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Review

Latin American Cattle Ranching Sustainability Debate: An Approach to Social-Ecological Systems and Spatial-Temporal Scales

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Abstract: The significance of Latin America (LA) in the global food supply is large and prominent. The livestock sector at this time faces social-ecological challenges that will be accentuated in the future and will be incredibly challenging for small and medium producers. We conducted a systematic literature review to understand the role of LA cattle ranching in the current sustainability debate. In addition, we identified the main components of cattle ranching social-ecological systems and evaluated the institutional and ecological interactions of livestock studies by identifying spatial and temporal scales. Our results show a broad debate on livestock sustainability in LA; nevertheless, efforts to measure sustainability and analyze cattle ranching systemically are scarce. The study of LA cattle ranching in the 21st century was geographically concentrated on the main producing countries (Mexico, Colombia, Brazil, and Argentina) and was consistently promoted by government and academic institutions aiming to understand management strategies that improve yields. However, it less often focused on analyzing their impacts on ecosystems and climate. The complexity and dynamism of cattle ranching in LA make it necessary to address sustainable planning from a systemic approach to guide viable transformations through spatial scales.

Keywords: livestock; ecosystem services; multifunctionality; collective action; scales

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1. Introduction

Cattle ranching has been studied in recent decades from the perspectives of global change and sustainability [1,2]. Within the economic dimension, livestock provides financial income to 1.3 billion producers and retailers. It is the basis of the livelihoods of 1 billion poor and 200 million smallholder families worldwide [3,4]. As part of the social dimension, livestock products supply one-third of the global protein consumption and are essential components of the diet of 800 million food-insecure persons [5]. The environmental dimension of sustainability has been approached from the biophysical implications of cattle ranching. Cattle have been introduced into most world ecosystems, and their extensive spatial distribution has led to changes in land use, soil fertility, water quality, water use, biodiversity, multifunctionality, and climate change [3,6]. Despite the ensuing environmental costs, production and consumption of livestock products continue to rise. The global demand for food of animal origin is expected to be at least 50% higher in 2030 than in the year 2000 [7], and it will be supplied mainly by the global south, where livestock production is already significant [8,9]. LA will increase beef production by 125% by 2050 to sustain meat demand with significant planetary implications. The spatial predominance of cattle ranching in LA underpins one of the most significant expansions of the agricultural frontier in the last 50 years on a global scale [10]. It can be understood by exploring the historical context.

Cattle arrived in the LA along with the European settlers; the first species introduced was the *Bos taurus* with minimal requirements for pasture extension, so silvopastoral

systems, a form of production using the forage provided by the trees and shrubs of forests and tropical forests, were maintained predominantly for more than 400 years until the introduction of zebu cattle (*Bos indicus*) [11]. The substitution of this type of cattle led to the massive opening of pastures at the expense of natural vegetation and favored the deforestation of large extensions of the territory. Since then, cattle ranching has led to significant transformations of ecosystems and the establishment of exotic pasture species from Africa and Asia [12]. The environmental problems caused by cattle ranching in LA are partly the result of the transformation of natural ecosystems into pastures with exotic grasses, some of which are invasive or potentially invasive [13].

Starting from the history of the extensification domain, currently, the LA region contributes to meeting the growing demand for food of animal origin and supports regional and global food security [14]. While LA represents only 16% of the world's total population and 34% of its rural population, it possesses 67% of the heads of cattle for meat production and 76% for milk production. This region generates 30% of the planet's meat and 28% of its bovine milk [15]. Therefore, the LA livestock sector contributes to 46% of the agricultural GDP, which is increasing by 3.7% annually; this exceeds the average global GDP growth rate (3.4%) [14,16]. The growth of the livestock sector has been mainly due to an increase in the number of animals and extensive areas that promoted deforestation of forests for cattle grazing. Moreover, agricultural frontiers, used to grow cattle feed, shifted to the tropics with new frontiers established in LA and promoted deforestation [10].

The role of LA in the regional and global food supply is broad and leading. The livestock sector currently faces social-ecological challenges that will be accentuated in the future and will be incredibly challenging for small and medium producers who raise and market cattle, for whom extensive practices will possibly cease to be viable as the primary source of income and livelihood [2,10]. In general, there is concern about managing the sector's growth so that these benefits can be attained at a lower environmental cost and to address the inefficient use of resources in cattle ranching systems [5]. The sustainability debate of cattle ranching systems in emerging regions such as LA often occurs within the theory of sustainable intensification, through which the market orientation of production systems is contemplated, combined with appropriate incentive policies that achieve the establishment of systems that remain within sustainability thresholds and increase not only production per unit area but also the provision of benefits in the same land area [5,9].

However, attempts at planning for sustainability in the livestock sector have been criticized for not handling growing conflicts caused, among other reasons, by a mismatch between the scale of management and the scale of the process being managed and poor understanding of ecological and social scales in geographic space [17,18]. Moreover, it has been neglected because of the importance of a systems perspective, which allows tracing the main elements that make up social-ecological systems (SES) [19]. It is recognized that place-based planning can help evaluate more sustainable alternative futures for SES [20]. The different components of livestock systems involve complex interactions at multiple scales, making a systemic approach necessary to trace possible solutions in favor of the social and ecological logic of the sector [21]. Therefore, exploring and driving comprehensive studies can help to understand and plan for sector sustainability tailored to the unique attributes of the contexts [17]. In that sense, we propose as objectives from a systematic literature review:

(1) to understand the role of LA cattle ranching in the current sustainability debate, considering the conceptual frameworks for SES and ecosystem services (ES), and the concepts of multifunctionality (MF) and collective action (CA) as critical tools for a comprehensive analysis;
(2) to identify the main ecological, social, and economic components frequently studied in livestock research in LA;
(3) to assess the institutional (the scale of management) and ecological (the scale of the process being managed) interactions of livestock studies by identifying spatial and

temporal scales at which research is conducted, and cattle ranching components are developed.

