# Parallel pandemics illustrate the need for One Health solutions

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**Abstract**

African Swine Fever (ASF) was reported in domestic pigs in China in 2018. This highly contagious viral infection with no effective vaccine reached pandemic proportions by 2019, substantially impacting protein availability in the same region where the COVID-19 pandemic subsequently emerged. We discuss the genesis, spread, and wide-reaching impacts of an epidemic in a vital livestock species, noting parallels and potential contributions to ignition of COVID-19. We speculate about follow-on impacts of these pandemics on global public health infrastructure and suggest intervention strategies using a cost: benefit approach for low-risk, massive-impact events. We note that substantive changes in how the world reacts to potential threats will be required to overcome catastrophes driven by climate change, food insecurity, lack of surveillance infrastructure and other gaps. We note that a One Health approach creating collaborative processes connecting expertise in human, animal, and environmental health is essential for combating future global health crises.

## Introduction

"One Health" is a recently coined, emblematic phrase representing a holistic approach to health care that defies simple definition and thus suffers from its inability to be easily comprehended. The Centers for Disease Control and Prevention (CDC), the One Health Commission, the United States Department of Agriculture (USDA), and the National Institutes of Health (NIH) define One Health as an approach, involving health of humans, animals (domestic and wild), and the environment (ecosystem, sometimes plants), and involving a wide lens and transdisciplinary effort[1]. The One Health Initiative Task Force, convened in 2008 by the American Veterinary Medical Association (AVMA), perhaps defines One Health most succinctly as: "the collaborative efforts of multiple disciplines working locally, nationally, and globally, to attain optimal health for people, animals and our environment"[2].

COVID-19 caused by SARS-CoV-2 is a putative zoonosis that emerged and spread globally within a matter of months. The COVID-19 pandemic is the most severe One Health crisis of our time. Examining the reasons underlying the emergence of SARS-CoV-2, its epidemic spread, effective ways to control the virus, and all the unforeseen consequences of COVID-19 will occupy pundits for decades. But SARS-CoV-2 did not emerge in a vacuum. A second pandemic caused by African Swine Fever (ASF) emerged in domestic swine populations in China just prior to COVID-19, spreading to Mongolia, Vietnam, and Eastern Europe by mid-2019. The ASF pandemic, while caused by a different virus in a different species, has strikingly similar drivers to COVID-19, and impacts of both infections have multiplied far beyond the original insult.

Here we describe the temporal and thematic links that reveal notably similar patterns in these two threats, also discussing factors associated with ASF that have compounded the COVID-19 pandemic. Commonalities between these pandemics include concerns surrounding transmission to and from wildlife, highly interconnected global travel networks, and concomitant

stresses on food supply and disease surveillance capacity. Potential future consequences of these pandemics include exacerbation of food insecurity and severe bottlenecks in surveillance capacity in the face of additional human or animal epidemics. These two pandemics underscore the need to incorporate many diverse and representative experts, as well as global cooperation, to improve disease control and prevention strategies and to overcome continuing threats. This approach is consistent with a One Health Framework.

**African Swine Fever**

Chinese consumers eat 28% of the global meat production, and pork remains the most preferred meat in China, accounting for 60-75% of meat consumption prior to the ASF outbreak. Chinese meat production has increased five-fold since 1980, with per capita consumption rising faster than production over that period and similar growth projected for the foreseeable future[3]. China remains the primary pork producing country globally, with half of the world's pigs, upwards of 700 million head per year, living in China. While Chinese pork production has historically been managed by smaller farming units, over the last decade, modern intensive swine rearing facilities have flourished to meet growing demands[4].

The Chinese pork market had been largely unhindered by serious disease threats during its expansion and intensification. However, production has been decimated by the recent emergence of ASF, a viral infection endemic in African swine and in feral swine (Fig. 1). ASF causes fever, lethargy, gastrointestinal disease, and respiratory illness typically leading to death in domestic swine[5]. ASF has been associated with serious economic ramifications during outbreaks in susceptible animals due to high mortality caused by the virus, the use of culling as a primary control measure, and trade restrictions with unaffected countries.

The first case of ASF in the current epidemic was recorded in China in August 2018, likely attributed to feeding of contaminated swill and/or movement of feral pigs from Mongolia and Eastern Europe into China[6]. In order to halt the spread of ASF, the Chinese government mandated strict culling laws, with a recommendation to slaughter every pig within 3km of a known infection[7]. Despite these orders, ASF has spread to all mainland provinces. Estimates of the number of slaughtered pigs range from 150-200 million, which represents 30% of all Chinese pigs, though the true figure may approach 50-70% of the total pig population[8], [9]. Although the economic impacts of ASF are still being tallied, some scenarios have calculated a 1% reduction in China's GDP ($100B U.S.)[10]. It is also estimated that the incursion of ASF into china killed half of breeding sow stocks, this resulting in lower production of pigs (China Ministry of Agriculture). As of August 2020, the virus has additionally spread to many Asian countries including Vietnam, Cambodia, Indonesia, and India, causing significant impacts to pork production across Asia and Europe[11], and ASF was recently reported in several feral swine in Eastern Germany[12].

