

NETWORK STRUCTURE FOR THE MOBILITY OF BOVINES PRODUCED IN THE STATE OF CHIHUAHUA, MEXICO, 2010–2019

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ABSTRACT

The Social Network Analysis (SNA) is a tool for studying the structure and importance of livestock markets and their elements. The aim of the investigation was to analyze the network structure for the mobility of bovines produced in the state of Chihuahua, Mexico, between the 2010–2019 period. The Social Network Analysis methodology was used, with centrality measures at origin and destination centers taken into account. In the 2010–2019 period, the structure of bovine livestock mobility was determined by 67 centers of origin (producers) and 32 destination centers (consumers). Producers mobilized 10 012 227 heads with the intentions of exporting calves for fattening (39.2 %), pasturing (26.6 %), fattening (13.9 %), slaughtering (13.5 %) and auctioning, breeding stock, and events (6.7 %). These seven products, which comprised three destination markets: export, national, and local, determined the structure and mobility of bovine livestock. The main center of origin was the municipal area of Chihuahua, whereas the main destinations were the USA and the municipal area of Chihuahua, which are therefore considered the main elements of the network and key nodes of the dynamism of bovine livestock in the state. It was also possible to confirm that the export of calves for fattening was the main purpose of cattle mobility for the state of Chihuahua.

Keywords: Bovine traceability, calf export, weaned calves.

INTRODUCTION

The Social Network Analysis (SNA) is a tool that is currently being applied for the analysis of the structure, performance, and importance of markets for supply, demand, sanitary control, and the planning of production. Unlike a marketing study, which analyzes commercialization channels and margins, SNA assists in identifying and quantifying the importance of each network element (Callejas-Juárez *et al.*, 2020;

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Callejas-Juárez and Rebollar-Rebollar, 2021). A cattle producer's primary concern will always be the market; under a traditional economic system, the producer relies on the market to acquire products after they are produced. Meanwhile, in the current market system, producers sell their products before they are produced. As a result, a polarizing tendency grows between the technological and family production systems (Jiménez-Jiménez *et al.*, 2019).

The importance of bovine production activity can be observed in the global beef market. In 2019, the value of global exports was \$25.4 billion USD, with Brazil accounting for 23.1 %; the USA, 13.0 %; and Australia, 14.9 %. In terms of demand, China imported 24.5 %; South Korea, 7.2 %; and Hong Kong, 6.2 % (The Growth Lab at Harvard University, 2019). The demand was clearly concentrated in Asia.

The importance of bovine livestock production in Mexico lies in the fact that it is widespread (Callejas-Juárez *et al.*, 2015) and accounts for the majority of farmland use (SIAP, 2020). In 2020, it produced 35.3 % of the country's beef (7.9 % less than poultry production). Its value is 43.1 % of the value of livestock production, and its inventory is worth a little over 35 million cattle heads. A little over 1.4 million cattle heads were exported (SIAP, 2020). Slaughterhouses sacrifice just over 1.1 million heads per year, with only 52.2 % of their capacity used (SADER, 2020). The structure of the bovine livestock in Mexico is composed of 45.3 % cows, 26.3 % animals in growth, 11.9 % heifers, 11.5 % fattening heads, 3.0 % bulls, and the rest is not classified (INEGI, 2019). Chihuahua, Mexico, has the most surface area in the country, accounting for 12.0 % of the total (INEGI, 2019). The cow-calf production system is developed on 17.5 million hectares of pastures and scrublands (Baez-González *et al.*, 1999). In 2020, Chihuahua had a bovine inventory of over 2.5 million cattle heads, providing 1.6 % of the volume of meat produced in the country, equivalent to 2.2 % of the national livestock value (SIAP, 2020). It is also the state that exports the most calves for fattening to the USA, with 479 100 heads (SDR, 2020). Locally, the bovine production activity represented 91.6 % of the volume of meat produced in the state and 94.4 % of the total production (SIAP, 2020).

According to Callejas-Juárez *et al.* (2015), the technological degree of meat bovine production in Chihuahua is determined by productivity variables such as herd mortality (4.0 ± 1.5 %), percentage of calving (68.8 ± 6.3 %), cull cows (8.8 ± 3.0 %), cull bulls (13.0 ± 11.2 %), production of meat per hectare (88.7 ± 7.8 kg ha⁻¹), production cost (1742.4 ± 947.6 \$ MXN cow⁻¹), and income (176.2 ± 123.7 \$ MXN ha⁻¹, 2613.0 ± 1440.8 \$ MXN fattening calf⁻¹ and 16.0 ± 8.5 \$ MXN kg of calves for fattening⁻¹), which explain the export volumes of bovine livestock to the USA.

