Epidemiological implications of network structures

Animal movements modelling (SNA and ERGM)
Compartmental epidemiological model (SimInf)

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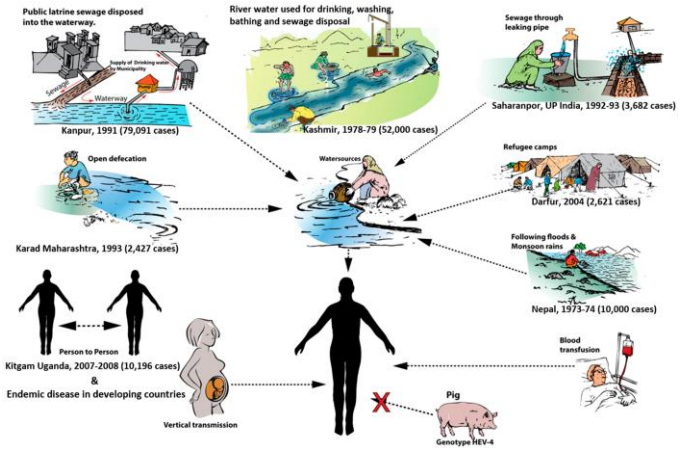
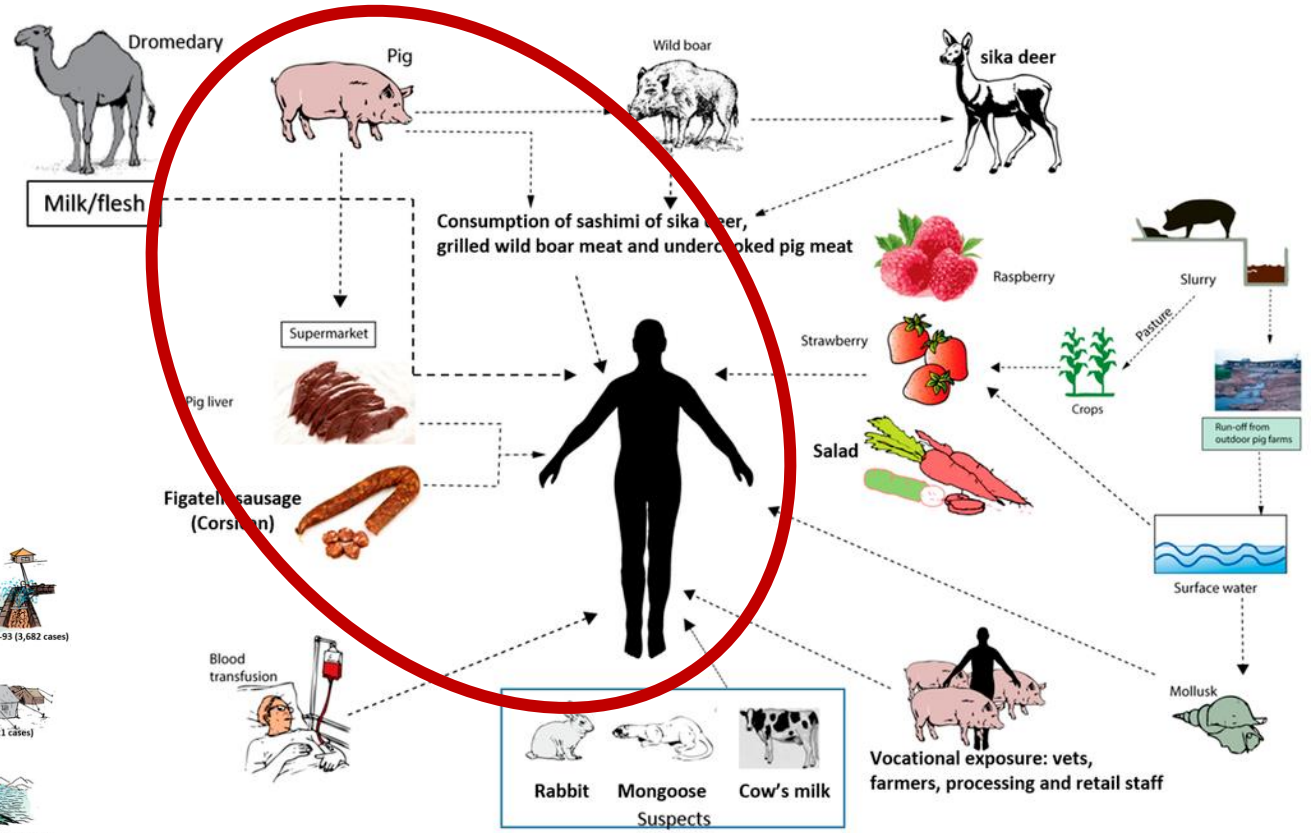
Hepatitis E Virus transmission

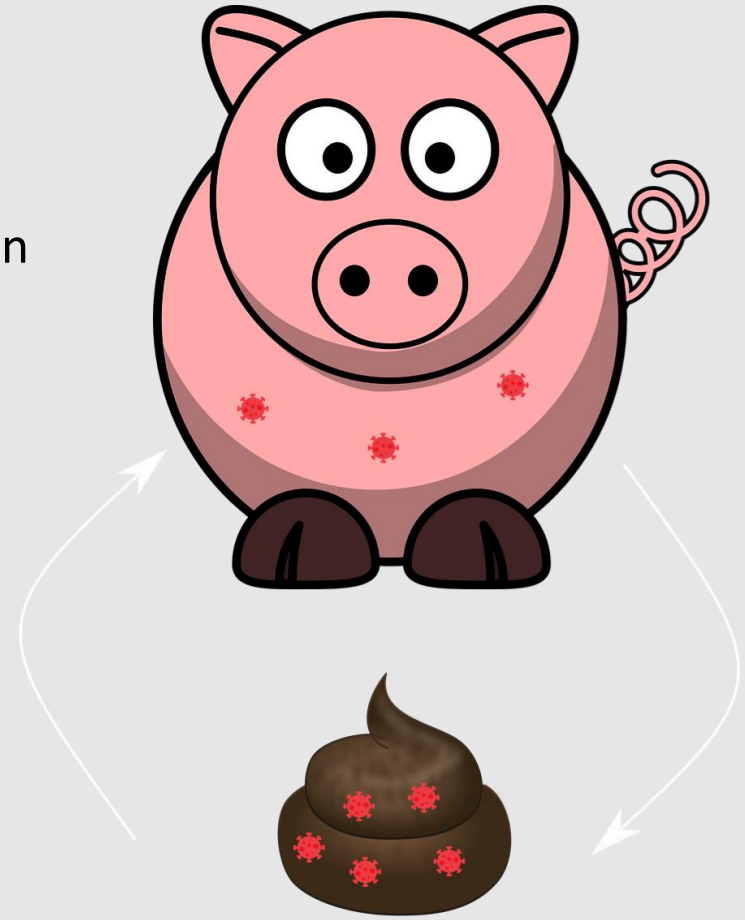




Khuroo, Mohammad, Khuroo, Mehnaaz, Khuroo, N., 2016. Transmission of Hepatitis E Virus in Developing Countries. Viruses 8, 253. https://doi.org/10.3390/v8090253

Hepatitis E Virus in swine

Asymptomatic
Detection: viro/sero
Faecal-oral transmission



Estimate HEV prevalence in pigs sent to slaughterhouses
Assess the impact of control and surveillance activities at national scale