The rapid spread of ASF has been influenced by a variety of factors, some intrinsically related to the virus, and others to governance, culture, and economy (Fig. 2). ASF is a hardy and stable virus, reported to survive both high temperatures and freezing, and can survive for long periods of time on food products, waste, fomites, and other pigs[13]. The feeding of kitchen waste (including both raw and cooked pork) is a common cultural practice in China, which results in a rapid chain of transmission between animals. Pig density was identified as the most important predictor of an ASF outbreak; thus, the economic drive trend for consolidation of pork production in intensive rearing conditions has also contributed to the spread of the epidemic[14].

In addition to viral attributes, environmental risks, and cultural practices, there are unique aspects of the Chinese food economies that likely contributed to the spread of ASF. The Chinese pork market is largely non-automated, emphasizing the affinity in China for "warm

meat" (Fig. 2). Warm meat describes a system of slaughter, process, and transport that relies on a truck-based refrigeration system to deliver pigs to markets within 24 hours[15]. Consequently, pigs raised in one province may be shipped hundreds of miles to a slaughterhouse and presented at market shortly thereafter, presenting challenges for disease outbreak tracing and containment. Another key element in the food culture of China that may have contributed to ASF spread is the decision to purchase food at a "wet market" versus a supermarket. "Wet markets" refer to those locations offering fresh meat, seafood, and produce, and differ from "wildlife markets", which specialize in the sale of live wildlife, both farmed and wild-caught[16]. These terms are often used interchangeably and in some wet markets, wildlife is also sold. Wet markets complicate ASF control as there are reports of live pigs and pig products in close association[15].

The Chinese government was reported to limit some initial communication on the spread of ASF[17]. In the fall of 2019, Chinese authorities increased positive media around pork production, using a strategy that was described by Chinese political analysts as a reaction to concern for "social stability"[18]. Although messaging around ASF was overshadowed by news about COVID-19 for several months, the Chinese government increased communications aimed at restoring pork production and expanding pork imports in early 2020[19].

Stability of the Chinese pork market faltered as ASF decreased pork supply. Government actors and suppliers began to look to other protein sources to meet demand, which rapidly induced global impacts on other commodity markets. The pork price was flat in 2018 (20 – 30 Yuan per kg) but saw an increase in 2019 of up to 55 Yuan/kg (China Ministry of Agriculture). The ASF outbreak resulted in a 17-85% increase in pork prices and a 63% increase in pork imports in 2019, as well as increased import of beef, chicken, and other meats[8]. The increased demand for meat by China quickly had global ramifications on pricing and production efforts. For example,

104 the European Union saw a 40% increase in producer prices[3]. Other pork-producing countries,
105 such as Canada and Brazil, saw increased shares in the global pork market, and imports from
106 these countries contributed up to one half of China's in-country market share[20].
107
108 The demand for alternative protein sources may have also impacted wildlife markets and
109 production systems. Most wildlife products are considered delicacies and are more expensive
110 than mass-produced livestock, and, accordingly, wildlife meat trade reportedly represents a
111 small component of meat consumption in China[21]. The Chinese government historically
112 encouraged wildlife trade as a form of rural economic development, enhancing through policy
113 rather than investment both farmed wildlife production and wild harvest[22]. Given its unofficial
114 status, this sector is prone to poor regulation, and official statistics on pricing or production are
115 scarce. Further, this sector is prone to contamination with illegal imports as China remains the
116 predominant destination for illegally trafficked wildlife species[23]. While it is unclear how
117 disruption to pork markets may have affected activity at wildlife markets, ASF is likely to have
118 stimulated demand for non-pork products given the increase in livestock meat prices and the
119 Chinese government's encouragement of alternative protein sources. The convergence of
120 circumstances outlined here suggest that acceleration of COVID-19 due to severe disruption of
121 the Chinese pork market is plausible.
122
123 The ASF outbreak has many elements of a 'One Health' pandemic, in that a convergence of
124 animal, human, and environmental conditions resulted in its ignition and subsequent epidemic
125 spread (Fig. 2). The consequences of the outbreak relating to food insecurity and potential
126 indirect amplification of SARS-CoV-2 emergence and the continuing spread of ASF across Asia
127 and Europe will require a focused effort among basic scientists, epidemiologists, the agricultural
128 sector, industry, and governmental representatives to thwart the worst potential outcomes of this
129 pandemic. .

