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Food security: The ultimate one-health challenge

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ABSTRACT

Food insecurity is a serious and immediate concern for the world due to challenges including overpopulation; conflicts; animal, plant, and human diseases; climate change; depletion of resources; and environmental degradation. Long-term solutions for food production must consider the impacts on the environment, water and other resources, human and animal health, and sustainable crop production.

The fundamental cause of food insecurity is the rapid and unprecedented increase in human population from approximately 2 billion people in 1925 to over 8 billion in 2023. The need for food has led to major expansion of both crop and food animal production including movement into new areas; increased production requires more resources, some of which are being depleted. This paper focuses on food animal production. Humans depend on three major species for most animal-origin food: Chickens (meat and eggs), cattle (meat and milk), and swine (meat). Each species is currently threatened by diseases that can rapidly spread internationally, and some have zoonotic potential. Diversification of animal-based food, such as expanding aquaculture can help to protect against food shortages should an epizootic occur in one or more of the above species.

Cutting-edge science is needed to improve food animal production and pathogen control. This requires an interdisciplinary one-world, one-health approach led by international organizations and funded by the developed world. An optimal response will involve scientists and policy experts from government, the private sector, and universities worldwide. Strengthening all nations' public health infrastructure and veterinary services is essential to this aim.

Fortunately, concerns about worldwide food security are concurrent with rapid advances in nearly all aspects of science, which can be applied to sustainably increase food production both locally and globally. There must be a collective will to apply science and to implement policies to solve current food security problems and to prepare for future challenges.

1. Introduction

Food insecurity [1] is a major problem for people in many areas of the world and will likely become more severe as the population increases. It is especially concerning in lower and middle-income countries (LMIC), but also affects people with limited resources in wealthy countries. Food insecurity has a major impact on human welfare, health, and productivity. Addressing food insecurity is a complex problem involving crop production, climate change, environmental degradation, animal health, plant health, pests, food distribution, and resource depletion.

All these factors are part of the concept of One Health and require the collaboration of many disciplines to address food security [2] effectively. *One Health, as defined by the U.S. Centers for Disease Control and Prevention (CDC) and the One Health Commission, is a collaborative, multisectoral, and trans-disciplinary approach - working at local, regional, national, and global levels - to achieve optimal health (and well-being) outcomes recognizing the interconnections between people, animals, plants and their shared environment.*

This manuscript will focus on several factors around food security, including population growth, food animal production, emerging disease threats, research needs, and opportunities for diversification of animal protein production.

2. Population and adaptation

The main driver for food insecurity is the rapidly increasing human population. Since the 1950s there has been a logarithmic increase in the worldwide population. The United Nations projects that the world's population will grow from 8 billion in 2023 to 9.7 billion in 2050 and

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could peak at nearly 10.4 billion in the mid 2080s then is predicted to decline by −0.1% per year [3]. The number of births would be slightly lower than the number of deaths, and the population would remain relatively stable for some period of time (Fig. 1).

Population growth differs throughout the world. In 2023, India and China were the world's most populous countries with 1.4 billion people each. India's population is expected to continue to grow, but China has shown a decline and expected to continue to decrease. The continent of Africa has the fastest growing population growth; the population of sub-Saharan Africa is projected to double by 2050 [3]. In contrast, many countries in Europe have declining populations as does Japan. The population of 61 countries or areas of the world are expected to decrease with many expecting a reduction of 10–15% by 2050 [4].

The global population curve is similar to the typical growth curve for bacteria grown in a closed culture environment (Fig. 2). After inoculating bacteria into nutrient media, there is a lag phase before the population begins to increase. This is followed by a log phase of a rapid increase in bacterial numbers, leading to a stationary phase followed by a decline phase due to nutrient depletion and accumulation of toxins in the media in the closed environment. The rapidly expanding human population, which is currently in the log phase, is predicted to move into a stationary phase after 2050. The rapid human population growth and the intense need for resources to support this population are leading to the depletion of resources and the buildup of "toxins" (e.g. CO_2 and other greenhouse gases) in the earth's environment, resulting in climate change [5]. On the whole, climate change and the depletion of resources will make food production in the future more challenging.