Assess national prevention, surveillance and control impact

Objectives

1: Simulate animals movements within and between farms

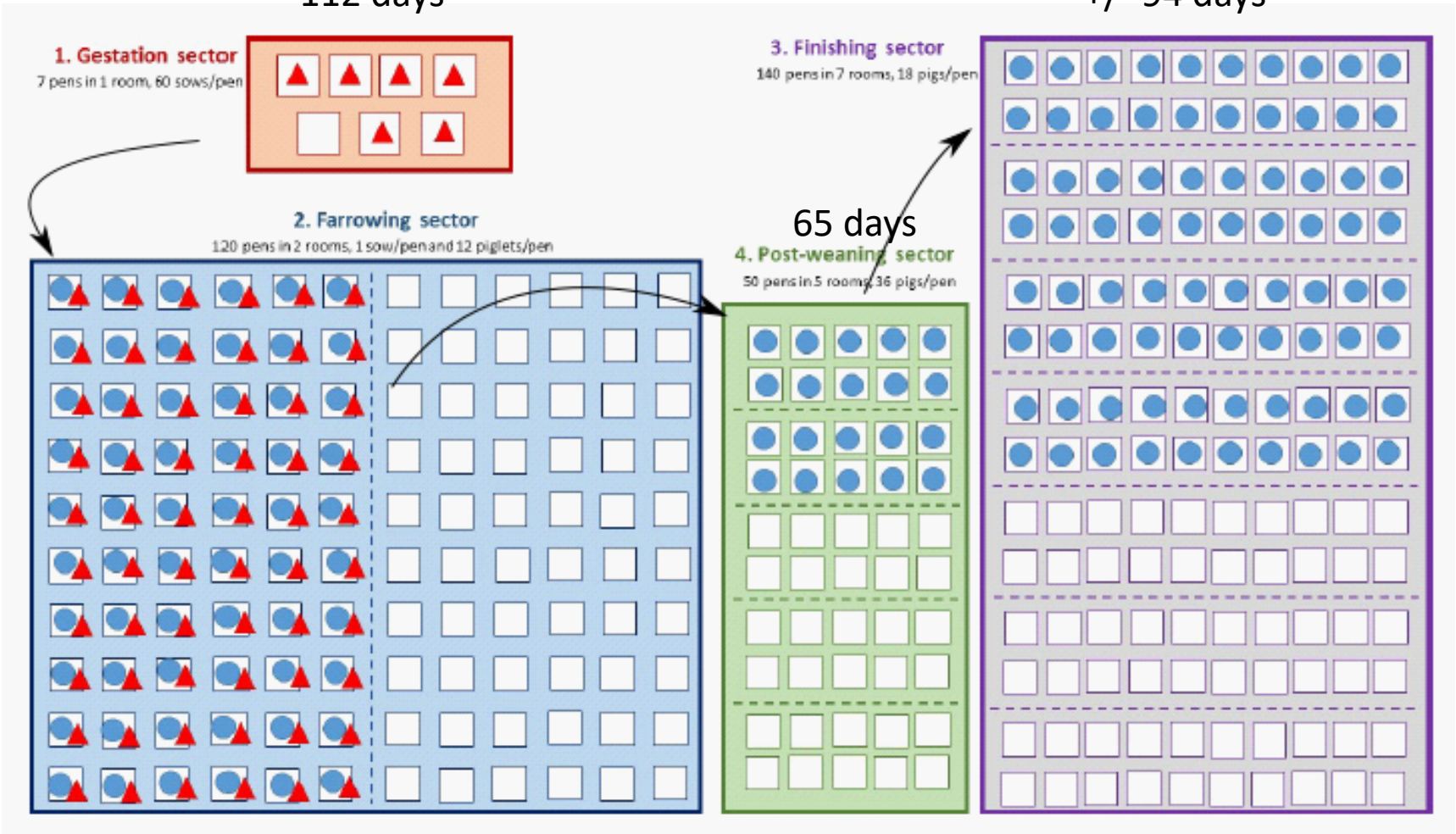
2: Simulate disease spread

3: Test prevention, surveillance and control measures

Production cycle of swine

112 days

+/- 94 days

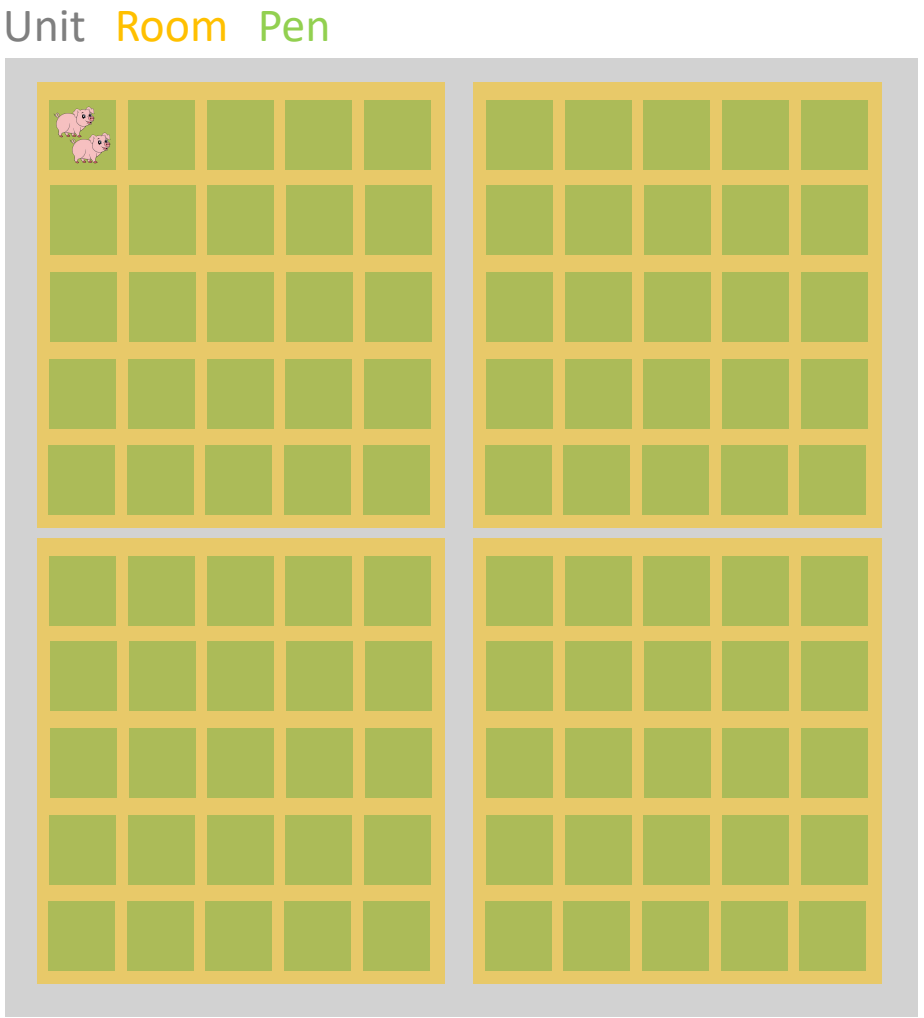


7 days sow +
21 or 28 days
with piglets

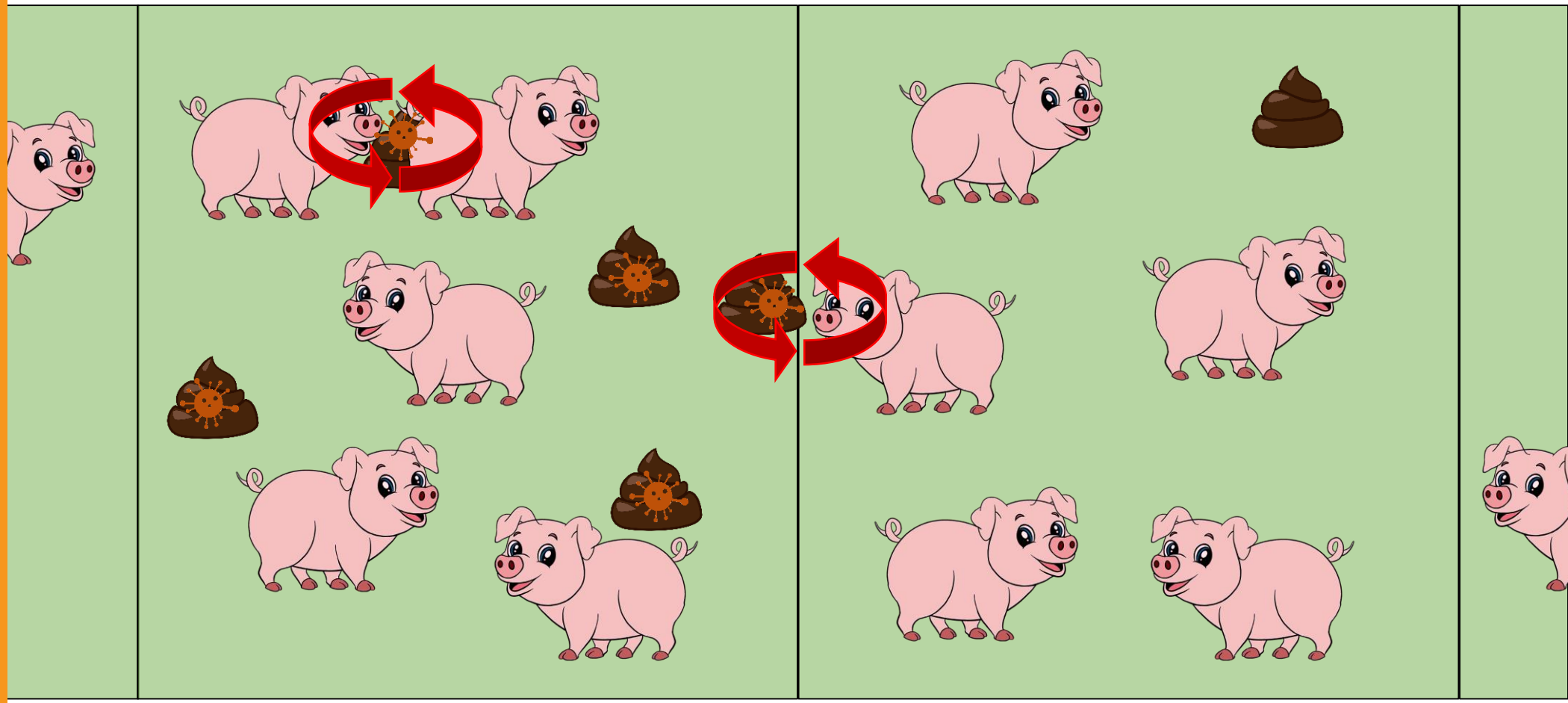
Deterministic schedule

Salines, M., Andraud, M., Rose, N., Widgren, S., 2020. A between-herd data-driven stochastic model to explore the spatio-temporal spread of hepatitis E virus in the French pig production network. PLoS ONE 15, e0230257. https://doi.org/10.1371/journal.pone.0230257