**COVID-19**

During the ASF outbreak in Chinese swine markets, a cluster of pneumonia cases were reported in Wuhan city, Hubei province, China, throughout December 2019 and reported to the World Health Organization (WHO) on December 31, 2019 (Fig. 1). Initial cases were linked to Huanan Seafood Wholesale Market, a wet market, causing public health officials to suspect a zoonotic origin owing to the presence of numerous live animal species at the market. The genome of the virus was sequenced and released by January 10th [24]. It was identified as a sarbecovirus (family *Coronaviridae*), closely related to the virus causing severe acute respiratory syndrome (SARS), and thus was named SARS-CoV-2[25], [26], [27]. Over a short period of time, the virus spread regionally and globally, and by January 31st, 2020, over 2,000 individuals in 27 countries were confirmed infected, culminating in the announcement of a Public Health Emergency of International Concern by the WHO[28].

Throughout the early stages of the pandemic, there was a great degree of speculation as to the evolutionary origins of SARS-CoV-2 and the animal species involved in the spillover event to humans[26], [27]. Virologists and epidemiologists conducted extensive environmental and animal sampling at the Huanan seafood market to determine whether SARS-CoV-2 was present at the Huanan market in December 2019. In May 2020, the director of the Chinese Centers for Disease Control and Prevention announced that all animal samples tested for SARS-CoV-2 were negative, suggesting that the Huanan Seafood Wholesale Market was likely a point-source outbreak rather than the location where the initial animal-to-human transmission event took place.

The first case of confirmed COVID-19 was admitted to a hospital in Wuhan on December 16th, 2019, and by January 2nd, 2020, 41 admitted cases had been diagnosed at the same hospital in Wuhan.[28] On December 30th-31st, information about the cases was shared with local physicians

and the public to spread awareness and try and curb community spread. The WHO and CDC were also notified on December 31st. While this rapid pace of scientific progress is virtually unprecedented, initial response by the Chinese government to recognize and warn of SARS-CoV-2 emergence has been criticized by other countries, particularly the United States[29], [30], [31]. This failure to take immediate action is perhaps most poignantly illustrated by the death of Dr. Li Wenliang of COVID-19 in early February 2020[32]. Dr. Li, an ophthalmologist working in Wuhan, warned fellow physicians about a new SARS-like outbreak in December 2019. He was detained and made to sign a document acknowledging false statements by the Chinese Public Security Bureau in January 2020[32]. Prior to his death, Li was quoted by the New York Times as stating, "If the officials had disclosed information about the epidemic earlier, I think it would have been a lot better"[33]. Conversely, top Chinese officials have defended Beijing's response to the emerging pandemic, and China has been commended for improving its response since the initial SARS outbreak in 2003 by some, while the United States has been widely criticized for its mishandling of the epidemic (Reuters, Nature, Guardian).

Human isolates of SARS-CoV-2 were made available to researchers, and characterization of the virus in laboratories across the world began in earnest in early 2020. Following the 2002-2004 SARS outbreak, several therapeutic and vaccine candidates were identified for SARS; however, due to a paucity of reliable animal models, questions surrounding duration of immunity and safety, and funding constraints, no vaccines made it past Phase 1 trials and no antivirals were brought to market or authorized for use by the United States Food and Drug Administration (FDA)[34], [35], [36] (Fig. 2). Informed largely by *in silico* and *in vitro* work, attempts have been made to develop new pharmaceuticals and repurpose existing ones for use against SARS-CoV-2, with several trials underway[37], [38]. To date, few therapeutic options exist, though FDA emergency use authorization was recently obtained for use of remdesivir, monoclonal antibody therapy, and convalescent plasma in severe COVID-19 cases in the United States[39].

The basic reproductive rate ($R_0$) of SARS-CoV-2 is estimated to be equal to or higher than the $R_0$ of SARS or 1918 influenza[40]. In addition to the ease of transmission and potential for aerosolization, a suite of other factors contributed to the rapid global spread of the virus[41] (Fig. 2). Asymptomatic and pre-symptomatic transmission contributed to several point-source outbreaks at nursing homes and other care facilities, and uncertainties surrounding incubation period complicated contract tracing and transmission network analysis[42], [28]. The inability to rapidly detect and quarantine cases owing to insufficient diagnostic capacity is considered to be one of the most significant disruptions to the COVID-19 response in the United States, the country with the highest number of cases [43](Fig. 2).

On February 24, 2020, the Chinese government instituted a ban on the trade and consumption of non-aquatic wildlife modeled on prohibitions instituted after the SARS-CoV 2003 outbreak, linked to trade in civet cats, that had been relaxed subsequent to social and economic pressures[44]. The current ban notably avoids any restrictions on wildlife trade related to Chinese Traditional Medicine (CTM), which drives a substantial portion of wildlife trade in China. Given the ubiquity of wet markets in SE Asian countries including Vietnam, other countries have also considered or implemented wildlife trade bans in response to the COVID-19 outbreak[45].

