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How to Assess Urban Food Resilience? Moving Towards Food Security in Chilean Cities

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Abstract

Background. Food resilience is the ability of the food system to adapt to external and internal disturbances and maintain the outcome of food security. This paper focuses on shaping the concept of urban food resilience regarding the operation of urban food infrastructure and its capacity to provide food security. Methods. To achieve this, a methodology based on the pillars defined by the Food and Agriculture Organization (FAO) for food security, i.e., availability, accessibility, and stability, is used, operationalized from a spatial approach, and evaluated in terms of urban food resilience. Three simple indexes are built, i.e., diversity, redundancy, and short-term stability, and combined into a composite index: the Urban Food Resilience Index (UFRI). Results. The results are analysed from a spatial and quantitative perspective, linking scores with urban surface area, population, and density. The study examines the reality of Chilean intermediate cities distributed throughout the country, using the La Serena–Coquimbo Conurbation as a case study. Conclusions. The ultimate goal is to provide a straightforward methodology for assessing urban food resilience in countries with limited data access, thereby providing a foundation for informed urban planning decision-making.

Keywords: infrastructure; diversity; redundancy; stability; density

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1. Introduction

Food resilience is the ability of the food system to adapt to external and internal disturbances and maintain food security [1]. This concept gains key relevance in an urban context where growing populations place extra demands on the supply and access to healthy food [2]. Urban food systems are embedded in global systems [3], making them vulnerable to shocks and stressors such as natural disasters, political, economic, and public health crises, or climate change [4,5]. However, urban food systems are essential to achieving most of the 17 Sustainable Development Goals, particularly "zero hunger" and "zero poverty", [6]. Therefore, developing the concept of urban food resilience regarding its role in providing food security [7,8] as well as methodologies and suitable measurement tools, is critical to achieving that goal.

International literature addresses food resilience at an urban scale from different perspectives. Some research refers to how the food supply chain generates and sustains food availability within urban spaces, and how it must ensure its resilience to diverse effects to guarantee food security [9–11]. On the other hand, several studies focus on analysing how communities with socioeconomic vulnerabilities can be resilient in both their daily food access and in adapting to adverse effects [12]. A third body of research involves articles examining how various models of urban agriculture can help mitigate the issue of economic access to unhealthy food and improve food security and resilience [13–15]. Finally, several papers centre on how cities plan and take responsibility for ensuring equitable spatial access within urban environments. In this regard, some studies focus on the effects that planning has on enhancing urban resilience [4], with some cases examining negative impacts [5,16]. Finally, a few studies focus on analysing how urban food infrastructure and its planning can support urban food resilience to ensure food security in the face of socio-natural or anthropogenic shocks.

This paper focuses on shaping the concept of urban food resilience, considering the operation of urban food infrastructure and its capacity to provide food security. To achieve this, a methodology based on the pillars defined by the Food and Agriculture Organization (FAO) for food security is applied, namely availability, accessibility, and stability, operationalized through a spatial approach and evaluated in terms of urban food resilience. Three simple indexes are built, diversity, redundancy, and short-term stability, and combined into a composite index: the Urban Food Resilience Index (UFRI). The results are analysed from a spatial and quantitative perspective, linking the scores with urban surface area, population, and density. The hypothesis is that greater diversity, redundancy, and temporal stability of urban food infrastructure contribute to a more resilient urban food system in the face of adverse effects.

The proposed UFRI focuses on evaluating how urban food infrastructure has the potential to offer diverse, redundant points of sale to provide food security under system perturbations. This index complements previous research that has been proposed to evaluate resilience in other links in the food chain, such as the resilient food production index [7], the enablers of resilience in food supply chains [11], or the household resilience index [17]. The UFRI indicator measures objective data from urban food infrastructure in a city, while other indexes, such as the Food Insecurity Experience Index [18] or RIMA II [7,19], assess perception. Additionally, in contrast to more complex and qualitative indicators that aim to understand urban resilience comprehensively and include the analysis of multiple layers of food security, such as the integral evaluation of metropolitan food resilience [5], or in contrast to qualitative models which examine the attributes of the resilience of the food system as a basis for the calculation of resilience values metrics, such as the sustainability/resilience index [1,20,21], the UFRI is focused on an in-depth analysis of a single aspect: the potential resilience of urban food infrastructure. Its aim is to thoroughly identify areas of low resilience within the city, thus providing a foundation for public policy-making and urban planning.

The study explores the reality of Chilean intermediate cities, spread throughout the country, using the La Serena–Coquimbo Conurbation as a case study. For the analysis of urban food infrastructure, two systems that provide food security in Chilean cities are examined: supermarkets and street markets [22–24]. The ultimate goal is to offer a simple methodology for evaluating urban food resilience in countries with limited data access, providing a foundation for urban planning decision-making.

Urban Food Resilience for Urban Food Security

Food security and food resilience are related but distinct concepts. The former is defined as an outcome of the food system [25]. In fact, according to the FAO, “Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” [26], p. 1. The latter refers to the ability of the food system to rapidly adapt to internal or external conditions, adjust to shocks, and produce food security under any circumstances [1]. Under this framework, the analysis of the network of food access points that provide fresh foods for a healthy diet to the population in cities, namely urban food infrastructure, and its capacity to provide food security under adverse conditions, makes an original contribution to reshaping the concept of urban food resilience.

