Entomological "Weapons" of Mass Destruction

by Thomas F. Moore

Although states have used a variety of systems to deliver weapons of mass destruction (WMD), we are, in fact, surrounded by practically ubiquitous delivery vehicles for WMD, insects, for example. States have worked to seize the benefits of these load-bearing bugs in the past, investing in programs that can leverage the unique benefits they afford. Insects are ideal delivery devices for launching a state-sponsored, biological-weapons attack and present an attractive option over mechanical-delivery vehicles because they are readily available, effective, and difficult to attribute. This article argues that the U.S. interagency consider insects as potential, biological-WMD-delivery vehicles, capable of harming U.S. citizens and agriculture. In this article, I first describe the benefits of insects as delivery devices for biological agents and discuss the advantages they provide over traditional, mechanical-delivery devices. Next, I provide a brief history of five states, all signatories to the Biological Weapons Convention (BWC), and their efforts to develop entomological warfare programs. Third, I discuss contemporary threats and highlight recent advances in biotechnology that exacerbate the threat of biological weapons today. Finally, I recommend that the interagency obtain a comprehensive understanding of why states might be incentivized to conduct an entomological attack.

The Benefits of Insects as Delivery Devices

There are a number of reasons why insects are ideal delivery devices for naturally-occurring or genetically-engineered pathogens:[1]

- Insects cost nothing and are abundant. They also serve as particularly effective hosts to disease. Many pathogens are not suited to live outside of a host because environmental factors, such as ultraviolet rays and temperature extremes, render their deadly potential ineffective. By carrying the pathogens (internally), insects overcome this common obstacle to the delivery of biological agents.

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- Insects are also easy to infect, making them carriers. They can feed on animals that have naturally-occurring or genetically-altered pathogens, creating "natural" weapons. Once internalized, the deadly microbes are shielded in the insects' tissues from environmental factors.

- Insects can also facilitate the reproduction of these microbes in their tissues, increasing their pathogenic payload.

- Finally, insects can vector (spread) pathogens as they randomly feed on animals or humans, transferring pathogens to these unsuspecting victims. Unlike other delivery platforms of biological agents, such as aerosol sprayers or bombs, insects actively seek out warm-blooded targets.

History of the State-Use of Insects as Delivery Devices

States including Japan, the Soviet Union, Germany, and the United Kingdom have been aware of the benefits of insects for decades. Despite being signatories to the BWC, a treaty that bans the production of biological weapons for warfighting purposes, all have invested in entomological warfare programs and employed insects with devastating effects. During World War II,[2] General Ishii Shiro ran Japan's Epidemic Prevention Research Laboratory,[3] where his work focused on protecting soldiers from disease and employing insects to induce epidemics. In 1932, Shiro established Unit 731, where he mass-produced insects and weaponized them for use in an attack. Shiro enlisted Manchurian captives to weaponize fleas with pathogens, allowing Japan to produce a half billion plague-infected fleas per year.[4] In 1940, Shiro's scientists developed the Type 50 Uji bomb, which could safely deliver 30,000 fleas to a target.[5] Japan refined this entomological weapon by conducting 4,000 tests on over 2,000 Manchurian subjects.[6] In 1940, Japan conducted an entomological attack on Quzhou in the Zhejiang province of China, setting off an outbreak that would continue for six years, killing over 50,000 people.[7] Days before attacking Pearl Harbor, Japan released 100 million infected fleas in Changteh in the Hunan province, claiming over 7,000 lives.[8]

Working solo, the Soviets began a biological warfare program and experimented with infecting their political prisoners with typhus. They also experimented with Q-fever, glanders, and melioidosis.[9] Later, near the end of World War II, Soviet troops invaded Manchuria and captured Japanese scientists and documents from Unit 731. Using these documents, Soviet Leader Joseph Stalin built an entomological weapons production facility in Sverdlovsk.[10] In 1943, Soviet soldiers planted typhus-infected lice among German troops occupying the Karachevo region, debilitating 2,808 German soldiers.[11]

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When Adolf Hitler took power in Germany in 1933, Germany had the infrastructure and expertise for a world-class, biological-warfare program. Nevertheless, Adolf Hitler initially prohibited offensive biological research with the exception of entomological research for defense purposes.[12] German scientists thus developed insecticides to protect German crops from an entomological attack, which led to the development of the organophosphorus compounds commonly known as nerve agents, e.g., Sarin, Soman, and Tabun. Knowing that France was preparing to employ the Colorado potato beetle on German potato fields, Germany's defensive focus was deemed necessary by the

Nazi regime.[13]

In the early1940s, the United Kingdom stockpiled yellow fever vaccine to protect its troops in India against a mosquito-induced epidemic. This vaccine was a product of British research involving offensive biological experiments.