**Comparison of parallel pandemics**

ASF and COVID-19 are examples of 'One Health Pandemics,' i.e. contagious spread of virulent infections across a significant portion of the globe because of animal, human, and environmental interactions. Prediction, prevention, mitigation, and restoration phases of such outbreaks require consideration of cultural, political, industrial, economic, nutritional, and psychological components of complex but interacting societies and habitats. It is impossible to 'solve' One Health pandemics unilaterally, as underlying social issues impact every phase of the outbreak. Review of the vastly different patterns of COVID-19 control and outcomes across

208 varied geopolitical units underscores how decisions at one site by one community, or even one
209 individual, can result in an unintended domino effect. The monumental effort required to
210 manage a spiraling pandemic requires resilience, unity, and foresight.
211
212 We note striking similarities between the complex biological histories and complicating factors
213 that resulted in rapid spread and stymied mitigation efforts in the ASF and COVID-19
214 pandemics (Fig. 2). Neither virus has approved antivirals nor prophylactic vaccines. Both
215 viruses are multi-host pathogens, complicating our understanding of the origins and/or
216 epidemiology of the virus within larger-scale systems. Both viruses have a suspected
217 connection to wildlife disease spillover; ASF is enzootic in many wild boar populations at a
218 prevalence high enough to facilitate periodic spillover into domestic swine populations, while
219 SARS-CoV-2 is speculated to have its origins in Rhinolophus spp. Bats[46], [27].
220
221 Importantly, both pandemics highlight the difficulty of adequately preparing for and containing an
222 outbreak due to complicating social and political factors. China published an ASF contingency
223 plan in 2015, requiring the culling of all pigs within a 3km radius of the initial site[7]. However,
224 when this plan was initiated as the virus spread rapidly throughout China, reporting of the
225 disease was stigmatized and culling of surrounding stock was often not performed[19].
226 Governmental subsidies were inadequate to support farmers with culled herds, and
227 enforcement of transport and slaughter regulations was sometimes poor[19]. Aggressive testing
228 and contact tracing were critical to the early containment of COVID-19, as reflected by the
229 discrepancy in outcomes in different regions. Among other countries, Austria and Germany
230 were pro-active in testing and closing public places to curb early spread. Vietnam, Singapore,
231 and Taiwan, having been significantly affected by the 2003 SARS outbreak and avian influenza,
232 had developed infrastructure to deal with a highly transmissible respiratory pathogen. As a
233 result, they witnessed lower fatality rates than the United States, Italy, France, and other

234 countries that implemented less aggressive diagnostic protocols and social distancing
235 measures.
236
237 The first SARS outbreak in 2002-2004 likely began at a wildlife market in Guangdong province.
238 In response to evidence of the virus circulating in masked palm civets (*Paguma larvata*) and
239 other live wildlife held at the Guangdong markets[47], [48]. China banned all markets from holding
240 live wildlife in 2003, though a decision to not enforce this ban occurred within months[49], [50].
241 Conversations surrounding the origins of SARS-CoV-2 in early 2020 have brought this
242 controversial issue to the attention of policymakers. Following evidence of SARS-CoV-2 having
243 its evolutionary origins in bats, wet markets shut down, though some re-opened as early as
244 February[51]. While many argue for a blanket ban against the existence of all wet markets, others
245 highlight issues of food insecurity that arise from their closures, particularly in light of the ASF
246 pandemic[52].
247
248 Controversies have arisen over implementation of control measures for human-to-human
249 transmission of SARS-CoV-2 in the United States, including issues such as length of
250 quarantine, mask wearing, importance of social distancing, and policy enforcement. Similarly,
251 there has been a lot of debate about eliminating backyard pig production systems responsible
252 for pig-to-pig transmission of ASF virus since these systems lack appropriate biosecurity
253 measures. However, these systems provide a robust support for and enhance welfare of and
254 livelihoods of smallholder farmers, and thus would have negative impacts on resource restricted
255 communities. Personal freedom, mental health issues, and economic concerns are all cited as
256 reasons to decrease protective regulations even in the face of active disease spread. Under-
257 reporting of disease incidences and misinformation about risk factors have been flagged as
258 contributors to the rapid growth of outbreaks in the United States and other countries, indicating

that the challenges noted in China's official response to both ASF and COVID-19 also occurred in other countries with different governing systems.

The coincident ASF and COVID-19 pandemics amplified the rate of spread and severity of each infection in several ways. The pork processing industry in China is highly reliant on manual labor. The spread of COVID-19 sharply limited the availability of the labor force at a time when the inspection, testing, and culling of pigs demanded an increase. There are reports that visual or symptomatic inspections were reduced or not performed during the initial months of the COVID-19 pandemic. In addition, imports of meat from South America and other countries in winter of 2019-20 were unable to be promptly transported from Chinese ports due to COVID-19 transportation disruptions and labor shortages[53]. And as previously noted, pork shortages drove dietary changes to increase other protein sources, potentially increasing human-to-human contact and exposures to wildlife that may have served as reservoir or intermediate hosts for SARS-CoV-2. The impact of the compounded economic, dietary, and psychological stressors caused by the two pandemics on the immune response and subsequent disease susceptibility and severity has yet to be determined, but there are undoubtedly other intersections of the two pandemics, at least in China.

