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Article

Causal model of the dynamics of free-roaming dogs in Huatusco, Veracruz: A mixed-methods analysis based on territorial and social evidence

Modelo causal de la dinámica de perros en situación de calle en Huatusco, Veracruz: Un análisis mixto basado en evidencia territorial y social

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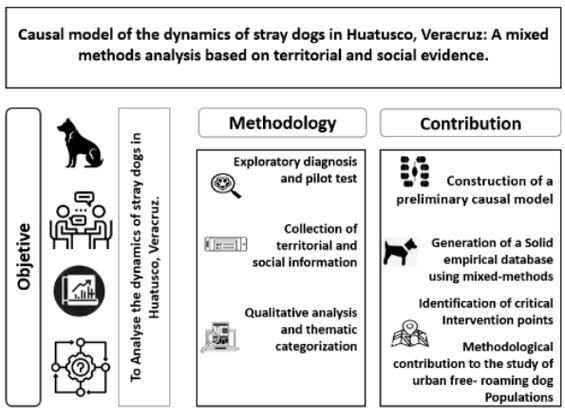
Abstract

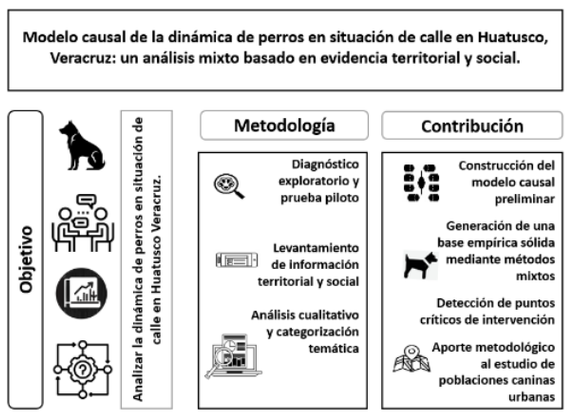
The study analyzes the dynamics of the free-roaming dog population in Huatusco, Veracruz, using a mixed-methods approach that integrates household surveys, georeferenced territorial transects, and interviews with key stakeholders. A total of 217 dogs were recorded in the surveyed colonies, and 240 questionnaires were administered, revealing perceptions of sanitary risk, irresponsible pet ownership, and low participation in control actions. Interviews with municipal authorities, the health sector, veterinarians, and animal welfare organizations helped identify structural drivers such as uncontrolled reproduction, abandonment, and food availability, among others. Based on this information, a causal model was developed to synthesize the relationships among the biological, social, and environmental factors that shape the system. The model highlights system components that require greater attention—such as sterilization, waste management, community education, and institutional coordination—and provides the conceptual basis for future stages of dynamic simulation.



Free-roaming dogs, Population Dynamics, causal model

Resumen

El estudio analiza la dinámica de la población de perros en situación de calle en Huatusco, Veracruz, mediante una metodología mixta que integra encuestas ciudadanas, muestreos territoriales georreferenciados y entrevistas a actores clave. Se registraron 217 perros en las colonias muestreadas y se aplicaron 240 encuestas que evidenciaron percepciones de riesgo sanitario, prácticas de tenencia irresponsable y baja participación en acciones de control. Las entrevistas con autoridades, sector salud, veterinarios y asociaciones civiles permitieron identificar causas estructurales como la reproducción no controlada, el abandono, la disponibilidad de alimento entre otras. Con esta información se construyó un modelo causal que sintetiza las relaciones entre los factores biológicos, sociales y ambientales que configuran el sistema. El modelo permite identificar los elementos del sistema que requieren mayor atención como la esterilización, la gestión de residuos, la educación comunitaria y la coordinación institucional, además constituye la base para futuras etapas de simulación dinámica.