Important questions for consideration are:

- How long can the Earth support 10 billion people?

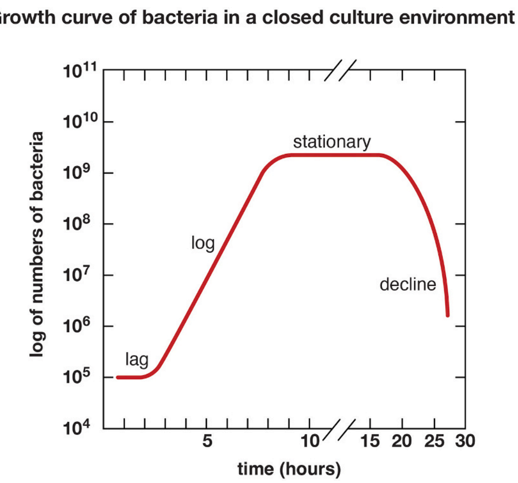

Fig. 2. Bacteria growth curve.
Typical bacterial growth curve in culture medium. The lag, log, stationary and decline phases are shown.
Reference: https://www.nature.com/articles/srep15159 (accessed June 7, 2024).
Designed by Andrew Kingsbury, CFSPH.

- What policies and incentives can be implemented so that the earth can sustainably support the human, animal, and plant populations humanely and equitably far into the future?

The analogy of the bacterial growth curve and the human population curve breaks down when considering the Earth is a complex and

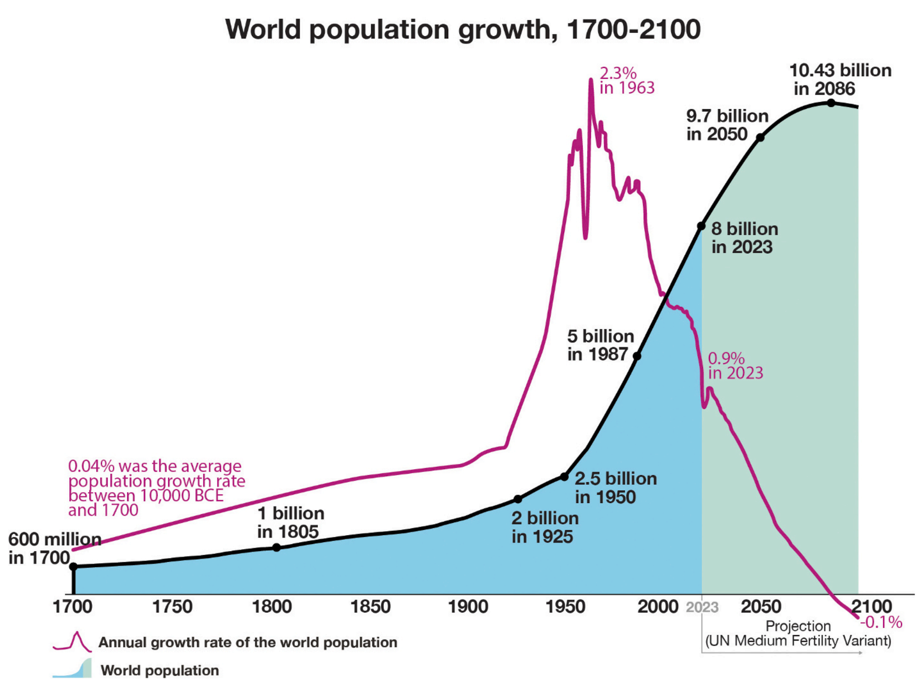

Fig. 1. World Population Growth, 1700–2100.
The area shaded in blue represents actual population growth, the area shaded in green is projected population growth (U.N. Medium Fertility Variant). The red line is the annual growth rate of the world population. https://ourworldindata.org/population-growth-over-time (accessed June 7, 2024).
Data Sources: Our World in Data based on HYDE, UN, and UN Population Division [2022 Revision]. Visualization from OurWorldinData.org, adapted by Andrew Kingsbury, CFSPH. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

dynamic environment. Forces of nature will cause the earth to adapt, which it has done for billions of years; these adaptations may not be advantageous for current animals, plants, and people. But adaptation can also occur due to human innovation. The International Symposium on One Health Research: Improving Food Security and Resilience held in Galveston, Texas from April 21–23, 2024 (that led to this special issue of the One Health Journal) focused on research to address food security both now and in the future. This multidisciplinary and collaborative research needs to include basic and applied research on food production that integrates and balances inputs for crop production and food animal production while protecting human health, animal health, and the environment while also conserving non-renewable resources. This will only be successful if resources, technology, and knowledge are shared and implemented in all countries.

