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ABSTRACT

Animal movement is inherent in the marketing between the rural productive units, establishing space-time connections between them. The relational nature of such information is kept in the Animal Transit Guides (GTA), a mandatory issuance in Brazil. When evaluating such set of information, this work aimed at characterizing the bovine movement network in the state of Pará through the application of concepts from Social Network and Network Theory analysis. Where the nodes and edges that structure the network are respectively the rural properties and the number of cattle moved between them. The results obtained characterize the bovine movement in the state, which show distinct patterns such as the movement of a great number of animals rambling and a clear seasonality due to commercialization purposes. The evaluation of the network components’ modularity also shows the subdivision of the state in four commercial clusters, where the central measures of its components define municipalities of economic and epidemiological interest. The results described herein help in the support of health surveillance and control measures, as well as the adoption of economic strategies and policies.

1. Introduction

Social Network Analysis (SNA) and the Theory of Networks are methodological concepts that describe the interactions between individuals in a group, as well as the collective behavior of a group [1]. Although widely adopted in the social sciences, psychology, and anthropology, SNA and the Theory of Networks have only recently been added to the analytical arsenal used to evaluate the nature and extent of relationships in the rural productive chain [2]. These methodologies allow researchers to evaluate the structure of the flow of animals between different productive units, and the impact that this has on the spread of a wide range of infectious agents [3–6]. SNA and the Theory of Networks also allow the extraction of characteristics of particular economic interest to the livestock industry, such as commercial patterns and commercial agglomerations [7–9].

The study of networks initially describes how the entities that networks are composed of are connected to each other, where the unit of interest is called the node and the connections between these are called edges [10]. Unlike in the human sciences, where the unit is the individual, in veterinary medicine the focus is on the collective unit. Municipalities and rural properties are represented by nodes and the number of animals moved between these are represented by the edges [11–12]. From an economic point of view, animal movement between productive units represents an...
important aspect of livestock commercialization, as it establishes
tensive spatial connections between different units [9]. This
movement also favors the occurrence and spread of diseases, as
movement of animals is of central importance to the dynamics of
diseases and occurrence of outbreaks [13,14]. In most
industrialized countries, measures are adopted to identify, record,
and trace animal movements as a prerequisite for the effective
adoption of disease surveillance and control measures [15].

In Brazil, the Animal Transit Guide (GTA), instituted by
Ordinance 22 on January 13th, 1995 [16] and updated in 2012 by
Normative Instruction No. 18, dated July 18th, 2006 [17], is the
official document mandatory for the intra and interstate movement
of animals, regardless of the purpose of the movement. It is an
important tool for sanitary control, and provides support for the
prevention of diseases that affect domestic species of production
[18]. Given the relational nature of the information contained in
the transit guides, these are readily converted into the attributes
that make up a network, where nodes represent the properties of
origin and destination, and their edges represent the animal
movement that occurs between them [19].

In the state of Pará, the issuance, control, and analysis of the
GTAs, as well as adoption of the necessary measures to maintain
the health of the livestock are the responsibility of the Agency of
Agricultural Defense of the State of Pará (ADEPARÁ).
ADEPARÁ is the government body responsible for animal health in
the state of Pará. The agency monitors the fifth largest national
cattle herd in Brazil, which comprises more than 19 million heads
[20]. This monitoring is done according to norms established by
the Ministry of Agriculture, Livestock and Supply (MAPA) [21].

The State of Pará, which contains approximately 9% of cattle
in Brazil, and experienced a 43% increase in the number of cattle
between 2004 and 2013, performed better than the states that
include the largest national herds, such as Mato Grosso, Minas
Gerais, Goiás and Mato Grosso do Sul [22]. Given the importance
of cattle breeding not only at the state level, but at the national
level, it is of prime importance to characterize animal movements
among the structural components of the production chain. Such
information will enable the implementation of effective measures
for sanitary, market, and managerial control [23]. Based on the
information described above, this work describes the main
characteristics of cattle movement in the state of Pará. We applied
network analysis techniques to the relational, temporal, and spatial
components of the dataset formed by the GTAs issued during the
year 2016 in the state of Pará.

2. Materials and Methods

2.1 Study area

The state of Pará is located in the Northern Region of Brazil,
and covers an area of more than 1,247,000 km$^2$. The state of Pará
has estimated population of over 8 million inhabitants, and in 2016
included more than 110,000 rural properties [24].

2.2 Animal Transit Guides

The information used to compose the cattle handling network
was made available by ADEPARÁ, and includes the compilation
of all GTAs issued during the year 2016 in the state of Pará. Each
GTA issued has a unique identifier associated with the date, party,
and issuing regional unit. Information relevant to the characterization of the movement carried out includes the type of
transport, the species transported, the purpose of the transport, the
number of animals transported according to sex and age group
(only for cattle and buffalo), municipalities and federal units of
origin and destination, as well as information identifying the
properties or establishments from where and to which the animals
were moved. The information comprised by the CPF/CNPJ
(Physical Person Registration/National Registration of Legal
Entities), name of the owner, and name of the property or
establishment of origin or destination, is assigned a unique
identifier established by ADEPARÁ. Spatial information, i.e. the
latitude and longitude of the municipalities of origin and destination
were added to the dataset.