**Downstream consequences of COVID-19 and ASF**

There are many tangible and unforeseen consequences of the COVID-19 and ASF outbreaks, including economic and social upheavals (Table 1). Consideration of follow-on consequences could aid in risk reduction of future scenarios and promote positive outcomes resulting from innovations and actions initiated in response to knowledge gained from these pandemics. Additional emerging infectious disease outbreaks are a significant concern, as medical, diagnostic, and supply infrastructure is currently severely stressed by urgent needs of these two pandemics. In the United States, many national animal health and veterinary

diagnostic laboratories are currently assisting with SARS-CoV-2 diagnosis, severely limiting capacity to survey ongoing zoonotic and endemic diseases of animals. A significant animal health disease outbreak could thus go undiagnosed or underdiagnosed, hampering control efforts[54], [55]. Highlighting the reality of this risk, avian influenza outbreaks have been reported in Australia, Taiwan, Hungary, Poland, and the United States during the COVID-19 pandemic. Additionally, research in important human diseases causing great morbidity and mortality in developing countries, such as HIV, TB, polio, and malaria is being neglected or hampered by resource restrictions, interfering with longstanding and painstaking efforts to control these diseases[56]. In the United States, changes in human behavior during the pandemic have resulted in record numbers of salmonella outbreaks (from backyard chicken rearing) and a fear of increased cases of Lyme disease (attributed to increased outdoor activities in the midst of a climate patterns favoring tick populations) as well as increased risk of health consequences due to inactivity, weight gain, and mental health issues[57],[58]. Alternatively, social distancing and sanitation behavior dictated by COVID-19 could enhance awareness on reasons for such practices and lead to the observation of biosafety and biosecurity in livestock production systems that require high levels of biosecurity. Finally, increased death rates have been noted and are suspected to be due to 'medical distancing' secondary to restricted access to health care and/or fear of SARS-CoV-2 infection at health care facilities[59].

Beyond infectious diseases, supply chain issues have interrupted food and material supplies, leading to euthanasia and disposal of livestock, food insecurity, and unpredictable shortages of goods ranging from toilet paper to Plexiglas (Table 1). Civil and social unrest, permanent modification of workplace and educational frameworks, and changes in protein consumption patterns are likely to be key outcomes of these two pandemics. On the positive side, investment, and discovery to advance diagnostics, therapeutics, vaccines, and other solutions

for infectious disease mitigation are rapidly developing, likely with impact far beyond COVID-19 and ASF (Fig. 2).

**How do we prepare for the next One Health Pandemic?**

A white paper authored by Senator Lamar Alexander entitled "Preparing for the Next Pandemic" was published in June of 2020[10]. In the paper Senator Alexander notes that “During the past 20 years, four Presidents and several Congresses enacted nine significant laws to help local, state, and federal governments, as well as hospitals and health care providers, to prepare for a public health emergency, including a pandemic. Congress received many reports from presidential administrations, Offices of Inspectors General, the Government Accountability Office, and outside experts throughout those 20 years warning that the U.S. needed to address the following issues: better methods to quickly develop tests, treatments, and vaccines and scale up manufacturing capacity; better systems to quickly identify emerging infectious diseases; more training for health care and public health workforce; better distribution of medical supplies; and better systems to share information within and among states, and between states and the federal government.” This informative report painstakingly catalogues a summary of past government efforts for pandemic preparedness, which clearly were not effective in stemming COVID-19’s rapid and complete spread across the United States, or the globe, with devastating health, economic, and social consequences. The report concludes with five common-sense mechanisms to quell the next epidemic, which, though sensible and obvious at this point in the pandemic, are hardly novel.

Why has it been so hard for the United States, in particular, and the world in general, to prepare for pandemics that have been repeatedly documented as a threat to the lives of millions of animals and humans, when we know the consequences are catastrophic? And what can we do to reverse this predictable trend?

Social, cultural, and political factors underlie our seeming inability to prepare for disease outbreaks. Pandemics are, on a whole, exceedingly rare events relative to the number of human-animal-environmental interactions that occur millions if not billions of times in a decade but do not result in spillover and epidemics of high morbidity or mortality (Fig. 3). For example, primary factors leading to SARS-CoV-2 emergence (human-animal interactions at wild-urban interface) and ASF (transport of food products across international borders) are events that happen routinely, every day. Thus low-risk, high-impact events resulting in infection in a target population ignite the beginnings of an outbreak. Investment in prevention of spillover follow-on infection, versus preventing the myriad of interactions with exceedingly small probabilities of ignition, would overcome the need to eliminate practices and behaviors that are vital to community identity or survival. Accordingly, development of strong local and regional surveillance networks and incentivizing data sharing and open communications are essential to change outcomes of future spillover events.