Perros callejeros, dinámica poblacional, modelo causal

Area: Advocacy and attention to national problems

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Introduction

The proliferation of stray dogs (Canis lupus familiaris) represents a complex and multi-phase problem that affects the vast majority of cities worldwide, characterized by the interaction of social, environmental and health factors (Kaczorkiewicz, A. J. 2008). The main objective of this study is to develop a dynamic model to analyze the complex interaction of factors that contribute to the presence of unsupervised dogs in public spaces in Huatusco, Veracruz, and its repercussions on public health and animal welfare. The problem is not only due to a lack of education and proper laws, but also poses a serious risk to the health of people, animals, and the environment.

From the perspective of systems thinking, complex urban problems such as the proliferation of stray dogs cannot be understood through simple linear relationships, but from the interactions between multiple social, environmental and biological factors. This approach coincides with the approaches of system dynamics, where the internal structure of a system determines its behavior over time (Forrester, 1961; Aracil & Gordillo, 1997). Under this logic, the phenomenon analyzed in Huatusco can be considered a system characterized by feedback loops that favor its persistence and that need to be represented by causal models to understand its functioning.

The population dynamics of stray dogs are influenced by a variety of interrelated factors (ICAM, 2019) The availability of food resources, such as garbage, plays a crucial role in sustaining homeless dog populations (Control of Stray Dog Populations; (De la Reta, et al., n.d.). The lack of adequate shelters, interaction between animals with and without owners, and irresponsible ownership practices also contribute to overpopulation, socioeconomic and cultural factors influence responsible pet ownership and the community's attitude towards stray dogs (Contreras Torres, E. G. et al., 2017).

The accumulation of waste, the presence of micro-dumps and vacant lots are associated with a greater presence of dogs, while areas with better waste management tend to have fewer stray dogs; (De la Reta, et al., n.d.).

From a health perspective, coexistence between humans and stray dogs increases the risk of transmission of zoonotic diseases, including rabies, leptospirosis, toxocariasis and hookworm. In addition, the presence of these animals in public spaces can generate hygiene problems and environmental pollution (Contreras, et al., 2017) The lack of control of canine populations also hinders efforts to eradicate rabies (ICAM, 2019) Finally, the uncontrolled growth of the canine population has a negative impact on animal welfare, exposing dogs to adverse living conditions, abuse, accidents, and diseases (Contreras Torres, E. G. et al., 2017) (ICAM, 2019). It is essential to understand the dynamics of this problem in order to implement effective and ethical population control strategies (ICAM, 2019) Mass sterilization is an essential tool for controlling overpopulation, as long as it is carried out with a humanitarian approach (Contreras Torres, E. G. et al., 2017), (Escareño, et al., 2023).

However, it must be part of a comprehensive program that also includes adoption, education, and legislation programs (ICAM, 2019). A dynamic model will make it possible to analyze these complex interrelationships and propose solutions based on data and scientific evidence (ICAM, 2019). The use of mathematical models and advanced statistical analysis is a promising approach for understanding, monitoring, and decision-making in dog population management, as long as periodic assessments are carried out (ICAM, 2019)

Methodology

The study was developed under an applied research approach, with the purpose of understanding the problem of stray dogs in Huatusco, Veracruz, and representing their interrelationships through a causal model. The methodology was structured in four successive stages, aimed at integrating quantitative and qualitative information until the formulation of the conceptual model. The use of a mixed approach, combining quantitative and qualitative analysis, is suitable for complex social phenomena such as the present. This type of design has been widely described in the methodological literature applied to social studies, where the integration of multiple sources of information allows for more complete and contextualized interpretations (Alaminos-Fernández, 2025).

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Stage 1. Exploratory diagnosis and pilot test

In a first phase, an exploratory diagnosis was carried out in the Reserva Territorial colony, where pilot sampling was applied in order to evaluate the relevance of the collection instruments.

Box 1

Figure 1
Colonia Reserva Territorial, Sampled stray dogs
Source: own elaboration

This stage allowed the identification of conditions of the urban environment, factors associated with the presence of stray dogs and initial perceptions of the population, Figure 1, the result of the transect sampling that was carried out in the Territorial Reserve can be seen. As a result, the questionnaire was validated and its usefulness in capturing information on citizen knowledge, attitudes and practices was determined.