2.3 Cattle Handling Network

The network structure is derived from the relational
information contained in each GTA issued, where the nodes
represent the productive units, and the edges represent the cattle
movement between them. The identification of each node
corresponds to that adopted by ADEPARÁ and its attributes
include the name, federative unit, and geographical position of the
municipality to which it belongs. The same strategy was adopted
to identify the edges, keeping the unique identifier designated by
ADEPARÁ to each GTA issued. The attributes include the date of
issue, the temporal component of the network, the purpose and
type of transport, the number of cattle transported according to age
and sex, and the identification of the origin and destination nodes.
The movement described by each edge carries implicit direction
information, starting at the origin and ending at the destination.
Therefore, node A connected to node B, represented by A-B, is
different from the connection B-A, where the distance between
them is defined as the lowest number of directed edges necessary
to connect them.

The network properties and characteristics were evaluated,
including their diameter, modularity, heavy grades of input and
output, centrality of intermediation, proximity centrality,
PageRank, and clustering coefficient. The network diameter is
defined as the path with the greatest number of edges between two
nodes A and B of the network [25]. Modularity is a measure of the
quality of the clustering of a given set of nodes [26]. The number
of edges arriving at a given node and the number of edges that start
from this are respectively the degrees of entry and exit [25]. The
weight or multiplier of these degrees was defined as the number of
animals moved between two nodes [27].

The number of shortest paths among all nodes of the network
passing through node A is defined as intermediation centrality of
node A [28]. The inverse of the sum of all distances from node A
to all other nodes of the network defines the centrality of its
proximity [29]. The PageRank of node A corresponds to the
probability of arriving at this node starting from a random network
node B [30]. The clustering coefficient indicates the degree to
which the network nodes tend to cluster [31].

The descriptive analysis, as well as conversion of the
information made available by ADEPARÁ, in the set of nodes and
edges that make up the network were performed using
development codes in R statistical software [32], with RStudio
2.11.1+ [33]. The analysis and extraction of the network
characteristics described above were performed using the R
package ‘iGraph’ [34] and the open access software Gephi 0.9.1
[35].

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f animals transported by road, a significant remaining in a region close to the origin, a responds to the maximum vehicle load capacity. Road transport is an important factor in determining the number of cattle (over 3 million) were moved on foot (Table 2), in spite of the number of GTAs involved road transport as a means for the movement of cattle (Table 1). This number corresponds to the distribution of the number of animals transported by GTAs, with a median of 25 cattle, which contributes to the local spread of diseases [36].

Table 1: Number and percentage of cattle and GTAs issued, according to the purpose of cattle movement

<table>
<thead>
<tr>
<th>PURPOSES</th>
<th>Cattle (n)</th>
<th>Cattle (%)</th>
<th>GTA (n)</th>
<th>GTA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAUGHTER</td>
<td>3515074</td>
<td>31.63</td>
<td>210438</td>
<td>48.54</td>
</tr>
<tr>
<td>FATTEN</td>
<td>6803942</td>
<td>61.23</td>
<td>193063</td>
<td>44.53</td>
</tr>
<tr>
<td>SPORTS</td>
<td>3267</td>
<td>0.03</td>
<td>139</td>
<td>0.03</td>
</tr>
<tr>
<td>EXPORT</td>
<td>174604</td>
<td>1.57</td>
<td>7733</td>
<td>1.78</td>
</tr>
<tr>
<td>EXHIBITION</td>
<td>2103</td>
<td>0.02</td>
<td>190</td>
<td>0.04</td>
</tr>
<tr>
<td>AUCTION</td>
<td>131214</td>
<td>1.18</td>
<td>5115</td>
<td>1.18</td>
</tr>
<tr>
<td>RESEARCH</td>
<td>1</td>
<td>~0</td>
<td>1</td>
<td>~0</td>
</tr>
<tr>
<td>Quarantine</td>
<td>243677</td>
<td>2.19</td>
<td>8105</td>
<td>1.87</td>
</tr>
<tr>
<td>Reproduction</td>
<td>182671</td>
<td>1.64</td>
<td>5819</td>
<td>1.34</td>
</tr>
<tr>
<td>Return of Agglomeration</td>
<td>55234</td>
<td>0.5</td>
<td>2939</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Table 2: Number and percentage of cattle and GTAs according to the type of transport