Successful pandemic preparedness, however, must also expand beyond local and regional borders. As has been potently demonstrated by the ASF and COVID-19 pandemics, disease is not constrained by boundaries of country or category. ASF may not be zoonotic, but it has far reaching impacts on the human population that involve economics, nutrition, environmental management, trade, food security, wildlife interactions, and others. Similarly, the impact of SARS-CoV-2 is far from just a human health concern and has affected nearly all aspects of human life around the globe from airline travel to consumption trends to environmental impact to mental health. The multifaceted impacts and influences of the ASF and COVID-19 pandemics strongly support a One Health approach to pandemic management that incorporates a team of diverse and transdisciplinary experts to cooperatively determine the most appropriate and comprehensive steps to handling and solving complex problems (Fig. 4).

One Health requires an inclusive process that breaks down barriers and brings together professions and organizations. For maximal efficacy, teams should be international, or hubs connected internationally, to help incorporate unique cultural and ethnic needs into truly workable solutions. Creating a funded network of One Health teams and Centers of Excellence across the United States and globally would provide a strong, coordinated means of addressing worldwide problems. Areas for investment to intersect early phases of pandemics, following a One Health framework, include the following: enhancement of local surveillance efforts, with enhanced capacity for data storage and analysis to detect new infections; communication strategies at local, regional, country-level and global scales, incentivized by investment of resources and recognition of scientific expertise and public health management; international training programs that inspire diverse early career scientists to engage in One Health collaborations; and One Health legislation and investment to operationalize roadmaps that outline plans for mitigation of future pandemics. Although challenging to implement, a One Health approach has immense potential to improve future outcomes not only for infectious disease concerns but other shared problems as well.

Indeed, creating a One Health framework that facilitates finding solutions to the "other shared problems" may be the key to truly successful disease outcomes moving forward. As Peter J. Hotez, a physician and vaccine developer, is quoted saying, "We must remove the conditions in which new diseases arise: poverty has more impact than any of our technical interventions….Political collapse, climate change, urbanization, deforestation: these are what's holding us back. We can develop all the vaccines and drugs we want, but unless we figure out a way to deal with these other issues, we'll always be behind" [60].

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## Author Contributions

All authors contributed extensively to the work presented in this paper. S.V., C.T., A.F., T.W., and G.W. wrote the manuscript. S.V. and T.W. conceived of the manuscript idea and discussion. G.W. contributed on content about wildlife trade. A. F. researched and wrote about COVID-19 and designed Fig. 1 and Fig. 3. C.T. researched and wrote about African Swine Fever, designed Fig. 2, and prepared manuscript. T.W. designed Fig. 4. E.O.A. reviewed manuscript and contributed to discussion of implications.

## Competing Interests

The authors have no competing interests to declare.

