African Swine Fever in the Republic of North Macedonia: Modeling disease spread and evaluating mitigation strategies

O'Hara, Kathleen, C.[1], Gómez-Vázquez, Jose Pablo[1], González-Crespo, Carlos[1], Beltrán-Alcrudo, Daniel[2], Hovari, Mark[2], Tabakovski, Blagojcho, Martínez-López, Beatriz[1]

1. Center for Animal Disease Modeling and Surveillance (CADMS), Department of Medicine & Epidemiology, School of Veterinary Medicine, University of California, Davis, USA
2. Food and Agriculture Organization of the United Nations (FAO), Regional Office for Europe and Central Asia, Budapest, Hungary
Contact Email: kcohara@ucdavis.edu

UC DAVIS VETERINARY MEDICINE

Introduction

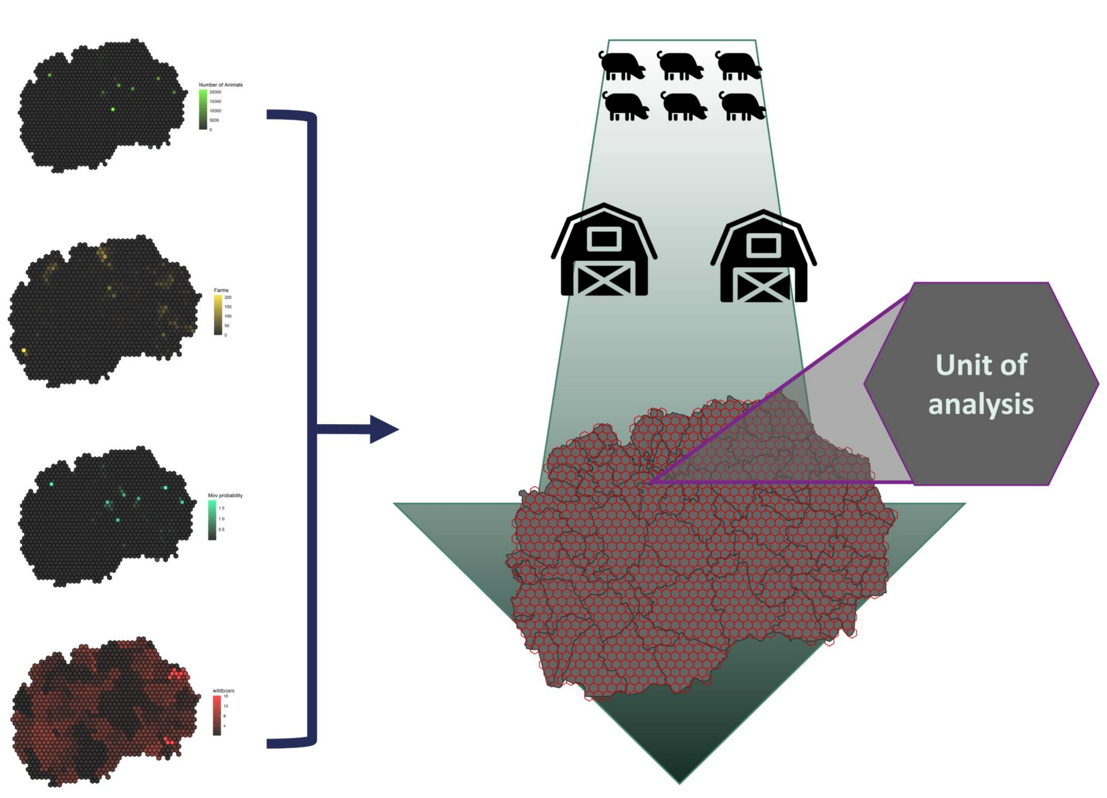
As African swine fever (ASF) continues to spread globally, countries need tools to predict which regions are at highest risk of disease introduction, to inform risk-based implementation of surveillance and enhanced biosecurity measures, and to effectively target response resources in the event of an incursion. The Republic of North Macedonia confirmed its first cases of ASF on January 6, 2022, on two small backyard holdings in the Eastern region of the country. The Food and Veterinary Agency (FVA) implemented a 3km protection zone and 10 km surveillance zone. Country-wide swine movements have been restricted, a ban on swine at animal markets has been implemented, and an extraordinary census with visits to perform health assessments and premises biosecurity risk classification has been performed. Stamping out, testing, appropriate carcass disposal, cleaning and disinfection, and epidemiological investigations were enacted on infected premises and within the 3km protection zone. A ban on keeping pigs in open holdings was also implemented within the protection zone. Within the 10 km surveillance zone, movement except to slaughter has been restricted, with animals inspected before movement. Hunting was banned within the Eastern region for one month; this was then revised to a ban within 20 km of the primary outbreak the following month. ASF was detected in 5 hunted wild boar March 15, 2022, and in an additional 2 wild boar found dead March 31, 2022. The FVA is currently focused on awareness campaigns, improving on-farm and hunting ground biosecurity, and increasing outreach to hunters to improve passive surveillance.