An example of human innovation to address food security is the Green Revolution. In the 1940s, Dr. Norman Borlaug developed disease-resistant, high-yield wheat. That innovation, along with improved genetics of other crops and technological innovations, including mechanized agriculture, fertilizers, and irrigation, are credited with preventing famine in India and China. In 1970, Dr. Borlaug received the Nobel Peace Prize for his part in the Green Revolution. In his Nobel Peace Prize Lecture, he said *"The green revolution has won a temporary success in man's war against hunger and deprivation; it has given man a breathing space. If fully implemented, the revolution can provide sufficient food for sustenance during the next three decades. But the frightening power of human reproduction must also be curbed; otherwise, the success of the green revolution will be ephemeral only."* [6].

In 1986, Dr. Borlaug established the World Food Prize to elevate innovations and inspire action to sustainably increase the quality, quantity, and availability of food for all [7].

Currently, the predominance of food insecurity is in LMIC in tropical areas of the world [8]. This also tends to be the region of the world from which new diseases emerge. Individuals, families, and societies that are food insecure must focus on the immediate need for safe and healthy food. They do not have the luxury of considering the long-term effects of their decisions on the environment, future food production, and disease emergence. Humans and multiple species of animals tend to live in close proximity in these regions. It is in the best interest of developed countries to assist the LMICs in addressing their food security, public health, and economic issues to reduce the potential for diseases to emerge and spread worldwide.

Many daunting problems need to be addressed to improve food security in the future. The rest of this review article focuses on the vulnerability of food security due to dependence on a few species of animals for most of the world's animal-based protein. The same vulnerability applies to crop production; the world's major crops are threatened by climate change which can cause variability in temperature and rainfall with increased periods of drought and periods of flooding [9]. Crops are also threatened by the emergence of pathogens and the depletion of groundwater, soil fertility, fertilizers, and other nutrients. Research is needed to increase the diversity of crops and to adapt current crops to the changing environment and depletion of resources. Climate change also has an impact on agricultural pests and are a concern for both crop and animal production. Rising temperatures can expand the geographic range of pests, increase overwintering survival, increase the number of generations of pests, and increase the risk of invasive insect species and disease transmission to both plants and animals [4,10].

3. Food animal production

Most of the world depends on three species for the majority of animal protein production: Chickens for meat and eggs, Cattle for meat and milk, and Swine for meat (Fig. 3). The dependence on these three species leaves animal protein production vulnerable to the emergence of diseases that may limit the production of protein for human food. In addition, in many regions of the world, production animals in these species lack genetic diversity.

The two major methods for producing animal protein to feed the increasing human population are "backyard" production and concentrated animal feeding operations. Both are needed to produce sufficient high-quality protein to feed the world [11].

- Backyard food animal production efficiently uses local feed sources and reuses waste from human food, reduces the need for transportation and packaging and is an important source of protein and