The goal of the Social Network Analysis (SNA) method is to measure the importance of the network's centrality nodes and prestige (Knoke and Burt, 1983) using metrics such as grade, proximity, intermediation, eigenvector, cumulative nomination, and others (Xiao, 2013). Individuals, organizations, and companies are nodes in the network, and centrality is used to measure the power, activity, and ease of communication of these nodes (Zhang and Luo, 2017). In Mexico, the use of the SNA in livestock production

systems is just getting started. Callejas-Juárez *et al.* (2020) analyzed the structure of the supply network of live pigs in Mexican slaughterhouses and found a low density in the network. In another study, Callejas-Juárez and Rebollar-Rebollar (2021) discovered that the distribution of live bovine meat in Mexico had a low degree of centralization due to the dependence of demand for consumption centers (slaughterhouses) on local supply.

Due to the above, the aim of this investigation was to analyze the network for the mobility of bovines produced in Chihuahua during the 2010–2019 period in order to generate information to explain the structure of bovine production in Chihuahua. In turn, the hypothesis is that the state's proximity to the USA makes it the main market for calve exports and that the municipal area of Chihuahua is the network's most central element.

MATERIALS AND METHODS

We worked with the population of bovines (N) produced in the state of Chihuahua, Mexico, for each study variable in the 2010–2019 period. The variables analyzed were the total volume of bovines mobilized per municipal area (V_i = heads), supply or origin of the production (X_i = 67 municipal areas), demand or production destination (Y_i = 29 federal entities of Mexico) and the use or purpose (z_1 = fattening, z_2 = export, z_3 = breeding stock, z_4 = pasturing, z_5 = sacrifice, z_6 = auctioning, and z_7 = exhibition/event/show). Data on the amount, origin, and destination of bovines were obtained from the Chihuahua state government's Secretariat of Rural Development (SDR, 2020), and the volume produced from the Agricultural and Fisheries Information System (SIAP, 2020).

To respond to the objective, three types of analyses were required: to study the trends of bovine livestock mobilizations with the average annual growth rate (AAGR), to analyze the bovine livestock mobilization network with network measurements, and to analyze the network tendencies. The estimated average values are presented along with their standard deviations ($\bar{x} + SD$). The network structure and relationships were developed and evaluated using the SNA theory proposed by Wasserman and Faust (1994) and Borgatti and Halgin (2011) through measures of density, cohesion, centrality, and graphic analyses. The network figures were obtained using the software UCINET developed by Borgatti *et al.* (2002).

The order of the network analyzed (m) contained 67 municipal areas as supply centers in the state of Chihuahua and 29 federal entities plus the USA as destination centers, whereas size (n) was in the range of 233 to 460 commercial relations, out of 2144 possible ones. The breeding stock distribution network $A(I, J)$ was made up of output centers (α_i), input centers (α_j) and commercial exchanges (α_{ij}) resulting from the intersection of α_i with α_j . For better management, $A(I, J)$ was dichotomized, assigning a 1 to the vertex that had a commercial exchange ($\alpha_{ij} - 1$) and 0 assigned in the opposite case ($\alpha_{ij} - 0$). Because the commercial exchange was carried out in only one direction (origin-destination), the network was directed and the importance of the vertices was

determined by the number of commercial relationships and the volume of heads of cattle mobilized (Table 1).

Table 1. Possible and existing nodes of the bovine network in the state of Chihuahua during the 2010–2019 period.

Year	Existing exchanges ($D_{ij} \neq 0$)	Destination centers (α_j)
2010	233	23
2011	354	28
2012	460	29
2013	420	28
2014	342	26
2015	238	25
2016	303	26
2017	302	29
2018	291	27
2019	286	27

To analyze $A(I, J)$, degree measurements were used, along with proximity and intermediation (Freeman *et al.*, 1979) and eigenvector centrality (Bonacich, 1987). The centrality degree of a network (G_{ij}) is the sum of the existing commercial relations in the network, whereas the average degree ($\bar{G}_{ij}$) is obtained as the quotient of G_{ij} between the total of possible nodes (N) (Equation 1). This indicator was obtained for each element of the network, as well as for the total network.

$$G_{ij} = \sum_j \alpha_{ij}; \bar{G}_{ij} = \frac{G_{ij}}{N} * 100 \quad (1)$$

The output degree (G_i) is the number of commercial relations in a supply center, whereas the input degree (G_j) is the number of commercial relations received by the destination centers (Equation 2).

$$G_i = \sum_{j=1}^{30} \alpha_{ij}; G_j = \sum_{i=1}^{67} \alpha_{ji} \quad (2)$$

The density percentage (D) measured the quotient of the number of commercial relations carried out (m) between the number of possible commercial relations ($n-1$) (Equation 3). The two possible results are that $D \leq 100\%$.