Unit structure

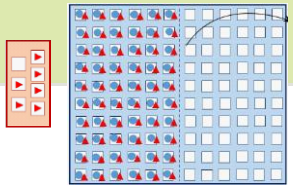


Within farm transmission

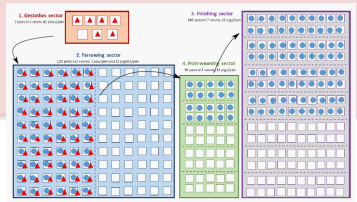


Farms structure - husbandry activity

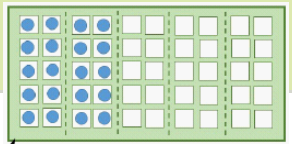
FARROWERS



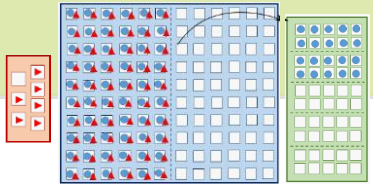
NUCLEUS



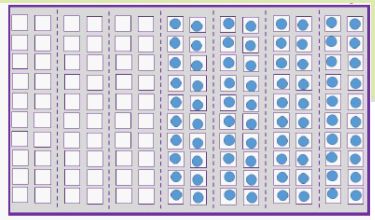
POST-WEANERS



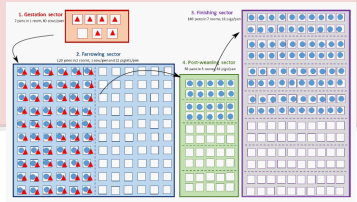
FARROWERS
POST-WEANERS



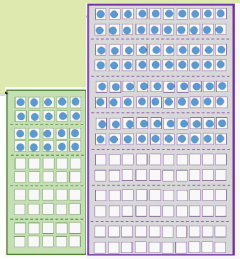
FINISHERS



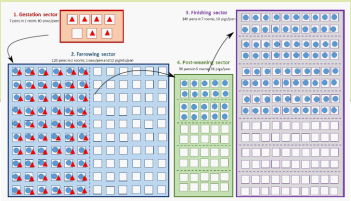
MULTIPLIERS



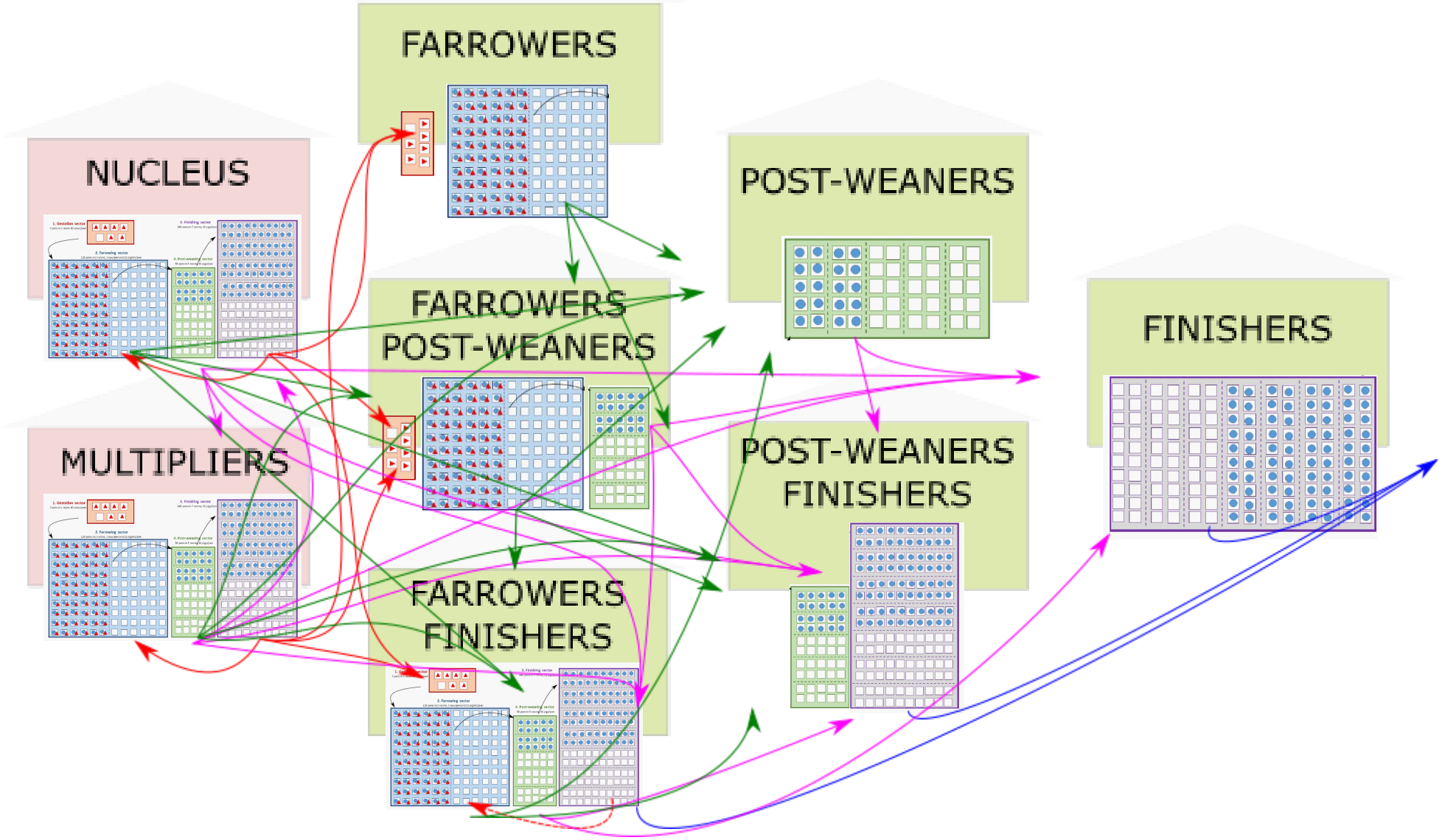
POST-WEANERS
FINISHERS



FARROWERS
FINISHERS



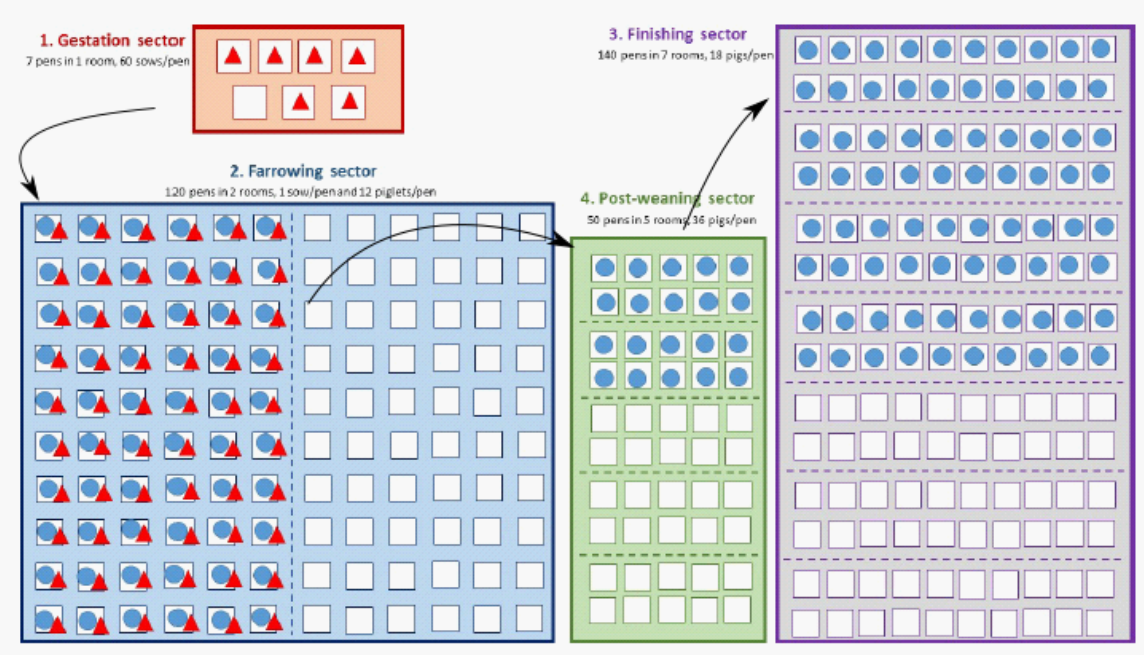
Between farm movements/spread



Salines, M., Andraud, M., Rose, N., Widgren, S., 2020. A between-herd data-driven stochastic model to explore the spatio-temporal spread of hepatitis E virus in the French pig production network. PLoS ONE 15, e0230257. https://doi.org/10.1371/journal.pone.0230257

Data were provided by the French national pig identification database (Bdporc)