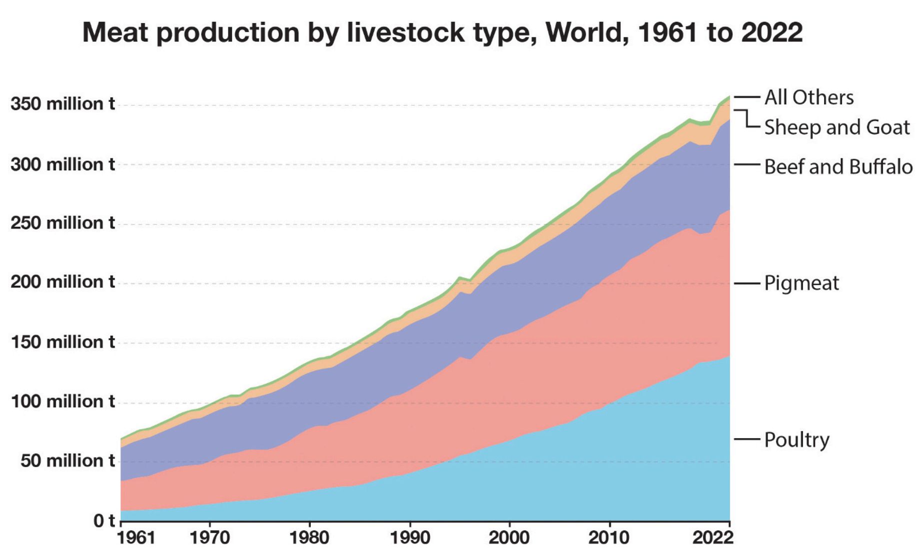

Fig. 3. Meat Production by Livestock Type, World, 1961–2022.
Most of world's food animal protein comes from poultry, swine, cattle and buffalo. Data represents dressed carcass weight, excluding offal and slaughter fats. Data Source: Food and Agriculture Organization of the United Nations (2023), https://ourworldindata.org/meat-production (accessed June 7, 2024). Visualization from OurWorldinData.org, adapted by Andrew Kingsbury, CFSPH.

income for families in LMIC. However, these animals may not receive sufficient veterinary care, vaccination, or biosecurity to protect them from disease. Close contact between animals, family members, especially children, and other people increases the potential for the spread of zoonotic diseases.

- Concentrated animal feeding operations in high income countries typically have good veterinary care, high health standards, good biosecurity, and produce high-quality protein at reduced costs. A disadvantage is that if an infectious agent gets into large populations of susceptible animals, it can quickly replicate and has an increased potential for mutation. Additional disadvantages can be environmental damage and animal welfare concerns if the animal feeding operation is not appropriately managed.

4. Emerging animal diseases

Transboundary and emerging animal diseases threaten both animal and human health and impact food security. Increases in human and animal populations coupled with international trade and travel enhance opportunities for pathogens to move within and between species. An example is the introduction of rinderpest from India to Africa in 1889. Rinderpest is a highly contagious, viral disease of cattle, domesticated buffalo, and some wildlife species. While not a zoonotic disease, it caused starvation and led to massive human fatalities in Africa. The disease killed approximately 90% of the cattle in sub-Saharan Africa as well as many sheep and goats. Wild buffalo, giraffe, and wildebeest populations were also impacted. The loss of draft animals, livestock and wildlife caused mass starvation. One-third of the human population in Ethiopia and two-thirds of the Maasai people of Tanzania died. Because of the vastly reduced number of grazing animals, thickets formed in grasslands. The thickets became a breeding ground for tsetse flies, the vectors for most trypanosomes, and resulted in an outbreak of trypanosomiasis (African sleeping sickness) in humans [12]. Some consider the rinderpest epidemic and the subsequent outbreak of trypanosomiasis to have been the most catastrophic natural disaster ever to affect Africa [13].

The Global Rinderpest Eradication Program, started in 1992, was a large-scale international collaboration, involving vaccination, local and international trade restrictions, and surveillance. Rinderpest was declared eradicated from the world in May 2011; it is only the second disease (after smallpox) to be globally eradicated. This effort is one of veterinary medicine's greatest achievements [14]. It is an excellent example of what can be accomplished through international collaboration and the application of science to an animal health and food security problem.

5. Examples of diseases currently threatening food animal production

Endemic diseases and parasites are a continuous threat to food animal production. They are managed daily through effective veterinary care, biosecurity, vaccination, prevention and treatment. The major food animal species are also currently threatened by emerging and re-emerging diseases that can spread rapidly through a region and between countries. Vaccines may not exist or be effective, and for these diseases, biosecurity practices may not be adequate. Four current examples are: (1) Highly pathogenic avian influenza (HPAI) in poultry worldwide and, recently an HPAI H5N1 virus has infected dairy cattle in the U.S.; (2) African swine fever (ASF) in swine in the Eastern Hemisphere and perhaps emerging in the Western Hemisphere; (3) lumpy skin disease (LSD) in cattle spreading in the Eastern Hemisphere; and (4) foot and mouth disease (FMD) is a constant threat to ruminants and swine in areas where it is endemic (Africa, the Middle East, Asia and a limited area in South America) and in countries that are free of FMD due to the devastating consequences of the disease if it is introduced.

