Analysis and dynamic visualisation of spatio-temporal network of bovine transit

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Abstract
The trade of cattle is important for epidemiological surveillance, since it is highly related to the transmission of infectious diseases. It is relevant to understand how the bovine trade network is organised in order to improve the control and prevention of the spread of diseases. The aim of this study, was to evaluate and visualise the dynamic of the bovine trade network of Espírito Santo State, Brazil, in 2015, identifying production zones and largest animal transit areas. To evaluate the characteristics of the network, the following measurements were calculated: in-degree, out-degree, betweenness, closeness, cluster coefficient and PageRank. Production zones were identified using a community detection algorithm. To improve the results a video was produced with the daily incoming and outgoing bovine movements between the municipalities of the state. The results allow the identification of the number of bovine movements, the geodesic distance between municipalities, the existence of premises that mediate the flow of animals, the formation of agglomerates, the importance of the municipalities in the network and four production zones. In conclusion, the methodology described in this paper can help describe the bovine trade network in the Espírito Santo, providing more information in the development of strategies to prevent and control the spread of diseases.

Keywords: *Livestock production, veterinary, network analysis, community detection*

Introduction
In veterinary epidemiology, the network analysis methodology has been used to obtain information about the transit of animals between premises, especially cattle, for their economic importance (1). This methodology provides information about network characteristics, production zones, and also allows simulations of disease spreading and control measurements (2,3). Therefore, for a region to be prepared to face futures challenges for health monitoring, their decision makers must understand the animal trade network. The aim of this study, was to evaluate and provide a visualisation of the dynamic of the bovine trade network of Espírito Santo State, Brazil, in 2015, identifying production zones and areas with the largest animal transit.

Materials and methods
The data from animals' transit guide of the State of Espírito Santo, Brazil, for 2015, showed a total of 62,442 bovine movements in that year. To assess the behavior of the network, measurements as in-degree, out-degree, betweenness, closeness, clustering coefficient and PageRank were calculated (4) for each one of the 78 municipalities of the state with the use of Epinemo (5) and Igraph (6) R's packages (7). In addition, production zones were identified with the use of a community detection algorithm described by Grisi-filho *et al* which defines a community as a group of nodes where a random walker stays more likely than the expected by chance. In other words, production zones will be defined as a group of municipalities of the state where an animal is more likely to stay during its life (3). To facilitate the visualisation of the network results, a video, using software R (7) was produced showing the spatio-temporal dynamics of the animal trade network. The scales high, medium and low in the maps were calculated considering the number of animal's incoming or outgoing due to trade between the municipalities. Furthermore, a scatter plot with the information of movements and number of animals transported was included to complement the map visualisation.

Table 1. Summary of cattle trade network parameters by municipality in the Espírito Santo State in 2015.

Parameters	Min	Med	Mean	Max
***In-degree**	9	6499	17350	119000
***Out-degree**	73	9614	17350	146200
Betweenness	0	91.9	261.8	2256
Closeness	0.002	0.003	0.0029	0.0039
Clustering coef. (incoming)	0.348	0.61	0.6088	0.9464
Clustering coef. (outgoing)	0.462	0.617	0.6283	1
PageRank	0.002	0.007	0.0128	0.1121

*Bovines moved

Results
Table 1 shows a summary of the evaluation on the network's measurements. According to the observations from this table, some municipalities had a maximum in-degree of 119,000 and a maximum out-degree of 146,200 bovine's movements; in addition, neither of these measurements showed 0 movements. Therefore, all of the state' municipalities have traded at least one animal with another municipality. This is confirmed with the clustering coefficient analyses, which also didn't show 0 values in the incoming and outgoing values. The drawn conclusion is that all municipalities of the state are connected with at least one municipality within the state. Also, it's possible to determine that some municipalities, almost 50% of them are connected with the other municipalities of the

state with clustering coefficient incoming and outgoing values close to one. In contrast, one or some municipalities have 0 betweenness value. Thus, the importance of these municipalities to link other municipalities is low. In Figure 1, the production zones and municipalities with higher and lower incoming and outgoing of cattle were identified. In the Figure 1A, two municipalities of the south belonging to the purple production zone buy more animal that the other municipalities of the state followed by the green production zone. In the Figure 1B, a municipality of the north belonging to the pink production zones sells more animals than the others municipalities of the state followed by one municipality of the purple production zone. In Figure 2, we show a scatter plot identifying zones using colors and municipalities with larger bovine movements, and also provide information on the number of animals moved. The dynamical visualisation of the network is available in https://www.youtube.com/watch?v=QPzsJe8MjVg (incoming animals) and https://www.youtube.com/watch?v=x6n1Cv1j9lY (outgoing animals).

Discussion

Descriptive network analysis is essential to identify cattle movement patterns between the municipalities of the Espírito Santo State, allowing the evaluation of the number of moved animals (degrees), the average shortest path between a vertex and all vertices in the network (closeness), the existence of premises that mediate the flow of animals (betweenness), the formation of municipalities clusters (clustering coefficient) and the importance of premises (PageRank). Similarly, the analysis of communities also provides relevant information to identify trade patterns within the state, identifying production zones, which can play an important role in the spread of disease in the network.