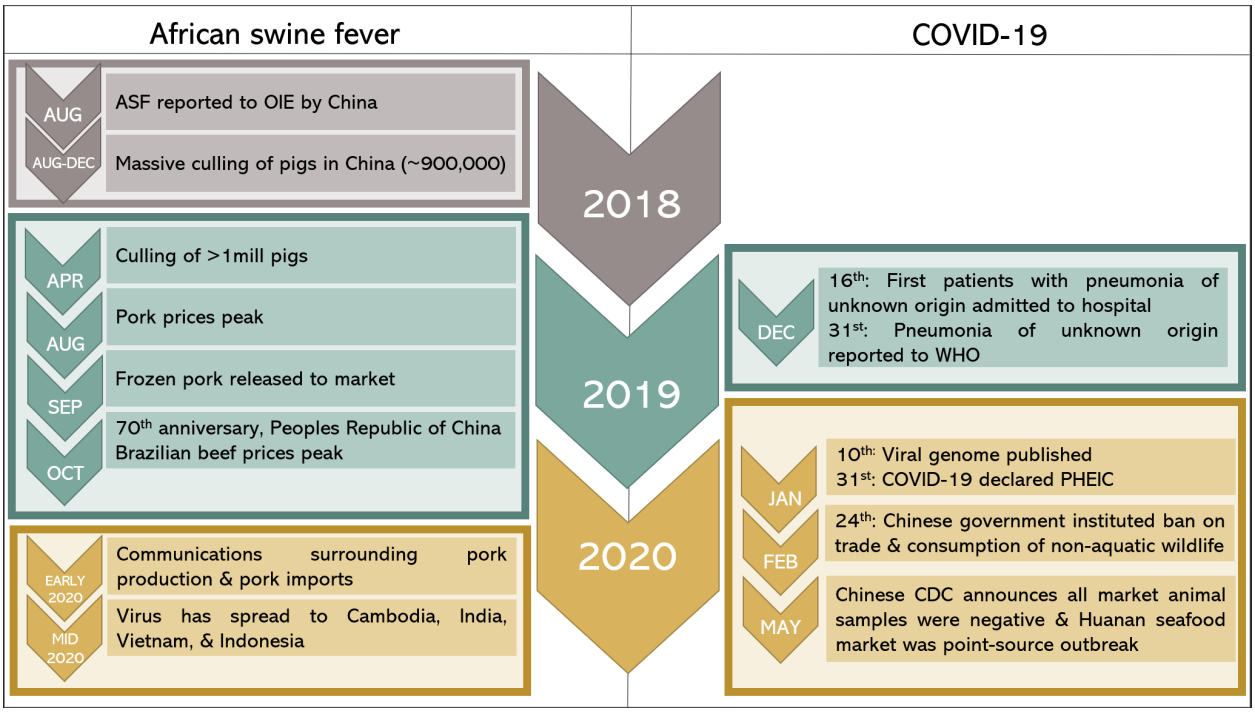
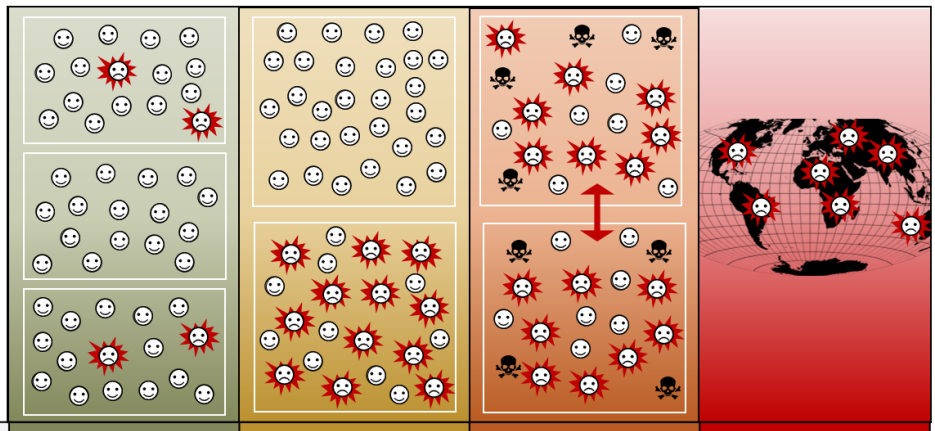



**Figure 1. ASF and COVID-19 timeline reveals overlap in pandemic emergence. Major outbreak milestones are indicated.**

| | DRIVERS | | OUTCOMES | |
|---|---|---|---|---|
| | ASF | COVID | ASF | COVID |
| **Biologic** | No vaccination at time of pandemic | | Development of vaccination and novel therapies | |
| | Previous knowledge of disease or family of viruses | | | |
| | Suspected wildlife vector | | Rapid regional spread | |
| | High mortality | Low mortality | | |
| | | | | |
| **Economic** | Robust Chinese pork market with frequent movement of swine | Wildlife trade: illegal and farmed | Collapse of Chinese pork industry | Market collapse across economic sectors |
| | Emphasis on warm chain meat | Wet markets as sector of food economy | Reliance on foreign meat markets | Widespread unemployment |
| | | | | |
| **Sociopolitical** | Initial support of disease surveillance and management | | Distrust of public health and science | |
| | Incentives missed | | Fractured, regionally-specific management plans | |
| | Spread of misinformation about extent of disease | | Spread of conspiracy theories | |

**Figure 2. Drivers and outcomes of ASF and COVID have animal, human, and environmental health implications.** This comparative framework identifies commonalities and predictable aspects of One Health pandemics.



| PARAMETER | STEADY STATE LOW-LEVEL EXPOSURE | LOCAL OUTBREAK | REGIONAL OUTBREAK (EPIDEMIC) | PANDEMIC |
|---|---|---|---|---|
| Populations affected | Many, ubiquitous | Single | Multiple connected | Global |
| Investment to prevent or predict | Extremely high | Moderate/high | Moderate | Low |
| Cost to mitigate outbreak | Low | Low/moderate | Moderate | Extremely high |
| Global impact of event | Low | Moderate | High | Extremely high |

**Figure 3. One Health pandemics are launched by low-risk, massive-impact events.** Humans and animals are engaged in a constant level of 'steady-state' activities that could potentially result in pathogen transmission. Most of these situations do not result in competent infection (panel A). However, rare spillover events following pathogen-individual interactions results in an 'index case', illustrated in Panel B. Infection in one individual does not typically result in a pandemic, but local or regional infections might occur when pathogens are well-suited for infection of the new host (Panel C). Regional outbreaks can potentially spread globally through transportation networks or via efficient individual to individual spread (Panel D). The investment to prevent or predict spread is best deployed at the local or regional scale to focus on true outbreak settings before mitigation costs are extraordinarily high. Investment in infrastructure for early detection and incentivizing early reporting and mitigation would minimize the risk of global pandemics.

