Multilayer Network Approach to Model African Swine Fever Spread in Poland

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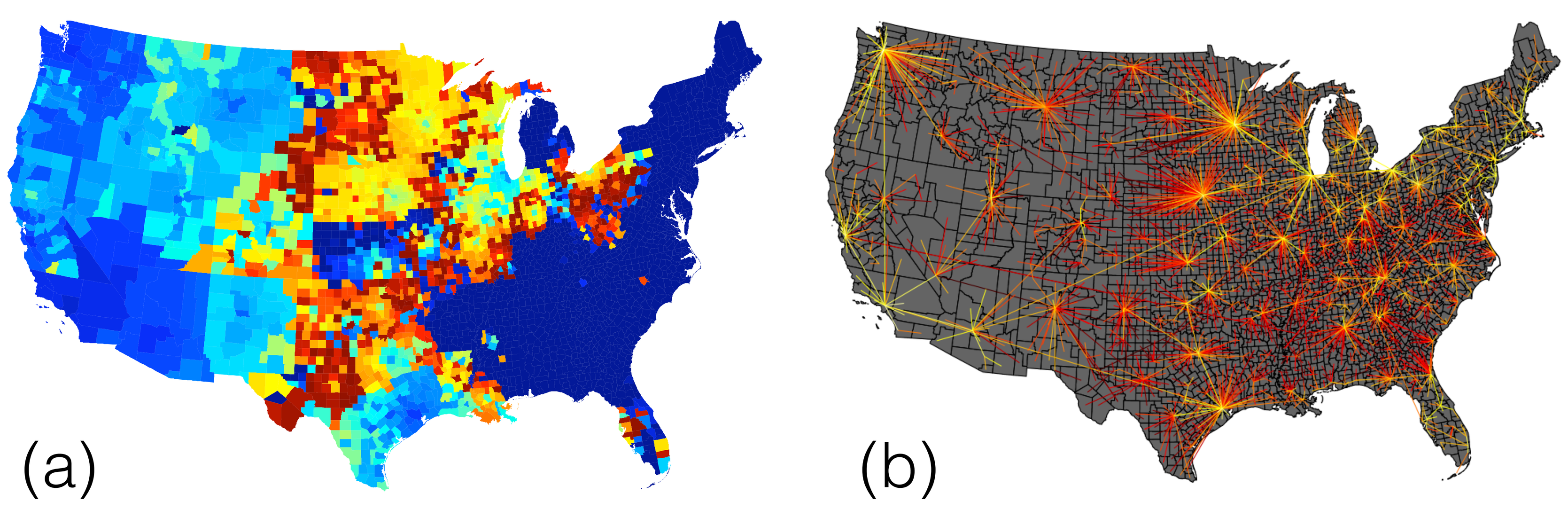
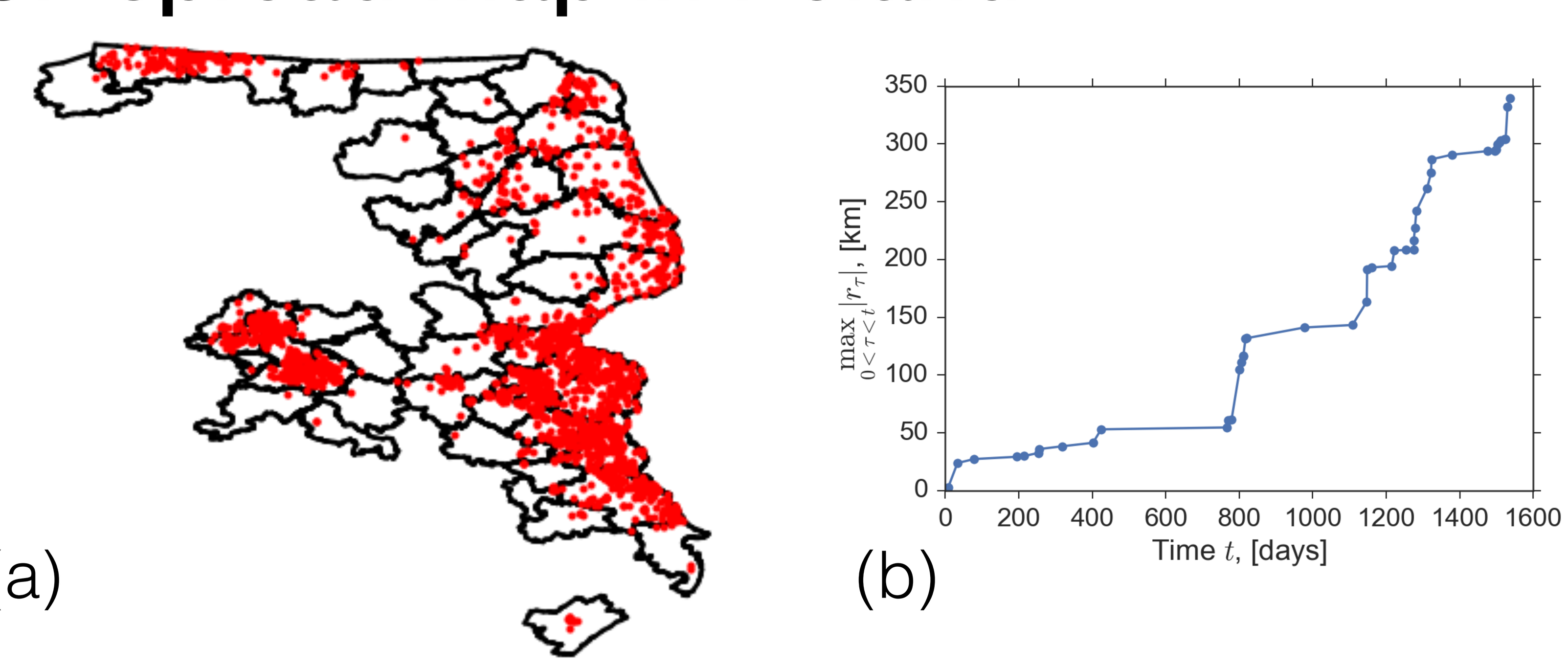
We report a novel effective network approach to infer possible spreading paths of the African Swine Fever (ASF) in Poland. The vertices (nodes) of the network represent counties (powiats). We consider several possible layers of transmission: wild boar, pig-related and possibly human-related. We present results for two-layer model and provide the corresponding risk assessment for every county in Poland. Our approach provides a possible way to incorporate the long range jump events of ASF-epidemics in contrast to only local spread attributed to wild boars.

