Complex networks for Foot-and-Mouth Disease (FMD) vulnerability

Authors: Jeisson Prieto & Francisco Gómez

COmputational Modeling of BIOlogical Systems (COMBIOS)
Universidad Nacional de Colombia, Bogotá D.C., Colombia

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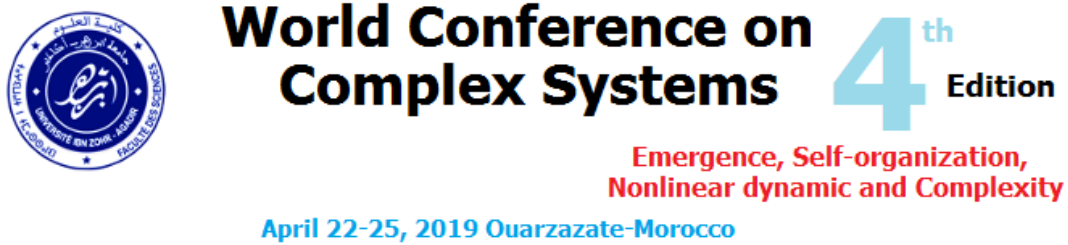
Outline

Outline

Academic Research

WCCS 2019

World conference on Complex Systems

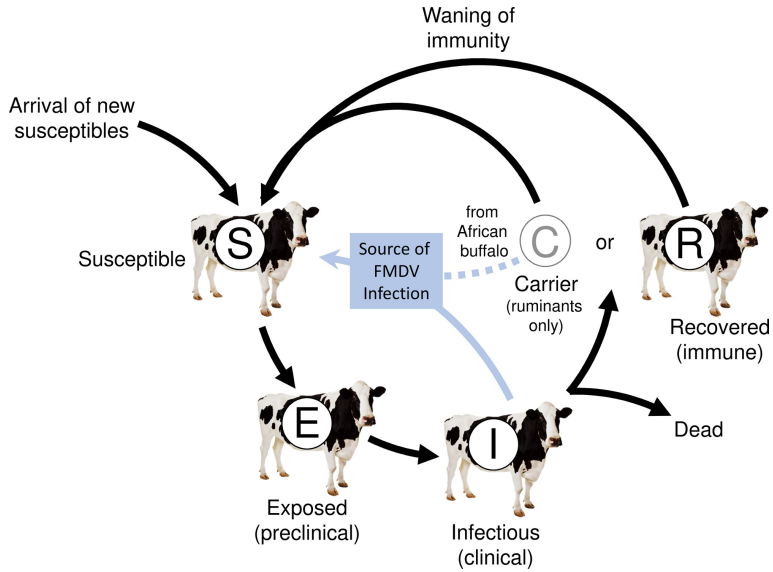


Pre-COSALFA 46

International Seminar "On the threshold of Eradication of Foot-and-Mouth Disease: Pending Tasks"

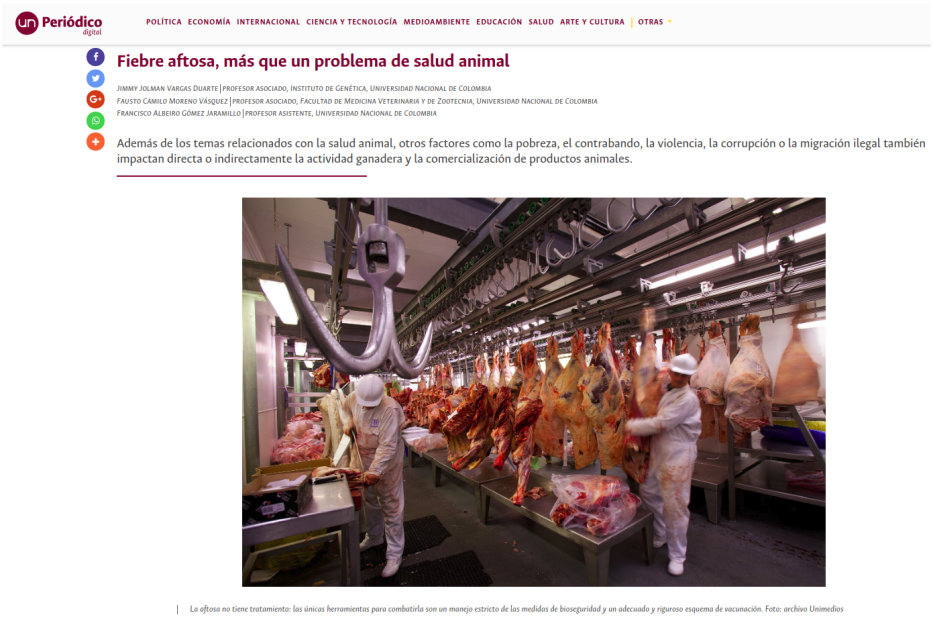
Definition [1]

- **Highly contagious viral disease**.
- Affects cattle, swine, sheep, goats and other cloven-hoofed ruminants.
- Severely affect the production and international trade of livestock and animal products.
- The morbidity rate may approach $100\,\%$ in susceptible cattle populations.



[1] OIE. (2018). Foot & Mouth disease (FMD).

The importance of FMD


Periódico digital

POLÍTICA ECONOMÍA INTERNACIONAL CIENCIA Y TECNOLOGÍA MEDIOAMBIENTE EDUCACIÓN SALUD ARTE Y CULTURA | OTRAS

Fiebre aftosa, más que un problema de salud animal

JIMMY JOLMAN VARGAS DUARTE | PROFESOR ASOCIADO, INSTITUTO DE GENÉTICA, UNIVERSIDAD NACIONAL DE COLOMBIA
FAUSTO CAMILO MORENO VÁSQUEZ | PROFESOR ASOCIADO, FACULTAD DE MEDICINA VETERINARIA Y DE ZOOTECNIA, UNIVERSIDAD NACIONAL DE COLOMBIA
FRANCISCO ALBEIRO GÓMEZ JARAMILLO | PROFESOR ASISTENTE, UNIVERSIDAD NACIONAL DE COLOMBIA

Además de los temas relacionados con la salud animal, otros factores como la pobreza, el contrabando, la violencia, la corrupción o la migración ilegal también impactan directa o indirectamente la actividad ganadera y la comercialización de productos animales.

La aftosa no tiene tratamiento: las únicas herramientas para combatirla son un manejo estricto de las medidas de bioseguridad y un adecuado y riguroso esquema de vacunación. Foto: archivo Unimedios

- FMD losses approximated USD $\$2$ billion [2].
- UK outbreak cost GBP $\$6$ billion [3].
- FEDEGAN - In 2016 there was 26'413.227 cattle [4].
- **ICA - 2018 outbreak cost USD $\$53$ million [5].**

[2] Yu *el* al. (1997). A risk-assessment model for foot and mouth disease (fmd) virus introduction through deboned beef importation.

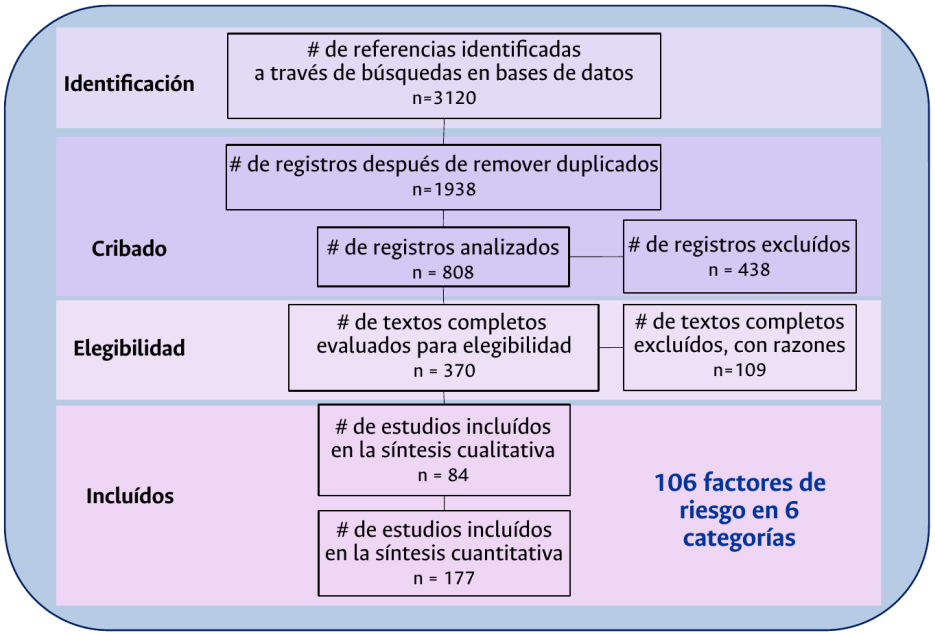
[3] Flood (2016). Foot-and-mouth disease epidemiology in relation to the physical, social and demographic farming landscape.

[4] FEDEGAN - Inventario ganadero. https://www.fedegan.org.co/estadisticas/inventario-ganadero.