Once validated, the instrument was prepared for application to a larger sample in various neighborhoods of the municipality. In addition, the methodology for the detection of stray dogs was refined, highlighting the need to carry out the route at the same time through several elements with the intention of avoiding duplication of counting.

Stage 2. Survey of territorial and social information

In the second stage, the fieldwork was extended to the entire urban area of the municipality through three main activities:

Survey Application

240 surveys were applied to inhabitants of different neighborhoods, with the purpose of obtaining a broader characterization of the citizen perception regarding the handling of stray dogs. It had the support of several students from the Higher Technological Institute of Huatusco of the Industrial Engineering career, who participated in the standardization and survey of the surveys.

Territorial sampling and direct observation

Transect tours were carried out that covered approximately 70% of the urban area, this can be seen in Figure 2.

Box 2

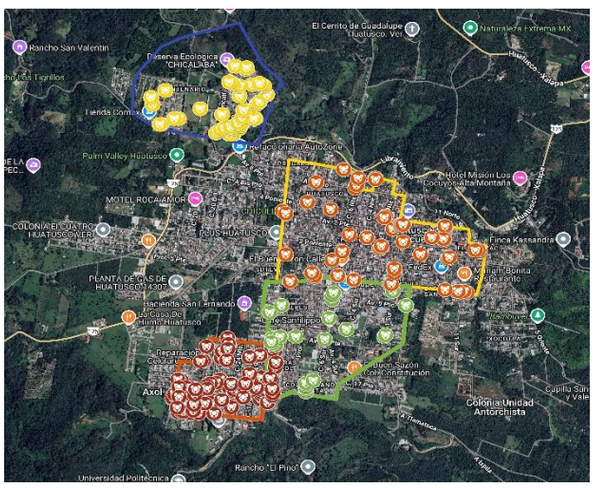

Figure 2
Map with the sampled colonies
Source: own elaboration

During these tours, georeferenced photographs of the dogs observed were recorded, with the aim of spatially locating the distribution of the phenomenon.

Semi-structured interviews

The thematic axes that guided the semi-structured interviews were defined based on the literature on urban wildlife management, animal welfare and public health, but also taking into account what was observed in the pilot phase and in the initial sampling of the project. The theoretical review made it possible to identify the central dimensions of the problem, such as:

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a. Structural causes
b. Health and environmental impacts
c. Current strategies
d. Institutional capacities and constraints
e. Citizen participation and perception

while fieldwork helped to adjust and prioritize these issues according to the local reality. This combination of theory and evidence made it possible to construct interviews focused on the key aspects of the phenomenon and with useful information for the development of the causal model.

The interviews were carried out with representatives of the Directorate of Environment and Ecology of the municipality of Huatusco, the Sanitary Jurisdiction, veterinarians and civil associations, in order to incorporate institutional and social perspectives into the analysis of the system.

Stage 3. Qualitative analysis and thematic categorization

The information obtained from the interviews was transcribed and organized using qualitative matrices. Recurrent thematic categories were identified and a comparative analysis was carried out between actors, which allowed the recognition of patterns, coincidences and contrasts.

This process served to integrate and triangulate the findings from interviews, surveys, and territorial sampling, generating the necessary conceptual basis for the causal model.

Stage 4. Construction of the causal model

From the systematized information, a preliminary causal model was constructed that represents the fundamental interrelationships of the system. In this stage, the connections between the identified elements were defined and the hypotheses that explain the observed behavior were established.

The result consisted of a causal diagram that integrates the main reinforcing and balancing feedback loops, constituting the conceptual structure of the system and serving as a foundation for future stages of dynamic analysis.

Results

Stage 1: Exploratory diagnosis and pilot test

The first stage of the project focused on carrying out an exploratory diagnosis that would allow understanding the initial conditions of the problem and evaluating the relevance of the selected methodological instruments. This phase was carried out in the Reserva Territorial neighborhood, an urban area characterized by a mixture of formal and informal housing areas, the presence of vacant lots and the constant circulation of stray dogs. The choice of this colony as a starting point responded both to preliminary empirical evidence and to citizen reports that indicated a high presence of animals without owners.

