Received: 5 August 2020 | Revised: 22 November 2020 | Accepted: 25 November 2020

DOI: 10.1111/conl.12784

Conservation Letters
A journal of the Society for Conservation Biology
Open Access
WILEY

POLICY PERSPECTIVE

African Swine Fever threatens Southeast Asia's 11 endemic wild pig species

Matthew Scott Luskin[1] | **Erik Meijaard**[2,3] | **Selly Surya**[4] | **Sheherazade**[4] | **Chris Walzer**[5,6] | **Matthew Linkie**[4]

[1] School of Biological Sciences, University of Queensland, Brisbane, Queensland, Australia

[2] Borneo Futures, Bandar Seri Begawan, Brunei Darussalam

[3] Durrell Institute of Conservation and Ecology, University of Kent, Canterbury, Kent, UK

[4] Wildlife Conservation Society, Indonesia Program, Bogor, West Java, Indonesia

[5] Wildlife Conservation Society, The Bronx, New York

[6] Research Institute of Wildlife Ecology, University of Veterinary Medicine, Vienna, Austria

Correspondence
Matthew Scott Luskin, School of Biological Sciences, University of Queensland, Brisbane, QLD 4072, Australia.
Email: m.luskin@uq.edu.au

Abstract

The spread of the most recent African Swine Fever (ASF) outbreak in Asia since late 2018 poses a significant threat to endemic pig species and socioeconomic security. Within domestic pigs and free-living Eurasian wild boars (both *Sus scrofa*) in Asia, ASF causes almost 100% case fatality. The ongoing ASF epidemic has so far caused the death of over one hundred million domestic pigs, causing unprecedented economic impacts on the global pork industry. Transmission among free-living wild boars has been reported, and transmission to threatened Asian pig species is probable but lacks research. Our assessment reveals a near-term risk for Southeast Asia's 11 endemic pig species, which have small population sizes and small ranges that may be insufficient to withstand the initial, lethal onslaught of the disease. The decline of pigs also triggers cascading impacts for endangered carnivores, plant communities, and livelihoods of millions of people. Our management recommendations include time-critical research themes, improved emerging infectious disease detection through site-based monitoring and surveillance paired with online reporting and proper carcass disposal.

KEYWORDS

cascades, emerging infectious diseases, livelihoods, pandemic, prey depletion, Red List, research priority, species conservation, Suidae, Sustainable Development Goals, virus, zoonotic disease

1 | INTRODUCTION

African Swine Fever (ASF) is an emerging infectious disease caused by a DNA virus that is lethal for many pig species, but is harmless to people and other animals (FAO, 2020). Transmission occurs through direct contact, indirectly via vectors, such as *Ornithodoros* ticks (Golnar et al., 2019), or through consumption of infected carcasses or even cooked pork products (FAO, 2020; Sur, 2019). Since 2019, the rapid spread of ASF in Asia has devastated pork producers and threatens wild pig conservation. Further, the decline of wild pigs could trigger cascading ecological impacts and affect millions of people that depend on wild pigs as an important protein source.

To address the potential threat ASF poses to native wild pig species, we first map the ongoing spread of the disease through Asia in relation to the pig species ranges, showing high likelihood that ASF will soon (or already

has) reached many of the region's threatened pigs. We then summarize factors contributing to the susceptibility of endemic pig species to ASF if it arrives in a region or island. We separate domestic and wild *Sus scrofa*, which is known to be affected by ASF, from the 11 threatened pig species for which there is no information about their susceptibility to ASF (Table 1). We assess the risk to specific species by considering the additional factors that could mediate local ASF transmission. This includes connectivity amongst regions or local religious prohibitions on pork consumption, which would lower the risk of native pigs being exposed to ASF, versus the presence of domestic pig husbandry or invasive *Sus scrofa*, which may increase the risk of being exposed to ASF.

The full severity of emerging infectious disease outbreaks and their potential cascading impacts are often underestimated (Lippi, Sanchi-Gomar, & Henry, 2020). Many countries lack adequate mitigation measures to prevent and control outbreaks in humans or animals, as suggested by patterns of delayed interventions, inadequate human health and veterinary care systems, and lack of cross-sectoral coordination to address human and animal health issues (Emanuel, 2020; Lippi & Plebani, 2020). Further, many institutions downplay or do not prepare for "tail-risks," an economic term defined as highly unlikely events that can have severe consequences (Acemoglu, Ozdaglar, & Tahbaz-Salehi, 2017). For example, the impacts of ASF in China have exceeded one trillion yuan (> $140 billion USD; Huang, 2020) and reduced calorie availability to people by 1–1.6% (Mason-D'Croz et al., 2020). The unexpected economic and human health impacts in China may foreshadow dire conservation problems in the rest of Asia. Specifically, the ongoing ASF epidemic poses an extinction threat for Asia's rarest pig species and the decline of wild pigs more generally will alter the forest ecology and cause socioeconomic impacts throughout the region.

2 | MAPPING THE SPREAD OF ASF IN ASIA

2.1 | ASF in domestic pigs

Domestic pigs (*Sus scrofa*) face almost 100% case fatality from ASF in Asia (Perez, Brihn, & Perez, 2019; FAO, 2020; USDA, 2020). The rapid spread of ASF in domestic pigs through mainland Asia started in northern China in August 2018 and moved south to Vietnam by February 2019 and the Philippines (Luzon Island) by July 2019 (Figure 1; FAO, 2020; Sur, 2019). Since late 2018, more than 100 million domestic pigs have died from the disease or been culled in China in an attempt to limit the spread of ASF (FAO, 2020). Almost all other Southeast Asian countries have now reported cases in domestic pigs. The disease has spread to northern India, south through Indonesia, east to the Philippines and Papua New Guinea, and now encompasses the range of rare warty pigs, pygmy hogs, and babirusa species (Figure 2; FAO, 2020; Sur, 2019; Zhong, 2020).

We note that our abilities to track ASF is influenced by each countries' surveillance, testing, and reporting abilities, and this is often politically motivated. Therefore, ASF reporting is often unreliable and not comparable between countries.