Approaches and Concepts

The concept of SES has proven itself the strongest and most convincing candidate in the contest for a boundary object relevant both to sustainability science and to the study of the manifold of interdependencies among natural and social processes along different temporal and spatial scales [22]. SES are cohesive, integrated systems characterized by strong connections and feedbacks within and between social and ecological components that determine their overall dynamics. The SES framework recognizes that society benefits from ecosystems to meet its needs and that the utilization of these ecosystems modifies them, thereby creating a continuously changing dynamic [20].

SES analysis can use conceptual and methodological tools drawn from systems, complexity, or graph theories based on a mathematically oriented definition of the term "system" [22]. This term can be approached from the definition of hard and soft systems. The difference between hard and soft systems approaches is given by how the external world is considered. From the hard systems approach, a system can be designed and constituted by the observer's interaction with the complex real world. The soft systems approach assumes that systems, including people, cannot be designed to achieve an ideal condition [23] The SES framework is situated in the realm of soft systems science because it is designed to synthesize qualitative information leading to an understanding of some system processes in varying social, ecological, and economic contexts that will never have an ideal state because of the variety of interests and realities [22].

The structure of the SES is transformed due to changing interactions at all scales. Hierarchies and adaptive cycles comprise the basis of SES across scales; together they form a panarchy. An adaptive cycle, proposed as a unit for understanding complex systems, can lie between long periods of aggregation and transformation of resources and short periods of innovation (Figure 1). Fast-moving cycles at small scales are more prone to innovations, whereas slow-moving cycles of larger scales stabilize and preserve the memory of successful events [24]. The adaptive cycle analyzes degrees of stability in complex systems over time and looks at how a complex system reacts to certain shocks and represents four phases: the growth (exploitation) phase (r phase), conservation phase (K phase), release phase (omega; Ω-phase, corresponding to the end), and reorganization phase (alfa; α-phase, corresponding to the beginning) [24]. The panarchy describes how a healthy system can invent and experiment, benefiting from inventions that create opportunity while being kept safe from those that destabilize because of their nature or excessive exuberance [25,26] (Figure 1). The concepts of resilience, vulnerability, transformation, and sustainability are needed to understand the dynamics of an intertwined SES through the adaptive cycle. Resilience is the capacity of a system to absorb disturbance and reorganize during the change to retain essentially the same function, structure, and feedback, and therefore identity. Typically, the resilience of a system is high in the r phase, declines in the advanced K phase, and increases in the transition from the Ω to α phase [27].

The concept of vulnerability has its roots in the study of natural hazards and poverty. Vulnerability includes the attributes of persons or groups that enable them to cope with the impact of disturbances. Transformation is presented as adaptive possibilities enabled by organizations or individuals, may be forced by system failures, or chosen in anticipation of collapse and movement to a new state of the SES [27–29]. On the other hand, sustainability promotes changes aimed at guaranteeing human well-being and environmental integrity [28]. Production systems are complex adaptive or self-organizing systems, such that their behavior changes over time due to internal processes of development and interactions of system components. The way the social and ecological systems of a SES interact causes the system to go through adaptive cycles [30].

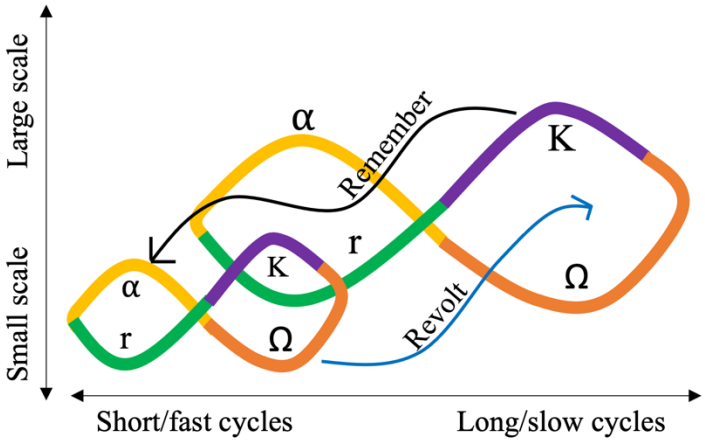

Figure 1. Panarchy of interconnected adaptive cycles at different spatial and temporal scales. A heuristic of nested adaptive cycles is observed that can be connected through re-member and re-volt across multiple temporal and spatial scales interactions simultaneously (Adapted from [26], Island Press).

A cattle ranching system is a local SES embedded in a complex system of multiple interactions across different levels and scales [31]. The aggregation level is a categorization used by a geographic observer to locate and classify a phenomenon within a hierarchy (e.g., home, ecosystem, landscape) [32]. Therefore, it can be arbitrary and have different meanings in different contexts. In contrast, spatial scales denote the size or spatial extent of a process, phenomenon, or study (e.g., local, regional, and global) [33]. However, SES operate across various spatial and temporal scales and aggregation levels that mix ecological and institutional hierarchies [34] that complicate their analysis.

In this sense, several analytical frameworks for approaching the SES facilitate their interpretation [35]. The ES analytical framework helps reveal the interaction between ecosystems and humans [35] and integrate environmental and cultural values according to the local context [31]. Social-ecological dynamics in livestock landscapes supply ES bundles; some parts of livestock territories can supply complete sets of ES [36] associated with the management strategies in place [37] under the prevailing ecological conditions. The maximization of ES in cattle production systems can be promoted from the MF [38] or CA approach. The MF of agroecosystems implies that, beyond their function in producing food and fiber, they perform other essential functions for the SES of which they are a part [39]. However, the recognition of ES provided by livestock should not obscure the need to weigh these services against their adverse effects (trade-offs) nor obscure the importance of promoting research and policies that ensure viable multifunctional landscapes [40].