During this pilot phase, a first set of surveys was applied with the aim of evaluating their clarity, internal coherence and ability to capture information on knowledge, attitudes and practices of the population regarding the management of stray dogs. The responses obtained showed that residents had diverse perceptions of the magnitude of the problem, while revealing that practices such as informal feeding, abandonment and lack of sterilization were mentioned recurrently. This first survey made it possible to verify that the items of the instrument were understandable and useful to characterize citizen perception, which is why the questionnaire was validated for application to a larger sample.

In addition, an exploratory territorial sampling was carried out in the same colony.

This exercise consisted of systematic tours of streets and spaces for public use, during which stray dogs were counted and environmental conditions were documented that favored their presence, such as accumulation of garbage, little traveled areas and uninhabited homes. Direct observation confirmed that there was a sustained presence of dogs (Figure 3), some with signs of active reproduction, which evidenced the relevance of including variables related to birth, abandonment, and food availability in the later stages of the analysis.

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The pilot phase also made it possible to establish the logistical feasibility of the project. The participation of Industrial Engineering students was key to evaluate the operability of the routes, the times needed to complete transects and the ability to georeference observations with mobile devices. This initial exercise demonstrated that it was feasible to scale the sampling to other colonies and that the field methodology was adequate to generate a reliable record of the stray dog population.

Finally, the triangulation between surveys, direct observation and field notes made it possible to refine the instruments and define more clearly the variables that should be studied at the municipal level. Among them, responsible ownership, abandonment, uncontrolled reproduction, the perception of health risk, informal feeding and citizen participation stood out.

Box 3

Figure 3
Stray dogs
Source: own elaboration

Based on these findings, the methodological route was established that gave way to the second phase of the project, in which the application of surveys was extended to 240 people and territorial sampling was extended to approximately 70% of the urban area of Huatusco.

Stage 2: Survey of territorial and social information

The second stage of the study allowed obtaining a broad and detailed characterization of both the territorial behavior of stray dogs and the perceptions, practices and experiences of the population regarding this problem. The integrated analysis of 240 surveys and 217 georeferenced records of stray dogs allowed to delimit clear patterns in the urban distribution, as well as in the social factors associated with the phenomenon.

2.1 Results of surveys of the urban population

The analysis of the data showed that social perception recognizes the presence of stray dogs as a problem of a mainly health and social nature. More than 60% of the people surveyed considered the problem as serious or very serious, coinciding with the presence observed in the sampled neighborhoods.

The direct experience with stray dogs was significant. Between 25% and 30% of the population reported having experienced risk situations such as bites, chases or attempted attacks, which reinforces the public health dimension identified in institutional interviews. The intersection between educational level and perception of the problem showed that, regardless of the level of schooling, people tend to perceive the presence of stray dogs as a health risk, although people with high school and higher education showed greater willingness to participate in adoption, sterilization or awareness campaigns.

Regarding responsible ownership practices, the data indicate that a considerable percentage of the population keeps dogs unsterilized, which coincides with the explanation given by veterinarians and activists around uncontrolled reproduction. In addition, people who have correct information about sterilization showed more favorable attitudes towards population control and lower tolerance to abandonment.

The analysis also showed that households with a higher number of pets are more likely to allow pets to go out into public space, indirectly contributing to the growth of the street population. This finding highlights the relationship between domestic practices and the presence of animals on public roads.

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Finally, the crossovers between perception of the problem and willingness to collaborate reveal that people who consider the problem as very serious are also those who show more openness to participate in community solutions, which constitutes an important potential for citizen involvement policies.

2.2 Results of territorial sampling and direct observation

The territorial sampling allowed the identification of 217 stray dogs distributed in four strategic neighborhoods:

- Territorial Reserve: 88
- Center: 62
- Centenary: 42
- Emiliano Zapata: 25

The Territorial Reserve concentrated the largest number of dogs observed, which is associated with the presence of uninhabited homes, large spaces, vacant lots and areas with little urban control. This type of environment creates favorable conditions for animal mobility, reproduction, and survival.