Within farm movements



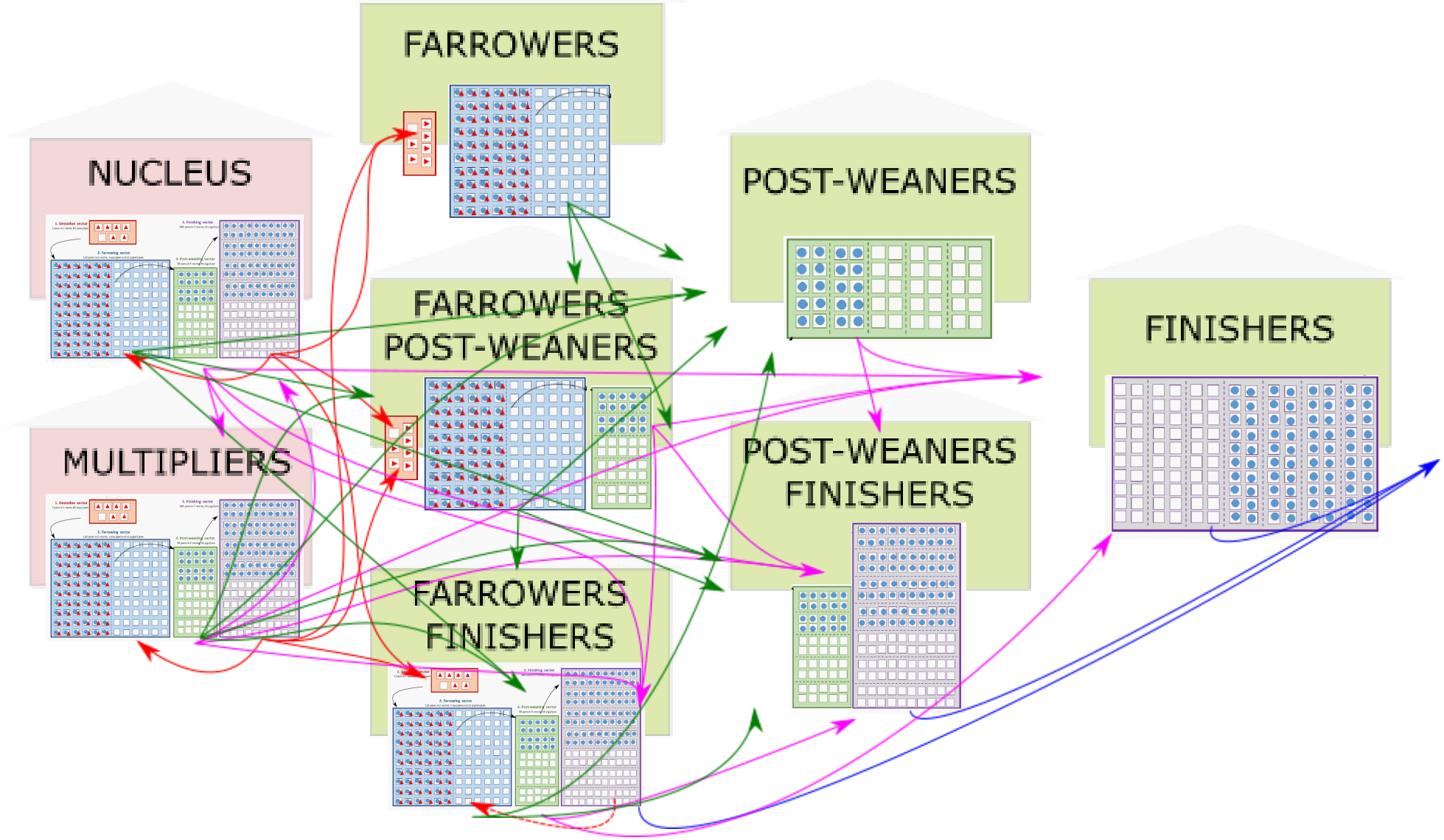
Farm variables:

- Farm type
- Number of rooms per unit
- Number of pens per room
- Number of animals per pen
- Duration of stay in each unit
- Duration of sanitary void in each unit

New features:

- 8 types of farms
- 5 batch rearing systems (dynamics – deterministic duration)
- Higher size variability
- Room scale

Between farms movements



Exponential Random Graph Models

Observed network

Variables :

Network structure

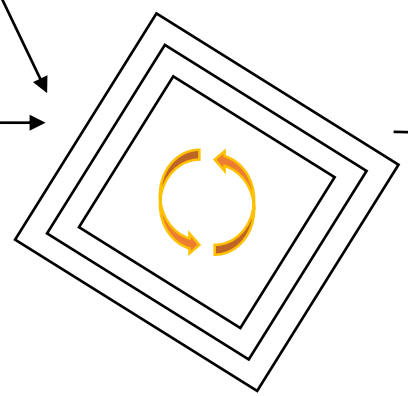
- Edges

Movements characteristics

- Distance

Farms characteristics

- Type
- Compagny
- Size
- Outdoor rearing system
- Batch rearing systems (duration of stay in each sector/number of simultaneous batchs)
- Corsica



Random simulated movements (ERGM)
Package statnet/ergm

Model selection using
Bidirectional stepwise procedure

Probabilities of contact

Relun, A., Grosbois, V., Alexandrov, T., Sánchez-Vizcaíno, J.M., Waret-Szkuta, A., Molia, S., Etter, E.M.C., Martínez-López, B., 2017. Prediction of Pig Trade Movements in Different European Production Systems Using Exponential Random Graph Models. Front Vet Sci 4, 27. https://doi.org/10.3389/fvets.2017.00027

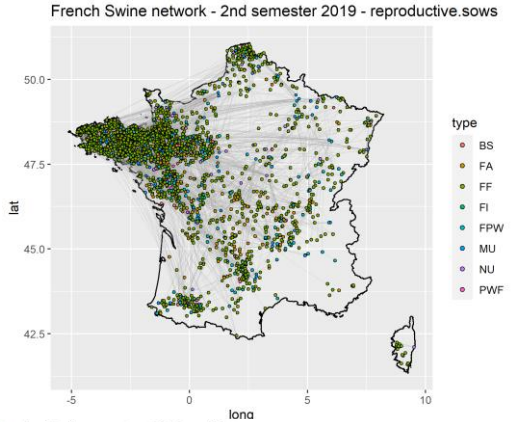
Hunter, D.R., Handcock, M.S., Butts, C.T., Goodreau, S.M., Morris, M., 2008. ergm: A Package to Fit, Simulate and Diagnose Exponential-Family Models for Networks. J Stat Softw 24, nihpa54860. https://doi.org/10.18637/jss.v024.i03

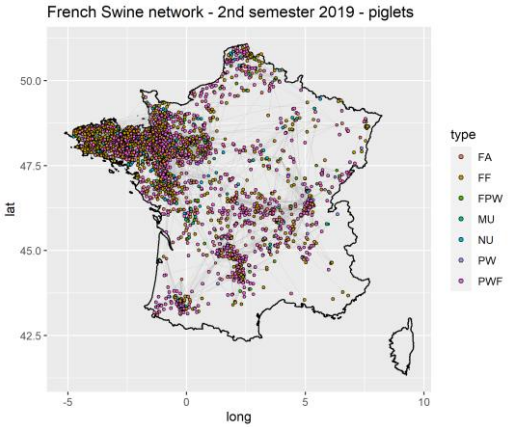
Salines, M., Andraud, M., Rose, N., 2017. Pig movements in France: Designing network models fitting the transmission route of pathogens. PLoS ONE 12, e0185858. https://doi.org/10.1371/journal.pone.0185858

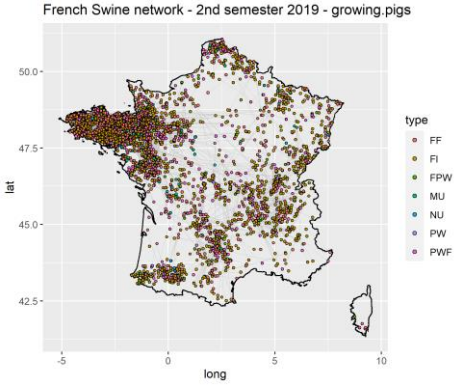
Data were provided by the French national pig identification database (Bdporc)

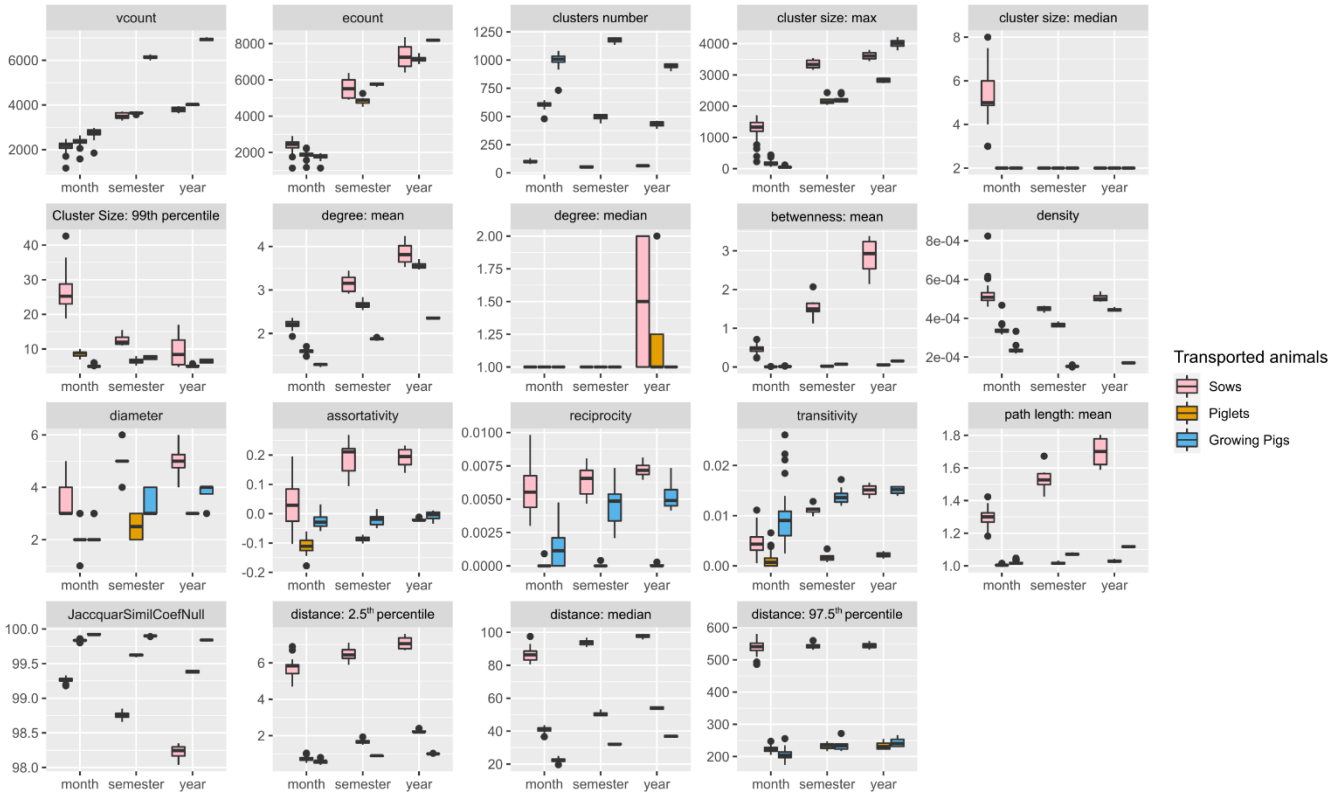
Network statistics – structural stability