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In 1943, President Franklin D. Roosevelt deviated from the "Fox Doctrine," which came from a report drafted in 1932 suggesting the U.S. refrain from any development of biological weapons,[14] and started a research and development program at Camp Detrick, MD. At Camp Detrick, Canadian and U.S. scientists collaborated to weaponize mosquitoes using several pathogens.[15] By 1946, U.S. Secretary of War Robert Patterson had come to believe that the U.S. required a biological weapons retaliatory capability for potential use against the Soviet Union.[16] As a result, the Camp Detrick operation grew and eventually would include 245 structures with over 5,000 workers. There, U.S. researchers experimented with fruit flies and screwworms to determine their ability to destroy agriculture.[17] U.S. scientists required vast quantities of deadly pathogens to weaponize insects, and the U.S. subsequently constructed the world's largest bacteria production facility in Vigo, IN to meet this need.[18]

Insects as Threats to Health

Insects have the capability to infect humans and non-humans alike. They can be equally threatening in the transmission of disease to and among humans as they can be in the spread of pestilence among other animals and plants. The interagency must take care to consider U.S. vulnerabilities to insect-spread diseases throughout its population and across its agricultural sector.

Historically, insects have been vehicles for the natural spread of disease. Their effects can be potent and far-reaching. Fleas, for example, were the vectors of bubonic plague in the fourteenth century. Transferring the *Yersinia pestis* bacterium from rodents to humans, fleas ultimately killed millions of Europeans. This disease is not, in fact, ancient history: in 2017, insects spread the same plague in Madagascar, killing 202 citizens.[19]

The 1999 West Nile virus outbreak demonstrated how vulnerable a state can be to insect-borne disease. Insects carrying the West Nile virus spread across the U.S. over a seven-year period, killing 654 people and sickening over 7,000.[20] U.S. scientists were incapable of stopping the disease and focused on managing their effects instead.[21] Additionally, the U.S. government spent over $50 million to protect U.S. citizens from a potential Zika outbreak.[22]

A new virulent strain of Rift Valley Fever, an acute, fever-causing, viral disease spread by mosquitos and most commonly observed in domesticated animals, revealed the devastating effects of re-emerged viral pathogens. Appearing in Egypt in 1977,[23] Rift Valley Fever caused 200,000 Egyptians to fall ill (2,000 lost their eyesight and 598 died of encephalitis).[24] The disease returned again in 2006 in Kenya, where it took the lives of 118 people. Rift Valley Fever returned once again in 2016 in Niger, where it infected 348 people, causing 38 confirmed fatalities.[25]

Likewise, Yellow Fever is an acute, viral, hemorrhagic disease transmitted by infected mosquitoes. It is lethal to 20–50 percent of its infected population.[26] In December of 2016, 326 Brazilians contracted Yellow Fever and an astonishing 202 (62%) died.[27]

It is important to note that every region of the U.S. has mosquitos capable of spreading pathogens, such as those that cause the West

Nile virus, Rift Valley Fever and Yellow Fever.[28] Without malicious intent and their weaponization, insects alone present a direct threat to humans.

Insects as Threats to Cattle and Agriculture

Disease can also spread across agriculture, whether or not the disease is introduced by insects, negatively impacting state economies. In 2001, approximately 2,000 livestock animals in England became infected with foot-and-mouth disease.[29] Even after slaughtering four million animals, it took nine months to bring England's foot-and-mouth disease outbreak under control.[30] The outbreak cost the United Kingdom £3 billion in the public sector and £5 billion in the private sector.[31] While livestock spread foot-and-mouth disease to other livestock, insects can also serve as vectors of foot-and-mouth disease in certain cases.[32]

Scientists discover new insects that threaten food supplies every year, and new insects that are resistant to the effects of pesticides are discovered every year. Agriculture contributes approximately $990 billion to the U.S. gross domestic product[33] and provides 21 million jobs (constituting 11 percent of total U.S. employment).[34] States considering a biological attack on the U.S. might be incentivized to target agriculture due to the high cost an attack could impose. Such an attack would bear similarity to a natural occurrence and be difficult to attribute—further incentive.