[5] Pre-COSALFA 46 (2019). FMD Outbreak 2018 and control.

Risk factors

Meta-analysis [6]



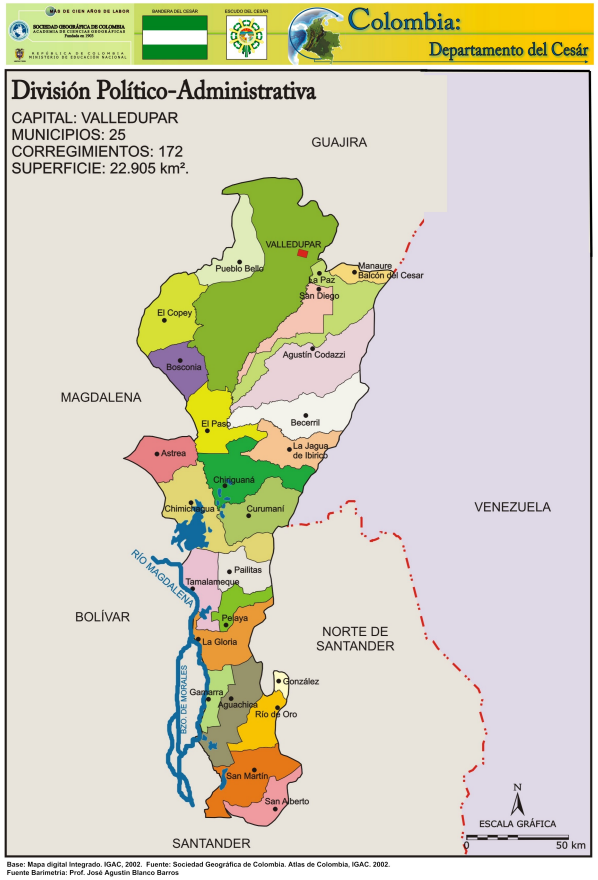
- Bovine herd
- **Animal mobilization**
- Productive process
- Health aspects
- **Biophysical space**
- Biophysical-environmental environment

[6] Morales *et* al. (2019). Metodología para el análisis espacial por vulnerabilidad y riesgo de la fiebre aftosa.

Case study

Cesar Region

- Animal mobilization
- Biophysical space



Outline

Justification

- **Cattle movement** is a principal cause of the initial dis semination of foot-and-mouth disease (FMD) [7].
- Therefore, transportation of these animals may represent an important risk for FMD propagation [7] [8].
- These movements records can be used to **construct a complex network** which structure can critically impact the transmission dynamic of many infectious diseases [8].

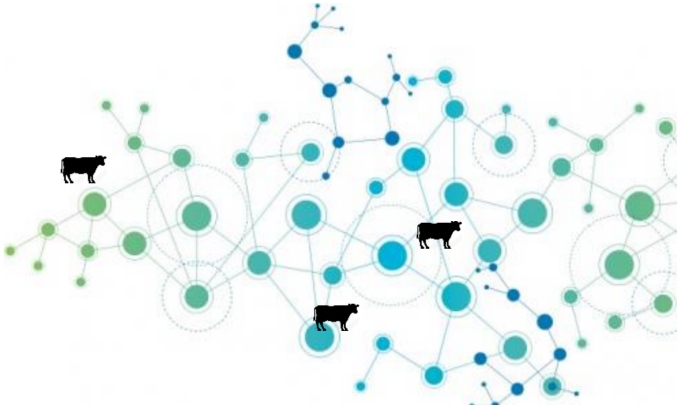
Understanding the structure of this transport network is of the utmost importance for preventing and controlling future epidemic outbreaks.

[7] Gibbens *et* al. (2001). Descriptive epidemiology of the 2001 foot- and-mouth disease epidemic in Great Britain: the first five months.

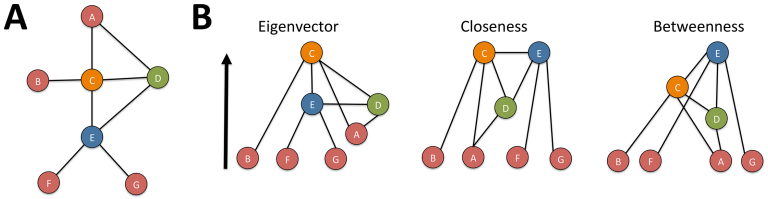
[8] Kiss *et* al. (2006). The network of sheep move- ments within Great Britain: network properties and their implications for infectious disease spread.

Super-spreaders for FMD

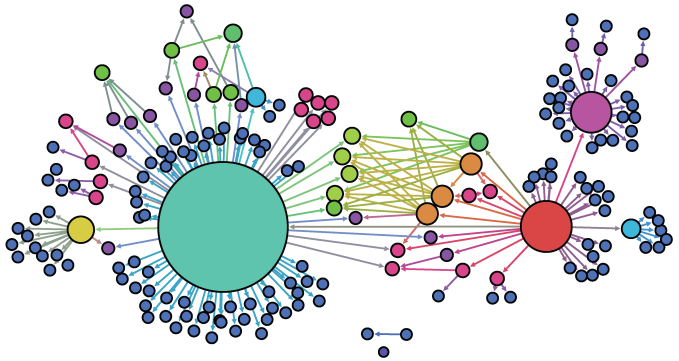
1. Cattle movement



2. Network construction



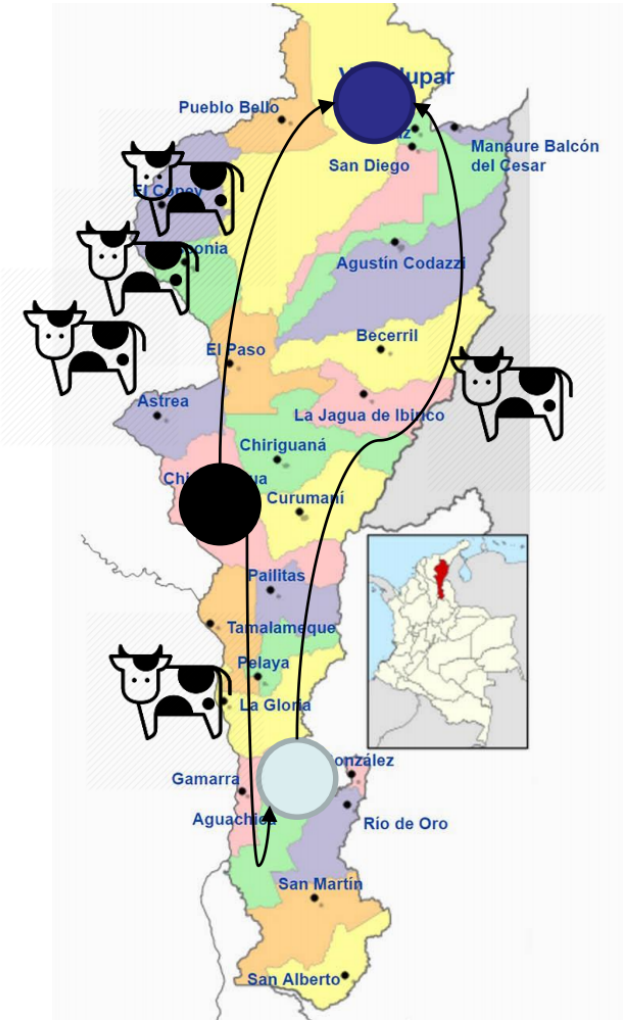
3. Graph characterization



4. Super-Spreader of Disease

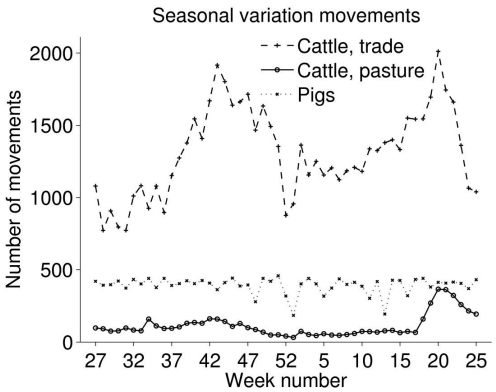
Movement definition [9]