Observed movements (SNA)
Package igraph





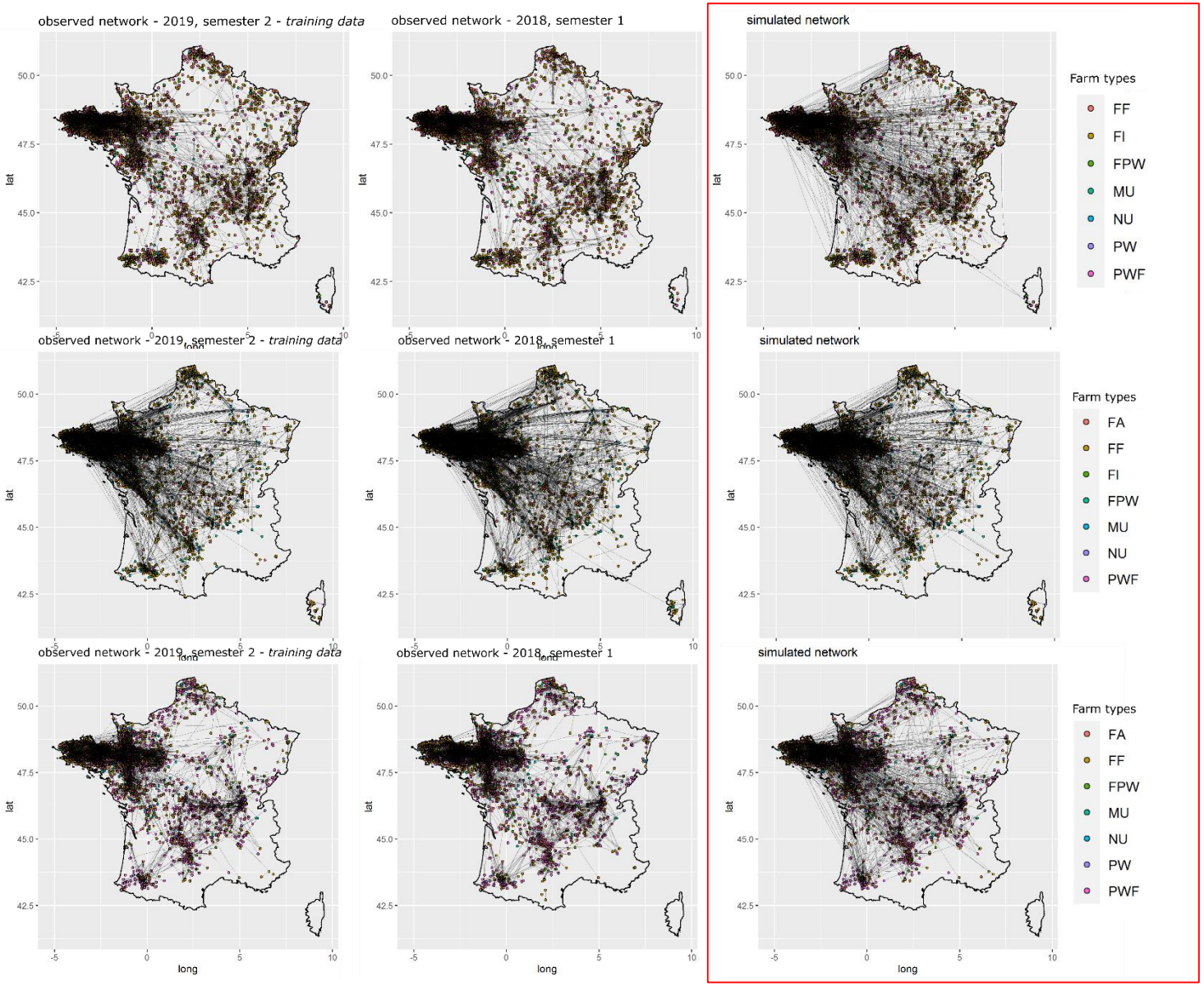




Visual validation

Simulated networks

Growing pigs

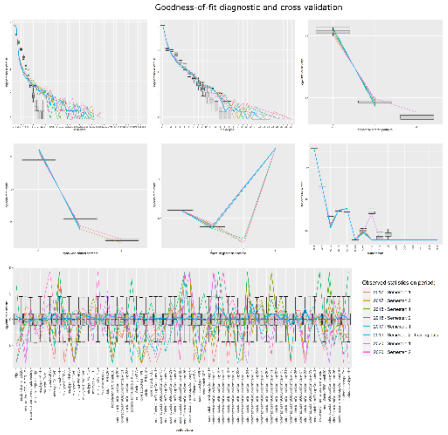


Piglets

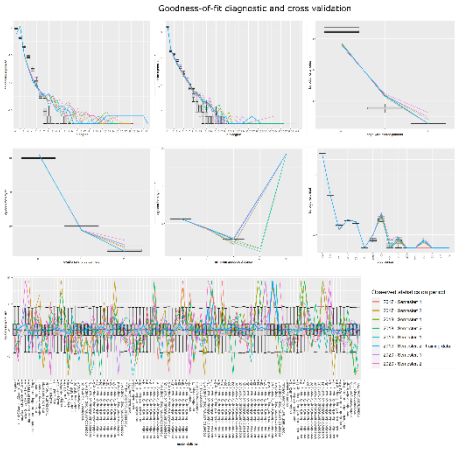
Breeding Sows

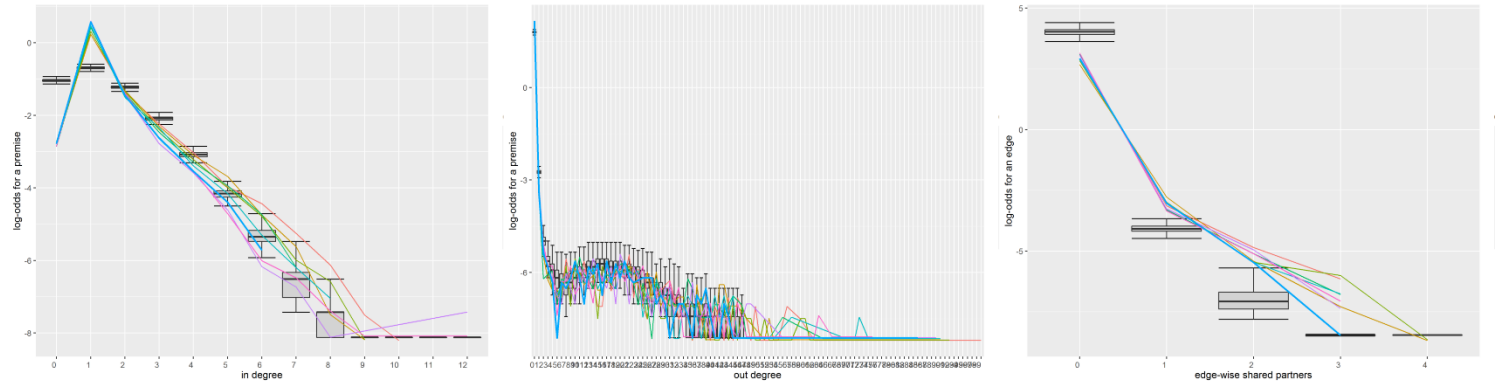
Goodness of fit

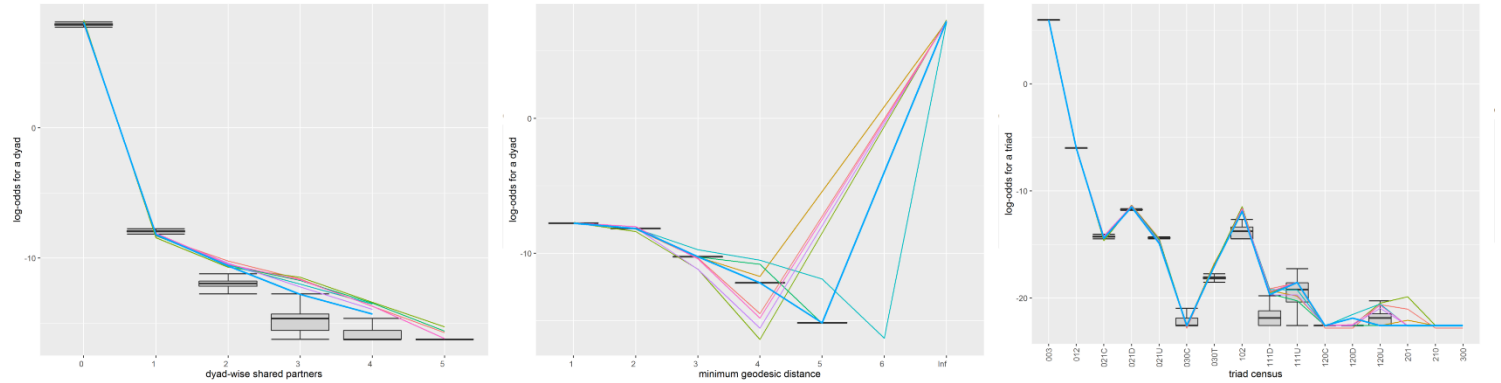
Piglets

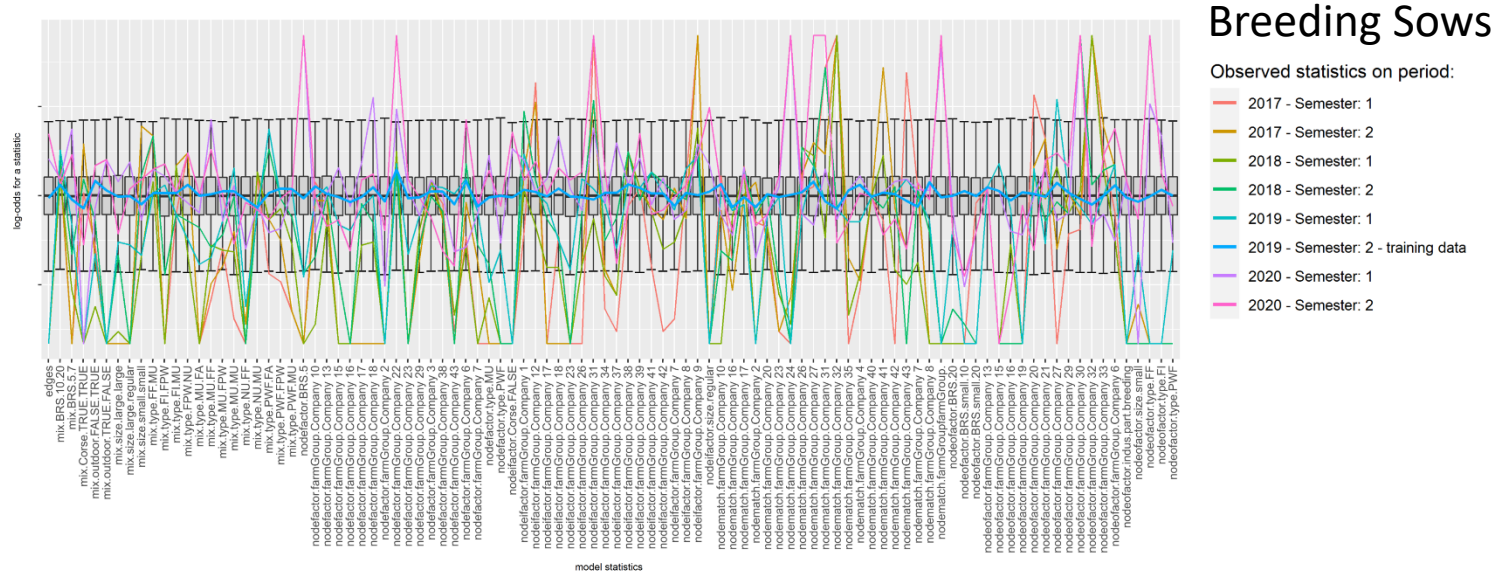


Growing pigs









Breeding Sows