The Centro neighborhood, with 62 registered dogs, presents different dynamics: the high commercial activity, the constant transit of people, the presence of food establishments and the accumulation of waste generate conditions that facilitate access to food. This confirms the hypothesis that informal feeding, both by available garbage and by human interaction, is a key factor in the structure of the system.

The Centenario and Emiliano Zapata neighborhoods, although with smaller numbers, maintain a significant presence. The observed characteristics (particularly areas of low surveillance and limited food availability) reinforce the role of the urban environment in the configuration of the system.

Box 4

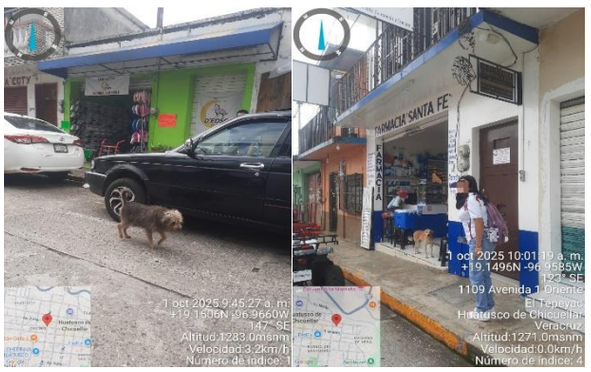

Figure 4
Stray dogs in the city center
Source: own elaboration

Photographic georeferencing made it possible to spatially locate the points where the presence of dogs is concentrated, identifying specific quadrants that function as corridors or micro-territories. These spatial patterns are consistent with the public perception that certain sectors present greater risk or greater interaction between people and animals.

2.3 Integration of social and territorial outcomes

The cross-results between citizen perception and territorial distribution show great coherence. The neighborhoods where the greatest presence of stray dogs was recorded coincide with the areas where the population expresses more health concern and greater frequency of conflicts with animals. Likewise, the data confirm that the problem is not distributed homogeneously, but is concentrated in environments with specific structural conditions: availability of food, low urban surveillance, housing density and the presence of abandoned spaces. The findings of this stage allow us to clearly identify the critical urban nodes, associated social behaviors, and interaction patterns that feed the dynamics of the system. This integration between territorial and social data constitutes the fundamental basis for the construction of the causal model in later stages.

Stage 3: Qualitative analysis and thematic categorization

The qualitative analysis allowed the integration of the information obtained through semi-structured interviews with municipal authorities, civil associations, veterinarians and health personnel.

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This stage was fundamental to identify the social, institutional and environmental elements that make up the dynamics of the system, as well as the relationships that support the causal structure developed later.

The transcriptions were organized into thematic matrices that allowed the discourses to be grouped into central categories, each associated with dimensions of the system that emerged recurrently among the different actors. The categories identified provided clarity on the structural factors, feedback processes and conditioning factors that influence the persistence of stray dogs within the municipality.

3.1 Structural causes of the problem

All the interviews agreed that the growth of the stray dog population is determined by structural factors that are repeated in different areas of the city. Among them are:

- Lack of preventive sterilization, pointed out by both activists and veterinarians, who report low demand for the service and economic and cultural barriers.
- Irresponsible tenure and abandonment, a problem described by all actors as a widespread practice reinforced by the lack of effective sanctions.
- Availability of food, either through access to garbage or informal food provided by citizens, which favors the survival and stability of canine groups.

These factors are configured as core components of the system, and will later give rise to variables such as fertile dogs, birth rate, abandonment, informal feeding and survival in the causal model.

3.2 Health, environmental and social impacts

The qualitative analysis revealed a shared concern about the effects of the presence of stray dogs. Among the main impacts mentioned are:

- Public health risks, especially bites, parasitosis, scabies and potential zoonoses.
- Pollution on public roads, associated with broken garbage bags, feces in the streets and bad odors.
- Negative perception and neighborhood conflicts, particularly in areas with a higher concentration of animals.