$$D = \frac{m}{n-1} * 100 \quad (3)$$

The node intermediation (B) is a network measurement that indicates the percentage of marketing routes that cross a node, thus representing the link between two nodes and being one of the main sources of information in the network. This intermediation work is common among conventional producers who lack the ability to commercialize directly due to their production scale (Méndez-Cortés *et al.*, 2019). Intermediation is obtained as the quotient of the sum of the shortest routes that cross the vertices (V) and the sum of the shortest paths between the vertices (S) (Equation 4).

$$B = \sum_{i=1}^n \frac{v}{s} \quad (4)$$

Proximity (R) is a measurement of the position or accessibility of one actor in the network which indicates how many actors the product must cross to reach another actor or all actors in the network (Equation 5).

$$R = \frac{n-1}{\sum_{i=1}^n d} \quad (5)$$

The eigenvector centrality (E) is a relative measure that represents the position or importance of each node and its relation with well-positioned nodes in the network. It measures the quality or importance of each node (Equation 6). E_i is the proportion of the eigenvalue of A multiplied by the sum of vectors adjacent to the supply center, whereas E_j is in relation to the consumption center:

$$E_i = \frac{1}{\lambda} \sum_{j=1}^n \alpha_{ij} x_j \quad (6)$$

where x_i / x_j indicates the centrality of the node i/j , α_{ij} represents an input of the adjacency matrix (A) ($\alpha_{ij} = 1$ if nodes i and j are connected by an edge and $\alpha_{ij} = 0$ in the opposite case) and λ indicates the highest own value of A .

According to Wasserman and Faust (1994), the social capital (SC) is a measure of how the elements of the network communicate (information) to benefit or harm the components (Equation 7). The social capital exists as a complement to the human capital (Burt, 2000). A triad is the closed relationship between three elements of the network.

$$CS = \frac{3 * \sum_{i=1}^n \text{Triadas existentes}}{\sum_{i=1}^n \text{Triadas posibles}} \quad (7)$$

Finally, homophily (H) is a measurement that indicates the preference of supply centers for the mobilization of cattle over consumption centers and vice versa (Equation 8). It

is calculated as the difference of the sum of the cattle mobilized outside (GMO) and the sum of the cattle mobilized inside (GMI) by the total of cattle mobilized ($GMT = GMI + GMO$).

$$H = \frac{GMO - GMI}{GMT} \quad (8)$$

The bovine livestock mobility system will have a higher homophily as the proportion of heads of cattle consumed in national and local markets grows. However, cattle mobilization to the USA market will be more desirable due to better prices in the market.

RESULTS AND DISCUSSION

During the analysis period (2010–2019), 10 012 227 bovine livestock heads were mobilized in 67 centers of origin (municipal areas) of the state of Chihuahua, which had 26.8 ± 1.9 destination markets, grouped into three classes: international (39.2 %), local (32.7 %) and national (28.1 %). However, the bovine livestock with pasturing as their destination were later sent to export, thus reaching 65.9 % of the cattle mobilized. By cattle type, 42.5 % were calves for fattening; 19.6 %, calves; 15.5 %, cows; 10.4 %, heifers; 6.9 %, steers; 2.5 %, bulls; 2.4 % young bulls, and 0.1 %, calves. In turn, there were seven purposes for the mobilization of cattle: export, pasturing, fattening, sacrifice, auctioning, breeding stock and exhibition (39.2, 26.6, 13.9, 13.5, 5.6, 0.7, and 0.4 %, respectively). The markets and purposes have helped to increase the degree of integration with the American market and to remain as the main source of weaning and pasturing calves. Something similar occurs with the bovine livestock industry in Sonora, where the export calves production has remained stable over the last years (Moreno-Medina *et al.*, 2021).

The network dynamics due to the mobilization of cattle helped identify two destination groups: the first, composed of pasturing, export, fattening, and sacrifice; the second group, by events, auctioning, and breeding stock. The dynamics of mobilization per cattle type showed that the cattle mobility fluctuated in a different way: for young bulls, it increased 6620.6 %; heifers, 79.9 %; calves, 40.7 %; cows, 33.7 %, and calves for fattening, 12.4 %. In turn, the mobilization of calves, steers and bulls fell by 98.7, 94.6 and 6.5 %, respectively. The dynamic of the meat bovine network is supported more by the production of weaning and pasturing calves intended for export to the USA than by the production of meat to supply the local market. Meat production in the state of Chihuahua is measured by the number of calves, which are considered the main output of the cow-calf system, whereas the demand for resources is complemented by the structure of the herd, such as cows, bulls, and heifers.