Observed statistics on period:

- 2017 - Semester: 1
- 2017 - Semester: 2
- 2018 - Semester: 1
- 2018 - Semester: 2
- 2019 - Semester: 1
- 2019 - Semester: 2 - training data
- 2020 - Semester: 1
- 2020 - Semester: 2

Demographic model

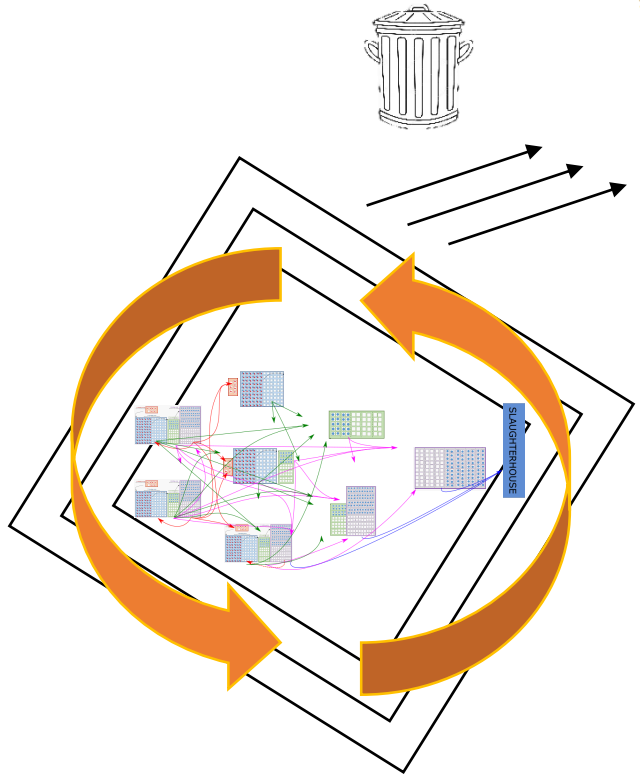
Farm structure
- *n* Units
- Rooms / unit
- Pens / room
- Animal / pen

Farms batch rearing systems
- Duration of stay in each sector
- Number of simultaneous batchs