These findings made it possible to identify variables related to incidents, health impact, environmental impact, and social pressure, all of which are fundamental to explaining how the effects of the system generate citizen and government responses.

3.3 Current strategies and their scope

The analysis showed that the existing actions to control the problem are reactive, sporadic and with limited resources. Among the main activities observed are:

- Rabies vaccination campaigns organized by the health sector.
- Intermittent sterilization campaigns promoted by civil associations.
- Specific actions of the City Council for capture or removal for specific incidents.

The qualitative information made it possible to differentiate between strategies with potential impact (such as sterilization) and actions with limited effect (such as temporary capture). These observations are subsequently translated into causal variables such as sterilization campaigns, institutional support, capture/removal, and mortality.

3.4 Institutional capacities and constraints

The interviewees agreed that institutions face important restrictions:

- Shortage of budget and specialized personnel in the municipal area.
- Absence of a permanent animal control program.
- Dependence on operational volunteers for rescue, dissemination and sterilization activities.

These limitations are elements that affect the strength of the system's balancing loops; they are then represented by variables such as institutional capacity or frequency of campaigns.

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3.5 Citizen participation and social perception

The interviews showed that citizens have a heterogeneous participation: while some sectors support with food, adoptions or donations, others express discomfort, indifference or rejection towards dogs or associations.

The relevance of these social perceptions coincides with studies on community-wildlife interaction, where local knowledge and citizen attitudes significantly influence management and conservation strategies (Lemus Ramírez, 2025).

Likewise, an incipient process of sensitization was identified in schools and among some families.

From this category, relevant social variables emerge such as citizen attitudes, willingness to collaborate and citizen reports, which subsequently interact with the generation of social pressure on the authorities.

3.6 Conceptual integration towards the causal model

The triangulation between the categories derived from interviews, the results of the surveys and the territorial distribution made it possible to clearly identify the endogenous components that structure the dynamics of the system.

From this stage emerge the conceptual foundations that will sustain the causal model, particularly around:

- Mechanisms of reproduction and survival,
- Population flows associated with adoptions and mortality,
- Health and environmental impacts,
- Citizen and institutional responses,
- Reinforcing and balancing feedback.

These relationships are formalized in the next stage through the construction of causal diagrams that synthesize the internal structure of the system and explain the persistence of the problem in the municipality.

4: Construction of the causal model

The fourth stage of the study consisted of the conceptual integration and formalization of the elements identified in the previous stages within a causal model, elaborated under the logic of system dynamics.

This model synthesizes the internal relationships of the system, organizes the factors detected through fieldwork and establishes the endogenous hypotheses that explain the persistence and evolution of the phenomenon of stray dogs in Huatusco.

The use of feedback-based causal models is based on the principles of system dynamics, where the internal structures of the system determine its behavior over time (Aracil & Gordillo, 1997).

The use of causal models and approaches based on system dynamics has been recommended to analyze urban and socio-environmental problems characterized by high levels of interaction and feedback, as shown by the dynamic modeling work developed for other complex urban systems (Linares-Fleites et al., 2016).

4.1 Identification of the central variables of the system

From the triangulation between the data from surveys, territorial sampling, and interviews, a set of variables was established that operate as essential components of the system. Among the most relevant are:

- Population of stray dogs
- Birth rate / fertile dogs
- Abandonment and irresponsible tenure
- Food availability (garbage, informal feeding)
- Survival
- Incidents and bites
- Citizen Reports
- Capture the retreat
- Mortality
- Saturation of shelters
- Adoptions
- Health and environmental impact
- Social pressure
- Institutional support
- Sterilization campaigns

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These variables were selected for their recurrence in the actors' discourse, their consistency with quantitative data, and their role within the social, biological, and urban processes observed.

It is important to note that the variables identified in this stage correspond only to the endogenous elements of the system. These variables reflect the internal structure of the phenomenon and allow us to understand how the dynamics of the dog population in Huatusco are generated and sustained.

On the other hand, the definition of exogenous variables will be carried out in later phases, once the dynamic model has been built and the simulation scenarios have been developed. These variables will correspond to external factors that influence the system without directly depending on its internal behavior.