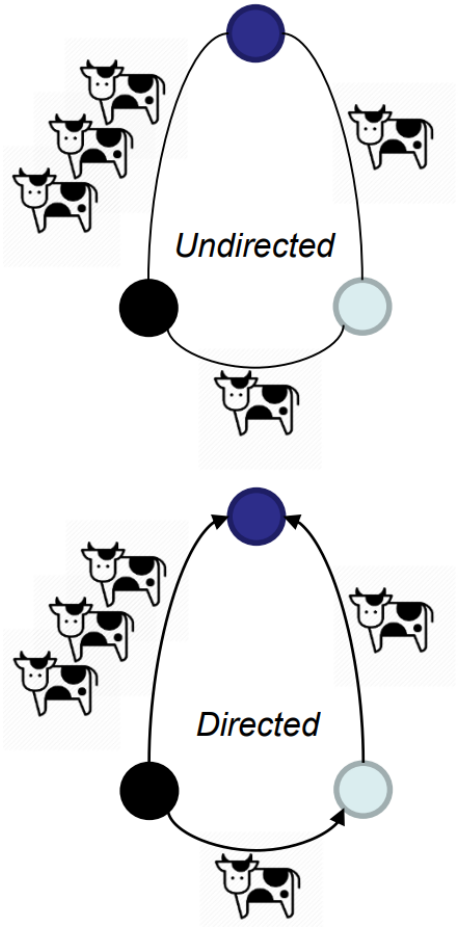
SIGMA

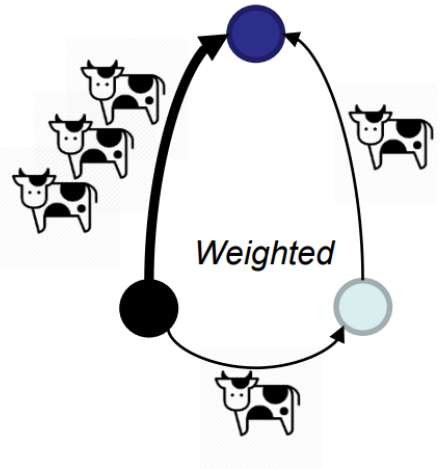


[9] SIGMA - Sistema de información para Guías de Movilización Animal. https://sigma.ica.gov.co/.

Movement characterization [10]





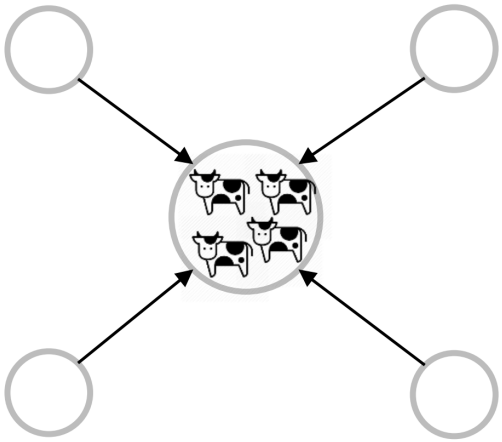


[10] Nöremark *et* al. (2009). Spatial and temporal investigations of reported movements, births and deaths of cattle and pigs in Sweden.

Graph Characterization

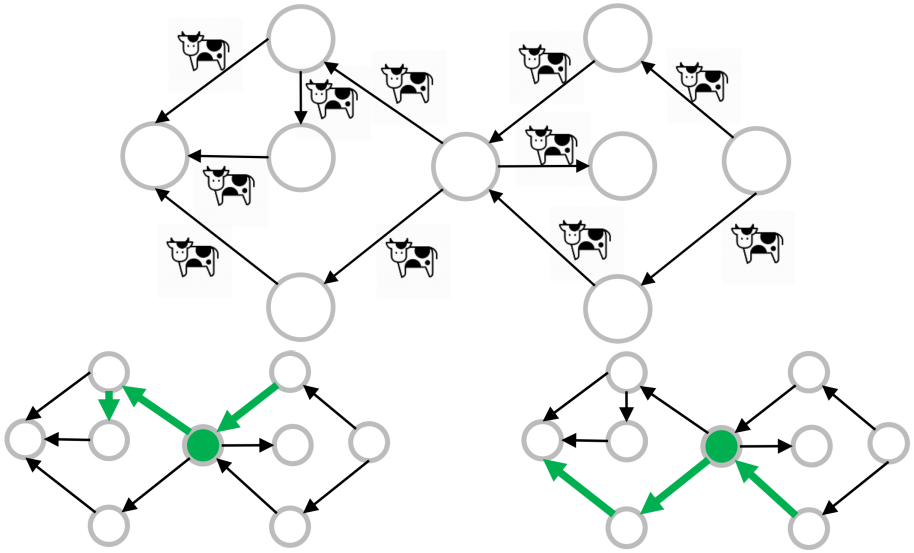
Degree

Direct contacts per holding



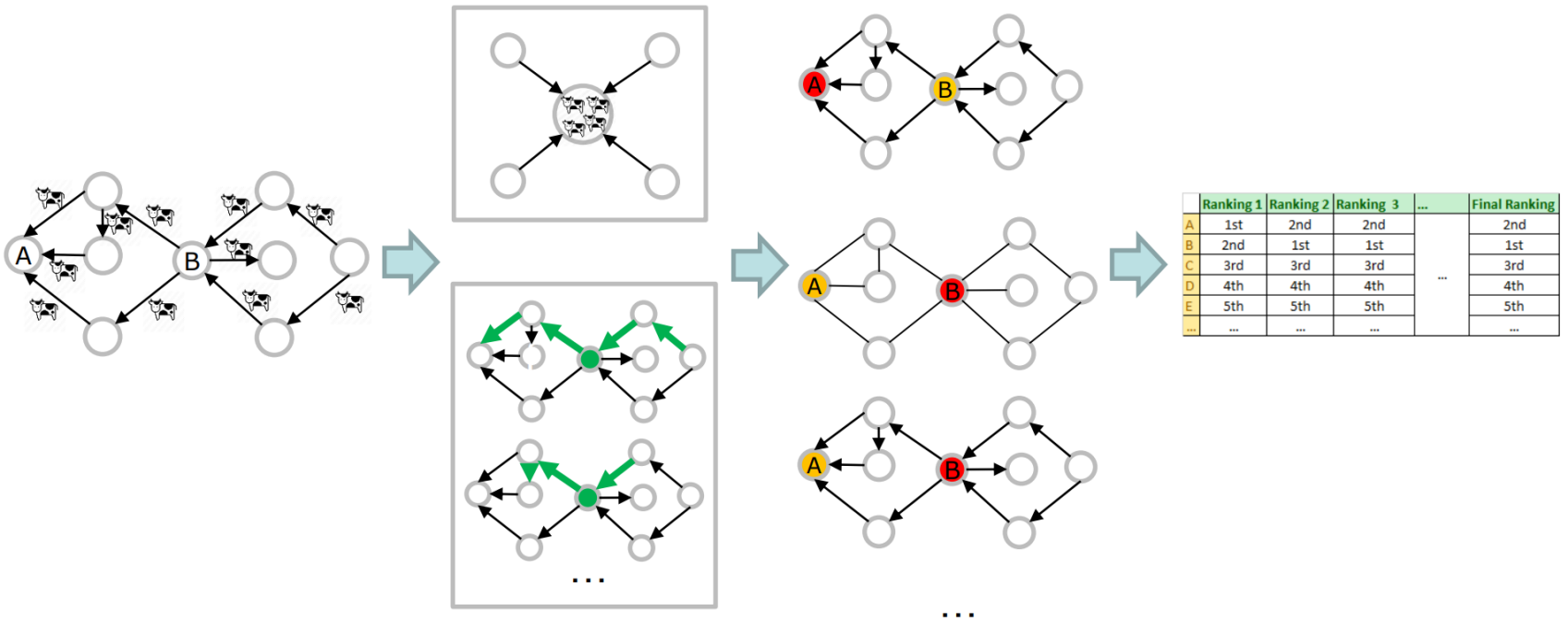
Betweenness

Frequency with which a cattle holding is in the shortest path between pairs of nodes in the network



Super-spreaders by mixing rankings

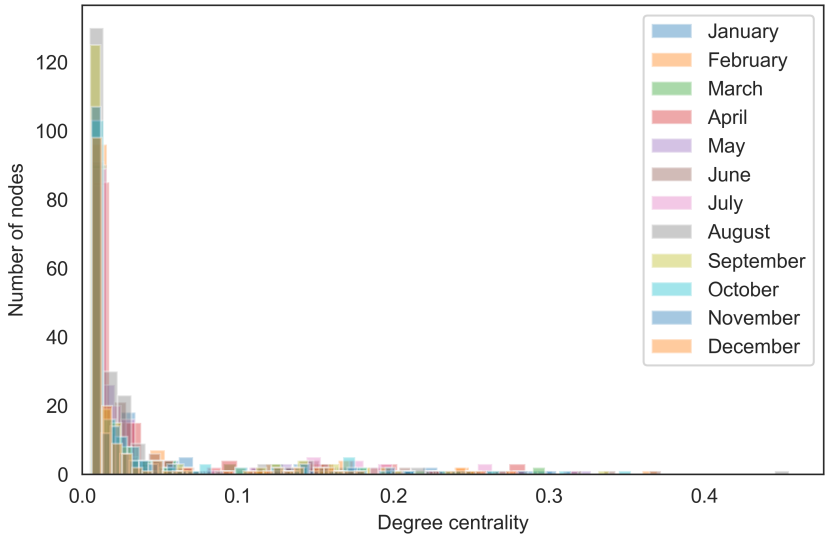
Borda's count aggregation method [11]