Although the CA theory was put forward to evidence challenges in the management of common property resources [41], it can also be helpful to improve the provision and governance of ES in systems that are not based on common property resources [42]. Cattle ranching systems in LA are not only part of communities [43]. There are also private land tenure schemes in which producers often make decisions collectively for expected benefits in the localities. The organized, cooperative management of cattle production can deliver human and ecological well-being in other territories through social, economic, and environmental impacts, since production and trade activities are connected at various spatial scales [44]. In synthesis, the concepts and approaches for managing sustainability through systemic analysis to ensure that livestock systems are economically viable for farmers, environmentally friendly, and socially acceptable [45] are described below.

- Social-ecological systems (SES) are complex adaptive systems formed by humans and nature. They comprise heterogeneous individual modules that interact and are physically, behaviorally, and even spatially transformed over time [46].

- Ecosystem services (ES) are the benefits that people obtain from the environment (support, provision, regulation, and culture) to satisfy their needs [47].
- Multifunctionality (MF) is the ability of ecosystems or agroecosystems to carry out multiple functions simultaneously that can potentially supply ES packages, providing ecological, social, and economic benefits to multiple actors [38,48].
- Collective action (CA) is the voluntary cooperation of various stakeholders to address a common ES management issue in each territory [42].

2. Materials and Methods

The systematic literature review is aimed at understanding the role of the LA livestock sector in the ongoing discussion on sustainability, considering the SES and ES framework and the MF and CA concepts as essential tools. In addition, the purposes are to identify ecological, social, and economic components emerging from cattle ranching SES in LA and to assess the institutional and ecological importance of livestock research in LA. We apply the SALSA (Search, Appraisal, Synthesis, and Analysis) framework to realize the systematic literature review as described below:

- Search

We searched for peer-reviewed scientific papers, whether conceptual or empirical. Conceptual studies present a theoretical characterization, develop a common language, or propose guidelines and frameworks for assessing the sustainability of cattle ranching. In contrast, empirical studies are based on analyzing actual observations or measurements.

The search was based on literature that was published in English and Spanish over 20 years (2000–2020) to examine the advances made by livestock research in the first two decades of the 21st century and evaluate the advances made by livestock research following the recognition of the livestock revolution in 1999 [49]. We searched the Scopus and Web of Science databases and the Google Scholar search engine. The search used combinations of keywords: Livestock, Latin America, Sustainability, Social-ecological systems, Multifunctionality, Ecosystem Services, and Collective Action.

- Appraisal

Included was every study that met at least one of the following four selection criteria in any of the search stages (title and abstract, and full text):

- It characterized cattle management in a LA country.
- It analyzed livestock systems using the SES approach.
- It analyzed the ES or trade-offs of cattle ranching.
- It examined or mentioned the MF or CA concepts in livestock systems.

- Synthesis

Examination of the 120 selected is presented in an Excel spreadsheet for analysis (Table S1). Data included document citation, title, author(s), year of publication, type of publication, journal name, the method used, keywords, issues addressed, study site, spatial scale or aggregation level, and temporal scale of analysis whenever this could be discerned.

- Analysis

Within the analytical phase, we identify the countries where the livestock research mentions the framework of SES and ES, sustainability, and the concepts of MF and CA. Additionally, we recorded the frequency with which these approaches and concepts were mentioned and measured; we identified the ecological, social, and economic components that were addressed within the selected articles, and the scales at which these components were analyzed. As spatial scales were often conflated with aggregation levels, we coupled two conceptual approaches to visualize the identified components in a hierarchy.

The spatial scales and aggregation levels reported in the studies were grouped into two distinct analysis levels following the logic of ecological and institutional hierarchies based on the proposals of Ruiz-Rivera and Galicia [32] and Hein et al. [34]. The first proposal

includes the concept of the scale and the different elements and dimensions that compose it: extension, resolution, level, and hierarchy [32]. The second proposal intermixes spatial scales and levels of aggregation in two classifications: (1) ecological scales (the scale of the process being managed) and (2) institutional scales (the scale of management) in interaction by the coupling between humans and the environment [34]. The resulting categorization reflects the aggregation levels and scales at which decisions are made, institutions and stakeholders that participate, and ecological processes reported in the literature on cattle ranching in LA.

3. Results and Perspectives

3.1. Trends in Livestock Research in Latin America

Livestock research in LA increased during the 21st century. In the review, livestock included ruminant species, namely cattle (*Bos taurus* and *Bos indicus*), sheep (*Ovis aries*), goats (*Capra hircus*), and buffalo (*Bubalus bubalis*), and non-ruminant species, namely pigs (*Sus scrofa domesticus*) and chickens (*Gallus domesticus*). However, 95% of the livestock studies analyzed address cattle production, processing, sale, distribution, or consumption issues—the remaining 5% study represented other livestock species. The current debate mainly focuses on cattle ranching systems; therefore, we will use the words livestock and cattle ranching as synonyms. Studies in just four countries accounted for 50% of all the articles reviewed: Mexico (17%), Colombia (12%), Brazil (12%), and Argentina (9%) (Figure 2a). These countries account for 70–80% of the production of the principal livestock species in LA [50], so it is not surprising that they are the countries where livestock research is strengthened.