Among the possible exogenous elements that could be incorporated are: the municipal budget allocated to animal control, changes in state or federal regulations, extreme weather events, urban growth processes or population migration, economic variations that affect responsible ownership and the intervention of external organizations through massive campaigns or extraordinary support, among others. Their inclusion will depend on the relevance and relevance they show during the experimentation phase of the model.

4.2 Internal relationships and causal hypotheses

The causal relationships identified between the variables constitute the endogenous hypotheses of the system, formulated from the evidence collected in surveys, interviews and territorial sampling. This approach coincides with the approaches of Forrester (1961), who established that social and urban systems present patterns of behavior derived from internal feedback structures.

These hypotheses describe the internal mechanisms that explain the persistence of the stray dog population in the municipality and allow structuring the causal model. Each of the identified hypotheses is described below:

a) First, it was established that the birth rate depends directly on the number of fertile dogs, so a greater number of unsterilized animals increases the probability of reproduction and, consequently, the stray population.
b) In a complementary way, the availability of food, whether through accessible garbage or informal food provided by people, favors the survival of dogs and contributes to the sustained growth of the system.
c) At the social and health level, it was observed that an increase in the street population increases the frequency of incidents, such as bites, neighborhood conflicts and risk situations, which in turn increases citizen reports. This relationship constitutes a hypothesis of reactive response, in which the authorities carry out capture or removal actions motivated by specific complaints, although with temporary effects and limited in scope.
d) The analysis also identified that the health and environmental impacts derived from the presence of dogs such as scattered garbage, feces on public roads and risk of zoonoses, intensify social pressure on municipal authorities. This pressure influences the probability of receiving institutional support, which conditions the frequency of sterilization campaigns. These campaigns reduce the number of fertile dogs and, with it, the birth rate, forming a control mechanism with significant potential, although dependent on limited resources.
e) Interviews with civil associations also showed that the saturation of shelters increases as the street population and rescues grow. This saturation restricts the ability to manage adoptions, which weakens the effectiveness of this strategy as a mechanism for population reduction.
f) Finally, mortality operates as a natural starting factor, but its effect is insufficient in the face of the mechanisms that favor reproduction and survival.

All the above-mentioned relationships identified, as well as internal relationships and endogenous hypotheses of the system are shown in Figure 5.

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4.3 Causal hypotheses

The causal model allowed us to identify several feedback loops that explain the dynamics of growth and regulation of the dog population.

As Forrester (1969) demonstrated in studies of urban dynamics, reinforcing and balancing loops explain why certain phenomena tend to persist or amplify even when there are partial interventions. This conceptual framework allows for a proper interpretation of the loops identified in the stray dog system.

a) Uncontrolled playback reinforcer loop.

The presence of fertile dogs increases the birth rate, which increases the stray population and perpetuates the number of unsterilized animals. This cycle favors a continuous growth of the system.

b) Facilitated survival reinforcer loop.

The availability of food increases the survival of dogs and increases the stray population, which in turn perpetuates practices and conditions that maintain the supply of food.

c) Sterilization balancer loop.

The social pressure derived from the health and environmental impacts affects the institutional response, promoting sterilization campaigns that reduce the number of fertile dogs. This mechanism has regulatory potential, although it depends on limited resources.

d) Reactive action balancer loop.

The increase in dogs increases incidences and citizen reports, which activates capture or removal actions. However, its effect is temporary and does not act on the structural factors of the system.

e) Adoption Balancer Loop (weak).

The saturation of shelters limits the ability to promote adoptions, reducing the influence of this mechanism on the street population. Its regulatory effect is marginal.