2.2 | ASF in wild *Sus scrofa*

The most common and widespread native pig in the region is the wild boar, which is listed as Least Concern for conservation by the IUCN Red List (Keuling & Leus, 2019). In previous outbreaks in Europe, the disease caused significant mortality of free-ranging wild boars (Chenais et al., 2019). In the 2007 outbreak, ASF spread to wild boars across Eurasia and to Madagascar and caused an initial epidemic phase with high fatality before becoming endemic with low transmission and mortality rates (Chenais et al., 2019; Schulz et al., 2019). ASF was eradicated from the Iberian Peninsula following intense control measures, but it remains endemic in Europe despite significant management efforts (Costard et al., 2013).

ASF is already spreading among free-living wild boars in Asia (Guberti, Khomenko, Masiulis, & Kerba, 2019; FAO 2020; Figure 2). For example, South Korea has deployed snipers and drones to kill wild boars crossing from North Korea in its efforts to limit the spread of ASF (Zastrow, 2019). However, there has been no targeted research on the transmission of ASF to and among free-ranging native wild boars in Asia, so the extent and prevalence remains unknown (Vergne, Guinat, & Pfeiffer, 2020). The outbreak may be widespread given the infectiousness and rapid spread of ASF among domestic Asian pigs that are genetically similar to wild boar (Frantz, Haile, & Lin, 2019). Further, the spread of ASF from domestic to wild boars in Asia is also aided by the lack of biosecurity measures of "backyard" pig production throughout the region, which is known to be a risk factor in other regions (Cwynar, Stojkov, & Wlazlak, 2019; Wang, Sun, & Qiu, 2018). The spread of ASF in free-ranging pigs is certainly underreported because of the chronic lack of resources devoted to monitoring wildlife diseases in the region, especially given recent COVID-19-associated fieldwork limitations, as well as political reasons for intentionally

TABLE 1 Summary of risk factors potentially associated with ASF for Asian endemic pig species. ASF already affects wild and domestic *Sus scrofa*. We did not include the presence of ticks that could transmit ASF because little is known about this for Southeast Asia. Note that conservation status is provided for the readers' reference and was not included in assessing threat of ASF infection

Species	Conservation status[1]	Domestic pig farming within range[2]	Trade within range[3]	Human density[4]	Human pork consumption within range (per capita)[5]	Sympatric *Sus scrofa* (vector)[6]	Overall risk
Sunda bearded pig (Borneo) (*Sus barbatus barbatus*)	VU	Low	High	High	High	No	High
Sunda bearded pig (Sumatra[7]) (*Sus barbatus oi*)	VU	Medium	Very high	High	High	Yes	Very high
Javan warty pig (*Sus verrucosus*)	EN	Low	High	Very high	Low	Yes	High
Sulawesi babirusa (*Babyrousa celebensis*)	VU	High	Medium	High	Medium	No	High
Hairy babirusa (*Babyrousa babyrussa*)	VU	Low	Low	Low	Low	No	Low
Togian babirusa (*Babyrousa togeanensis*)	EN	Low	Low	Low	Low	No	Medium
Sulawesi warty pig (*Sus celebensis*)	NT	High	Very high	High	High	Yes	Very high
Visayan warty pig (*Sus cebifrons*)	CR	Medium	Very high	Very high	High	No	Very high
Palawan bearded pig (*Sus ahoenobarbus*)	NT	Medium	High	Medium	High	No	High
Philippine warty pig (*Sus philippensis*)	VU	Very high	High	Very high	Very high	No	Very high

(Continues)

TABLE 1 (Continued)

Species	Conservation status[1]	Domestic pig farming within range[2]	Trade within range[3]	Human density[4]	Human pork consumption within range (per capita)[5]	Sympatric*Sus scrofa* (vector)[6]	Overall risk
Mindoro warty pig (*Sus oliveri*)	VU	Medium	High	High	Very high	No	Very high
Pygmy hog (*Porcula salvania*)	CR	Very low	High	Very high	Medium	Yes	High

[1]IUCN Red List of Threatened Species, https://www.iucnredlist.org/.

[2]Pig farming, determined by the annual number of pigs in 1 year: very low: < 100,000; low: 100,000–500,000; medium: 500,000–2,000,000; high: 2,000,000–4,500,000; very high: >4,500,000. Data from Indonesia: Directorate General of Livestock and Animal Health of Indonesia, "Livestock and Animal Health Statistics 2018" (Ministry of Agriculture, 2018). Malaysia: Q. N. bin H. Nizam & S. bin S. Ibrahim, "Livestock Farming in Malaysia" presented at Livestock Asia Expo & Forum, Kuala Lumpur, Malaysia, 20 April 2018. Brunei Darussalam: pig farming is banned. Timor Leste: FAO, "Timor-Leste and FAO achievements and success stories" (FAO Emergency Office in Timor Leste, 2011). Philippines: Philippine Statistics Authority, "Swine Situation report January-December 2018" (2019). Baksa: Ministry of Micro, Small, and Medium Enterprises Government of India, "Brief Industrial Profile of Baksa District" (2011).

[3]Trade within range, determined by the number of voyage/ship calls. Very high: >80,000 ships/year; high: 40,000–80,000; medium: 20,000–40,000; low: 5,000–20,000, very low: < 5,000. Data from: Indonesia: BPS-Statistics Indonesia, "Sea Transportation Statistics" (Catalog: 8304003, 2017). Malaysia: All Ports and Marine Department, "Total Number of Ships Calling by Ports, Malaysia" (2017) (available at http://www.apamalaysia.com/downloads/maritime-transport-statistic/). Timor Leste: Atlassian, "Timor-Leste Port of Dili" (2019) (available at https://dlca.logcluster.org/display/public/DLCA/2.1+Timor-Leste+Port+of+Dili). Philippines: Philippine Ports Authority, "Summary Port Statistics" (2017) (available at http://www.ppa.com.ph/content/statistics-1).