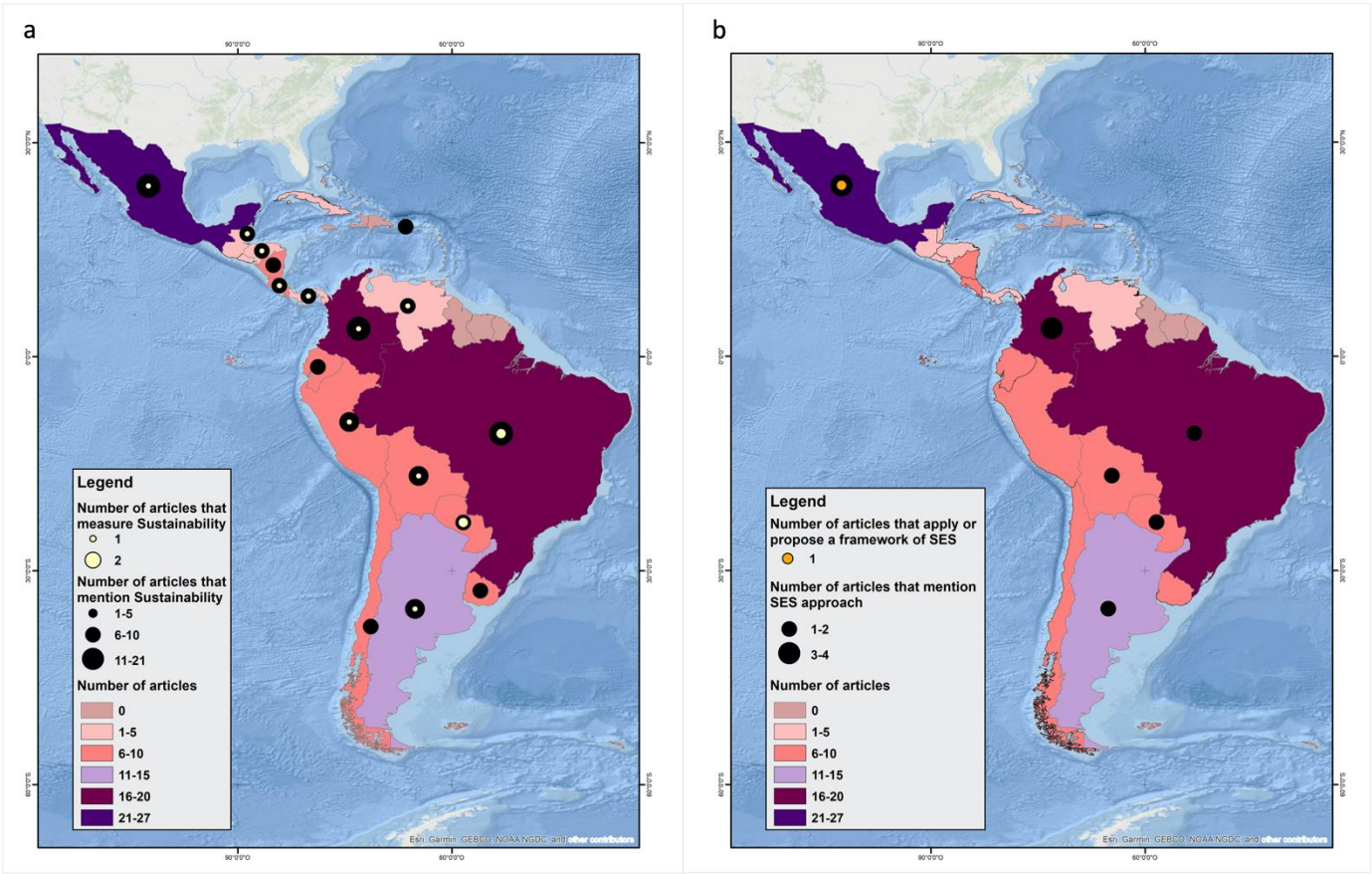

Figure 2. (**a**) Spatial distribution of livestock research in Latin America between 2000 and 2020 where sustainability is mentioned and measured; (**b**) Spatial distribution of livestock research in Latin America between 2000 and 2020 where a conceptual framework of SES is mentioned and applied.

We identified a disconnection between recognizing and measuring the approaches and concepts that are key to encouraging sustainability and the notion and quantification of sustainability in formal livestock research. Although cattle research mentioned sustainability in most LA countries (Figure 2a), its measurement was weakly explored. In this regard, the significant conceptual advance was recognizing the sustainability (83% of the studies mentioned the concept); however, only 4% of the studies applied a method to quantify sustainability, most of them in Mexico (Figure 3).

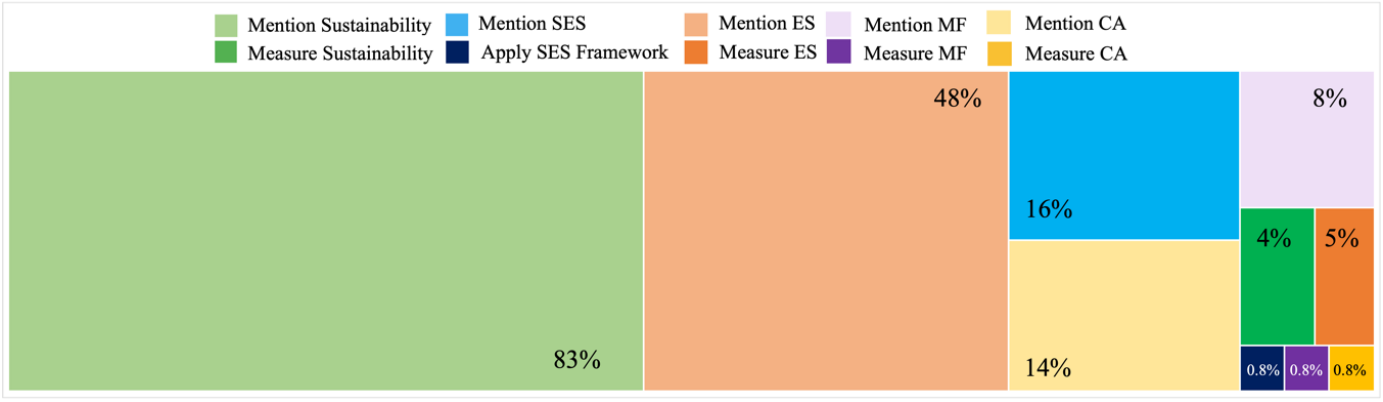

Figure 3. Proportions (blocks) and percentages (values) of mentions and measurements of critical approaches and concepts in the study of cattle ranching in LA.