Box 5

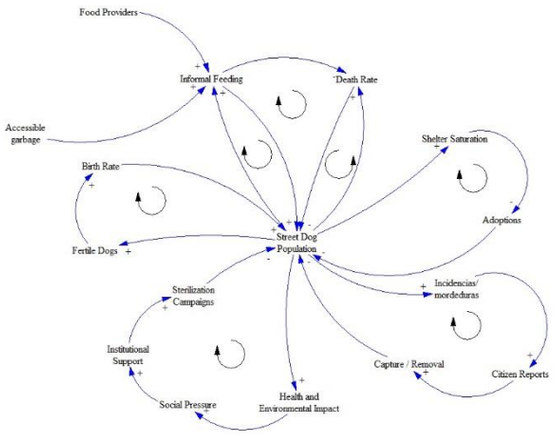

Figure 5
Causal Model of Stray Dog Population Dynamics
Source: own elaboration

Conclusions

The present study allowed a broad understanding of the problem of stray dogs in Huatusco, Veracruz, evidencing that it is a complex system where biological, health, social, and institutional factors interact, as indicated by the international literature on urban wildlife management (Contreras Torres, E. G. et al., 2017); (OIE, 2011); (ICAM, 2019). The mixed approach employed that included surveys, georeferenced territorial observation, and semi-structured interviews provided a solid empirical basis to characterize the local dynamics and support the construction of the causal model.

The evidence points to the possibility that the stray dog population in Huatusco is maintained by the joint action of internal reinforcing mechanisms, especially uncontrolled reproduction, abandonment and the wide availability of food through garbage or informal feeding practices. This behavior coincides with previous studies that highlight the importance of food supply and irresponsible ownership as key drivers of the growth of unsupervised dog populations (De la Reta, et al., n.d.); Benítez-García & Miranda-Cabrera, 2018). It is also presumed that regulatory mechanisms such as sterilization, adoptions, reactive capture or mortality have a limited scope. The intermittency of campaigns, the saturation of shelters, budget insufficiency, and low social accountability can contribute to the fact that balancing loops are significantly weaker than reinforcers, which coincides with what has been reported in the literature on the failure of fragmented or non-continuous strategies.

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The causal model constructed synthesizes these interrelationships and shows the possibility of why the dog population tends to remain high and expand in areas with favorable conditions, such as accumulation of waste, presence of vacant lots or lack of territorial control. The analysis of loops reveals that the structure of the system favors population permanence and growth, while existing interventions fail to modify the structural causes of the problem. This reinforces the need, already pointed out by international organizations (OIE, 2011); (ICAM, 2019), to implement comprehensive, sustained, and multi-stakeholder strategies.

Likewise, the model allows the identification of critical points of intervention, including continuous sterilization with a preventive approach, proper waste management, citizen education to promote responsible ownership and effective coordination between authorities, the health sector, veterinarians and civil associations. The systemic perspective used shows that these elements cannot be addressed in isolation, since their interaction is what determines the behavior of the system.

Although this research does not yet advance towards the dynamic simulation of levels and flows, the formulation of the causal model is a fundamental step. The developed scheme offers a robust conceptual structure to guide future computational modeling efforts, evaluate intervention scenarios, and support evidence-based decision-making. Consequently, the results of this study lay the foundations for moving towards a dynamic model that allows us to assess, in a quantitative way, the potential impact of different population control policies.

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Hernández-Armenta, Abigail: I carry out the collection of information, coordination in the application of surveys and automation of information, as well as the development of interviews with the different actors identified, as well as in the writing of the article.

Córdoba-Gómez, Luis Tomás: Contributes to the collection of information on current public policies regarding the proliferation of stray dogs; also in the coordination of transects for the count of stray dogs in the city; also supports in the interviews with the different actors identified in the project.

Jiménez-Solís, Miguel Ángel: I carry out the design of the research and the analysis of the data, reviewed and participated in the writing of the article, as well as in the elaboration of the causal model.

Calderón-Palomares, Luis Antonio: I contribute to the elaboration of the causal model, I also contribute to the evaluation of its variables and hypotheses.

Availability of data and materials

The project's data were obtained through three complementary strategies: surveys applied to inhabitants of different neighborhoods of Huatusco, territorial sampling with georeferenced photographic record of dogs observed on public roads, and semi-structured interviews conducted with key actors such as municipal authorities, the health sector, veterinarians, and civil associations

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