Networks (generic epidemic)



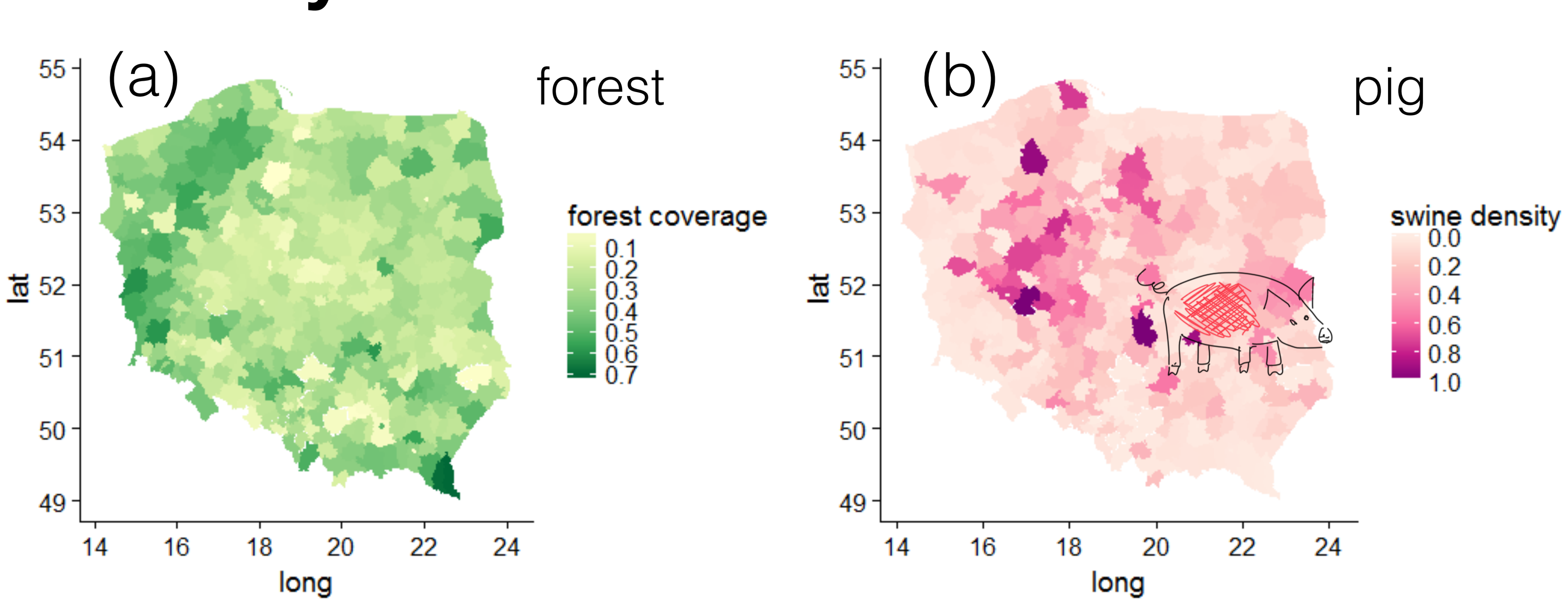
(a) Simulated (human) epidemics in USA originating in Los Angeles. Color code reflects the fraction of infected: from blue (no infecteds) to yellow (many infecteds). (b) Underlying mobility network (minimum spanning tree) as revealed by the analysis of dollar bill trajectories (http://wheresgeorge.com/) [1][2].