Recent Advances: Controlling Insect Flight

Recent advances in insect flight control stand to improve entomological warfare capabilities, increasing the overall threat. In 2009, for example, the U.S. Army was successful in harnessing the flight of the giant flower beetle.[35] These scientists used "oscillating electrical pulses" applied to the beetle's optic lobes to trigger takeoff and cease flight.[36] They used the same technique applied to wing muscles to steer the bugs right and left.

In 2016, engineers at Nanyang Technological University in Singapore found that controlling insect flight had two advantages over using remote controlled drones.[37] First, insects could access areas drones could not. Second, insects could control their own flight stability, without requiring constant flight corrections—as drones do. In 2017, engineers at the Draper Company in Massachusetts combined miniaturized navigation, synthetic biology, and neuro-technology to control flight in a dragonfly.[38] The scientists used synthetic biology to modify the nervous system of the dragonflies so they would respond to pulses of light. They inserted genetic material into the insects so that their neurons could either be activated or inhibited by various colors of light.[39] This represented a bold advance in harnessing the power of insects for spreading disease: scientists could now control both guidance and navigation systems of insects outside of the laboratory setting.[40]

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Recent Advances: The Gene-Edited Insect

Since the conclusion of the Human Genome Project, an international scientific effort that mapped all the genes of the human genome, scientists have identified over four thousand kinds of DNA mutations that cause genetic disease.[41] Genome editing, or "gene editing," enables scientists to delete, add, or change DNA in a genome (the entire set of genetic material in a living being or thing). Whereas gene editing tools were once expensive and required the mastery of complex scientific techniques, new technologies are altering this reality. The clustered regularly interspaced short palindromic repeats (CRISPR)-CaS9 tool, for example, now provides scientists (and non-scientists) with the ability to have exacting control over the genomes of humans, plants, and animals.[42]

In 2017, scientists at the University of California–Riverside used CRISPR-Cas9 to edit the genome of a mosquito and create a yellow, three-eyed, wingless version.[43] While this research bodes well for scientists' ability to incapacitate mosquitos to prevent the spread of infectious diseases, it also reveals how the genetic code might also be corrupted to do harm in living organisms.

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Recent Advances: The Gene-Edited Virus

Plasmids are small DNA molecules within cells that are essential for gene editing. They are also commercially available through gene repositories. Addgene, one such repository, has shipped hundreds of thousands CRISPR-related plasmids to eight different countries at the cost of approximately $65 per sample.[44] To illustrate the danger of making DNA molecules widely and commercially available, in 2013, synthetic biologists purchased plasmids to genetically alter plants to have a bioluminescent effect. To drive their point home, the biologists mailed genetically-altered seeds to 6,000 people, effectively releasing an uncontrolled genetically engineered organism into the environment.[45] However, in 2017, Dr. David Evans, a Canadian virologist, conducted a similar—albeit scarier—exercise. Evans used mail-ordered genetic material to resurrect the extinct horsepox for a cost under $100,000.[46] States intent on launching a biological-weapons attack could replicate Evan's methods to resurrect other poxviruses, including smallpox.[47] Moreover, CRISPR-Cas9 edited genes reveal no trace of human involvement, rendering attribution impossible.[48]

While the interagency was aware of this exercise, the U.S. government had no regulations in place to stop it. Finally, in 2016, the U.S. Director of National Intelligence added gene editing technology to the list of threats posed by WMD and proliferation.[49]

Recent Advances: The Gene-Edited Human

Genetic engineering has been applied to the human genome in a similar manner. In 2003, Austin Burt proposed a way to harness dominant genes to ensure offspring had a 100-percent probability of inheriting a given segment of DNA.[50] Today, bioengineers can "drive" genes and their associated traits into populations. CRISPR, in fact, serves as a gene drive when injected directly into a species' germ cells.[51] In 2016, the ETC Group, a Canadian biotech watchdog organization, warned that gene drives could be weaponized against the human genome and major food supplies.[52]

Newer threats thus dwarf the entomological warfare programs of WWII. States have unprecedented opportunities to employ insects with pandemic-like effect and little chance of retribution.