During the analysis period, 39.2 % of the 10 012 227 cattle heads mobilized were shipped to the USA market, 32.7 % to the local market, and 28.1 % to the national market. Likewise, the national and international markets increased their participation by 21.1 and 7.6 %, respectively, whereas the local market decreased 1.4 %. Despite this,

the dynamism for the local, national, and international markets was not significant ($p = 0.182$). For the main market (international), the volumes exported yearly were different ($p = 0.425$). This supports the hypothesis that the beef production system in Chihuahua is becoming increasingly dependent on the US market, whereas the non-exported calves for fattening were mobilized to the national and local markets. In the 1970–2011 period, the price of calves for export increased by 42.5 %, whereas the increase in the national market was only 18.4 %, disincentivizing the production of national meat (Cruz-Jiménez and García-Sánchez, 2013).

In this sense, destination markets were important to define the structure of the bovine livestock industry in the state. The first group was composed of cattle heads taken from the state for export, pasturing, and sacrificial purposes (9 337 744 cattle heads, 93.3 %). For export purposes, 94.0 ± 2.3 % of the centers of origin mobilized 3 928 472 (39.2 %) cattle heads; the five most important centers of origin accounted for 39.8 %: Chihuahua 24.9 ± 3.3 %, Cuauhtémoc 11.5 ± 1.5 %, Hidalgo del Parral 5.4 ± 0.8 %, Namiquipa 4.8 ± 0.8 %, and Santa Isabel 4.5 ± 1.9 %. For pasturing purposes, 100 % of the centers of origin mobilized 2 665 607 cattle heads; the five most important municipal areas accounted for 39.8 ± 3.9 %: Chihuahua 24.9 ± 3.3 %, Madera 4.3 ± 2.0 %, Santa Isabel 3.7 ± 0.08 %, Guadalupe y Calvo 3.6 ± 0.8 %, and Balleza 3.2 ± 0.8 %. For fattening purposes, 88.8 ± 12.5 % of the centers of origin mobilized 1 390 722 cattle heads; the five most important centers of origin accounted for 50.1 %: Chihuahua 17.8 ± 2.7 %, Cuauhtémoc 16.6 ± 7.3 %, Hidalgo del Parral 6.3 ± 2.6 %, Camargo 4.9 ± 2.8 %, and Delicias 4.4 ± 2.8 %. Finally, for slaughtering purpose, 97.5 ± 2.5 % of the centers of origin mobilized 1 352 943 cattle heads and the five most important centers provided 56.5 %: Chihuahua 17.9 ± 5.1 %, Delicias 16.8 ± 3.6 %, Cuauhtémoc 11.1 ± 2.5 %, Saucillo 6.6 ± 1.7 %, and Riva Palacio 4.1 ± 1.1 % (Figure 1).

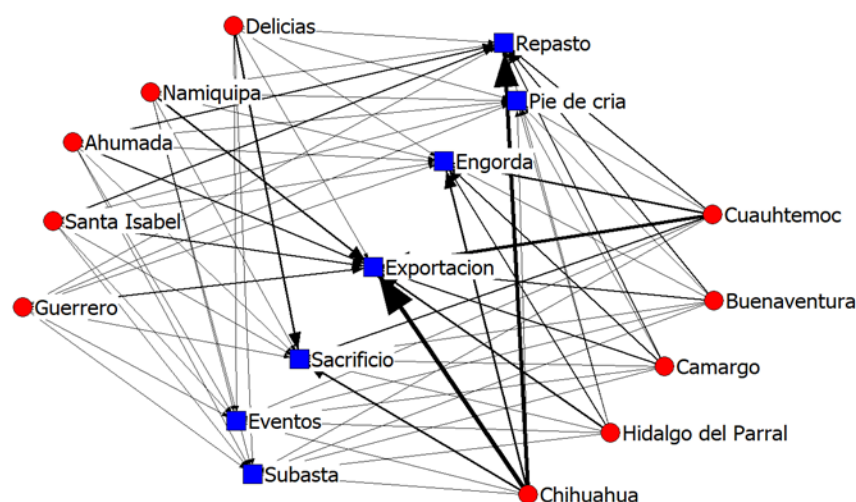


Figure 1. Network by mobilization purpose of bovine livestock in the state in Chihuahua in the 2010–2019 period.