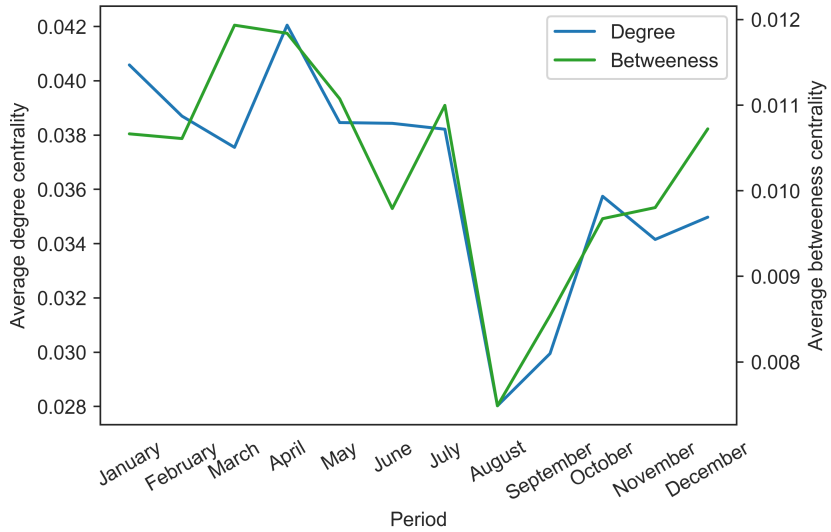
	Ranking 1	Ranking 2	Ranking 3	...	Final Ranking
A	1st	2nd	2nd		2nd
B	2nd	1st	1st		1st
C	3rd	3rd	3rd	...	3rd
D	4th	4th	4th		4th
E	5th	5th	5th		5th
...	...	...	...		...

[11] Madotto & Liu (2016). Super-Spreader Identification Using Meta-Centrality.

Network...