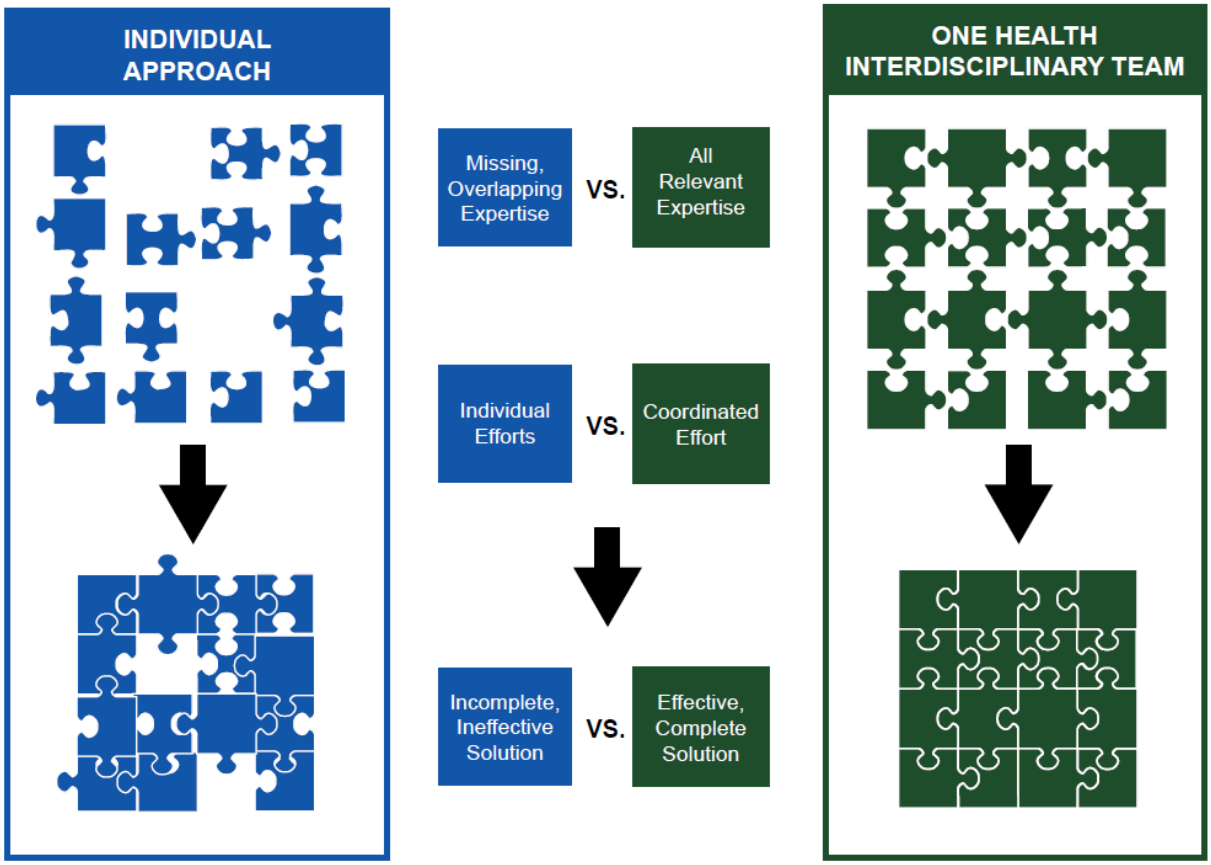



**Figure 4. A One Health approach brings together a diverse, inclusive, multidisciplinary team of experts to address complex problems resulting in coordinated, effective, complete solutions.** One Health teams incorporate individuals from all science disciplines including but not limited to data, math, computer, engineering, behavioral, social, economic, cultural, natural, applied, biomedical, agricultural, and environmental sciences. Creating a framework for One Health teams with international connections can decrease the challenges and costs associated with multiple individual efforts towards concerns with global impact such as the ASF and COVID-19 pandemics.

| Positive Direct/ Indirect Effects | Negative Direct/Indirect Effects |
|---|---|
| Acceleration of discoveries that allow more rapid and accurate disease diagnosis | Worsening of health and wealth disparities |
| New vaccine and therapeutic approaches and improved understanding of virus-host interactions | Worsening of food insecurity |
| Empowerment of a new generation of politically active citizen | Amplification of misinformation campaigns and distrust of government agencies |
| Decreased carbon emissions from significantly curtailed global travel | Increase in incidental diseases due to behavioral changes |
| Decreases in communicable diseases resulting from public health practices | Increase in secondary disease from health care disruption |
| Neutral Direct/Indirect Effects | |
| Changes in protein consumption patterns | |
| Permanent modification of workplace and educational practices | |
| Shifts in geopolitical power and economic structures | |

Table 1. Downstream consequences of COVID-19 and ASF pandemics.