[4]Human population density (persons /km^2). Very high: >1,000 people/km^2; high: 100–1,000; medium: 100–500; low: 50–100, very low: < 50. Data from: Indonesia: Badan Pusat Statistik (BPS-Statistics Indonesia), Kepadatan Penduduk menurut Provinsi, 2000–2015 (Indonesian Population Density Based on Province, 2000–2015) (2015) (available at https://www.bps.go.id/linkTableDinamis/view/id/842). Malaysia: Department of Statistics Malaysia, Population Distribution and Basic Demographic Characteristic Report 2010 (2011) (available at https://www.dosm.gov.my/v1/index.php?r = column/ctheme&menu_id = L0pheU43NWJwRWVSZklWdzQ4TlhUUT09&bul_id = MDMxdHZjWTk1SjFzTzNkRXYzcVZjdz09). Timor-Leste: Worldometers, Timor-Leste Population (2019) (available at https://www.worldometers.info/world-population/timor-leste-population/). Philippine Statistics Authority, "Philippine Population Density" (2016, https://psa.gov.ph/content/philippine-population-density-based-2015-census-population). Baksa: Census 2011, "Baksa District: Census 2011–2019 data" (2019) (available at https://www.census2011.co.in/census/district/141-baksa.html).

[5]Pork consumption per capita (kilograms per person per year). Very high: > 20; high: 10–20; medium: 5–10; low: 2–5, very low: < 2. Data from: Indonesia: Center for Agricultural Data and Information System of Indonesia, "Statistics of Food Consumption" (Secretariat General—Ministry of Agriculture, 2018). Malaysia: Q. N. bin H. Nizam & S. bin S. Ibrahim, "Livestock Faming in Malaysia" presented at Livestock Asia Expo & Forum, Kuala Lumpur, Malaysia, 20 April 2018. Timor-Leste: National Directorate of Fisheries and Aquaculture, "Fish and animal protein consumption and availability Timor-Leste" (Ministry of Agriculture and Fisheries Timor-Leste, 2011). Philippines: Philippine Statistics Authority, "Consumption of Selected Agricultural Commodities in the Philippines Volume 2" (2017). Assam (where Baksa is located): R. Deka, W. Thorpe, M. L. Lapar, & A. Kumar, "Assam's pig sub-sector: Current status, constraints and opportunities" (International Livestock Research Institute, 2007).

[6]W. Oliver & K. Leus, *Sus scrofa* (2008) (available at https://www.iucnredlist.org/species/41775/10559847).

[7]Also present in Peninsular Malaysia.

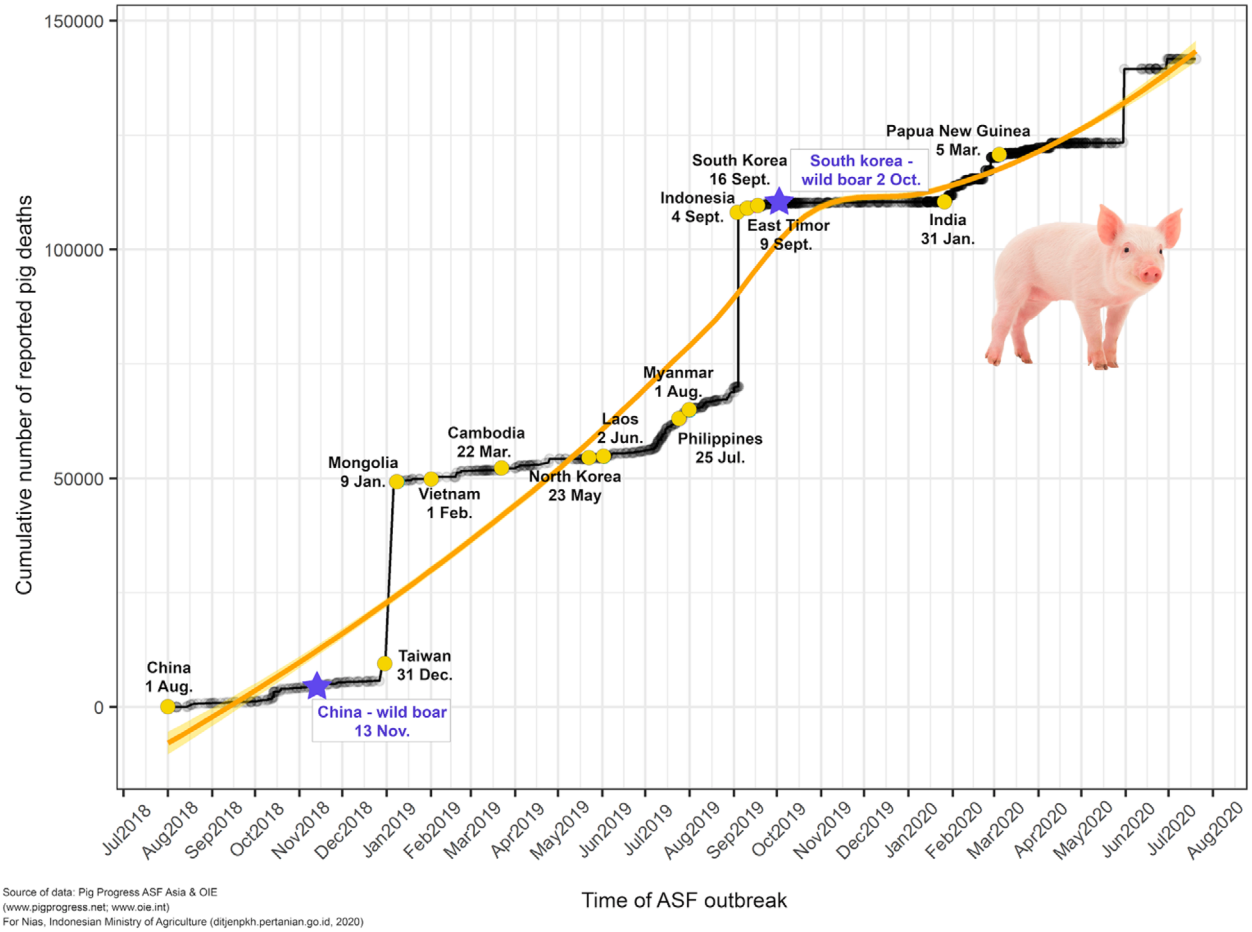

FIGURE 1 **Timeline of African Swine Fever spread in Asia and domestic pig deaths (not culled)**. Yellow points denote time of first positive ASF case in domestic *Sus scrofa* reported for each country, purple stars show when ASF was first reported in wild boars in each country. The orange spline shows smoothed temporal trend. Pig deaths come from incidences reported to the World Organisation for Animal Health (their widely used acronym is OIE) and do not include the deaths from culling of domestic pigs implemented to prevent the spread of ASF, which is estimated to exceed 100 million. The deaths reported are influenced by each countries' surveillance, testing, and reporting abilities, and thus should only be used to assess general trends. This graph illustrates that ASF pig mortality is increasing over time, but the threats to wild *Sus scrofa* and endemic pig species remain largely unknown

underreporting (Vergne et al., 2017; Zhong, 2020). There are also few clear channels for sending samples or even communications to relevant authorities (Guberti et al., 2019; Vergne et al., 2020). Integrating these risk factors means that ASF will likely remain endemic among free-living wild boars in Asia for the foreseeable future (Vergne et al., 2020).