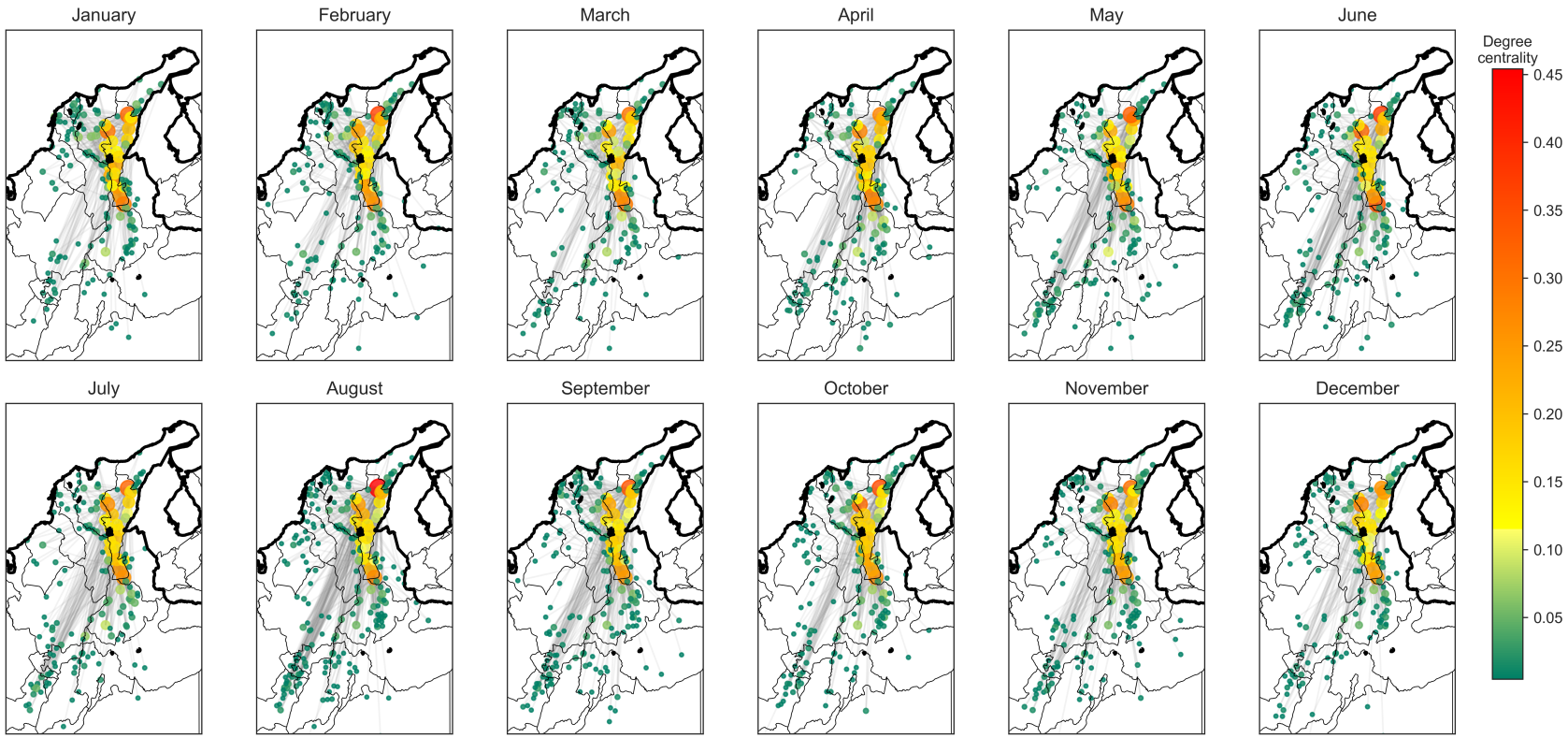


Heavy tailed distribution for degree

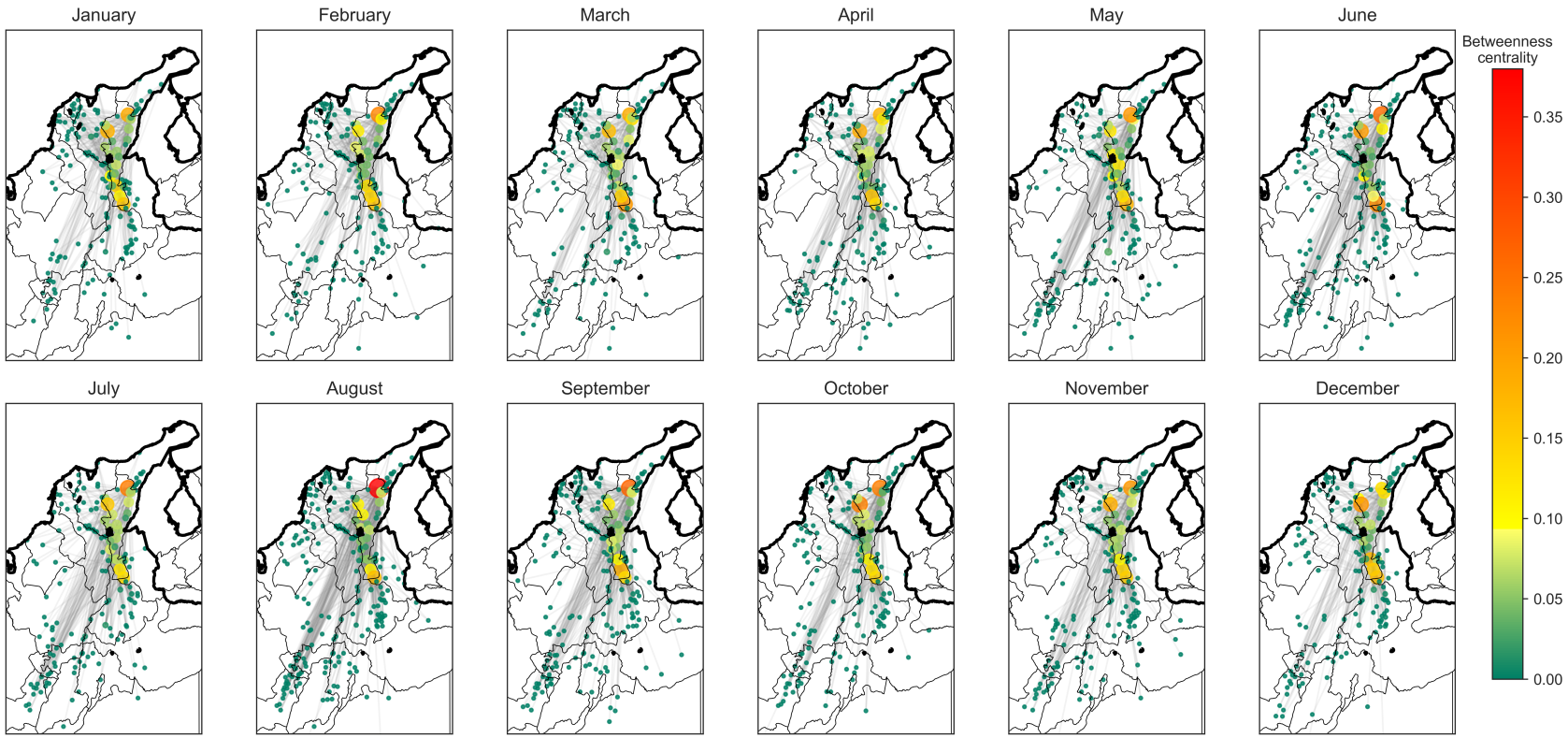


Seasonality in animal transportation

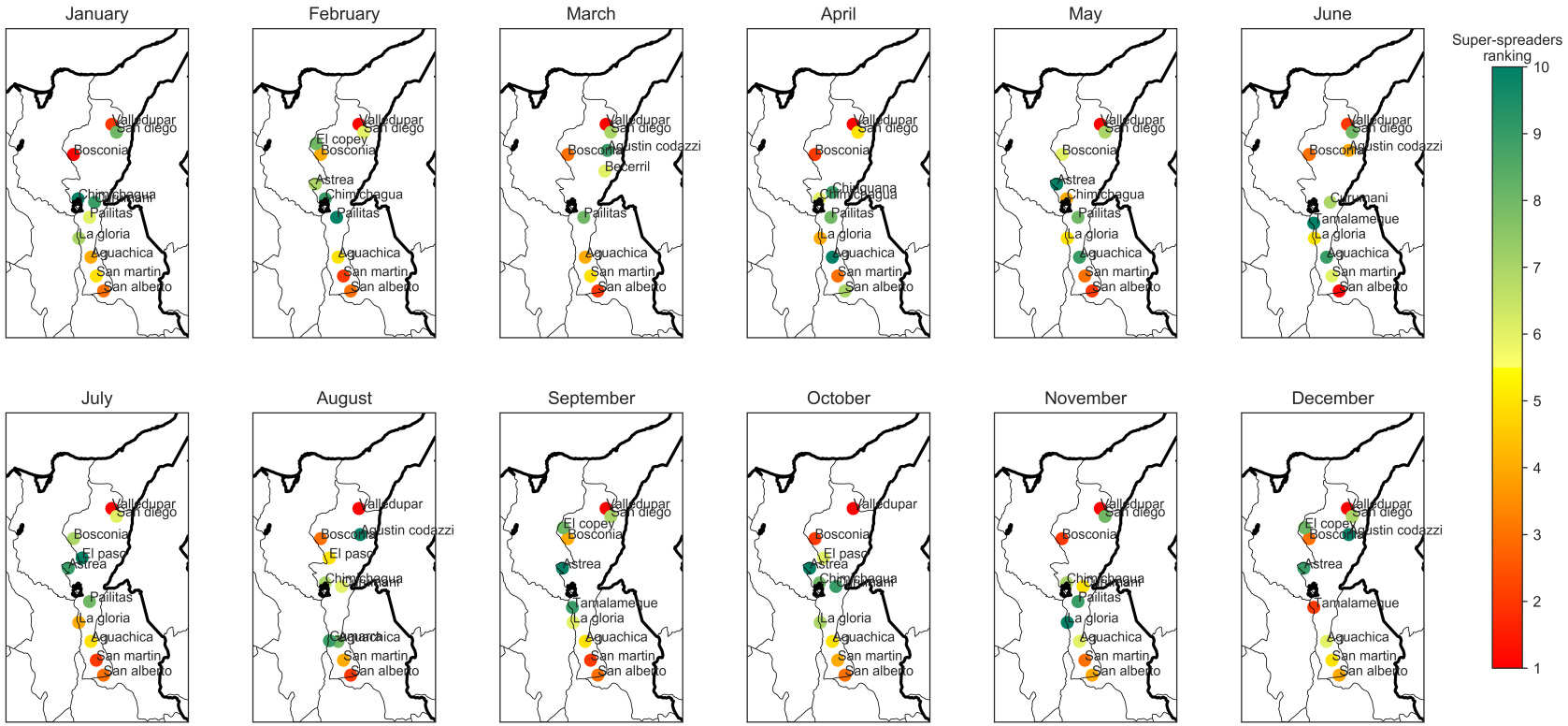
Undirected Degree Centrality



Undirected Betweenness Centrality

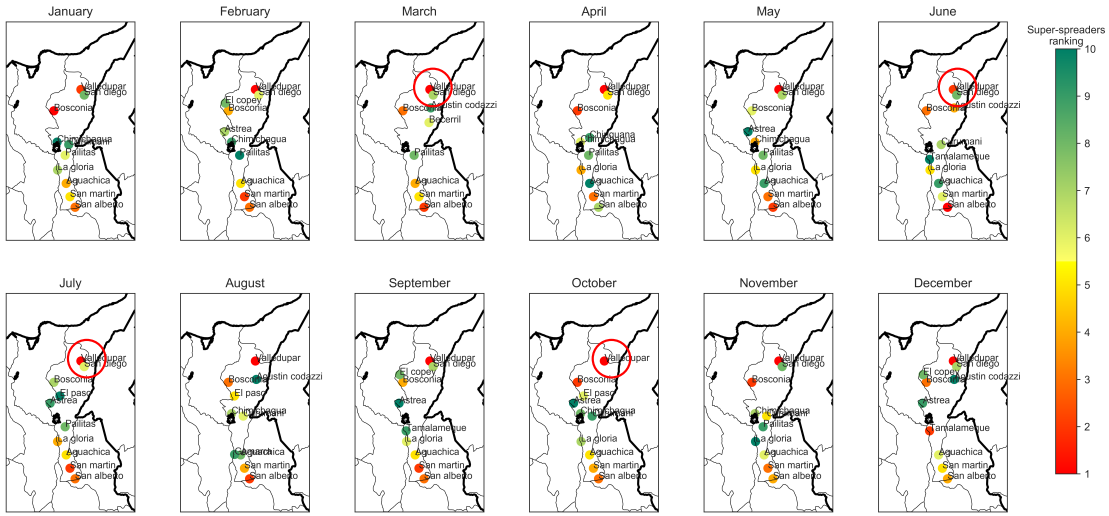


Super Spreader Ranking [12]



[12] Gómez *et* al. (2019). Identification of Super-Spreaders of Foot-and-Mouth Disease in the cattle transportation network: The 2018 outbreak case in Cesar (Colombia).

Conclusion



GOBIERNO DE COLOMBIA · MINAGRICULTURA · ICA Instituto Colombiano Agropecuario

RESOLUCIÓN No. 00034689
(22/10/2018)

"Por medio de la cual se establece una cuarentena en el municipio de VALLEDUPAR, departamento del Cesar, por presentación de un foco de FIEBRE AFTOSA"

1. Prohibir toda movilización de animales susceptibles a Fiebre Aftosa desde y hacia el municipio de Valledupar, Cesar, a excepción de los municipios de La Paz, Agustín Codazzi y San Diego, por encontrarse éstos en cuarentena por Fiebre Aftosa según Resolución No. 00034138 del 11 de octubre de 2018. Las movilizaciones provenientes de otros municipios que necesariamente deben transitar por el municipio de Valledupar, Cesar, deberán detenerse en los puestos de control ubicados para verificar la Guía Sanitaria de Movilización Interna – GSMI, que deberá llevar durante todo el trayecto de la movilización, ser desinfectados y precintados. Las movilizaciones dentro de la zona cuarentenada serán autorizadas por los funcionarios del ICA, previa evaluación del riesgo sanitario.

Outline

Justification

- Strategies for the prevention and control of (FMD) are based on vulnerability levels at **farm level** [13].
- Risk factors **NOT** associated with animal movement [14] [3]:
  - People movement between farms.
  - Permeability of physical barriers.
  - Machinery movement (Fomites).

The design of epidemiological strategies for the management of FMD is based on the quantification of these factors.

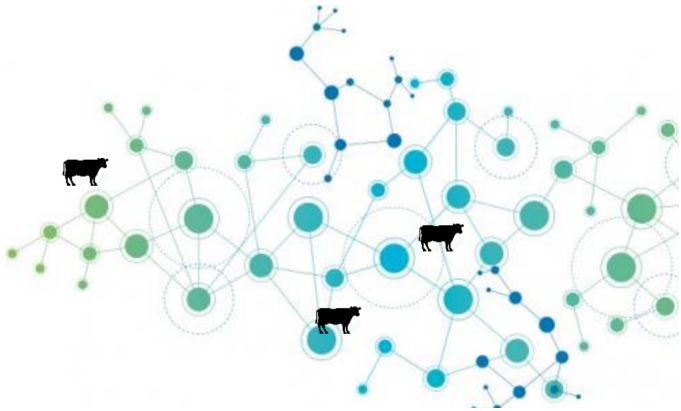
[13] Martínez-López *et* al. (2014). A multi-analysis approach for space-time and economic evaluation of risks related with livestock diseases: The example of FMD in Peru.

[14] Jori *et* al. (2009). A qualitative risk assessment of factors contributing to foot and mouth disease outbreaks in cattle along the western boundary of the Kruger National Park.