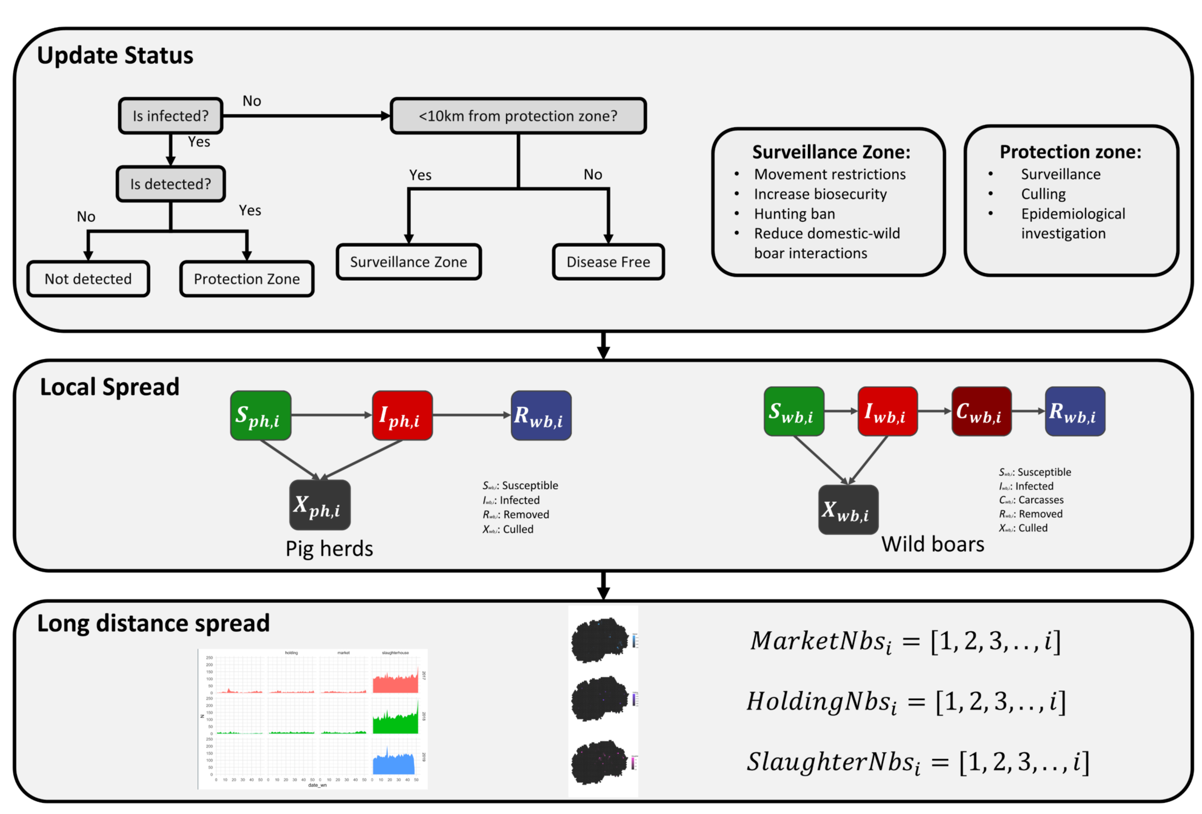
An extensive swine industry survey led by the Food and Agriculture Organization (FAO), in partnership with the FVA, in 2019 previously summarized the practices of North Macedonia's swine sector and generated farm-level biosecurity risk scores. Social network analyses of North Macedonia's live pig movement network provided risk-based targets for increased surveillance and enhanced biosecurity. This work aimed to combine data from these previous analyses to inform a model to explore potential routes of ASF transmission, identify areas at highest risk for disease spread, and to evaluate mitigation strategies for disease control.

Methods

A spatially-explicit, stochastic, agent-based disease spread model was informed by domestic pig and wild boar population demographics and live pig movement data from 2017-2019. The country was divided into a hexagonal grid, with ASF spread simulated within and between 10 km radius cells. Disease transmission within each cell was modeled using a susceptible-infected-removed compartment approach.

Disease mitigation strategies were modeling by scaling disease spread parameters. The removal of infected herds, the pre-emptive culling of herds in the protection zone, and improved biosecurity were evaluated for domestic pigs. The impact of infected carcasses was modeled for wild boars; this factor can be scaled to represent the detection and removal of these carcasses during a response.