3 | ASF IN ENDEMIC ASIAN PIG SPECIES

Eleven other endemic Asian pig species are at risk from ASF. Currently, there has been no direct testing of whether ASF can spread to other Asian pig species but relevant epidemiological research on ASF suggests this is highly likely (Netherton, Connell, Benfield, & Dixon, 2019). ASF can infect at least five pig species from four genera (Netherton et al., 2019). In Africa, ASF infects common warthog (*Phacochoerus africanus*), bushpig (*Potamochoerus porcus*), and giant forest hog (*Hylochoerus meinertzhageni*) with frequent spillover events to domestic pigs (Penrith & Vosloo, 2009). Previous exposure to ASF or many other viral diseases is highly unlikely for any of Asia's isolated and insular endemic pig species, further reducing the likelihood of disease resistance. Many of the region's pigs in the *Sus* genus (warty pig and bearded pig species) interact or interbreed with wild, invasive, or domestic *Sus scrofa* (Melletti & Meijaard, 2017) and Southeast Asian pigs in the *Sus* genus have been predicted to be similarly susceptible to ASF as *Sus scrofa* (Netherton et al., 2019). There are also numerous tick species in Asia and since these are

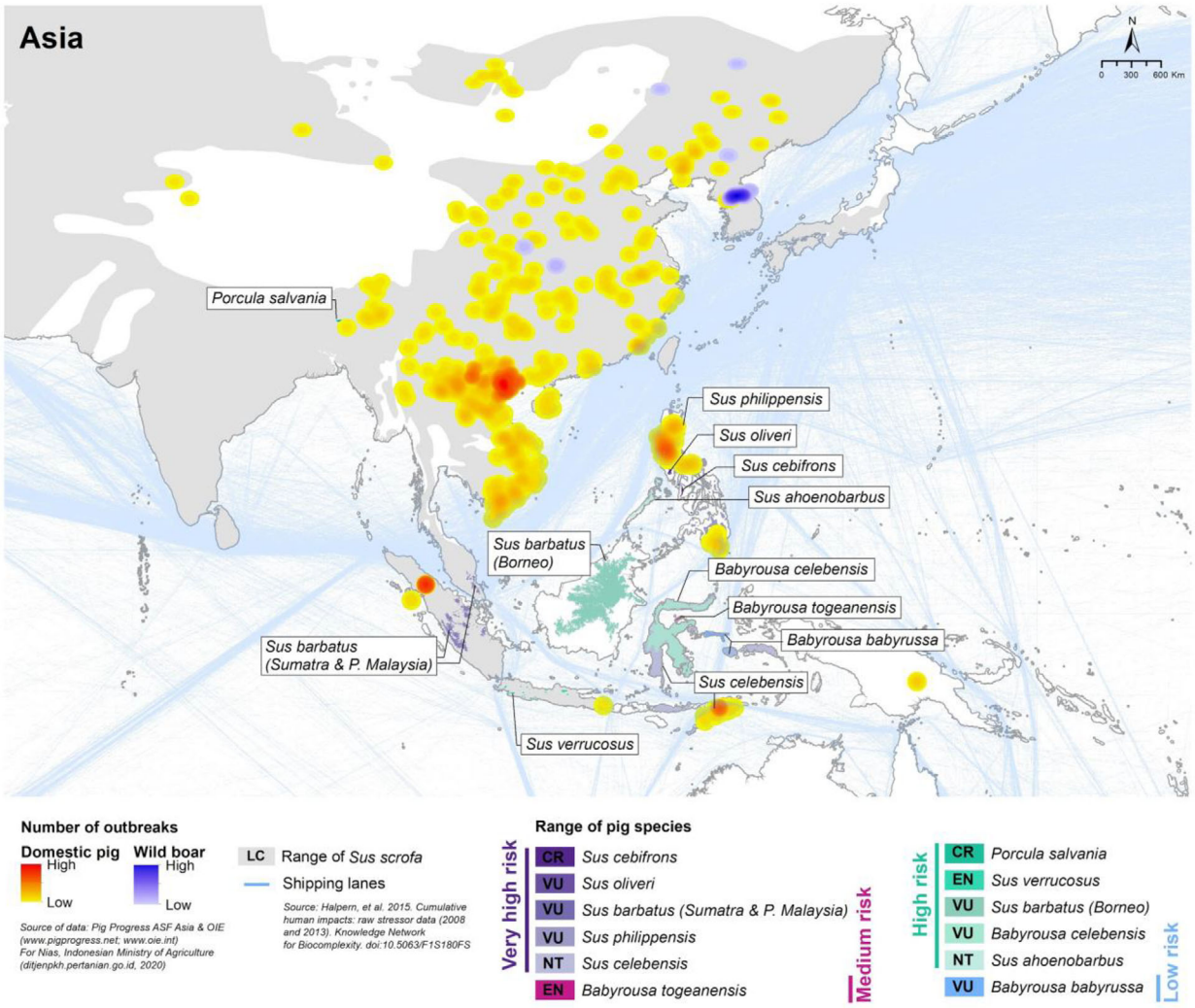

FIGURE 2 **The spread of African Swine Fever threatens Southeast Asia's 11 wild pig species**. Hotter transparent colors correspond to larger outbreaks (more pigs infected) as of early August 2020 (*1*). The ranges of wild pigs species in Asia are shown with solid colors (*4*). Letter codes within the pig species legend (colors) denote IUCN threat level, listed here in increasing order: Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR). Risk was qualitatively assessed by indicators shown in Table 1

rarely host specific, they may serve as a vector between pig species and ticks may also act as a reservoir that increase viral persistence (since some ticks live > 1 year; Golnar et al., 2019). However, there is no research on Asian ticks' ability to transmit ASF specifically, so this is speculative, and ticks were not included in our species-level risk assessments. Taken together, there is a high chance that Asia's endemic pigs will be exposed to ASF and as there is little evidence suggesting they would be immune to ASF.