<table>
<thead>
<tr>
<th>Type of Transportation</th>
<th>Cattle (n)</th>
<th>Cattle (%)</th>
<th>GTA (n)</th>
<th>GTA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON FOOT</td>
<td>3299532</td>
<td>29.69</td>
<td>26138</td>
<td>6.03</td>
</tr>
<tr>
<td>RAILWAY</td>
<td>1059</td>
<td>0.01</td>
<td>32</td>
<td>0.01</td>
</tr>
<tr>
<td>MARITIME / FLUVIAL</td>
<td>329155</td>
<td>2.96</td>
<td>13648</td>
<td>3.15</td>
</tr>
<tr>
<td>ROAD</td>
<td>7482269</td>
<td>67.33</td>
<td>393727</td>
<td>90.82</td>
</tr>
</tbody>
</table>

3. Results and Discussion

With 135 regional management units and 1,841 users registered in the system, the State Agency of Agricultural and Livestock Defense of the State of Pará issued 433,545 GTAs for cattle between January 1st and December 31st, 2016. The animals transported had origins or destinations in one of the 82,010 registered properties, which were distributed in 929 municipalities of 24 federative units. In Pará, there are 78,362 properties distributed in 142 municipalities, with more than 32% of the state’s properties concentrated in only 10 municipalities.

Over 90% of GTAs involved road transport as a means for the movement of cattle (Table 1). This number corresponds to the distribution of the number of animals transported by GTAs, with a median of 25 cattle, which contributes to the maximum vehicle load capacity. Road transport is an important factor in determining the strategies for epidemiological control, given the possibility of rapid spread of diseases by movements over large territories [9]. In spite of the number of animals transported by road, a significant number of cattle (over 3 million) were moved on foot (Table 2), with an approximate average of 126 animals per GTA issued. In this type of movement, the animals are moved in large numbers over short distances, remaining in a region close to the origin, a factor that contributes to the local spread of diseases [36].

In Pará, beef cattle farming is very important, as shown in Table 1, and 31% of cattle moved in the state are destined for slaughter, and 61% of cattle are moved for fattening. The low index of animals moved for breeding (1.64%) is related to two marketing moments, after rearing and after fattening. The number of cattle moved for quarantine purposes (2.19%) is related to the export of live cattle, with 1.57% of the cattle moved for export purposes (Table 1). This information is also supported by the temporal evaluation of the GTAs issued (Figure 1 and Figure 2), which indicates an increase in the number of cattle destined for quarantine during the months of May and June, which precedes the increase of GTAs issued for export during the months of June and July, which is end of the rainy season, and the period that cattle gain the most weight.

Figure 1 shows a clear seasonality of cattle breeding in Pará, with an increase in the number of cattle destined for fattening during the months of April and October, and a progressive increase in the number of cattle slaughtered between May and August. Cattle moved for fattening in October are slaughtered in early May, and those moved for fattening in April are slaughtered at the end of the rainy season in mid-August. Cattle moved for exhibitions and sports are concentrated in the months of July and August (Fig. 1 and Fig. 2), which are critical time points for the monitoring of these cattle in order to prevent the spread of diseases [2].

Table 3: Number and percentage of cattle moved according to age and sex.

<table>
<thead>
<tr>
<th>Age (months) and Sex</th>
<th>Bov (n)</th>
<th>Bov (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 36 (males)</td>
<td>1812238</td>
<td>16.31</td>
</tr>
<tr>
<td>&gt; 36 (females)</td>
<td>2978358</td>
<td>26.80</td>
</tr>
<tr>
<td>Total (males)</td>
<td>6247834</td>
<td>56.23</td>
</tr>
<tr>
<td>Total (females)</td>
<td>4864181</td>
<td>43.77</td>
</tr>
</tbody>
</table>
Figure 2 - Number of cattle moved during the year 2016 according to the purpose of the GTA.

Figure 3 - Properties of the cattle movement network in the state of Pará according to the modularity class to which the municipality belongs.

Figure 4 - Properties of the cattle movement network in the state of Pará according to the modularity class to which the municipality belongs.
The commercialization of male cattle in Pará is independent of age. The high number of females of reproductive age transported for slaughter (Table 3) and export purposes (Table 1), has a direct impact on the number of cattle in the state, reducing the population growth rate, and keeping the number of cattle stable. In disease surveillance programs, categories of epidemiological importance are those composed of animals susceptible to disease [37]. Therefore, determining the sample group of interest reduces the number of samples necessary for statistical confirmation of the establishment of disease in the population, as well as its spread, reducing the time required for detection and response by the responsible health agency [23].

The diameter of the net of cattle movement obtained is equal to 5, which, in other words, indirectly represents the number of municipalities through which an animal must pass to cover the largest geodesic distance of the net. Using the latitude and longitude information of each municipality, the average distance between the municipalities is approximately 220 km, with a magnitude of approximately 8,736 km, which is the sum of all distances. These results highlight the vast territory of the state.

4. Conclusion

Although the analyses and metrics evaluated were used in the state of Pará, they can be applied and expanded to other states, as well as to other production species. The quantitative description of the cattle movement network proposed in this study allowed us to reveal factors that shape the commercialization and displacement patterns of cattle in Pará. This data can contribute to the development of effective strategies to control and monitor the diseases that occur in cattle.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References