ASF spread map in Poland



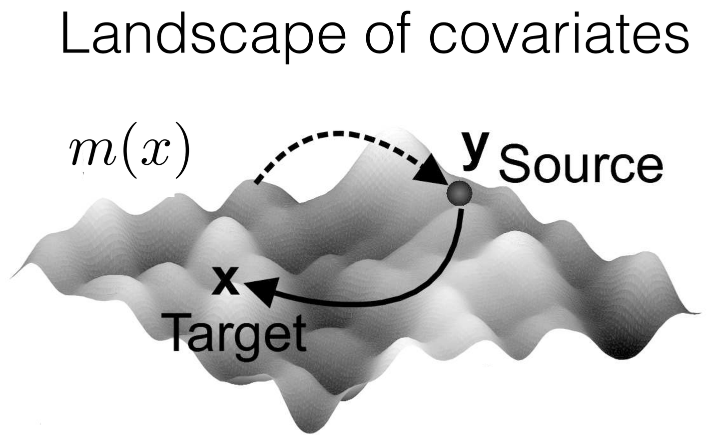
(a) Every point represents an outbreak (both in wild boar and domestic pig) reported to OIE (until Sep 2018) (b) Maximal distance from the "source" (the very first outbreak) up to the time *t* giving effective speed of 200 m per day.

Multi-layer networks



Covariates used for effective transmission network reconstruction in Poland. (a) Distribution of forest used as a proxy of wild boar density. (b) Distribution of domestic pig density.

Effective transmission network



Transmission probability

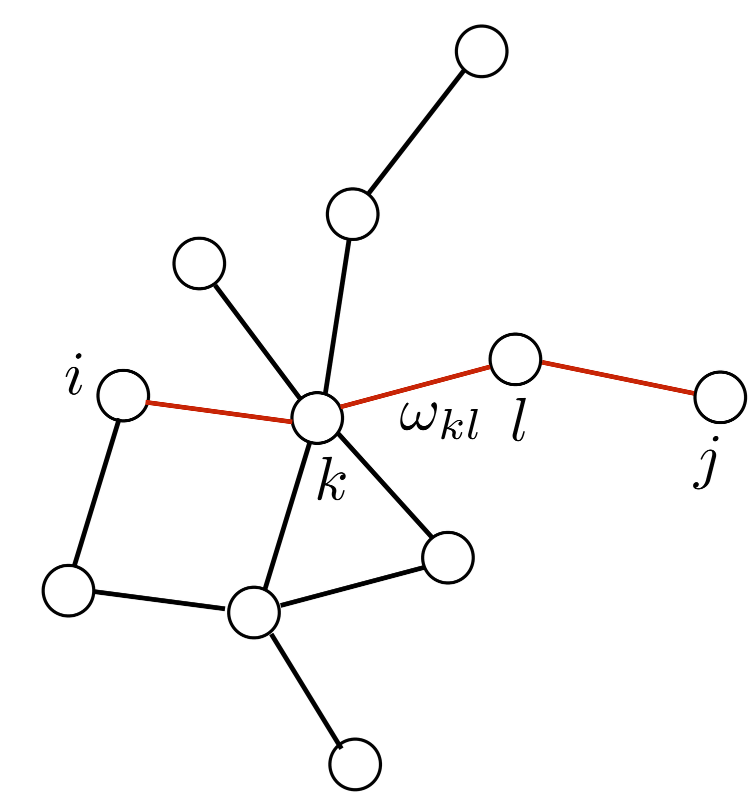
$$\omega_{xy} \propto \frac{m(x)m(y)}{r^{\mu}}$$