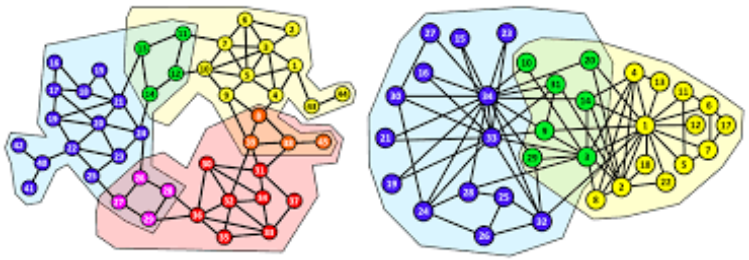
[3] Flood (2016). Foot-and-mouth disease epidemiology in relation to the physical, social and demographic farming landscape.

Vulnerability index for FMD

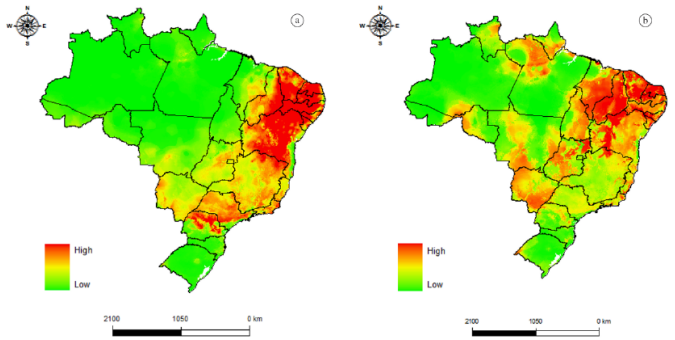
1. Farms location



2. Network construction

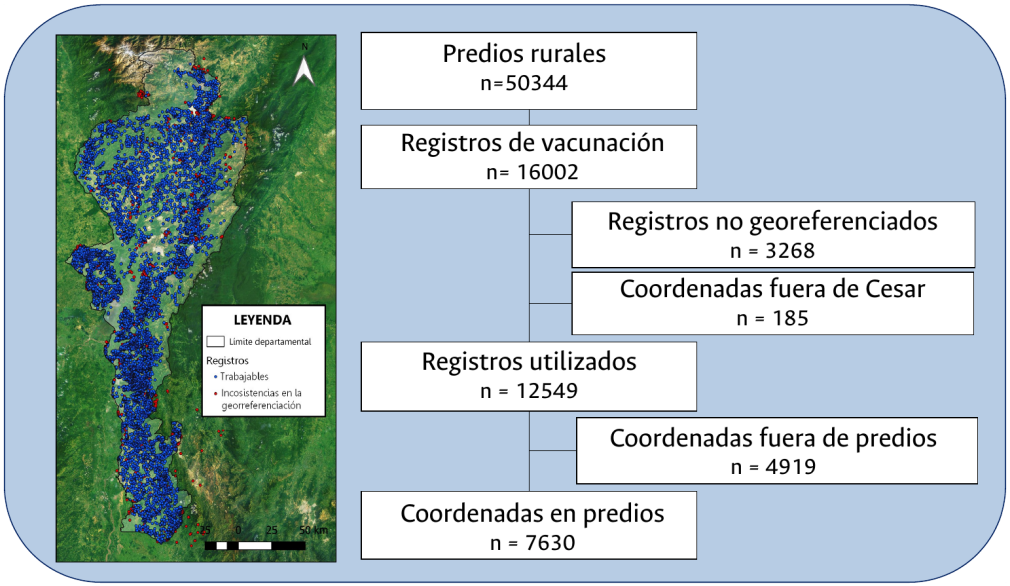


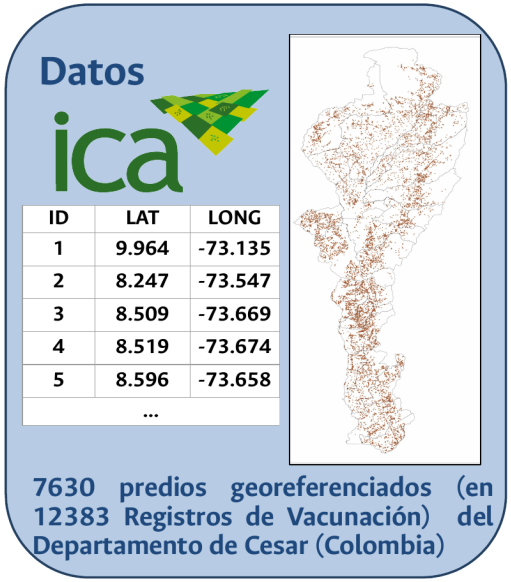
3. Community detection



4. Vulnerability index

Cesar information [6]

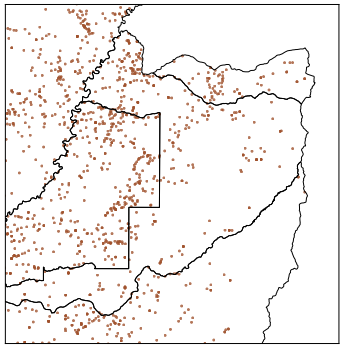


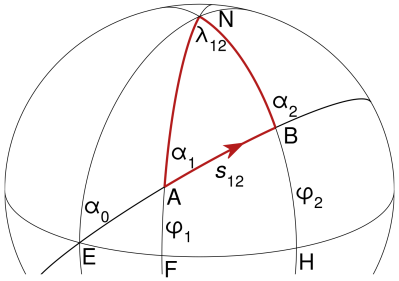


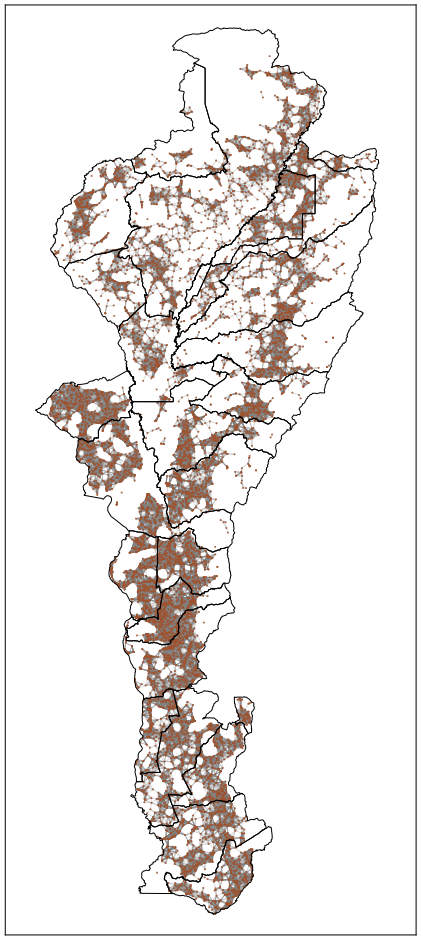
[6] Morales *et* al. (2019). Metodología para el análisis espacial por vulnerabilidad y riesgo de la fiebre aftosa.

Contiguity Network

Geodesic distance [15]







Create connections [3]

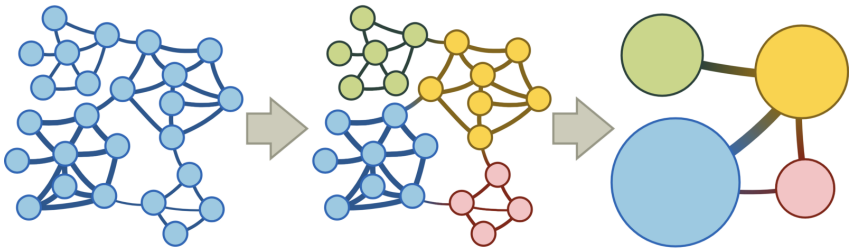
	A	B	C	D	E
A	-	Yes	No	No	No
B		-	No	Yes	No
C			-	Yes	No
D				-	No
E					-

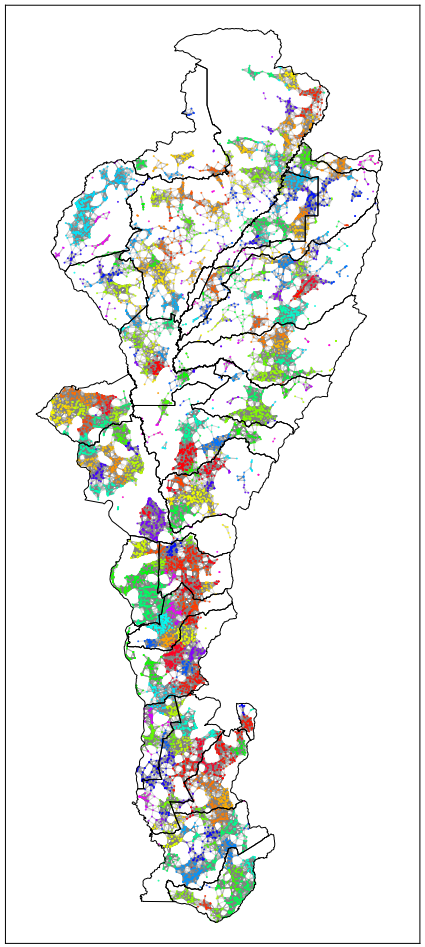
[15] Hilbert & Cohn-Vossen (1999). Geometry and the Imagination.