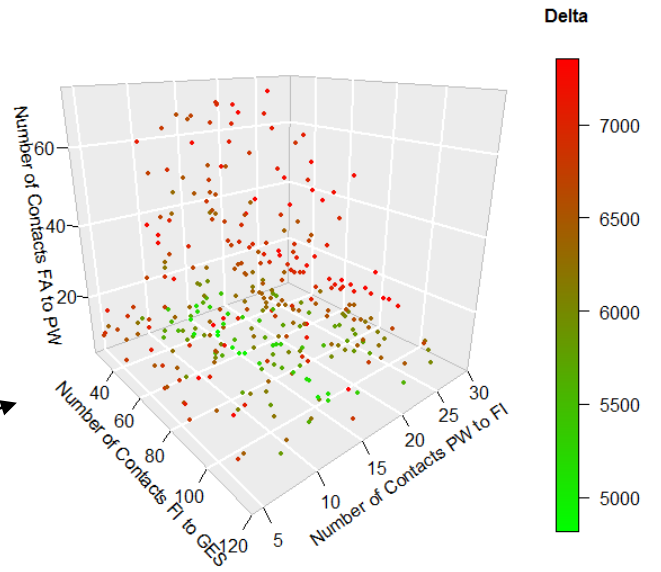
Deterministic schedule

Farm contacts per type of animals
- Contact IDs
- Associated probabilities

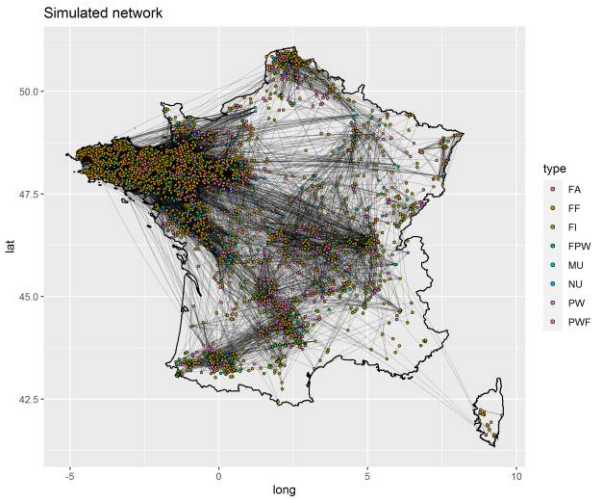
Stochastic destinations



Parameters estimation
incomplete sampling plan



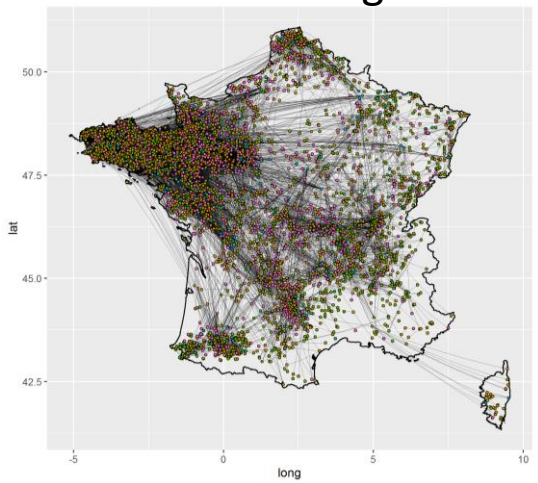
Random networks



Pen scale
Daily time step

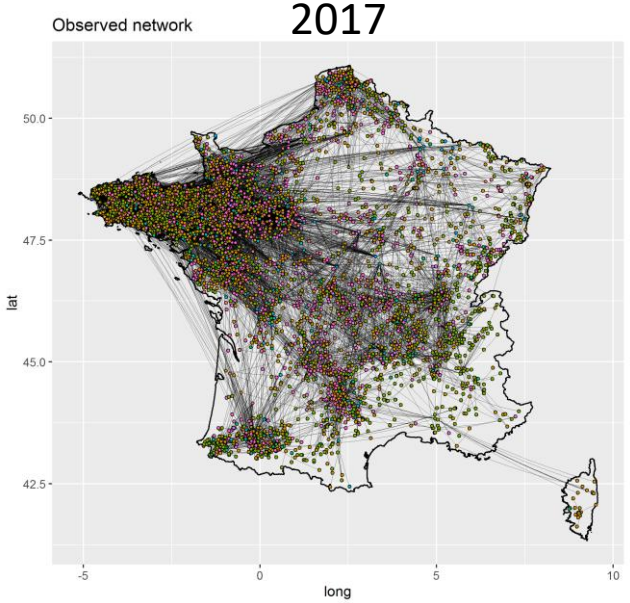
Visual validation

2019 – training data

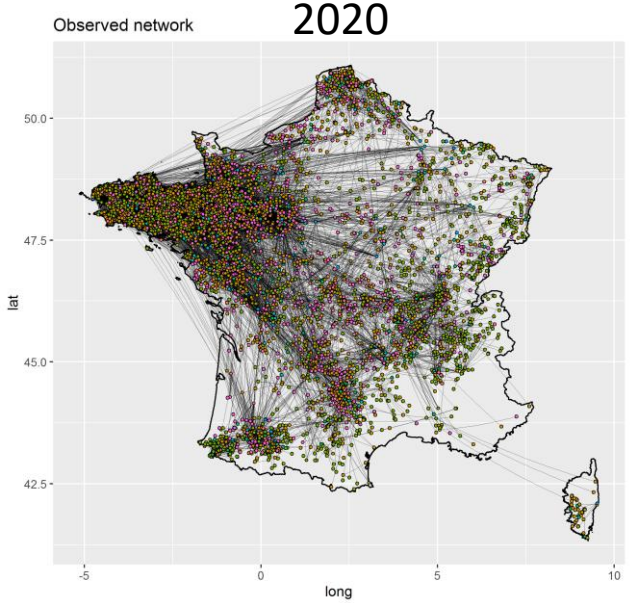


Cross-validation

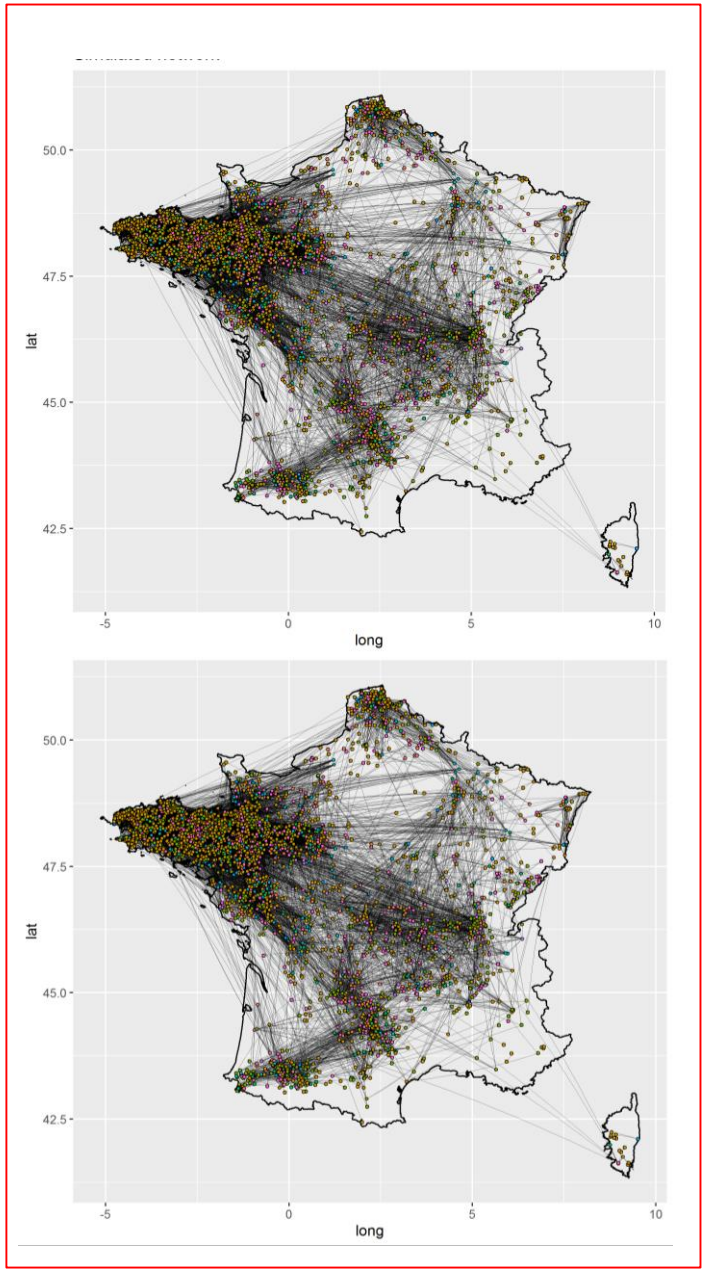
2017



2020

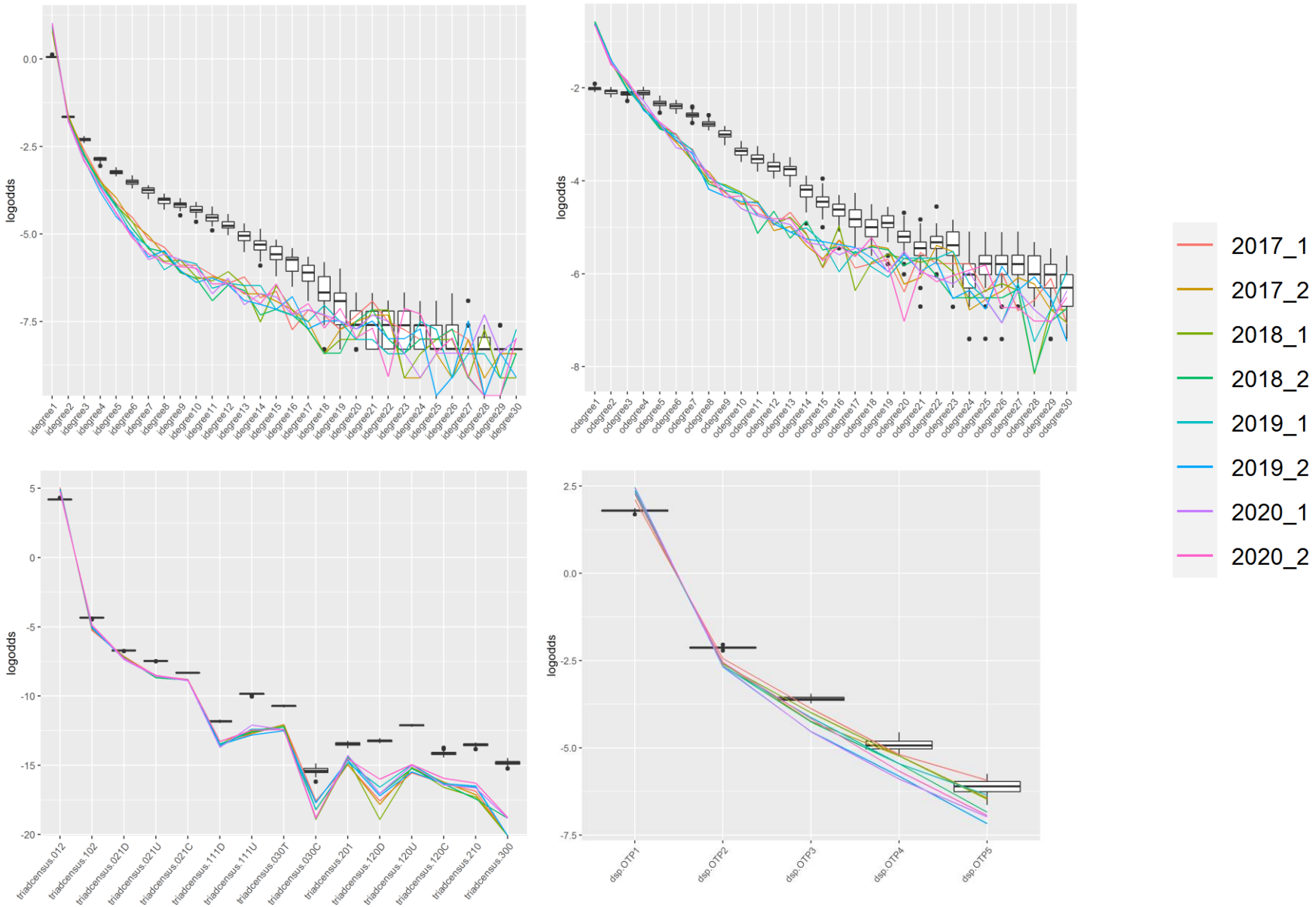


Simulated networks



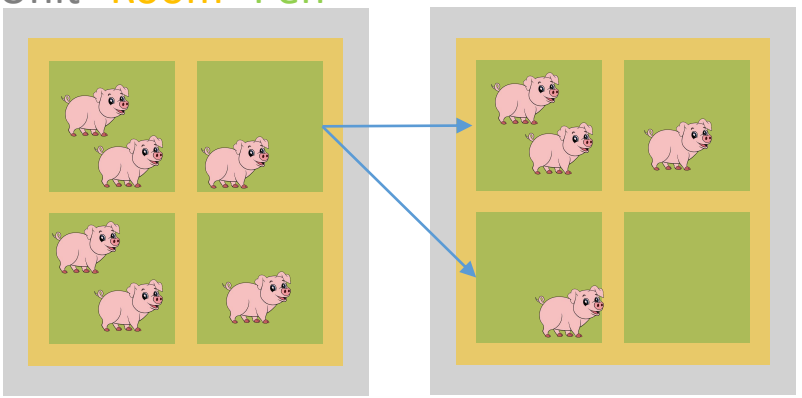
+ Average number of slaughtered pigs per year