Research from Mexico, Colombia, Brazil, Bolivia, Paraguay, and Argentina mentioned the integrative SES approach and recognized its usefulness for systematically studying cattle ranching (Figure 2b). The SES concept was mentioned in 16% of the studies. However, less than 1% of them (only one study) applied SSE theory to examine through a framework the relationship between local social-ecological components and livestock management (Figures 2b and 3) [51]. The inclusion of the SES framework in livestock research was incipient, possibly because the diversity of people, interests, and power asymmetries involved throughout the agri-food system in LA (production, processing, marketing, and consumption) make it challenging to plan the sector holistically, as is the case with the study of soft systems [23].

MF was mentioned in 8% of the documents but was explicitly measured in less than 1% of papers (Figure 3). Lack of understanding of MF has already been reported for SES research, just as a comprehensive treatment of multi-scale systems containing closely interdependent components within SES is still lacking [52]. ES were mentioned in 48% of the reviewed studies but were quantified or mapped in only 5% (Figure 3). Our results support that livestock is an essential driver of most rural landscapes and economies in emerging countries [53], where certain benefits derived from cattle ranching are recognized. On the other hand, the various ES that livestock systems provide to society, beyond food production, are often overlooked and rarely quantified or mapped [40]. Steering livestock towards sustainability involves improving the provision and quantification of all types of ES, as well as ensuring communication of their importance for improving ecosystem conservation, making the existing cultural and spiritual relationships visible, and moving towards profitable and productive management with less environmental impact [40].

CA was recognized in 14% of the documents reviewed but was included in a conceptual framework in only 1% of them (Figure 3). The scarce mention and measurement of CA processes in LA livestock contexts visualize a primary challenge for cattle breeding and marketing in the region, as CA has the potential to strengthen governance and improve the livelihoods of farmers living from livestock production [42]. This is essential, as the fragility that results from poor governance and weak cooperation and organization among people is compounded throughout the supply chain and amplified across scales, problems that hinder the development of the sector and that have been reported in other poor regions

of the world [54,55]. The inequities in power relationships based on the governance of the supply chain highlighted potential points of entry and exclusion for smallholders [56]. Moreover, along with inequalities, systemic traps that maintain the status quo in the hands of the powerful undermine sustainability [57]. An improvement to one part of the supply chain, say for instance production, without concomitant interventions in better processing and marketing capacity, could lead to higher production without an adequate market outlet, further depressing prices for smallholders [56].

Including CA in community and private livestock management would promote the sector's sustainability. Specific strategies of organization and cooperation between producers and institutions can orient cattle production and trade towards sustainability [42]. Current strategies (e.g., the market orientation of production systems, combined with appropriate incentive policies that achieve the establishment of systems with less environmental impact) [8] and future strategies must consider the many market failures in the form of high transaction costs, information and power asymmetries, limited organizational capacity, externalities, regulatory deficiencies in LA where smallholders often have little bargaining power [56]. About 43% of the documents used qualitative methods; 26% used quantitative methods; and the remaining 31% combined qualitative and quantitative approaches, thus reflecting and supporting the predominance of studies at levels of institutional analysis so far this century. Among the documents reviewed, 66% were research articles; 27% were review articles; and 7% were book chapters (Table S1).

3.2. The Components of Cattle Ranching in LA

Understanding the sustainability debate depends on the interactions between internal components (e.g., social, ecological, or economic) and external factors (e.g., global environmental problems, political conflicts) [25,26]. Livestock systems represent a potential pathway out of poverty for many smallholder farmers in the developing world; however, understanding their social, economic, and ecological components in a disaggregated manner can help identify opportunities for real-life environmental and social justice improvements. The identified components are part of cattle ranching systems that use land in LA. They are managed by small and medium producers who face problems of unsustainability (e.g., degradation of pastures, soil fertility and erosion problems, loss of biodiversity, etc.) in contexts of high vulnerability [6,58,59].

Ecosystems establish the biophysical conditions necessary to maintain MF at high levels, ensure ES, and sustain livestock management strategies as viable livelihoods over time [60–63]. The ecological components identified include biotic and abiotic factors of ecosystems. Abiotic factors are non-living physical and chemical components (e.g., soils, water, rocks). In contrast, biotic factors are the living components of an ecosystem (fauna, flora, and their interactions). Ecological components within cattle ranching SES are analyzed on local-regional spatial scales over days and months of studies, usually in experimental designs (Figure 4). However, many ecosystem processes occur over hundreds and thousands of years (e.g., soil formation, altered climatic regimes) and change within long/slow adaptive cycles (Figure 1), often overlooked in livestock research. These components shape two primary management practices used in LA to produce beef, milk, or both: extensive pastures (EP) and silvopastoral systems (SPS) (Figure 4). EP uses extensive areas of natural vegetation where only herbaceous plants are grown for use as forage, along with rudimentary facilities to house cattle and store production-related materials [64,65]. In the EP, the removal of tree cover and low density of cattle per unit area highlights the inefficient conversion of energy into animal products typical of production in tropical regions of LA. In contrast, SPS includes trees and shrubs associated with grasses to form a landscape of multi-layered vegetation for forage [66]; they also include forage banks and living fences to delimit individual pastures and provide additional wood and forage [67]. SPS also retains or includes shrubs and trees that increase the capacity of the system to convert solar energy into biomass and enhance the complexity of the habitat [68]. There is broad academic support for SPS in terms of environmental benefits. However, there has

been little exploration of their role in the household economy in LA, where there are no differentiated value chains to commercialize what is produced in lower environmental impact livestock management systems [56].