Networks parameters here studied were previously associated with time to infection and risk of infection (8). Network degree provides information to help identify the more central premises in the population, which can be useful to predict a risk of infection (8). We identified the municipalities that had the largest incoming animals (in-degree), which could be at a higher risk to get a disease, and the municipalities that had the highest outgoing animals (out-degree), which could be most likely to spread a disease. Thus, this information can be used to guide the surveillance system in prevention and control strategies.

The spatio-temporal dynamic visualisation of the trade network allows to easily understand trade patterns over time.

Conclusion

We can observe that the methodology used in this paper can help to describe the behavior and spatio-temporal patterns of an animal trade network.

Figure 1. Map of the State of Espírito Santo by municipalities and Production zones. A) Incoming bovines and B) Outgoing bovines. The movement's intensity is given by white and black scales, where high white intensity is high animal movement. Each production zones is given by one different color (purple, red, green and violet).

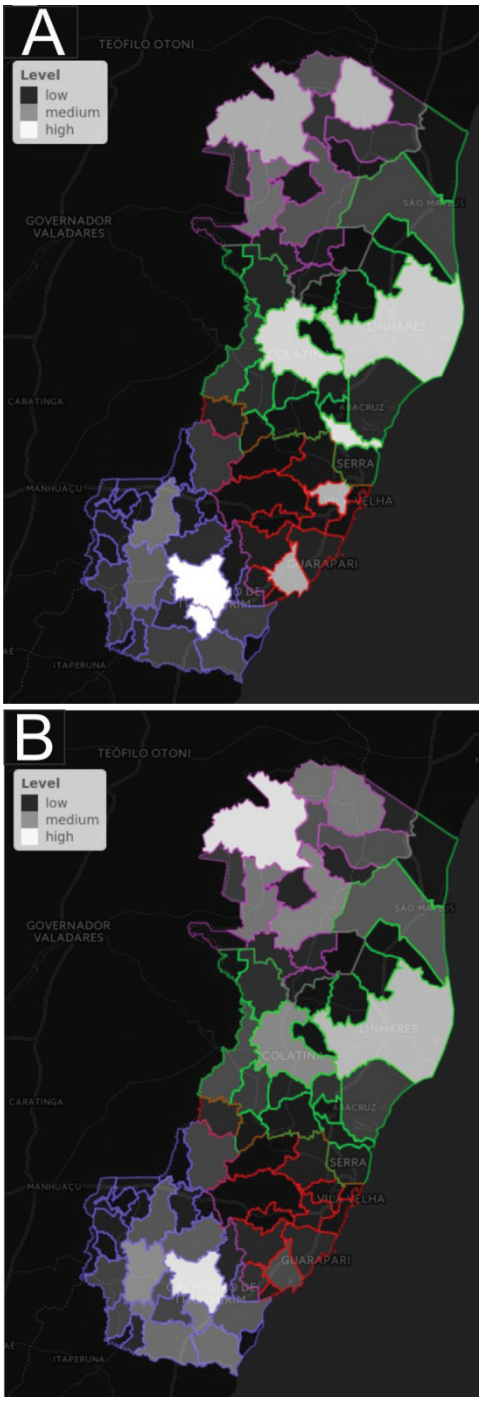
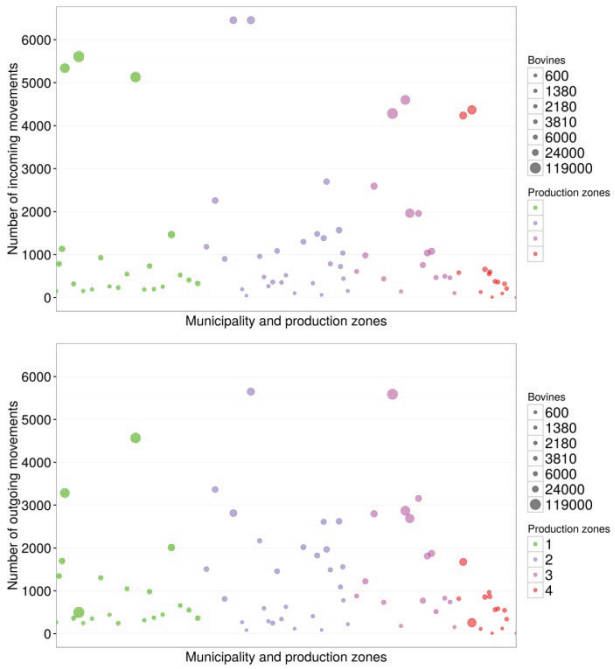


Figure 2. Scatter plot of the number of movements by municipality and Production zones and by number of animals moved. A) Incoming bovines and B) Outgoing bovines.



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