Domestic Pigs:

$$S_{ph,i} = -\frac{\beta_{ph,i} I_{ph,i} S_{ph,i}}{N_{ph,i}} - \frac{\mu S_{ph,i}}{N_{ph,i}}$$

$$I_{ph,i} = \frac{\beta_{ph,i} I_{ph,i} S_{ph,i}}{N_{ph,i}} - \frac{\mu I_{ph,i}}{N_{ph,i}}$$

$$R_{ph,i} = \gamma C_{ph,i}$$

$$X_{ph,i} = \frac{\mu S_{ph,i}}{N_{ph,i}} + \frac{\mu I_{ph,i}}{N_{ph,i}}$$

γ = 1/days to detection and removal of infected herds

Removed infected herds

μ = Speed of culling

Culled pig herds

Wild Boar

$$S_{wb,i} = -\frac{\beta_{wb,i} I_{wb,i} S_{wb,i}}{N_{wb,i}} - \frac{\nu_{wb,i} C_{wb,i} S_{wb,i}}{N_{wb,i}} - \frac{\mu S_{wb,i}}{N_{wb,i}}$$

$$I_{wb,i} = \frac{\beta_{wb,i} I_{wb,i} S_{wb,i}}{N_{wb,i}} + \frac{\nu_{wb,i} C_{wb,i} S_{wb,i}}{N_{wb,i}} - \frac{\mu I_{wb,i}}{N_wb,i}$$

$$C_{wb,i} = \gamma_1 I_{wb,i}$$

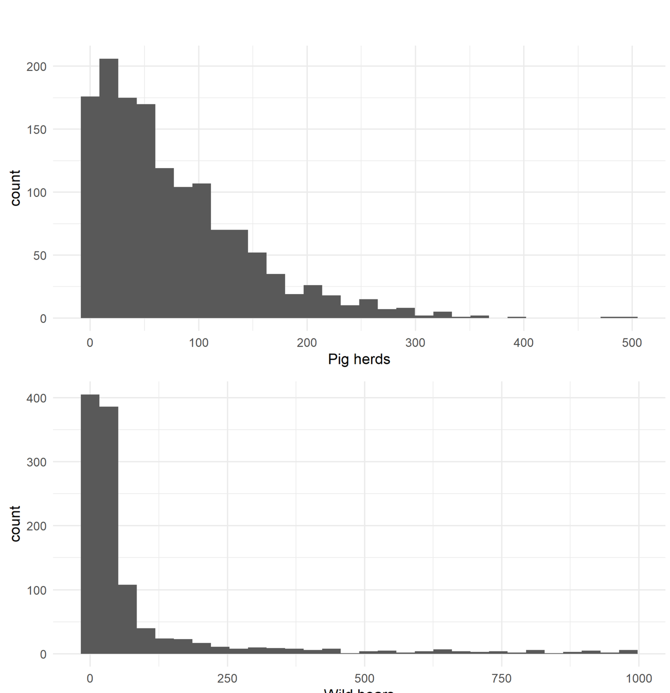
$$R_{wb,i} = \gamma_2 C_{wb,i}$$

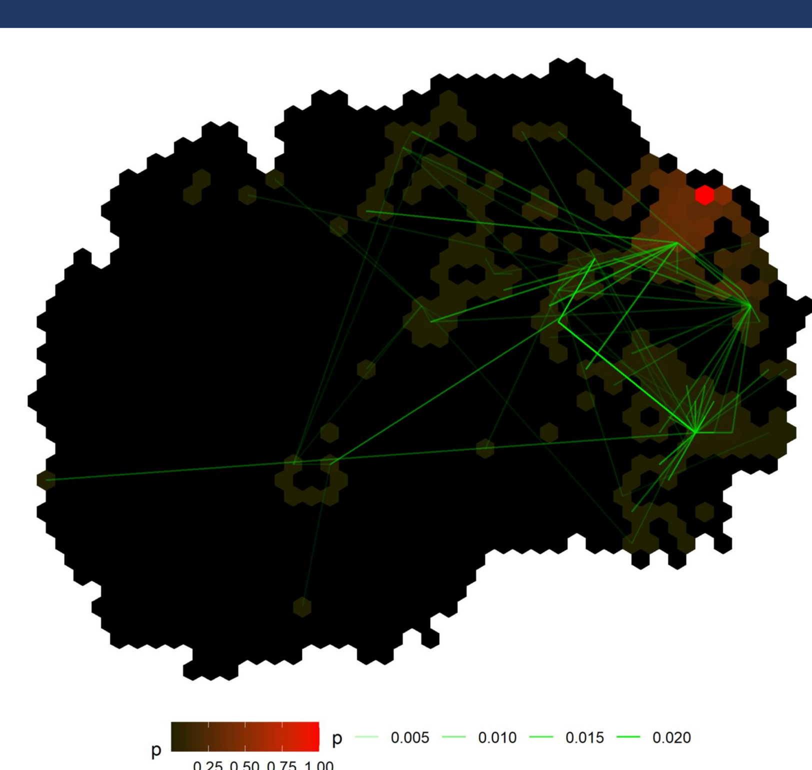
$$X_{wb,i} = \frac{\mu S_{wb,i}}{N_{wb,i}} + \frac{\mu I_{wb,i}}{N_wb,i}$$