Constraints on the Use of Insects as Delivery Devices

Given the increasing ease with which a state might use an insect to deliver a weaponized virus, state leaders might be tempted to reconsider the merits of their since-abolished biological-weapons programs. They may be further tempted if they believe that using insects as weapons does not violate norms or negate their good standing as a signatory to the BWC. While the BWC bans the use of biological weapons in warfare, it does not specifically mention insects as a delivery device. Article I, however, is comprehensive and forbids signatories to "develop, produce, stockpile, or otherwise acquire or retain biological agents or toxins and the weapons or means of delivery designed to use such toxins for hostile purposes or in armed conflict."[53]

Today, widespread compliance with the BWC combined with modern medicine, hygiene, and pesticides allow most U.S. citizens to think of insects as a mere nuisance. Interagency officials should be wary of attempts to leverage insects' natural destruction against U.S. citizens and agriculture. Such attacks could take a toll on U.S. life and treasure and be difficult to attribute and discern from a natural occurrence. Officials must also take measures to continually assess and ensure that U.S. citizens and agriculture are protected from entomological threats.

Critique of Entomological Warfare

Critics wary of whether entomological warfare is truly a rising threat might argue that using insects as WMD is foolish for two reasons: first, it would be unlikely for an entomological attack to achieve WMD effects; and second, an entomological attack would violate international norms and treaties such as the BWC.[54] However, new technologies and capabilities—including the ability to edit the genome of insects and to "drive" certain genes—enable biological nightmare scenarios that far surpass any use of biological weapons seen to date. In particular, nefarious actors could conceivably purchase DNA and use CRISP-Cas9 to resurrect extinct viruses or construct a variant of an existing virus for which no known cure exists. Used with gene-driving technologies, states could conceivably flood agricultural areas with pesticide-resistant insects carrying diseases that have no antidotes. These insects could later reproduce, ensuring all offspring were delivery vehicles of the same incurable pathogen.

Nefarious states could feel enticed to employ insects because they have every chance of attaining their objectives and little chance of getting caught. Some states might even consider it foolhardy not to use entomological warfare to achieve their objectives. The interagency ought, therefore, to coordinate prevention and response efforts and activities sooner rather than later.

While several members of the interagency share biological threat awareness responsibilities, countering the use of biological weapons from a state-sponsored. entomological-weapons program likely does not appear on the radar of agency priorities. Fortunately, the U.S. 2018 National Biodefense Strategy may contribute to raising awareness by referencing "naturally occurring, accidental and deliberate biological threats to the U.S. citizens and agriculture."[55] Beyond mentioning these threats, the 2018 National Biodefense Strategy focuses interagency biodefense efforts by identifying a mechanism within the Department of Health and Human Services to coordinate federal biodefense activities.[56] While these are timely policy changes, a malicious state could still attempt to couple gene editing and gene drives to induce a pandemic that could mimic a naturally-occurring outbreak and enjoy complete anonymity. With the convergence of gene editing, advanced computing, and commercially available DNA, it could be only a matter of time before insects are employed against U.S. citizen or U.S. agriculture.

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Conclusion

Locust swarms and the bubonic plague are not necessarily relics of biblical and medieval times. In the wrong hands, the locust and the flea could re-emerge to cause death and destruction. Nefarious actors can now employ pesticide-resistant insects weaponized with a poxvirus or another engineered disease with no cure yet in existence. Gene drives amplify the effects of such an entomological attack, ensuring 100 percent of the insects' offspring retain the state-selected trait as they multiply. These entomological-delivery vehicles of WMD would not only be hard to kill, they could create a pandemic that would confound scientists and law enforcement officials. ***IAJ***

The views expressed in this article are those of the authors and are not an official policy or position of the National Defense University, the Department of Defense or the U.S. government.

NOTES

1 While the term pathogen includes any disease-causing agent or microorganism (bacteria, viruses, fungi, worms, or protozoa), this article primarily focuses on transmission of viruses and bacteria by insects.

2 Entomological warfare refers to employing insects in a direct attack to vector pathogens against humans and animals or to destroy agriculture. The principal focus of this article is on insects. However, the tick, a common arthropod, is included with insects when discussing Tularemia transmission.

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