The second destination group was composed of the purposes of auctioning, reproduction, and events within the state of Chihuahua, representing 6.7 % of the total mobilized in the analysis period. With the purpose of auctioning, 88.4 ± 5.9 % of the centers of origin mobilized 564 120 heads of cattle and the five most important municipal areas mobilized 34.4 %: Satevó 7.3 ± 1.9 %, Chihuahua 6.5 ± 2.6 %, Guerrero 6.2 ± 1.5 %, Santa Isabel 5.3 ± 2.1 %, Huejotitán 4.5 ± 1.4 %. For the purpose of breeding stock, 45.4 ± 10.4 % of the centers of origin mobilized 70 328 heads of cattle; the five most important municipal areas mobilized 79.1 %: Juárez, 25.6 ± 31.2 %, Chihuahua 24.8 ± 13.0 %, Delicias 15.7 ± 15.7 %, Santa Isabel 7.9 ± 10.4 %, and Saucillo 5.1 ± 9.0 %. Except for Chihuahua, which mobilized cattle for the production of beef, the other centers of origin mobilized for the production of milk. Finally, for the purpose of events, exhibition or shows, 54.8 ± 12.0 % of the centers of origin mobilized 40 035 heads of cattle; the five most important centers of origin mobilized 46.9 %: Chihuahua 21.9 ± 5.7 %, Cuauhtémoc 14.6 ± 10.9 %, Santa Isabel 5.0 ± 4.2 %, Guerrero 2.9 ± 2.0 %, and El Tule 2.4 ± 3.6 %. This implies that the bovine livestock activity in Chihuahua is aimed at the markets outside of the state, mainly for the export of calves. The vegetation's poor situation and low production indicators of cattle ranches confirm this (Baez-González *et al.*, 1999).

The annual supply and type of cattle vary by municipal area in Chihuahua. As a result, the average number of mobilized bovine livestock during the study period was not statistically different between years ($p = 0.997$), but it was between cattle types ($p < 0.001$). All the centers of origin marketed breeding stock every year. However, not all municipal areas marketed with all destinations every year. On average, the centers of origin mobilized bovine livestock every year in an interval of 25.2 to 28.4 destination centers. This means that, with the exception of the USA, the state of Chihuahua marketed bovine livestock with every state in Mexico, except for five which, due to the amount sent (less than 10 heads of cattle in 10 years), were considered negligible (Baja California Sur, Guerrero, Campeche, Quintana Roo, and Mexico City).

Origin-destination

The structure or importance of stockbreeding in Chihuahua was determined by the importance of volume and market information. The two most important destinations for cattle mobilization received 87.7 % of the cattle mobilized (Chihuahua 48.5 % and USA 39.2 %), whereas the third place was Baja California with 6.7 % of the total; the remaining 29 destinations concentrated only 5.6 % of the bovines mobilized. On the other hand, the participation in the municipal market of Chihuahua, as a destination, grew 8.7 % during the analysis period, whereas the USA's decreased 8.4 %. Practically, Chihuahua won over the market directly from the USA, since it has the roles of both a supply center and an intermediary, as 100 % of the centers of origin used the municipal area of Chihuahua as an intermediary. On the other hand, the places of origin also reduced their shipments to Baja California, since they found a better alternative in the export market (Figure 2).

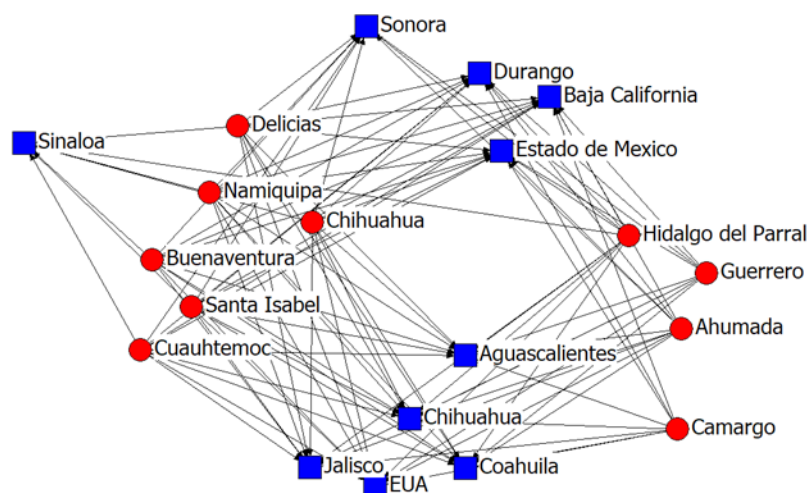


Figure 2. Main origins (red) and destinations (blue) of the bovine livestock in the state of Chihuahua during the 2010–2019 period.

It is clear that the importance of the bovine livestock production in Chihuahua is relevant in almost all national and international markets. However, in the case of the national market, 67.0 % of the calves are sent to Baja California. As a result, Chihuahua is primarily reliant on two markets: the USA and Baja California. In this sense, the beef market in Mexico presents a low mean density of connections between producers and slaughter centers, indicating market inefficiency (Callejas-Juárez and Rebollar-Rebollar, 2021). The relationship between Chihuahua and the latter only represented 1.0 % of the total number of bovine cattle heads mobilized in the period of analysis.