- **HPAI:** In 1997, a highly pathogenic H5N1 avian influenza virus emerged in Asia and became established in poultry. Despite control efforts, these viruses and their descendants have continued to circulate and evolve in some regions. A highly pathogenic H5N8 avian influenza virus, which spread widely in Asia and Europe, reached the United States and Canada in 2014 and reassorted with North American avian influenza viruses. Some of the resulting viruses infected wild birds and poultry. One reassortant, a highly pathogenic H5N2 virus, caused extensive and devastating outbreaks among turkeys and laying hens in the U.S. Midwest in 2015. There were no reports of human illnesses linked to this H5N2 virus; however, other avian influenza viruses throughout the world, most notably an H7N9 virus in China and the H5N1 virus previously mentioned, have occasionally caused symptoms ranging from conjunctivitis or mild upper respiratory signs to life-threatening systemic disease with a greater than 50% case fatality rate and are considered zoonotic influenza viruses. HPAI H5N1 clade 2.3.4.4b virus has killed hundreds of millions of poultry and wild birds and sporadically infected various mammals, including dogs, cats, pigs, cattle, horses, zoo animals, multiple species of wildlife [15,16], and humans, and continues to evolve. In 2024, the HPAI H5N1 virus was reported to infect mammary glands in dairy cattle in the U.S. [17]. As of the date of this publication, there have been a few infections of humans associated with infected dairy cows, resulting in mild symptoms and no apparent human-to-human transmission.
- **ASF:** African swine fever was first identified in Africa in the early 1900s. It is now endemic in most of Sub-Saharan Africa. The European continent, except for the Mediterranean island of Sardinia, was free of ASF from the mid-1990s until 2007, when the disease was introduced to the Caucasus region, an area at the boundary of Eastern Europe and Western Asia. Since then, ASF has spread into adjacent regions, including parts of Europe, most of Asia, and most recently to the Western hemisphere on the Caribbean Island of Hispaniola (see Fig. 4) [18,19]. The animal health, economic, and food security impacts of this disease are staggering [20]
- **LSD**: Lumpy skin disease is a poxviral disease with significant morbidity in cattle. While the mortality rate is generally low, economic losses result from loss of condition, decreased milk production, abortions, infertility and damaged hides. The virus seems to be mainly spread by biting insects, and outbreaks can be widespread and difficult to control. It was confined to Africa at one time but has now spread to parts of the Middle East, Southern Europe, Russia, Armenia, Azerbaijan, Turkey, China, India, and Southeast Asia [21–23].
- **FMD:** Foot and mouth disease is a highly contagious viral disease that affects cloven-hooved animals (cattle, sheep, goats, pigs, deer, etc.). The disease is estimated to circulate in 77% of the global livestock population, in Africa, the Middle East and Asia, as well as in a limited area of South America. Countries with FMD in their livestock cannot export animals or uncooked animal products [24]. FMD can be controlled by extensive and carefully designed and executed national vaccination programs. An outbreak of FMD in the U.S. would shut off exports and have a devastating effect on the agricultural and related industries. Since the U.S. is a major exporter of swine, beef, and milk products, an FMD outbreak in the U.S. could reduce availability and increase the cost of these products for other countries,

