clave
Armas biológicas – Diversidad biológica – Diversidad genética – Enfermedad – Epizootia – Fauna salvaje – Ganado – Terrorismo biológico.

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