Networks

Through its indicators, the SNA helps visualize, measure, and analyze the position of municipal supply, international, state, and local demand, as well as the types of products in the network structure. The mobilization network for the bovine livestock produced in the state of Chihuahua was characterized by 100 % of municipal areas mobilizing cattle during the period of analysis. On average, the network made offers to 26.8 ± 1.9 out of 29 destination centers, beginning with 23 in 2010 and reaching a maximum of 29 in 2012 and 2017. Even when all the supply centers mobilized cattle, the two main centers were the municipal areas of Chihuahua and Cuauhtémoc. Meanwhile, the municipal area of Chihuahua and the USA were the two most important two destination centers due to their demand.

This can be observed in the three most important SNA measurements to determine the structure of the network. In the period of analysis, the network performed 812 movements out of the 2144 possible ones. The output centers had an average degree of activity of 17.9 ± 38.4 %, a network proximity of 51.7 ± 1.7 %, and a characteristic vector

of 12.7 ± 0.7 %. On the other hand, the input centers had an average degree of activity equal to that of the output centers, a proximity of 78.3 ± 1.1 % and a characteristic vector of 11.4 ± 0.2 %.

The analysis of the 10 most important municipal areas for their supply and the three SNA measurements showed that, for the centers of origin, the range of the network degree was from 3.0 to 100 %: 25 % of the supply centers had a degree of up to 22.0 %, 50.0 % up to 34.0 %, 75.0 % up to 26.0 %, and only Chihuahua had a degree of 100 %. One measurement of the power of the network was the degree of proximity, which was in the range of 73.0 to 100 %: 25.0 % of the centers of origin had a degree of proximity of up to 77.0 %, 50.0 % of up to 80.0 %, 75.0 % up to 85.0 %, and only Chihuahua reached a degree of 100 %. In turn, the range of the measurement of the characteristic vector was from 1.0 to 21.0 %: 25.0 % of the centers of origin had a measurement of the characteristic vector of up to 8.0 %, 50.0 % of up to 11.0 %, and 75.0 % up to 16.0 %. Another measurement of power in the network is the degree of intermediation to keep it together, which was, on average, 0.68 ± 1.6 %; the center of origin with the highest measurement was Chihuahua with 11.7 % and Juárez with 5.0 % (Table 2).

Table 2. Measures of centrality for the origin centers of bovine livestock in the state of Chihuahua during the 2010–2019 period.

Supply center	Degree	Proximity	Characteristic value	Intermediation
Chihuahua	1.00	1.00	0.21	0.12
Santa Isabel	0.78	0.92	0.18	0.03
Juárez	0.78	0.92	0.19	0.05
Camargo	0.75	0.91	0.17	0.02
Hidalgo del Parral	0.72	0.90	0.18	0.01
Buenaventura	0.72	0.90	0.18	0.01
Cuauhtémoc	0.66	0.88	0.18	0.03

For destination centers, the degree range went from 7.0 to 100 %: 25.0 % of the destination centers had a range of up to 13.5 %, 50.0 % up to 33.5 %, 75.0 % up to 55.0 %, and only Chihuahua reached a degree of 100 %. Likewise, the degree of proximity had a range of 51.0 to 100 %: 25.0 % of the destination centers had a maximum degree of proximity of 53.0 %, 50.0 % of up to 59.0 %, 75.0 % of up to 68.0 %, and only Chihuahua reached a degree of proximity of 100 %. As in the centers of origin, the characteristic value of the destination centers was low, with a range of 3.0 to 32.0 %: 25.0 % of the destination centers reached a characteristic vector measurement of 6.25 %, 50.0 % up to 15.0 %, and 75.0 % up to 22.7 %. The degree of intermediation for the destination centers was 2.8 ± 8.8 %. In this case, for Chihuahua, it was 44.4 %, for the USA, 24.3 %, and for Baja California, 6.5 % (Table 3).

The measurement of the degree of the destination centers reveals the high quality of the cattle mobilized by the centers of origin, with the variables that explain this

Table 3. Measures of centrality for the destination centers of the bovine livestock in the state of Chihuahua during the 2010–2019 period.

Destination center	Degree	Proximity	Characteristic value	Intermediation
Chihuahua	1.00	1.00	0.32	0.18
USA	0.94	0.94	0.31	0.13
Baja California	0.82	0.84	0.30	0.07
Durango	0.81	0.83	0.30	0.06
Aguascalientes	0.67	0.75	0.26	0.04
Coahuila	0.63	0.72	0.25	0.04
Chiapas	0.58	0.70	0.23	0.04
Sonora	0.55	0.68	0.23	0.03
Querétaro	0.55	0.68	0.22	0.03
Mexico City	0.52	0.67	0.22	0.02

being the cattle breeds, the position in the market (due to the export of calves for weaning), and the TB-free sanitary situation. According to the findings by Carmona-Martínez *et al.* (2007), 100 % of the producers surveyed bought recorded cattle, which has improved the genetic quality of their herd by 3.7 %. The greatest centrality of the state of Chihuahua, as the center of origin (Table 2) and destination (Table 3), explains its importance in the entire mobility network and positions it as the most influential in terms of receiving and spreading information about the local, national, and international markets.