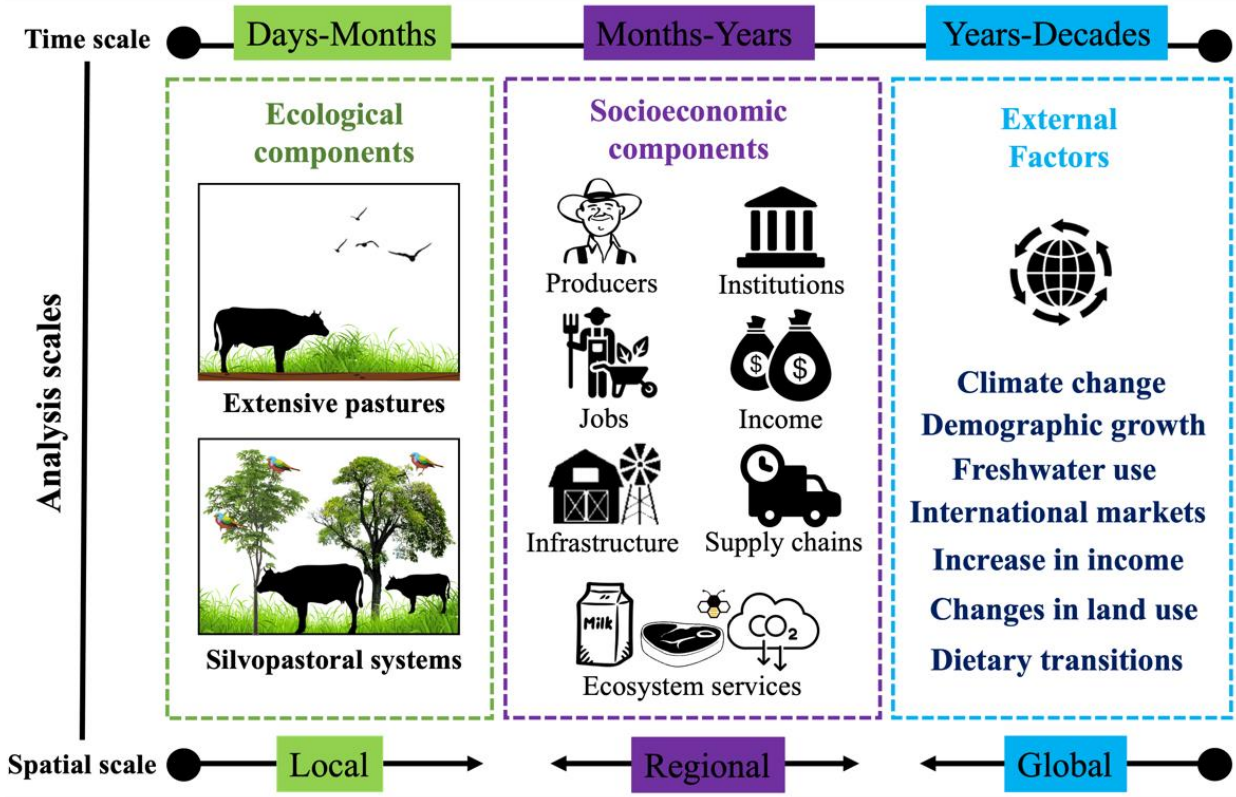

Figure 4. Ecological (green box) and socioeconomic components (purple box) integrate the cattle ranching SES in LA in interaction with external factors (blue box) identified in the papers reviewed. In addition, it shows the spatial and temporal scales at which these components and factors are usually analyzed.

We also recognized through the review critical socioeconomic components that are most frequently analyzed in livestock research in LA at local and regional spatial and temporal scales that include months and years: producers, supply chains (shorts and longs), income, institutions (governmental and non-governmental institutions), infrastructure, jobs generated, and the ecosystem services they provide (Figure 4), but which change within short/fast adaptive cycles (Figure 1). The current way of trading cattle means that producers remain dependent on conventional channels based on intermediaries and are monopolized by large companies that control the distribution of meat and milk. In this sense, the value chain approach thus provides a framework to analyze the nature and determinants of competitiveness in value chains where small farmers can participate. It also provides the basic understanding needed for designing and implementing appropriate development programs and policies to support market participation [56].

Beyond the value chain approach, it is necessary to consider the socio-ecological interactions arising from the injustice in which livestock buyers and consumers develop the sector and the severe consequences for long-term sustainability. However, tracking the components and understanding their relationships alone will not achieve the changes needed to move toward sustainability. Working with organizations—people who are persuaded to undertake some activity or change some operation—can help. Organizations might be considered "political cauldrons" where different and shifting coalitions emerge to get things accomplished. Understanding who has power (in its different forms) is key to making changes [69].

A short food supply chain can be any marketing strategy based on a maximum of one intermediary between a producer and a final consumer. In contrast, a long supply chain involves more than one intermediary [70]. Cattle producers frequently use EP with limited financial and social capital, modest infrastructure, and few opportunities to diversify their livelihoods beyond cattle ranching. They are isolated from urban centers and government institutions, often segregating them from trade routes, subsidies, and other incentives [71]. In general, the lack of financial capacity to access technological improvements, scarce government support, little training on alternative production strategies, non-existence of special competitive supply chains, and excess of intermediaries that retain a percentage of the profit and poor governance [72,73] hinder the sustainability of livestock in LA. Although it is not possible to establish a single profit threshold for intermediaries along livestock product supply chains, it is known that the percentage they retain depends on three factors: (i) the contribution of intermediaries to the generation of total value added in the chain (which sometimes damages product quality), (ii) the value-added captured by the intermediary as a percentage of total value added in the chain, and (iii) whether or not the intermediary's income is generated to the detriment of producers' income and capacity building [72]. The cattle ranching systems are characterized by long supply chains featuring great distances, numerous phases of weight gain and feeding regimes, many levels of traders and transactions, a multitude of steps and stages of processing, and various employment-creating services and expense generators [56].