In lieu of targeted research on this subject, it is prudent as a precautionary measure to consider that Asian wild pig species would be infected and impacted by the ASF virus (Vergne et al., 2020). We have thus established that ASF has or will likely arrive in areas with threatened endemic pigs that it can likely infect these species, and next we assess the likelihood it will infect endemic pigs.

4 | RISK ASSESSMENT FOR ENDEMIC ASIAN PIGS

4.1 | Assessing risk

Unlike the previous outbreaks in wild boar where ASF became endemic and did not cause local extinctions, Asia's endemic pig species have dramatically smaller populations and smaller ranges that may be insufficient to withstand the initial and lethal onslaught of the disease. We assessed the threat of ASF on wild pig populations by assuming that transmission was possible and its likelihood was correlated with the contact frequency with pork production (pig farming), pork products, and international trade (Figure 2). The virus can spread via processed cooked or frozen products manufactured in China, so we included trade as

a risk factor (CNN, 2020; FAO, 2020). We scaled threat of ASF from trade by overall trade connectivity, the number of pork-consuming people within the range of each pig species, and we also assessed whether pork production (pig husbandry) was common within each species range (see Table 1 for details on methods). Exposure to pork trade and thus ASF may be lower where the majority population follows Halal practices that forbid pork production and consumption, such as in the predominantly Muslim areas of Peninsular Malaysia, Brunei, Indonesia, and the southern Philippines (Luskin, Christina, Kelley, & Potts, 2014). However, we accounted for pork-consuming Buddhist or Taoist Chinese minority populations are found throughout the region, as well as Christians and animists in Kalimantan, North Sumatra, Sulawesi, and other Indonesian smaller islands such as Bali and East Nusa Tenggara. Finally, we assumed the presence of *Sus scrofa* would also facilitate transmission to other species through direct interactions, tick vectors, or if other endemic pig species foraged on infected *Sus scrofa* carcasses. We qualitatively scored each of these threat factors from low (score = 1), medium (score = 2), high (score = 3), and very high (score = 4), and then summed their scores to produce an overall threat level for each species. Scoring was assessed by four assessors of the IUCN Red List for Suidae and based on information gathered by a literature review.

To date, ASF has spread to the Indonesian provinces of East Nusa Tenggara and North Sumatra, all of which have strong local cultures of pork production and consumption and high frequency of international trade (Table 1; FAO, 2020). Thus, the transmission of ASF to wild *Sus scrofa* in these locations was likely, while in Sumatra, there is also the potential for transmission to the sympatric subspecies of bearded pig (*Sus barbatus oi)*, whose population is already at higher risk than the Bornean subspecies (*Sus barbatus barbatus*) due to habitat loss (Ke & Luskin, 2019). These ASF hotspots in Indonesia are well connected to Java, Kalimantan and Sulawesi by dozens of daily boat, plane and car-ferry travel routes. This is especially concerning for the Javan and Sulawesi warty pigs (*Sus verrucosus* and *Sus celebensis*, respectively) and Sulawesi's babirusa (*Babyrousa celebensis*). Sulawesi is at a particularly high-risk because of its strong culture of pig production and consumption, and its prevalence of wildlife hunting and markets (Latinne et al., 2020), where zoonotic diseases may emerge and spread. The Togian islands are more accessible than Sula and Buru islands, so the risk for Togian babirusa (*Babyrousa togeanensis*) is higher (medium) than to Hairy babirusa (*Babyrousa babyrussa*), which we consider low.

Pork consumption, trade, and production are all common in the Philippines (except the far south) and thus the four species of endemic pigs, the Palawan bearded pig (*Sus ahoenobarbus*), Visayan warty pig (*Sus cebifrons*), Philippine warty pig (S*us philippensis*), Mindoro warty pig (*Sus oliveri*), are all at high or very high risk (Table 1). In particular, in the central Philippines, there is the critically endangered Visayan warty pig, which survives on only two small islands, and the vulnerable Mindoro warty pig, which is only found on a single island (Linkie et al., 2017).

4.2 | Dealing with uncertainty

ASF presents immense conservation threats to wild pig species in Asia but the lack of direct research findings inhibits definitive claims. There are two ways to view this uncertainty. The first is to wait until there is sufficient data before raising concern about ASF and mobilizing research and management resources. The second option is to apply the precautionary principle and highlight the potential for serious conservation problems based on the fundamental principles in biology, previous ASF outbreaks, and the currently available evidence described here. We caution that delays in the proactive management of ASF in these regions will have dire ramifications for these threatened species.

5 | CASCADING IMPACTS ON PREDATORS, PLANTS, AND PEOPLE

The spread of ASF to native free-living wild boars poses a threat to populations of large carnivores and human livelihoods. Wild boar is a principal prey species for the endemic and critically endangered Sumatran tiger (*Panthera tigris sumatrae*) and Javan leopard (*Panthera pardus melas*) in Indonesia, the Siberian tiger (*Panthera tigris altaica*), and Amur leopard (*Panthera pardus orientalis*) in China and Russia (Ripple et al., 2014). The decline of principal prey species threatens dwindling carnivore populations or may shift wild carnivore diets toward forest-edge livestock, which has been shown to increase human–wildlife conflict (Braczkowski et al., 2018; Lubis et al., 2020).

If ASF reduces Asian pig populations, there would also be significant cascading impacts on terrestrial habitat structure and plant communities. Asian pig species act as ecosystem engineers through their behaviors of soil rooting, wallowing, seed predation, and nest building (Ickes, Paciorek, & Thomas, 2005). In particular, in unhunted areas, bearded pigs have been shown to be the dominant force shaping tree seedling recruitment (Curran & Webb, 2000; Harrison et al., 2013). On the contrary, in Sumatra and Peninsular Malaysia, *Sus scrofa* is unnaturally abundant due to crop raiding (Luskin et al., 2014), as are crop-

raiding bearded pigs on Borneo (Love et al., 2018), and the cascading impacts of abundant pigs can reduce tree recruitment by up to 62% in the region (Luskin et al., 2017).