[3] Flood (2016). Foot-and-mouth disease epidemiology in relation to the physical, social and demographic farming landscape.

Community detection

Complex networks to characterize the farms through community detection [16].





[16] Radicchi *et* al. (2004). Defining and identifying communities in networks.

Vulnerability index

Vulnerability ranges [6].

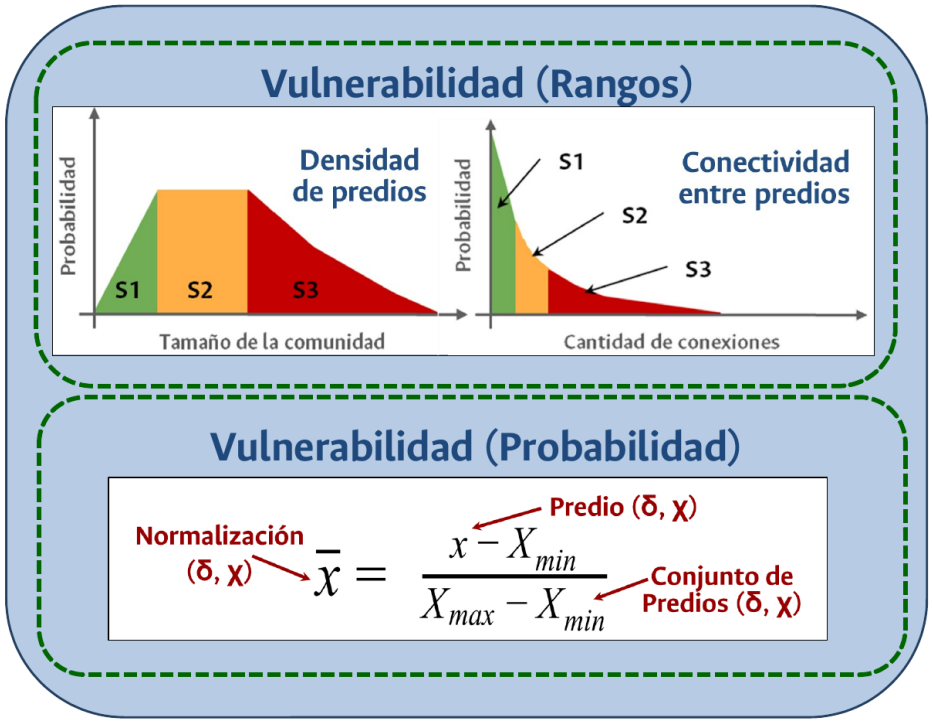
El riesgo se definió de acuerdo a USDA (1994)

- S3: *Hay transmission, supervivencia y contacto del virus.*
- S2: *Hay transmission, supervivencia del virus pero no contacto.*
- S1: *No hay transmission o supervivencia del virus.*

La vulnerabilidad se definió de acuerdo a Jori *et al.* (2009)

- S3: *La ocurrencia del evento es probable.*
- S2: *La ocurrencia del evento es possible en la mayoría de los casos.*
- S1: *La ocurrencia del evento solo es posible en la minoría de los casos.*

Community vulnerability analysis[17].

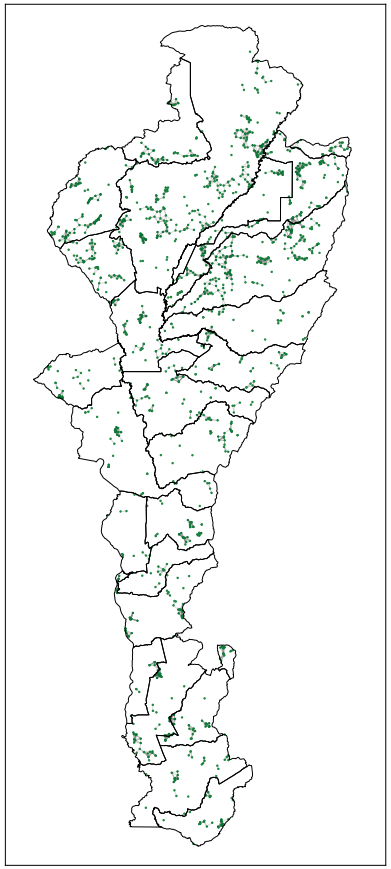


[6] Morales *et* al. (2019). Metodología para el análisis espacial por vulnerabilidad y riesgo de la fiebre aftosa.

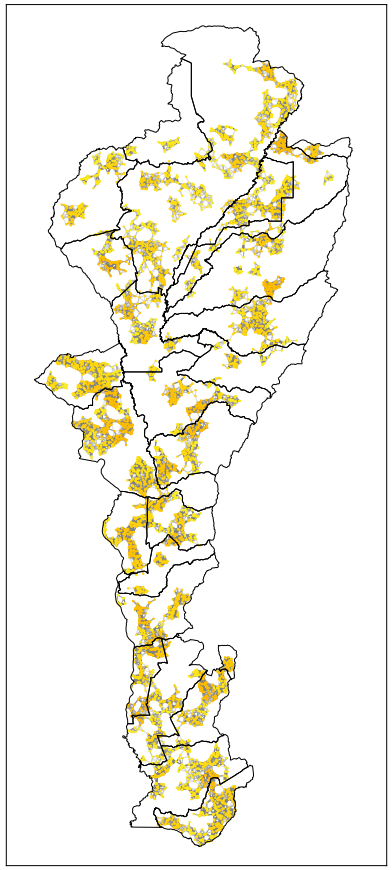
[17] Prieto *et* al. (2019). Contigüidad de predios como factor de Riesgo: Análisis de Redes aplicado a esquemas de bioseguridad para Fiebre Aftosa.