Despite commercial constraints, the trade and consumption of animal products reduce the vulnerability of households to seasonal shortages of food and income for producers, workers, intermediaries, and butchers and improve food security and the nutritional status of the most vulnerable population [14,58,74]. It is essential to increase jobs in the agricultural sector and improve hiring conditions and the income of producers and workers in livestock production systems to reduce the vulnerability of rural families in LA [75]. In addition, it is a priority to guarantee from government institutions that farmers have access to inputs, capital, infrastructure, technological improvements, technical information, and awareness to sustain management strategies with less environmental impact over time [76] associated with higher investment costs [77,78].

The cattle ranching in the LA region is related to factors external to bovine SES analyzed predominantly on a global scale and time scales of years and decades: international markets, global increase in income, demographic growth, use of freshwater, changes in land use, dietary transitions with more significant preferences for livestock products and the contributions to climate change, primarily associated with the deforestation of forests [74,79–82] (Figure 4). Some of these factors change within short/rapid cycles (e.g., changes in land use, dietary transitions) and others within long/slow adaptive cycles (e.g., climate change) (Figure 1). Other critical features include the changes in land use and freshwater use, as livestock production takes up about 70% of the total agricultural area (farmland and EP) worldwide [21], and its processes consume large volumes of freshwater (~8% of the global water supply) [83]. International markets (especially meat) are external factors stemming from a telecoupled world that maintains long-distance social, economic, and environmental interconnections among livestock production, processing, trade, and consumption [84–86]. On the other hand, population growth, increases in income, dietary transitions, and climate change [87,88] can trigger changes at regional and local scales and affect social and economic systems.

3.3. Institutional and Ecological Interactions across Spatial Scales

Despite the broad range of spatial scales and aggregation levels of livestock research in Latin America, 76% of the studies analyzed it at the institutional level, and 24% reported ecological analyses. However, the number of studies on cattle ranching and the number of documents, including ecological analyses, increased since 2015 (Figure 5), thus reflecting a growing concern about the environmental implications of cattle production and commercialization from LA. Institution-level studies focused on understanding yield improvements

and the export potential of LA to meet the growing demand in other continents [50]. Studies including ecological analyses characterized production systems [59,89] and the impacts of livestock on ecosystems, particularly about climate change (greenhouse gas (GHG) emissions and land-use change), soil degradation (nutrient depletion, soil erosion), and pollution caused by the use of fertilizers supplying nitrogen and phosphates [9,73,77,90,91].