Homophily is a SNA indicator that strengthens the indicators of centrality and density in the network structure. Identifying the network elements with the highest homophily also aids in understanding the reason for the relationship between centers of origin (municipal areas) and destination centers (markets). The homophily of exports and the local and national markets were, on average, -33.0 ± 41.4 %; 25.4 % of supply centers presented a positive homiphilia ($17.613.1$ %) and 74.6 %, a negative homophily (-50.2 ± 32.6 %). Out of the latter, four centers of origin presented complete homophily (-100 %). On the other hand, the homophily of the local and national market was 15.8 ± 44.5 %; 70.1 % of the supply centers presented positive homophily (39.8 ± 22.8 %), and 29.9 % negative homophily (40.6 ± 29.4 %). A low proportion of homophily in centers of origin and destination was related to high quality in the mobilized cattle (mainly calves for export), whereas for the rest of the cattle mobilized, except for dairy cows, the proportion of cattle consumed in the centers of origin was low. This indicator adds to the aim and hypothesis of the investigation that the bovine cattle industry of the state of Chihuahua has an affinity for outside markets.

Finally, the last measure that defines the structure of a network is the social capital (SC), which is defined as the degree of association of knowledge between farmers that helps in the better utilization of human, financial, and natural resources of the livestock production systems (Macías-López *et al.*, 2019). The SC of the network was 51.4 ± 5.1 %, although it displays a tendency to decrease (6.8 %). This is due to the municipal area

of Chihuahua increasing its participation as an intermediary in the export of calves for fattening to the USA through the Regional Livestock Union of Chihuahua (*Unión Ganadera Regional de Chihuahua - UGRCH*). In the case of the production of calves, in the face of a higher dependence on one single buyer (USA = 39.2 %) and a higher dependence on a local market (Chihuahua = 48.5 %), the flow of information decreases as a condition for decision-making.

Analysis

The centers of origin, the seven purposes for cattle mobilization, three markets, and the destination centers defined the structure of bovine cattle mobility from Chihuahua. The centers of mobility (origin and destination) had a low variation (32.5 18.0), indicating that the centers had similar activity due to a high rate of dependence or commercial loyalty between them.

An important fact that changed the tendency for cattle mobilization was the frost that fell in (with temperatures of down to -20 °C), which brought a series of negative externalities in the inventory and the mobility of bovine cattle, mainly cattle for beef. The 2011 frost affected 15 municipal areas of Chihuahua. Along with the 2011–2012 drought, it affected more than seven million hectares of crops and losses of over 4 billion \$ MXN (Brito-Castillo and Pedrozo-Acuña, 2015). In the 2010–2012 period, the volume of mobilized cattle increased by 42.3 %, but fell to 39.4 % in 2012–2014, eliminating the growth of the previous period.

In 2019, the mobility of bovine cattle displayed some recovery and was only 1.4 % below the export of calves for fattening, which displayed a negative TCMA between 2010 and 2013 of 24.3 %, followed by a positive TCMA of 53.9 %. However, the purposes of the mobilization with negative TCMA were fattening (72.1 %), slaughtering (53.8 %), pasturing (43.0 %), auctioning (28.0 %), and export (7.5 %); whereas exhibition and breeding stock increased (35.0 and 107.7 %, respectively). Starting in 2014, all mobilization purposes had positive TCMA, except exhibitions, (1.1 %): breeding stock, 251.6 %; fattening 249.7 %, auctioning, 46.0 %; export, 40 %; slaughtering, 16.5 %; and pasturing, 3.5 %.

The network structure was determined by 100 % of the municipal areas of the state of Chihuahua, yet the municipal area of Chihuahua represented the central element that controlled local, national and international information. Meanwhile, bovine production in the state of Chihuahua has commercial relations with all other states in Mexico, although it had two central elements—Chihuahua and the USA— which determined the structure of the destination centers. The network was determined by at least 50.0 % of the cattle mobilizations in the state of Chihuahua, and removing it from the network would cause all centers of origin to become disconnected. Likewise, a strong dependence on the export market (39.7 %) improved productivity.

For the analysis period, four municipal areas concentrated 36.2 % of the mobilized bovine cattle in the state. However, out of every 100 heads mobilized, almost 20 (19.6 %) travelled through the municipal area of Chihuahua (state capital). For

the two main centers of origin, a variable that explained the importance of the state capital was the Regional Livestock Union, which carries out weekly auctions, whereas for Cuauhtémoc, it was attributed to its geographic location with access to the Sierra of Chihuahua and its role as a collection center. Thus, the main destination of bovine cattle mobility in Chihuahua is two consumption centers, the state capital and the export market in the United States, which together demanded 88.2 % of the bovines mobilized. The third most important destination was Baja California, which demanded an average of 6.4 % of the bovines mobilized. Furthermore, when the export market for fattening calves shrinks, this destination absorbs them, as was the case in 2012 and 2016 (Table 4). Unlike Chihuahua, which had long-distance livestock mobilizations (Chiapas at 2248 km and Jiménez-Ciudad Juárez at 584 km), Robinson and Christley (2007) discovered that in England, cattle were mostly transported to nearby destinations or to local markets, which may be due to market structure.