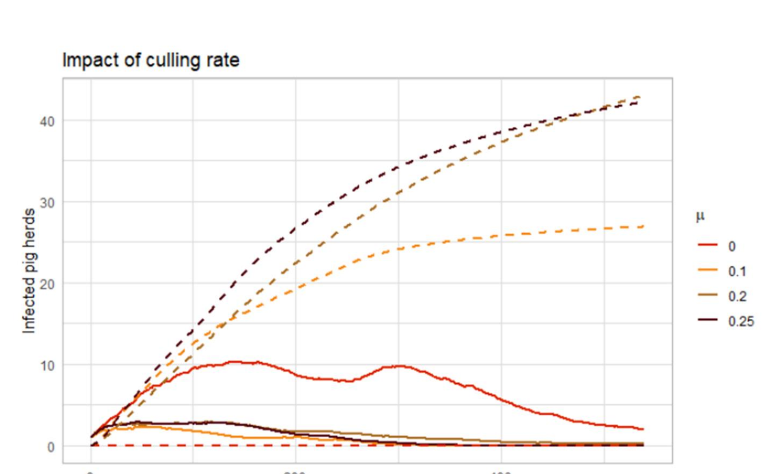
New infections by carcasses

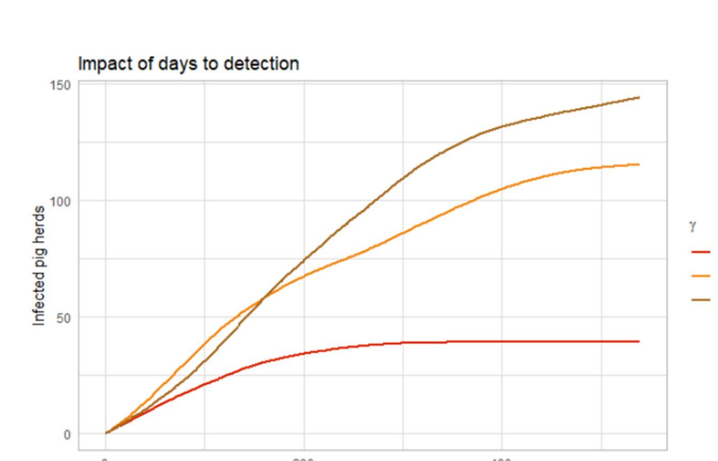
ν = Contribution of infected carcasses to new infections

Results









Without intervention, our model estimated the expected number of infected pig herds and infected wild boar within 6 months following disease introduction would be 30 (28, 32) and 26 (23, 28), respectively. Stamping out infected pig herds reduced affected herd estimates to 23 (19, 27). Reducing the average time to detection from 30 to 14 days reduced the expected number of infected pig herds to 12 (7, 17). The number of infected farms was reduced to 14 (9, 18) with improved biosecurity. The spread of disease is predicted to remain highly localized, with those areas adjacent to the primary outbreak having the highest probability of introduction. Rare long-distance jumps were predicted based on historic movement data.

Discussion

When resources are limited, targeting response efforts to those areas and premises at highest risk for disease introduction, and using methods with the highest impact, can improve the efficacy and efficiency of disease control efforts. This model provided projections of the spatiotemporal spread of ASF following disease introduction into North Macedonia's Eastern region and evaluated the efficacy of stamping out, culling, and improved biosecurity. These analytic approaches were implemented with limited baseline information and demonstrate tools that may be used in the early phases of preparedness planning and outbreak response to inform data gaps and initial resource mobilization. As additional information becomes available models can be refined.

Work is ongoing to expand the model and better incorporate wild boar movements, the role of infected carcasses and the impact of their timely removal, and to fine-tune the risk of disease spillover events. Additionally, as control strategies evolve, these additional measures will be included.

This work provided information that can be used by North Macedonia's Food and Veterinary Agency to support risk-based, cost-effective ASF prevention and response efforts, directing resources to areas with the highest risk of disease spread, and informing the most impactful and cost-effective mitigations. Further, this study provides data on the swine industry in this region, informing future outreach, risk assessments, and modeling efforts.

Acknowledgements

This work was supported by The Ecology and Evolution of Infectious Diseases Program, grant no. 2019-67015-28981 from the USDA National Institute of Food and Agriculture, the UC Davis Graduate Group in Epidemiology, and by the Technical Cooperation Programme (TCP) project on "African swine fever Preparedness in the Balkans" (TCP/RER/3704) of the Food and Agriculture Organization (FAO).

The views expressed in this paper are those of the author(s) and do not necessarily reflect the views or policies of FAO.