A final predicted critical impact of ASF is on the region's people. Locally raised domestic pigs represent a vital food for > 100 million people in the Philippines, Timor-Leste, and parts of Indonesia (BPS, 2010; RPNSO, 2014; Figure 1). In North Sumatra, there were protests against the culling of domestic pigs to control ASF because it would affect local livelihoods. Indeed, a modeling study suggests ASF has significantly reduced incomes, calorie intake, and protein for people in Asia (Mason-D'Croz et al., 2020). Hunting of bearded pigs play a particularly important role for many of Borneo's non-Muslim communities' diet and culture (Bennett, Nyaoi, & Sompud, 2000; Kurz et al., 2020). However, there is little other guidance on wild pigs importance to human diets and culture in other places. Therefore, ASF undermines livelihoods and food security in the region, mainly through lost domestic pork, and could indirectly lead to increased hunting pressure on wildlife species (Pattiselanno & Koibur, 2018).

6 | RECOMMENDATIONS

The current ASF outbreak highlights the lack of measures in place to contain and then curtail its spread. To better prepare for future outbreaks, we make the following key management recommendations:

6.1 | Carcass and waste disposal

ASF is transmitted via wild and domestic pigs encountering or scavenging carcasses of pigs that died of ASF, or scavenging infected pork products (FAO, 2020). This can be ameliorated with proper destruction and disposal of infected carcasses, such as incineration or sealing carcasses in plastic bags and burying them deep enough to avoid boars or other animals digging them up (European Commission, 2020). Food waste should also be disposed carefully to prevent wild or domestic pigs from accessing infected pork products. We urge governments and conservation groups to devote resources to educating and addressing these issues, especially in rural areas where wild boars can access discarded domestic pig carcasses and trash (Strait Times, 2020).

6.2 | Surveillance capacity

We advocate increasing testing capacity and implementing diagnostic sampling of all suspicious deaths of domestic, feral, and wild pigs as an early detection system to protect the wild populations of six threatened warty pig species, two bearded pig species, and the three babirusa species on Southeast Asian islands. This must be paired with an open-access online monitoring and reporting system, such as is already being implemented in Europe (The European Food Safety Authority, 2020). Disease surveillance in wild pigs will also aid in the management of ASF in domestic pigs.

6.3 | Biosecurity measures

For both carcass disposal (#1) and testing infected animals and products (#2), it is critical to implement strict biosecurity measures to prevent the accidental spread of ASF by those in close contact with the disease. This should involve segregation of duty to ensure that veterinary staff or facilities handling contaminated pigs and products are not also connected to farms or wild pig captive breeding centers. Finally, to facilitate contact tracing, we suggest new protocols for recording and sharing information about the trade in domestic pigs, pork, and pork products.

6.4 | Research

A key knowledge gap is how ASF affects different wild pig species in Asia and we propose urgent investments into research on disease transmission, as well as increased research into assessing and updating the conservation status of these species, for which many lack reliable population data or rely on outdated data (Linkie et al., 2017). Second, the presence of a vector can dramatically change the ecology of the virus, and there is little known about ASF vectors in Southeast Asia. Third, an important limitation for assessing the risk of ASF circulation in Asian wild pigs is the limited information on density estimates for any pig species. There is a need basic ecological studies on pigs and other common hosts of zoonotic diseases.

6.5 | Public outreach

Management of ASF may also be complicated by people's dependence on pork; for example, in the Indonesian province of North Sumatra, thousands of people from the pork industry, including farmers and restaurant owners, took to the streets to protest against the government's recommended culls (Strait Times, 2020). Thus, clear effective communication about tradeoffs, threats, and policies is also important.

6.6 | Capacity building

Tracking the spread of ASF in Asia is hindered by expensive disease transmission work that requires laboratories with biosecurity clearance. It may be strategic for local wildlife epidemiologists to coordinate with the additional people and resources being devoted for addressing COVID-19 and other emerging diseases in Asia and globally. Diseases are also blind to borders. Given the looming economic threat ASF poses for developed countries with large pork industries, such as the United States, we suggest they invest in aggressively tackling the disease before it reaches their shores. This would entail partnerships to build capacity in the Southeast Asian countries that are currently on the front lines of the disease. Such efforts could dovetail with initiatives for new wildlife epidemiology research to proactively identify risks for human pandemics and for food systems (Aiyar & Pingali, 2020).

6.7 | Intersectoral collaborations

Developing relationships between researchers, governments, and local communities that promotes trust, reciprocity, and free flow of data will be central to zoonotic disease detection and control. There are already organizations well positioned to facilitate these collaborations for ASF, such as the One Health initiative (Gibbs, 2014). Further, detection and mitigation activities should be integrated between wild and domestic pigs. An important challenge is therefore promoting intersectoral collaborations between forestry and agricultural departments to address ASF.

7 | CONCLUSION

There is a non-zero chance that ASF could cause multiple mammal extinctions in the near future and this represents an unacceptable tail-risk within conservation biology. Even in more conservative scenarios, such as if ASF remains confined to domestic and free-living *Sus scrofa*, the epidemic constitutes a serious threat to endangered carnivores, forest plant ecology, and human food security throughout Southeast Asia. Current shortfalls in the response to ASF include insufficient testing to understand transmission and mortality rates, delayed interventions in containing the virus due to economic concerns and politics, and underestimating cascading impacts on livelihoods. We strongly urge developed countries whose pork industries are threatened by ASF to invest in understanding and controlling the disease in the Asia, which will also help mitigate the future impacts of ASF on threatened wild pig species. Otherwise, ASF may limit the ability of affected countries to meet their Sustainable Development Goals of ending hunger and conserving biodiversity.

ACKNOWLEDGMENT

We thank George Wittemyer and two anonymous reviewers for helpful comments on this manuscript.

AUTHOR CONTRIBUTIONS

MSL, ML, and EM wrote the manuscript. S and SS compiled the data and made the maps. All authors contributed to the final version.