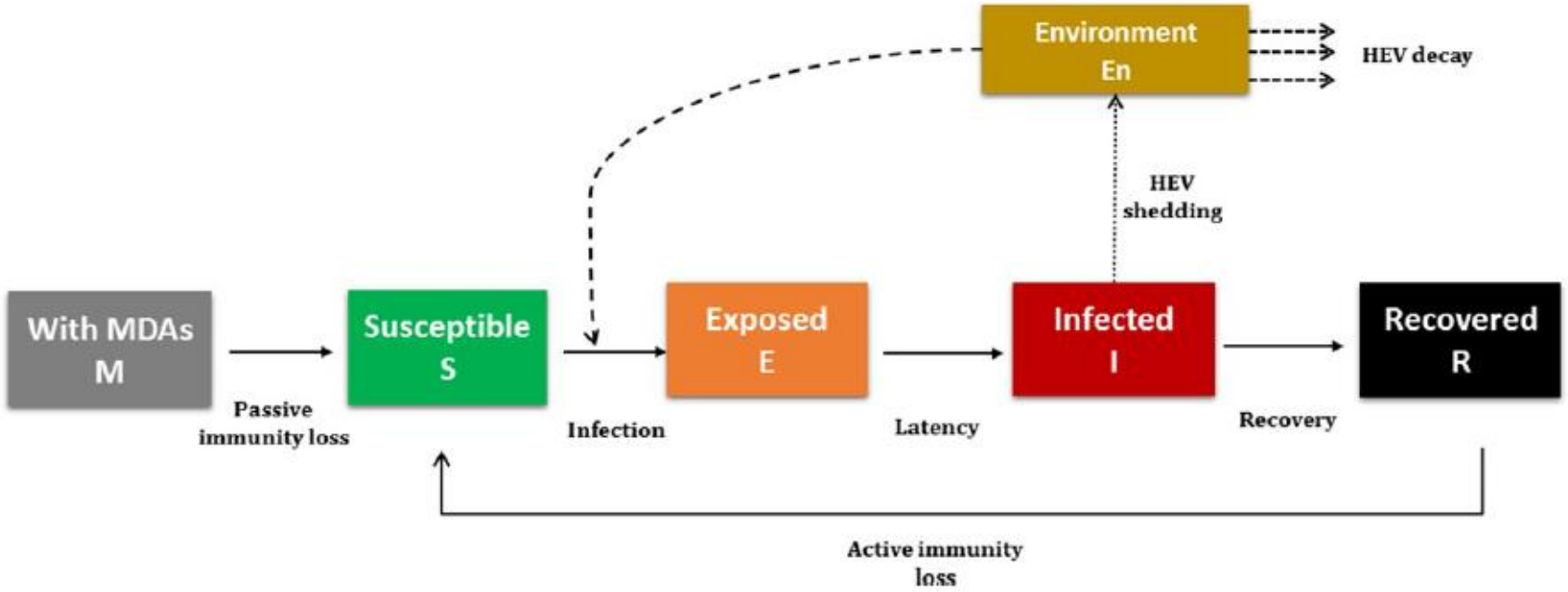
Goodness of fit



Epidemiological model

MSEIR-En model -SimInf





Direct transmission within pen between susceptible and infectious pigs

Indirect fecal-oral transmission through environment – within pen and with neighboring pens

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Epidemiological model

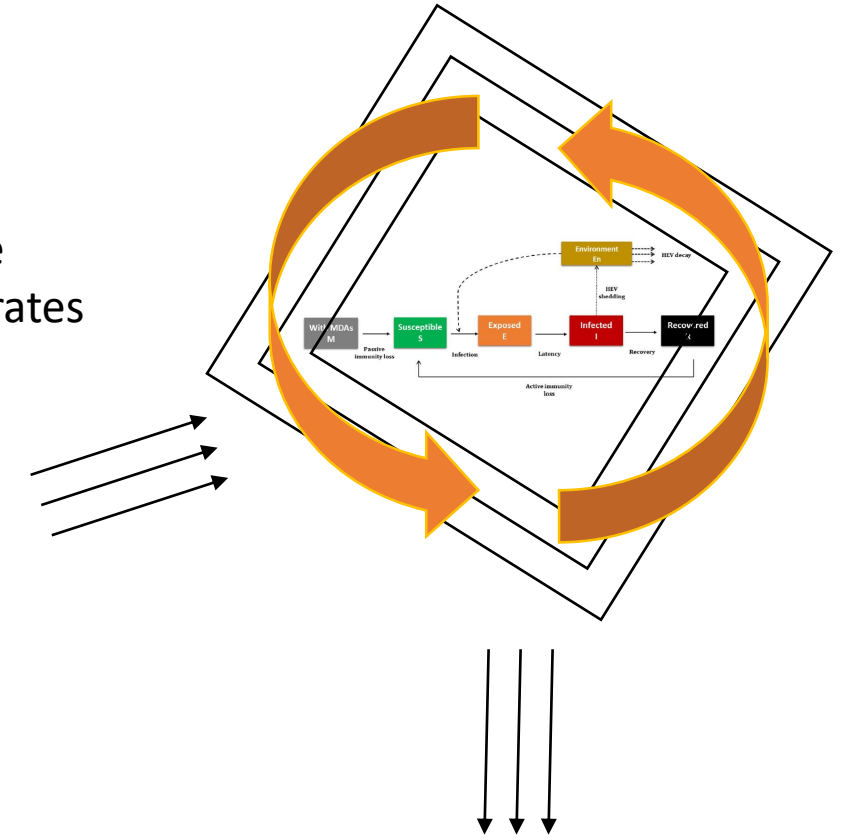
Farm-Unit level

- Direct
- Within-pen environmental transmission rate
- Between-pens environmental transmission rates
- External biosecurity level
- HEV Latency duration (days)
- HEV Infectious period (days)
- Cleaning rate

General variables

- Quantity of faeces/pig/day
- Quantity of faeces/sow/day
- Duration of maternal antibodies
- …

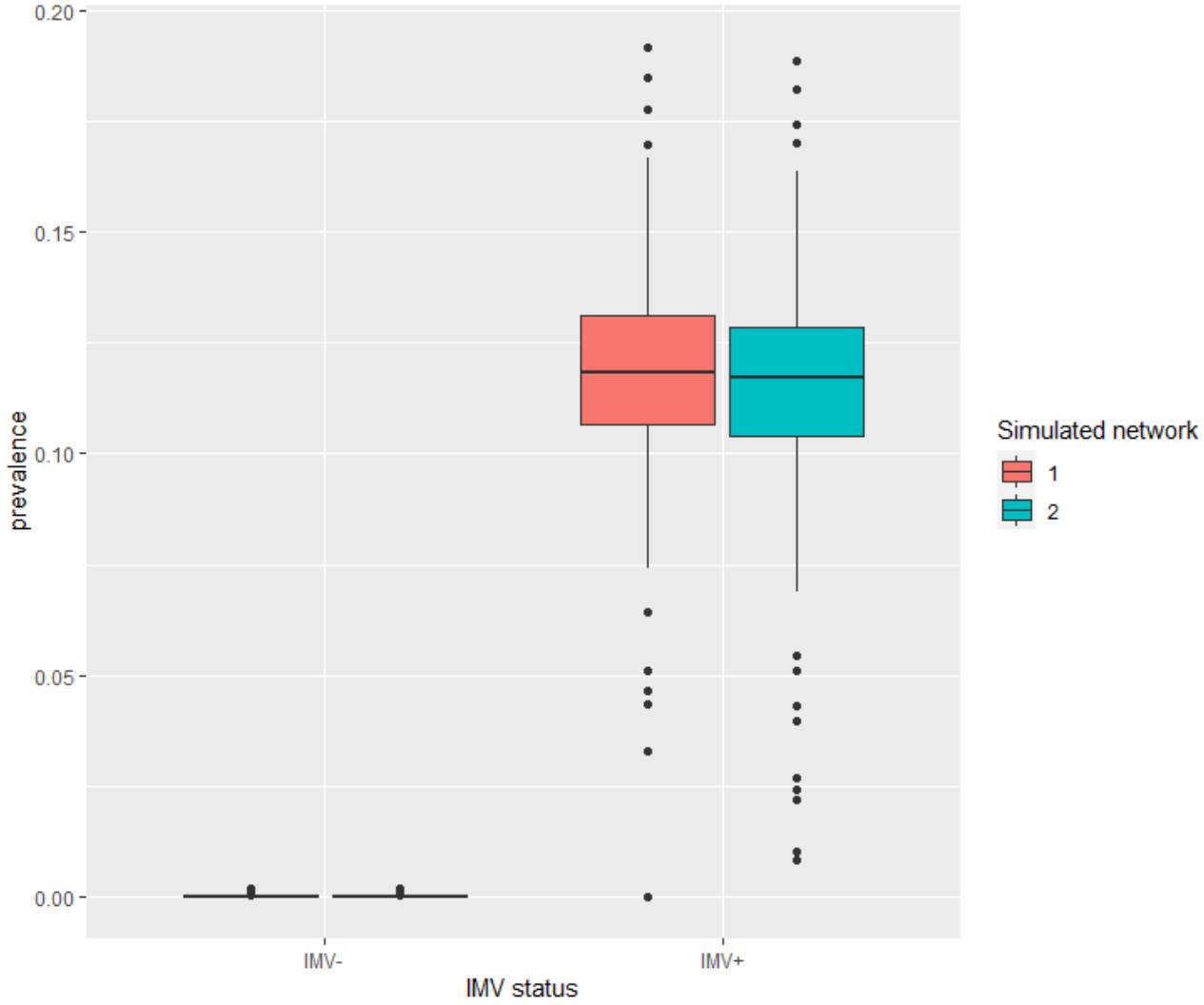
Random networks



Number of animal and send to slaughterhouses and associated epidemiological states

Exemple of outputs

Prevalences in slaughterhouses over five years



Take home messages

Flexible tool to simulate population dynamics and disease spread

Simulation of pig movements between pens

- Deterministic: based on duration of stay in each unit
- Stochastic between farms movements based on contact probabilities (ERGM)

Simulation of disease spread using SimInf

- Continuous-time Markov chains using the Gillespie stochastic simulation algorithm
- Direct contact within pens
- Environmental viral charge neighboring pens

P. Hammami, S. Widgren, V. Grosbois, A. Apolloni, N. Rose and M. Andraud. Complex network analysis to understand trading partnership in french swine production. *Submitted*.