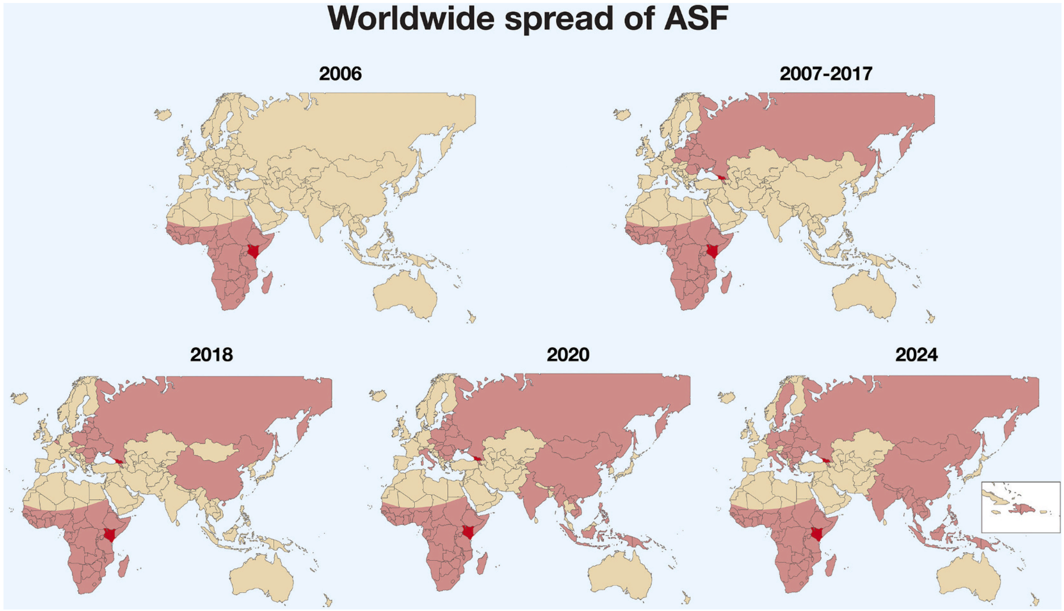

Fig. 4. African Swine Fever Spread, 2006–2022.
In 2006, ASF was confined to Africa and the island of Sardinia, but spread to Eastern Europe and Russia between 2007 and 2017. In 2018, ASF spread to China. By 2020, it had spread to most of Asia, and by 2024, there was further spread in Europe. ASF was detected in the Caribbean Island of Hispaniola in 2021.
Data sources: World Organization for Animal Health, WAHIS Analytics page. https://wahis.woah.org/-/home (accessed June 7, 2024).
USDA APHIS. https://www.aphis.usda.gov/african-swine-fever-asf-story-map (accessed June 7, 2024).
Graphic designed by Andrew Kingsbury, CFSPH.

6. Zoonotic diseases which could threaten food animal production and human health

The rapidly expanding human population and a corresponding increase in food animal populations have led to new zoonotic diseases in humans. Fig. 5 lists newly emergent or re-emergent zoonotic diseases since 1980. These diseases have had major impacts on human health, well-being, and society. It is reasonable to expect a similar list of newly emergent zoonotic diseases in the next 40 years.

Especially concerning would be the emergence of zoonotic diseases in food animals with a high case fatality rate in people. Potential examples are:

- **Avian influenza viruses:** HPAI viruses (discussed above) are highly contagious and are currently having a major impact on poultry production in many countries of the world. The Asian origin H5N1 highly pathogenic avian influenza (HPAI) clade 2.3.4.4b viruses emerged in 2013 and are of particular concern [15]. They have spread to most countries in the world and have infected numerous mammalian species in addition to poultry [16]. This has heightened the concern that it can potentially mutate into zoonotic viruses with transmission from human to human. If an HPAI virus arises that still infects poultry and has a high potential for transmission to humans with human-to-human spread, it could severely limit the ability to raise poultry for meat and eggs.
- **Nipah virus:** In 1998, a never-before-observed virus emerged in the Malaysian pig population, causing severe respiratory and neurologic signs. The virus spread to swine farmers and caretakers, resulting in more than 265 cases and over 105 human deaths in Malaysia and Singapore. There were also reports of infections and illnesses in some other mammals in contact with pigs. A novel paramyxovirus, which was named Nipah virus, was isolated from a human patient. Teams of experts developed diagnostic tests and control strategies (including the culling of more than one million pigs) that resulted in the eradication of the virus from the swine population [25]. However, healthy fruit bats carry the virus, and it is still present in fruit bats in