ETHICS STATEMENT

The research fell outside of the ethics requirements at our institutions.

DATA ACCESSIBILITY STATEMENT

There is no data associated with this manuscript.

CONFLICT OF INTEREST

There are no conflicts of interest.

ORCID

Matthew Scott Luskin https://orcid.org/0000-0002-5236-7096
Erik Meijaard https://orcid.org/0000-0001-8685-3685
Sheherazade https://orcid.org/0000-0002-0070-250X

REFERENCES

Acemoglu, D., Ozdaglar, A., & Tahbaz-Salehi, A. (2017). Microeconomic origins of macroeconomic tail risks. *American Economic Review*, *107*(1), 54–108.

Aiyar, A., & Pingali, P. (2020). Pandemics and food systems—Towards a proactive food safety approach to disease prevention & management. *Food Security*, *12*, 749–756.

Bennett, E. L., Nyaoi, A. J., & Sompud, J. (2000). Saving Borneo's bacon: The sustainability of hunting in Sarawak and Sabah. In J. G. Robinson & E. L. Bennett (Eds.), *Hunting for sustainability in tropical forests* (pp. 305–324). New York: Columbia University Press.

BPS. (2010). Badan pusat statistik—Penduduk menurut wilayah dan agama yang dianut, Indonesia (Indonesian Population Based on Province and Religion). *Diambil dari https://www bps go id*.

Braczkowski, A. R., O'Bryan, C. J., Stringer, M. J., Watson, J. E. M., Possingham, H. P., & Beyer, H. L. (2018). Leopards provide public health benefits in Mumbai, India. *Frontiers in Ecology and the Environment*, *16*, 176–182.

Chenais, E., Depner, K., Guberti, V., Dietze, K., Viltrop, A., & Ståhl, K. (2019). Epidemiological considerations on African Swine Fever

in Europe 2014–2018. *Porcine Health Management*, *5*(1), 6. https://doi.org/10.1186/s40813-018-0109-2

CNN. (2020). Seized pork dumplings from China test positive for African Swine Fever. *CNN Philippines*. Retrieved from https://www.cnnphilippines.com/news/2020/1/25/african-swine-fever-pork-dumplings-manila-china.html

Costard, S., Jones, B. A., Martínez-López, B., Mur L., de la Torre A., Martínez, M., … Wieland, B. (2013). Introduction of African swine fever into the European Union through Illegal importation of pork and pork products. *PLoS ONE*, *8*(4), e61104–e61107. https://doi.org/10.1371/journal.pone.0061104

Curran, L. M., & Webb, C. O. (2000). Experimental tests of the spatiotemporal scale of seed predation in mast-fruiting Dipterocarpaceae. *Ecological Monographs*, *70*, 129–148.

Cwynar, P., Stojkov, J., & Wlazlak, K. (2019). African Swine Fever status in Europe. *Viruses*, *11*, 310.

Emanuel, E. J. (2020). Fair allocation of scarce medical resources in the time of COVID-19. *New England Journal of Medicine*, *32*(1), 1–7.

European Commission. (2020). Strategic approach to the management of African Swine Fever for the EU. Working document from the Directorate-General for Health and Food Safety, Brussels. Retrieved from https://ec.europa.eu/food/sites/food/files/animals/docs/ad_control-measures_asf_wrk-doc-sante-2015-7113.pdf

European Food Safety Authority. (2020). Epidemiological analyses of African Swine Fever in the European Union (November 2018 to October 2019). *European Food Safety Authority*, *1*, 1–11.

FAO. (2020). ASF situation update—African Swine Fever (ASF)—FAO Emergency Prevention System for Animal Health (EMPRES-AH). Retrieved from http://www.fao.org/ag/againfo/programmes/en/empres/ASF/situation_update.html

Frantz, L. A. F., Haile, J., Lin, A. T., Scheu, A., Geörg, C., Benecke, N., … Larson , G. (2019). Ancient pigs reveal a near-complete genomic turnover following their introduction to Europe. *Proceedings of the National Academy of Sciences*, *4332*(3), 69–75.

Gibbs, E. P. J. (2014). The evolution of One Health: A decade of progress and challenges for the future. *Veterinary Record*, *174*, 85–91.

Golnar, A. J., Martin, E., Wormington, J. D., Kading, R. C., Teel, P. D., Hamer, S. A., & Hamer, G. L. (2019). Reviewing the potential vectors and hosts of African Swine Fever virus transmission in the United States. *Vector-Borne and Zoonotic Diseases*, *19*, 512–524.

Guberti, V., Khomenko, S., Masiulis, M., & Kerba, S. (2019). *African Swine Fever in wild boar ecology and biosecurity. FAO Animal Production and Health Manual*. Rome: FAO, OIE and EC.

Harrison, R. D., Tan, S., Plotkin, J. B., Slik, F., Detto, M., Brenes, T., … Davies, S. J. (2013). Consequences of defaunation for a tropical tree community. *Ecology Letters*, *16*, 687–694.

Huang, Y. (2020). Why did one-quarter of the world's pigs die in a year? *The New York Times*. Retrieved from https://www.nytimes.com/2020/01/01/opinion/china-swine-fever.html

Ickes, K., Paciorek, C. J., & Thomas, S. C. (2005). Impacts of nest construction by native pigs (*Sus scrofa*) on lowland Malaysian rain forest saplings. *Ecology*, *86*, 1540–1547.

Ke, A., & Luskin, M. S. (2019). Integrating disparate occurrence reports to map data-poor species ranges and occupancy: a case study of the Vulnerable bearded pig Sus barbatus. *Oryx*, *53*(2), 377–387. http://doi.org/10.1017/s0030605317000382.

Keuling, O., & Leus, K. (2019). *Sus scrofa*. The IUCN Red List of Threatened Species 2019: E.T41775A44141833. Retrieved from https://doi.org/10.2305/IUCN.UK.2019-3.RLTS.T41775A44141833.en.