$$\omega_{ij} = \gamma\frac{F_iF_j}{r_{ij}^2} + (1-\gamma)\frac{P_iP_j}{r_{ij}}$$

$$\gamma \leq 1$$

Given landscape of covariates *m(x)* one can construct an effective transmission network (with transmission probabilities ω_{ij} from location *j* to location *i*) using a pseudo gravity ansatz [3], where F_i and P_i are forest and domestic pig density correspondingly.

Effective distance

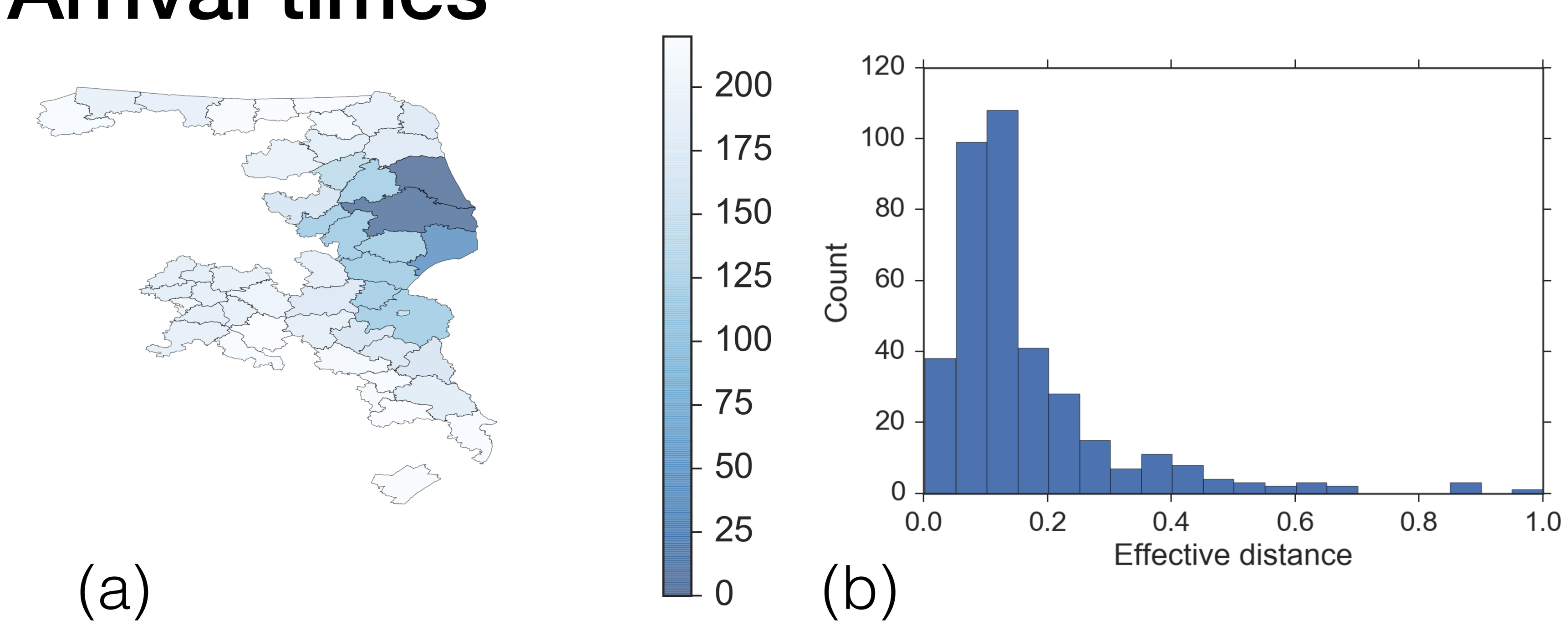


$$d_{ij} = -\log P_{ij}$$

$$P_{ij} = \prod_{(k,l)\in\Gamma_{ij}} \omega_{kl}$$

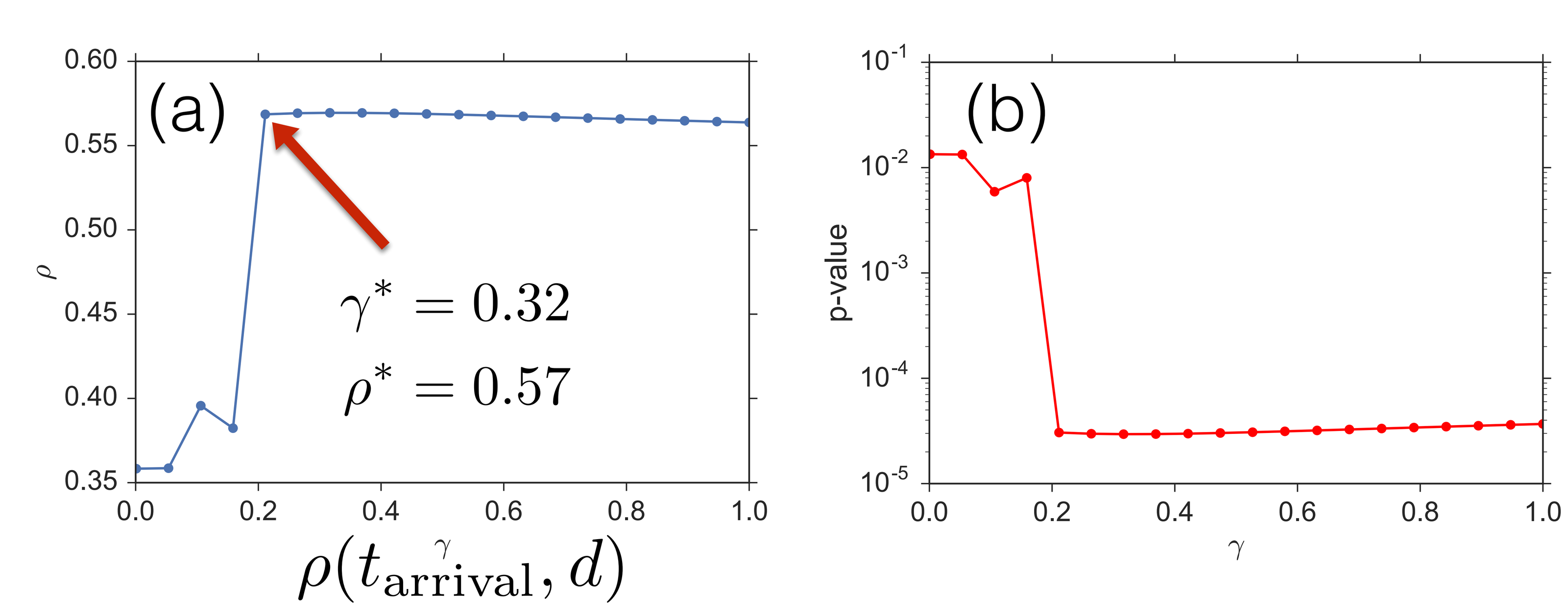
Effective spreading distance d_{ij} and probability of invasion P_{ij} on a weighted network as defined in Ref. [4].

Arrival times



(a) Map of first arrival times for ASF (in weeks). The counties are colored according to the time of first ASF-event. The hypothesis is that the effective distance is correlated with the arrival times and could thus serve as a future risk predictor for ASF appearance in a given county. In (b) the distribution of effective distance for all Polish counties is shown.

Effective distance vs. arrival time



Pearson correlation coefficient (a) between the effective distance and the arrival time and the corresponding p-value (b) in dependence on the wild boar weighting factor γ.

Conclusion

Motivated by recent advances in the modeling of spreading processes on networks [4] we applied the effective distance ansatz to the effective spreading network constructed from the covariate landscape based on the pseudo-gravitational law [3]. The model could be used to make risk assessment for ASF introduction into other countries as well as to develop more sophisticated machine learning [5] predictive approaches to ASF spread.

References

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