Ranges: Farm density δ

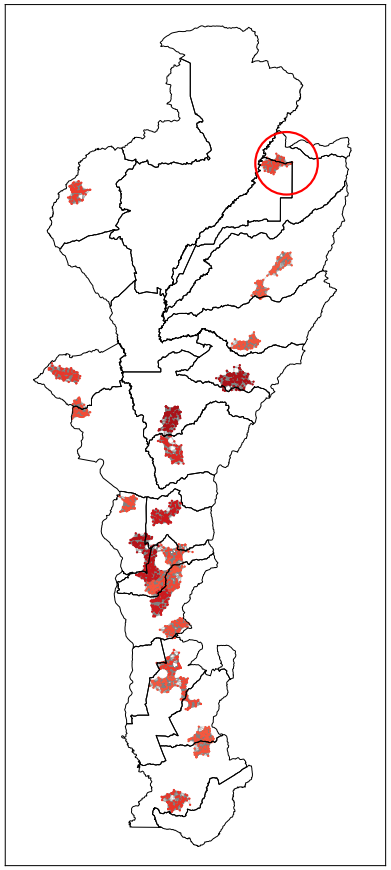
Event happens in minority cases



Event happens in most cases

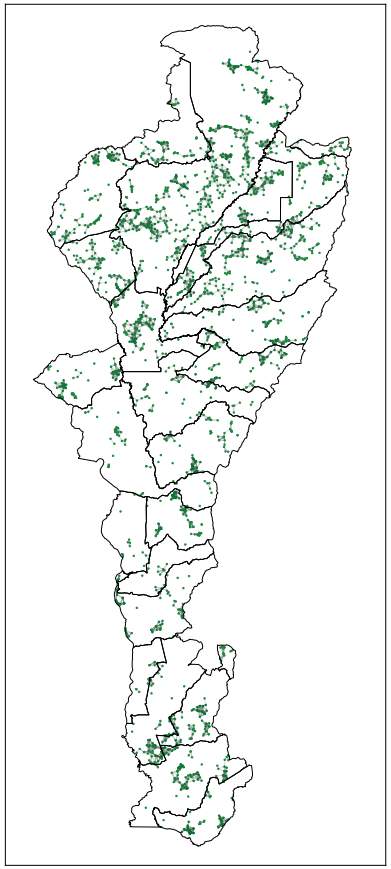


Event is likely to occur

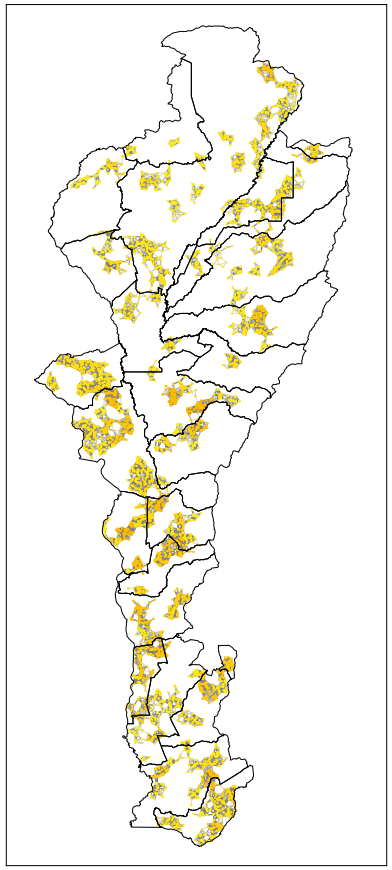


Ranges: Farm connectivity χ

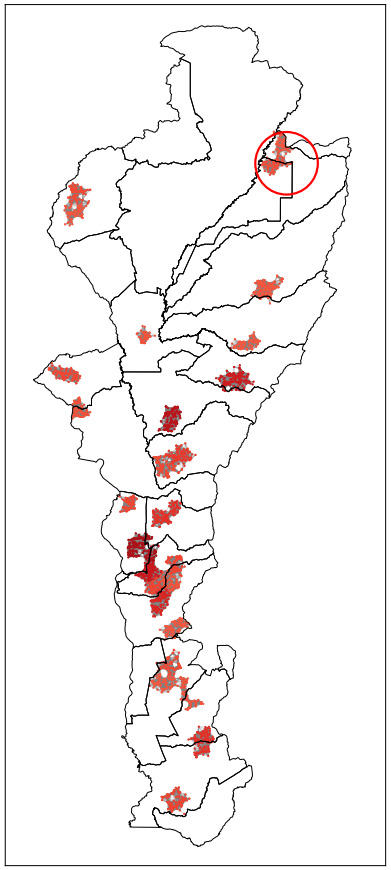
Event happens in minority cases



Event happens in most cases

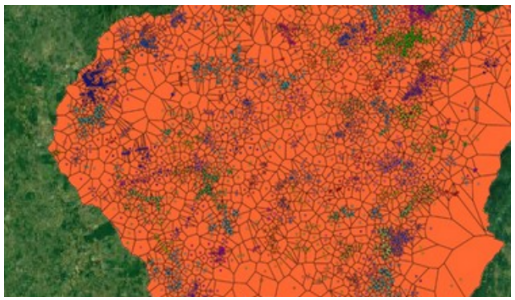


Event is likely to occur

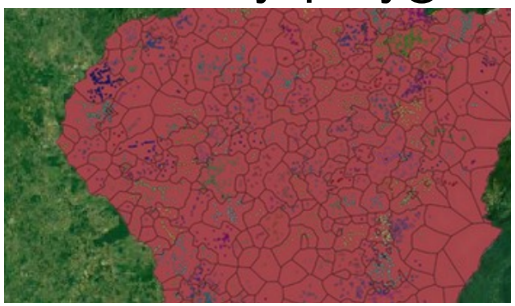


Spatial analysis: Voronoi diagram

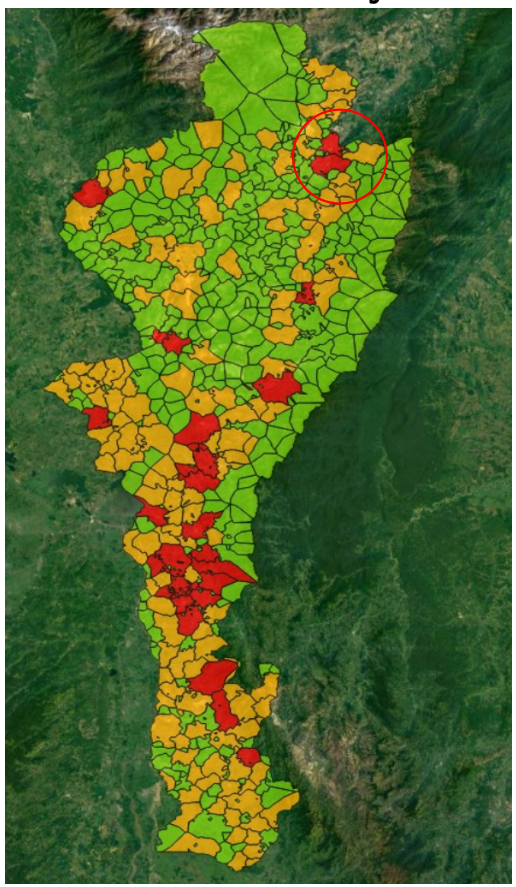
Farm polygons



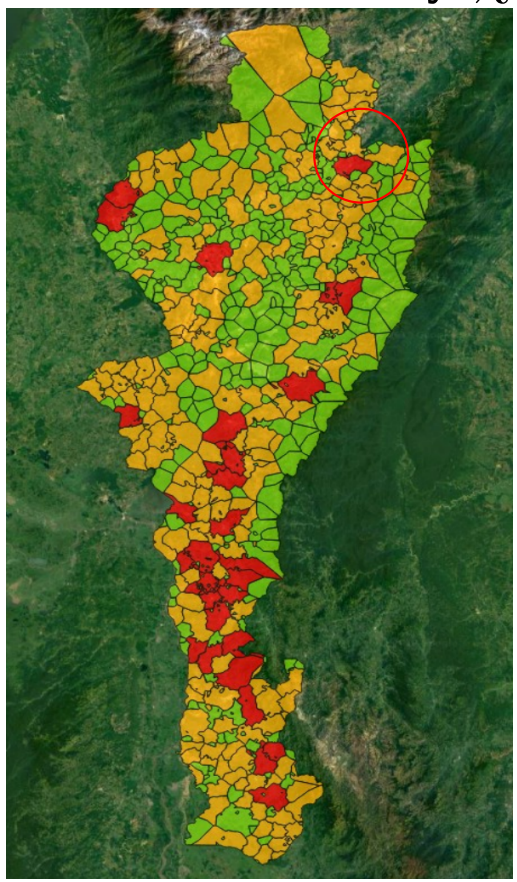
Community polygons



Farm density δ

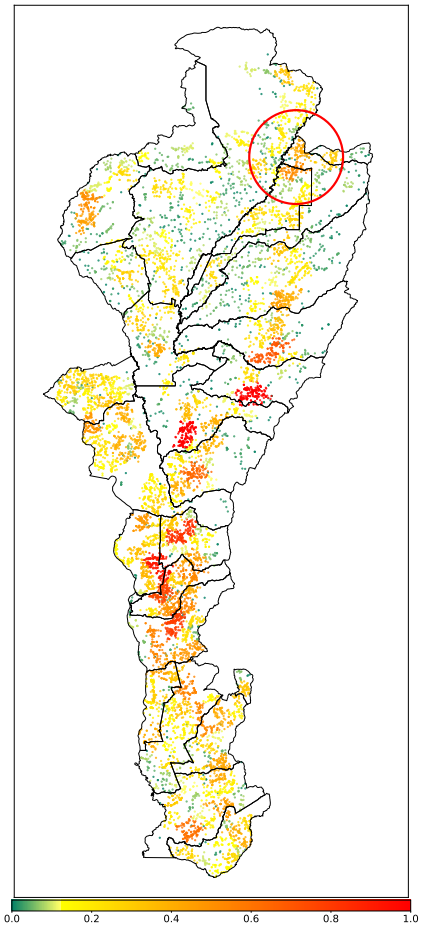


Farm connectivity χ

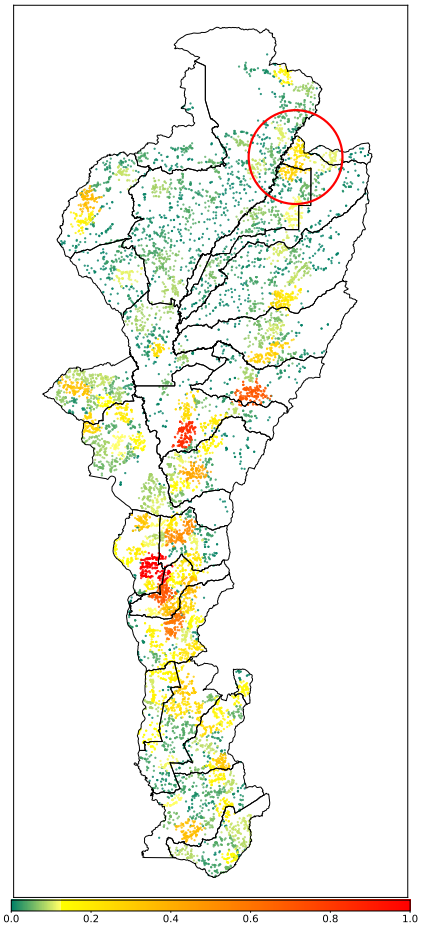


Probability

Farm density δ



Farm connectivity χ



Outline

Conclusions

- The strategies are able to properly target **highly susceptible (Vulnerable) areas** of infection and propagation of the virus.
- (1) A strategy to characterize **FMD super-spreaders** nodes in the cattle transportation network is proposed.
- (2) **Spatial analysis strategy** to characterize vulnerability (bio-security) and / or risk (bio-containment) is proposed.
- This information can be used to inform existing national FMD control program and suggest new guidelines to **prevent FMD outbreaks** in the country.
- The flexibility in the visualization, allows to implement the strategies in different spatial scales (farm, town), for **decision making** by the health authority and / or territorial planners.

Questions?