Kurz, D., Saikim, F. H., Justine, V. T., Bloem, J., Libassi, M., Luskin, M., … Potts, M. D. (2020). *Oil palm expansion reshapes indigenous hunting: Kadazandusun-Murut bearded pig hunting practices in Sabah, Malaysia* (preprint). EcoEvoRxiv. https://doi.org/10.32942/osf.io/5ckg3

Latinne, A., Saputro, S., Kalengkongan, J., Kowel, C. L., Gaghiwu, L., Ransaleleh, T. A., … Pamungkas, J. (2020). Characterizing and quantifying the wildlife trade network in Sulawesi, Indonesia. *Global Ecology and Conservation*, *21*, e00887. https://doi.org/10.1016/j.gecco.2019.e00887.

Linkie, M., Ng, J., Lim, Z. Q., Lubis, M. I., Rademaker, M., & Meijaard, E. (2017). The IUCN Wild Pig Challenge 2015. *Oryx*, *51*, 477–481.

Lippi, G., & Plebani, M. (2020). The critical role of laboratory medicine during coronavirus disease 2019 (COVID-19) and other viral outbreaks. *Clinical Chemistry and Laboratory Medicine (CCLM)*, *58*(7), 1063–1069.

Lippi, G., Sanchi-Gomar, F., & Henry, B. M. (2020). Coronavirus disease 2019 (COVID-19): The portrait of a perfect storm. *Annals of Translational Medicine*, (March), *8*(7), 497–497.

Love, K., Kurz, D. J., Vaughan, I. P., Ke, A., Evans, L. J., & Goossens, B. (2018). Bearded pig (Sus barbatus) utilisation of a fragmented forest–oil palm landscape in Sabah, Malaysian Borneo. *Wildlife Research*, *44*, 603–612.

Lubis, M. I., Pusparini, W., Prabowo, S. A., Marthy, W., Andayani, N., & Linkie, M. (2020). Unraveling the complexity of human–tiger conflicts in the Leuser Ecosystem, Sumatra. *Animal Conservation*.

Luskin, M. S., Christina, E. D., Kelley, L. C., & Potts, M. D. (2014). Modern hunting practices and wild meat trade in the oil palm plantation-dominated landscapes of Sumatra, Indonesia. *Human Ecology*, *42*(1), 35–45. https://doi.org/10.1007/s10745-013-9606-8

Luskin, M. S., Brashares, J. S., Ickes, K., Sun, I. F., Fletcher, C., Wright, S. J., & Potts, M. D. (2017). Cross-boundary subsidy cascades from oil palm degrade distant tropical forests. *Nature Communications*, *8*, 1–7.

Mason-D'Croz, D., Bogard, J. R., Herrero, M., Robinson, S., Sulser, T. B., Wiebe, K., … Godfray, H. C. J. (2020). Modelling the global economic consequences of a major African Swine Fever outbreak in China. *Nature Food*, *1*, 221–228.

Melletti, M., & Meijaard, E. (2017). *Ecology, conservation and management of wild pigs and peccaries*, New York, NY: Cambridge University Press.

Netherton, C. L., Connell, S., Benfield, C., & Dixon, L. K. (2019). The genetics of life and death: Virus-host interactions underpinning resistance to African Swine Fever, a viral hemorrhagic disease. *Frontiers in Genetics*, *10*, 402. https://doi.org/10.3389/fgene.2019.00402

Pattiselanno, F., & Koibur, J. F. (2018). Returns from indigenous hunting in the lowland coastal forests of West Papua, Benefits threatened wildlife species. *Journal Manajemen Hutan Tropika*, *24*, 45–49.

Penrith, M. L., & Vosloo, W. (2009). Review of African Swine Fever: Transmission, spread and control. *Journal of the South African Veterinary Association*, *80*(2), 58–62.

Perez, S., Brihn, A., & Perez, A. (2019). Swine disease global surveillance report. Swine Health Information Center, University of Minnesota.

Ripple, W. J., Estes, J. A., Beschta, R. L., Wilmers, C. C., Ritchie, E. G., Hebblewhite, M., … Wirsing, A. J. (2014). Status and ecological effects of the world's largest carnivores. *Science*, *343*, 1241484.

RPNSO. (2014). Republic of the Philippines national statistics office—The Philippines in figures. Retrieved from https://psa.gov.ph/

Schulz, K., Olševskis, E., Staubach, C., Lamberga, K., Seržants, M., Cvetkova, S., & Sauter-Louis, C. (2019). Epidemiological evaluation of Latvian control measures for African Swine Fever in wild boar on the basis of surveillance data. *Scientific Reports*, *9*(1), 1–11.

Strait Times. (2020). Thousands attend rally against plan to cull pigs amid African Swine Fever outbreak in North Sumatra. Retrieved from https://www.straitstimes.com/asia/se-asia/thousands-attend-rally-to-protest-plan-to-cull-pigs-amid-african-swine-fever-outbreak

Sur, J. H. (2019). How far can African Swine Fever spread? *Journal of Veterinary Science*, *20*(4), e41–e49.

USDA. (2020). *United States department of agriculture and foreign agricultural service livestock and poultry: World Markets and Trade*. Washington DC. Retrieved from http://apps.fas.usda.gov/psdonline/circulars/livestock_poultry.PDF

Vergne, T., Chen-Fu, C., Li, S., Cappelle, J., Edwards, J., Martin, V., & Roger, F. L. (2017). Pig empire under infectious threat: Risk of African Swine Fever introduction into the People's Republic of China. *Veterinary Record*, *181*(5), 117–117.

Vergne, T., Guinat, C., & Pfeiffer, D. U. (2020). Undetected circulation of African Swine Fever in Wild Boar, Asia. *Emerging Infectious Diseases*, *26*, 2480–2482.

Wang, T., Sun, Y., & Qiu, H. J. (2018). African Swine Fever: An unprecedented disaster and challenge to China. *Infectious Diseases of Poverty*, *7*, 111.

Zastrow, M. (2019). South Korea deploys snipers and drones to fend off deadly pig virus. *Nature News*. Retrieved from https://www.nature.com/articles/d41586-019-03237-5

Zhong, J. (2020). Unstoppable: African Swine Fever deaths to eclipse record 2019 toll. *The Guardian*.

How to cite this article: Luskin MS, Meijaard E, Surya S, Ssheherazade S, Walzer C, Linkie M. African Swine Fever threatens Southeast Asia's 11 endemic wild pig species. *Conservation Letters*. 2020;e12784. https://doi.org/10.1111/conl.12784