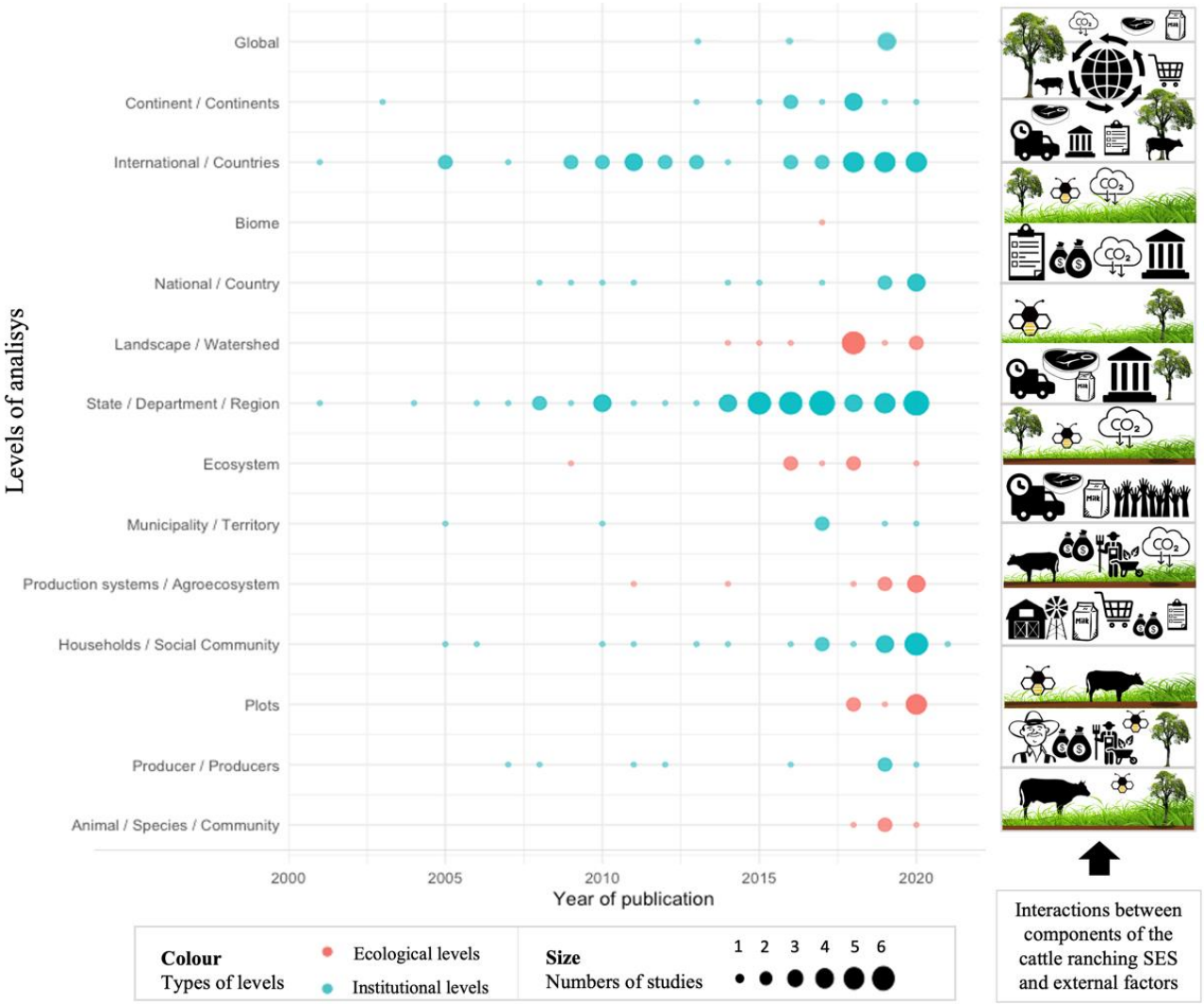

Figure 5. Levels of analysis reported in studies on livestock in Latin America and ecological/socioeconomic components and external factors identified within different levels in constant interaction. The color indicates the types of levels (institutional or ecological), and the size of the bubble indicates the number of studies reported for each year of analysis.

Our results reflect that socioeconomic components and external factors were analyzed mainly at institutional levels (producer level, household, municipality, state, region, country, countries, continents, and global) and to a lesser extent at ecological levels (plot, production system, ecosystem, landscape, and biome) for the consideration of ES and the estimation of GHG emissions (Figure 5). For their part, ecological components (biotic and abiotic) were studied almost strictly within ecological levels of analysis (animals, species, plots, production systems, ecosystems, landscapes, and biomes) (Figure 5). This approach to livestock from a purely disciplinary view highlighted the socio-ecological disconnect within biological studies with potential implications for sustainability management. In other words, the evaluated ecological studies on cattle ranching in LA were predominantly reductionist because they did not connect the social and economic dimensions that largely

shape ecosystems. The study of cattle in LA during the first two decades of the 21ST century was consistently promoted by government and academic institutions to understand management strategies that improve yields and animal welfare [92]. Nevertheless, it rarely focused on analyzing its impact on ecosystems, landscapes, and climate, which makes the lack of a holistic perspective explicit. The complexity and socioeconomic and environmental dynamism of the cattle ranching SES in LA make it necessary to address sustainable planning from a systemic approach to guide viable transformations.

Insight into the scales and their interactions in space and time remains a challenge for SES management and for informing policy [93]. The primary role of humans in the configuration of ecosystems implies that the interpretation of sustainability in SES depends on the environments created by humans [94]. Although agriculture and livestock have radically altered natural landscapes with multiple social-ecological effects [3,9,91,95,96], the issue of spatial scales in the SES theory has been little explored [94,97]. The poor understanding of the linkages between the processes of social-ecological change at different scales leads to errors in estimating impacts and the design of public policies for land-use planning and adaptation [98]. Therefore, this research contributes to reducing the scalar gap. Considering the current trend in livestock production and consumption, we are facing an unprecedented challenge in sustainability throughout the agri-food system [99], so exploring the viability of SPS within the ecological, social, and economic dimensions represents a priority for the region. Sustainable solutions will have to be constructed by combining personal and political actions that guide the transformation and ensure ecological, social, and economic benefits that can last over time [100] and strategically amplify across space and sustained over time.

4. Conclusions

Livestock research in Latin America so far in the 21st century has been geographically concentrated in Mexico, Colombia, Brazil, and Argentina, mainly due to the leading role of these countries in the production and commercialization of cattle on the local, regional, and global scale. In addition, it shows a decoupling between institutional interests associated with the amplification of production (ecological and socioeconomic components) and the possible planetary consequences (external factors) associated with maximizing yields in extensive systems and opening markets every time more distant and demanding. The inclusion of the SES framework in livestock research has been incipient, possibly due to the difficulty of sizing and integrating the diversity of capacities, worldviews, interests, and power asymmetries in LA agri-food systems. However, the complexity and socioeconomic and environmental dynamism of LA's cattle ranching SES make it necessary to address sustainable planning from a systemic approach to guide viable transformations that address unsustainability.

Promoting sustainability implies, on the one hand, improving its measurement to assess the current state of SES and, on the other hand, improving the provision and quantification of all types of ES, as well as ensuring the communication of its importance to improve the conservation of ecosystems, make visible the existing cultural and spiritual relationships, and move towards profitable and productive management with less environmental impact.

The scarce mention and measurement of CA processes in LA contexts visualize a primary challenge for cattle ranching production and commercialization in the region, as CA has the potential to strengthen governance and improve the livelihoods of producers who make their living from cattle management. The consolidation of organizations within which organizational processes are strengthened can be a strategy through which different and shifting coalitions emerge to get things accomplished. Working with organizations is indispensable to understanding the forms of power; they are crucial to leveraging changes and establishing cooperation with institutions.

The lack of financial capacity to access technological improvements, limited government support, poor training on alternative production strategies, the absence of special

and competitive supply chains, an excess of intermediaries who keep a percentage of the profits, and poor governance hinder the sustainability of livestock farming in LA. These issues must be addressed systemically, recognizing their multi-scale, multi-temporal, and multi-sectoral dimensions.

Livestock studies in institutional levels of analysis in LA include predominantly socio-economic components and external factors to the local SES but also integrate environmental issues, which show better social-ecological integration. However, studies conducted at ecological levels of analysis maintained a strictly environmental focus, and most of them ignored the social and economic dimensions that shape ecosystems and are indispensable for improving sustainability. Knowing the scales and their interactions in space and time remains challenging for SES management and informing policy. In that sense, this research contributes to reducing the scalar understanding gap.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14148924/s1. Table S1: Data matrix derived from systemic review.

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