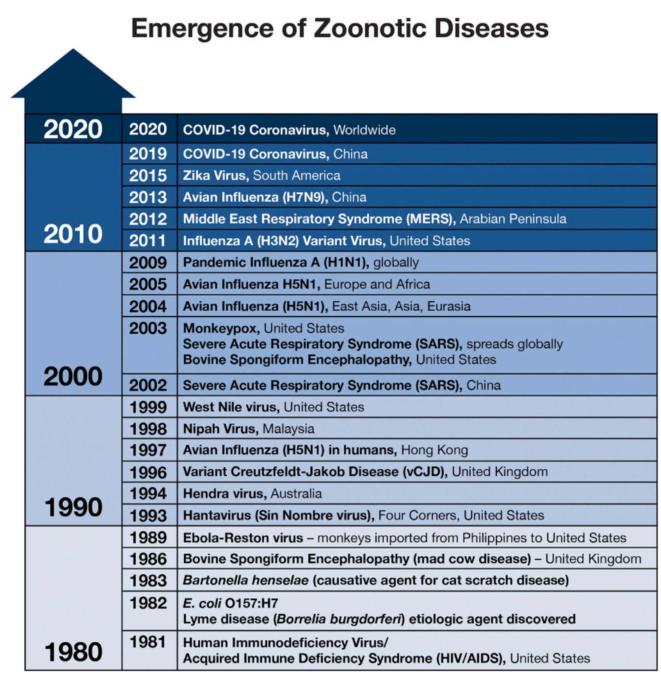

Fig. 5. Listing of emergent or re-emergent zoonotic diseases between 1980 and 2020.
This graphic contains the year, disease, and location of 23 emergent zoonotic diseases since 1981.
Data Sources: CFSPH Fact Sheets https://www.cfsph.iastate.edu/diseaseinfo/ (accessed June 7, 2024); World Health Organization https://www.who.int/emergencies/disease-outbreak-news (accessed June 7, 2024); Centers for Disease Control and Prevention https://www.cdc.gov/outbreaks/index.html (accessed June 7, 2024).
Designed by Andrew Kingsbury, CFSPH.

Southeast Asia; human cases of Nipah virus encephalitis have been reported in Bangladesh and India, in some cases due to eating fruit or drinking unpasteurized fruit juices contaminated by fruit bat urine or saliva. Subsequent human-to-human transmission has also occurred. The Bangladesh strain (NiV-B) is often associated with severe respiratory disease, whereas the Malaysian strain (NiV-M) is often associated with severe encephalitis [26–28].
- **Ebola viruses**: Swine can be experimentally infected with and shed Reston ebolavirus, Zaire ebolavirus, and Bundibugyo ebolavirus. The role of swine in initiating and transmitting Ebola virus infection during outbreaks in humans in Africa is unknown. Additional research is needed on the potential for these viruses to infect pigs and their potential to transmit to humans [29–35].

The diseases listed above have the potential to emerge as zoonotic diseases with a high case fatality rate. This could severely impact the ability to use these species for food production.

The emergence of human and animal diseases is facilitated by inadequate public health and veterinary services infrastructure in many countries. Infectious diseases flourish when large numbers of susceptible individuals are present in cities or animal production facilities. Zoonotic diseases flourish when there is extensive interaction between people, backyard animal production, and wildlife. Intensive animal production facilities and backyard food animal production are both necessary to feed the current and anticipated human population. However, they can lead to the emergence of new food animal diseases and zoonotic diseases. To address the issues described above, additional investments in research, public health infrastructure, and veterinary services are needed.

7. Research opportunities

- Improved surveillance through better diagnostic tests, especially field deployable rapid diagnostic tests. These tests must be inexpensive and validated for sensitivity and specificity.
- Integration of human and animal surveillance data to provide a near real-time operational picture.
- Improved vaccines, especially platform vaccines that are validated for purity, potency, and safety and can have genetic material from novel pathogens inserted and be rapidly produced to target newly emerging pathogens.
- Improved understanding of the pathogenesis of rapidly emerging diseases to elucidate potential methods to interrupt disease transmission, especially to humans.
- Improved communication with the public to improve implementation of public health and animal health recommendations.

8. Aquaculture opportunities

Fish and other aquatic animals are an important source of animal protein in the human diet. However, capture fisheries reached their limit for production in about 1990 [36]. Aquaculture has the potential to increase the diversity and quantity of animal protein production. Aquaculture production has increased dramatically in East Asia and the Pacific (Fig. 6). Other areas of the world could follow this successful example. Aquaculture production using indoor controlled recirculating systems can occur in any region of the world and can include effective biosecurity for disease control. Water can be purified and reused if it is a limiting resource.