Table 4. Origin and destination of the mobilization of bovine livestock from the state of Chihuahua (in percentages).

Year	Origin				Destination			
	O1	O2	O3	O4	D1	D2	D3	D4
2010	20.1	8.3	3.3	3.6	46.7	46.1	4.9	2.4
2011	23.9	9.1	4.7	2.6	47.6	34.8	11.1	6.6
2012	20.9	9.3	4.6	3.7	44.5	29.1	14.7	11.7
2013	19.3	9.6	4.4	3.9	48.1	33.4	10.5	7.9
2014	19.5	8.5	4.3	4.3	46.0	44.4	4.7	4.9
2015	18.8	8.2	4.6	3.3	50.5	42.7	3.5	3.3
2016	19.0	7.8	3.5	3.5	51.6	38.9	5.0	4.5
2017	18.1	9.5	3.6	3.7	50.0	42.2	3.6	4.1
2018	18.6	9.5	3.3	4.3	49.5	42.9	3.1	4.5
2019	18.0	9.3	3.5	4.2	50.7	42.2	3.2	3.9

O1: Chihuahua; O2: Cuauhtémoc; O3: Hidalgo del Parral; O4: Namiquipa;
D1: Chihuahua; D2: USA; D3: Baja California; D4: others.

Only 3.1 % of the centers of origin (supply) had a probability of over 75.0 % of relating to all the destination centers (demand), 15.6 % less than 25.0 %, and 81.3 % between 25.0 to 75.0 %. Likewise, 96.9 % had a probability between 25.0 and 75.0 % of relating to all centers of origin, 3.1 % less than 25.0 %, and none higher than 75.0 %. Therefore, the density of the network is considered low, since it had an efficiency of 40.0 %, which was reflected in low centrality degree and measurement of the characteristic vector values, unlike the measurement of proximity, which was relatively high for the output centers, and medium for the input centers. The most important variable to explain this density was the high centrality of the municipal area of Chihuahua as a destination center, since it has commercial relations with the 67 centers of origin, with the 32 states of Mexico and the market of the USA.

The high degree of centrality of the municipal area of Chihuahua (center of origin) implies that it has a stronger relationship with the mobility of bovine livestock, both as a supply center and a destination center, and because it has the highest degree of proximity and intermediation, it becomes the ideal channel of information to broadcast information to the other municipal areas, even more than to the export market. Variables such as the Livestock Union, its position as the state capital, being the center of communication, offering auctions, and being the most important collection center in the state make it the ideal channel for the establishment and dissemination of public policies. The second most important supply center was Cuauhtémoc, being the main entrance to, or exit from, the Sierra de Chihuahua and having the second most important collection center in the state. Finally, Chihuahua was the main center of origin for mobilizing bovines for export, pasturing, fattening, and sacrifice, while Satevó was the main center for auction events. However, a problem with centrality is that it promotes epidemiological communication (Brieger and Kendall, 1996). Homophily indicates a medium dependence of supply centers on local and national markets; that is, supply centers prefer the national market because the homophily of the local market is low, and it is related to supply centers finding better alternatives in national and export markets than in the local market. The importance of the municipal area of Chihuahua as a destination center for 100 % of the centers of origin has contributed to the formation of social capital, which is practically at 50.0 % and is supported by the continuous information received by the network of the market, composed of the 67 centers of origin and international through the export of fattening calves. Two aspects of social capital are information and reciprocity (García-Valdecasas, 2011), which can be seen, due to their volume of mobilization, in three elements of the network (USA-Municipal area of Chihuahua-Baja California) of Chihuahua bovines. These results highlight the importance of analyzing the distribution network for live cattle, which not only helped identify the main centers of origin, the main destination centers, the relationship between centers of origin and destinations, but also the transfer of the information generated in the network which helps the network elements make decisions.

CONCLUSIONS

The methodology of the network analysis helps identify and analyze the structure of the bovine livestock in the state of Chihuahua. The structure of the mobility of bovine livestock in Chihuahua is determined by four products and three markets. Similarly, the USA and the municipal area of Chihuahua are the main components of the network and are critical to the dynamism of cattle breeding in the state of Chihuahua. Finally, to speak of bovine livestock breeding in the state of Chihuahua is to speak of the production of calves for fattening and mobilization out of the entity.

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