Additional research is needed on nutritional requirements and diet formulation for some aquatic species, as well as on disease detection and prevention using biosecurity, vaccines, and immune stimulants [37]. Technology and infrastructure could be developed to promote and enhance aquaculture production in new regions. Needs include:

- o Equipment for recirculating systems to produce aquatic animals.
- o Production of commercial diets for optimal growth and health
- o Research on beneficial uses of byproducts from fish production and processing
- o Additional harvest facilities for processing aquatic animals for human food.

9. Conclusion

Addressing the scientific, economic, social, health, and environmental issues related to food production will be one of the greatest political challenges in the 21st century. Essential elements for a successful One Health approach to food security include:

- A one world, one health approach to disease control
- International collaboration, led by international organizations and funded by the developed world

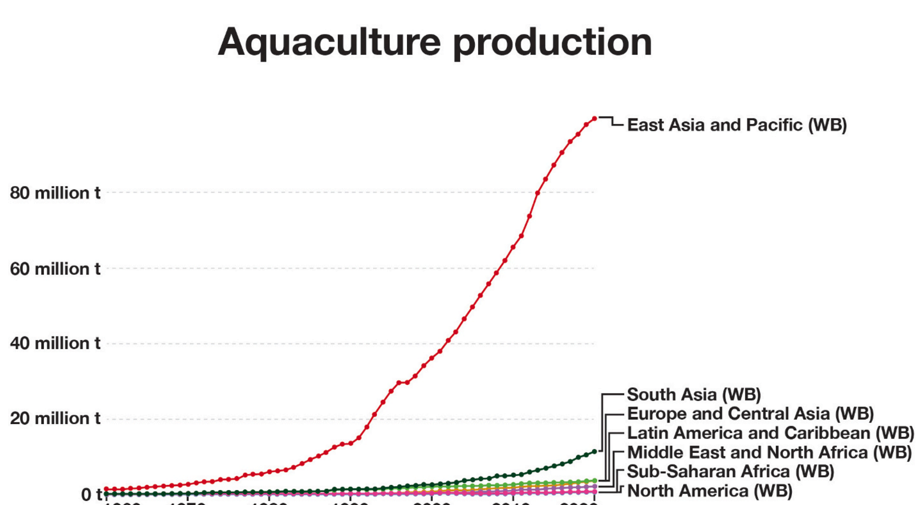

Fig. 6. Aquaculture Production in selected regions, 1960–2020.
Aquaculture production has increased dramatically in East Asia and the Pacific since 1990.
Data Source: Food and Agriculture Organization of the United Nations (via World Bank), https://ourworldindata.org/fish-and-overfishing (accessed June 7, 2024). Visualization from OurWorldinData.org, adapted by Andrew Kingsbury, CFSPH.

- A comprehensive effort to strengthen public health infrastructure and veterinary services in all nations
- Collaboration among government agencies, international organizations, the private sector, and academia to accelerate the application of modern science to improve crop production, food animal production, diagnostics, vaccines, and pathogen control. This will require increased funding and a streamlined approach to regulatory hurdles.
- Reform complex global regulatory processes that often prevent vaccines and medicine from being transitioned into regions of need.
- Evaluate trade policies. Governmental policies that prevent vaccination for transboundary and emerging diseases, such as HPAI, should be addressed.

Fortunately, concerns about worldwide food security are occurring at the same time as rapid advances in nearly all aspects of science, which can be applied to sustainably increase food production both locally and globally. There must be a collective will to apply science to solve current problems and to prepare for future challenges. This challenge mandates the need for the medical, veterinary, public health, agriculture, and environmental communities to work together locally and internationally to protect human health, animal health, plant health, food safety, food security, and the environment.

CRediT authorship contribution statement

James A. Roth: Writing – review & editing, Writing – original draft, Conceptualization. **Jane Galyon:** Writing – review & editing, Writing – original draft, Project administration.

Declaration of competing interest

The authors have no competing interests to declare.

Data availability

No data was used for the research described in the article.

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