The FAO has defined food security under four pillars: availability, access, utilization, and stability [26]. Those pillars depend on and are deeply impacted by culture [27]. However, just three of them can be directly applied to the study of urban food infrastructure [28]. **The first pillar is food availability**. It essentially determines whether food is actually or potentially present to provide food access to the population. Although its original meaning refers to the entire food chain, including food production, logistical distribution and exchange, when focusing on the urban food system and its critical infrastructure, it considers, the *offer* side, or the existence of diverse food systems within the city, such as the variety of food retail options, e.g., supermarkets, grocers, markets, farmers' markets, connected with different food chains [21,29–32]. Some research adds complexity to the concept of diversity, specifying that functional and spatial complementarity between different options regarding food systems and urban distribution provides urban food resilience [20,33]. In fact, the coexistence and integration of distinct yet complementary supply chains (both short and long) are essential for urban-scale resilience, as they help prevent dependence on an insufficient number of operators or exchange points [34]. Finally, diversity is also applied to the geographic foodsheds of the urban supply, enhancing the resilience of the urban food system against climate-related production failures [10].

The second pillar is food access. This refers to when physical availability exists, whether households have sufficient access to food in both spatial and economic terms. When focusing on urban food infrastructure, it considers the *demand* side. This means the existence of redundancy in access [9] or the presence of multiple or duplicated elements within the food system that can fulfil a similar purpose [21]. It is the ability of a system to have backups and replace its components [20]. Specifically, it refers to the number of retail options within urban food infrastructure that households have within walking distance to ensure continued operation in the event of a perturbation of the system [32,35]. Redundancy should be responsive to the needs of the system [20]. In this sense, the modernization or development of new food markets and the decentralization of distribution could serve as bulwarks against future disruptions, enhancing the flexibility of the system [3]. However, the system should be *optimally redundant*, because this characteristic inevitably increases the system's inefficiency [33].

The third pillar is stability. This refers to the condition that availability and access remain constant, guaranteeing food security at all times. When focusing on the urban food resilience approach, it means that, even under perturbations of the system, stability should be provided in the short term, as well as in the medium and long term. In the short term, it means that the urban food system should be analysed via a dynamic approach, evaluating the cyclical dynamics that food access can have throughout the year, a week, or even on a daily basis [24,36,37]. Some research adds that temporal heterogeneity helps to provide urban food resilience [33]. In the medium and long term, multiple crises can impact urban food systems, including environmental, health, social, and climate change crises [4]. However, hitherto urban scale research has mainly focused on the evolution of food access to understand the dynamics and changes of food environments, such as the capitalization of the retail food sector [38], the effect of a recession [39], or neighbourhood gentrification [40].

2. Materials and Methods

2.1. Case Study

Chilean cities have undergone rapid urbanization processes in recent decades, reaching an urbanization rate of 87.8% in 2017 [41]. Moreover, the Chilean urbanization model tends to disconnect agricultural production from consumption, making urban food infrastructure a means of supply and access to food a critical factor in assessing the population's food security.

This study explores the operation of the urban food system in intermediate Chilean conurbations, which can be found throughout the country. Urban food security is mainly provided by two urban food infrastructures, each linked to different food systems: supermarkets and street markets [23,24]. Supermarkets are large national chains that operate under a free market logic. They are installed according to market segmentation criteria and housing densities that guarantee a certain level of demand. Street markets play a critical role in ensuring continuous access to healthy food, which is essential for the population's food and nutrition security [42], because of their affordability and despite their intermittent operation. They are an ephemeral and weekly aspect of food infrastructure, where several stands obtain authorization from municipal governments to operate in public and designated spaces, which in most cases are not designed for this purpose. Neither of them receives public assistance; however, open-air markets may be planned by municipal authorities and relocated to areas where they are most needed.

Other forms of public food infrastructure, such as municipal markets, persist in only a limited number of cities, underscoring the limited role of the state in the provision of food within urban contexts. Charitable activities have played a significant role in past events, such as the COVID-19 pandemic [43], but they are spontaneous collaborative networks lacking formal institutional frameworks. There are also additional food systems in Chilean cities. However, retail shops do not usually provide enough diversity to provide food security, and although informal trade, alternative food networks and community gardens do exist, none of them account for a significant proportion of the city's food supply. Besides, often local producers rely on street markets as their primary means of commercialization.

La Serena–Coquimbo is chosen as the representative case study. Located in northern Chile, 500 kilometres north of Santiago, it comprises two municipalities and has a population of 513,860 inhabitants, according to the 2025 Population and Housing Census of the National Statistics Institute (INE, in Spanish). It features a morphology of compact fragments and several degrees of dispersed growth towards the periphery [44] (Figure 1).

In this case, it is possible to identify marked patterns of socio-spatial and socio-economic segregation [45,46] with several publicly subsidized housing neighbourhoods predominantly inhabited by individuals from the lowest socioeconomic segments. In La Serena, the downtown area is located on the south bank of the Elqui River. Residential urban growth has developed toward the north, in the Las Compañías sector, which features a high density of social housing; toward the east, in the medium-density La Antena and La Florida sectors; and toward the south, in the low-density La Pampa sector (Figure 2).

In Coquimbo, the center is located on the peninsula, next to the harbor. The municipality has two large residential growth centers: the first, located around the historic district beside the port, to the north of the peninsula, is the medium-density Parte Alta; and to the south, the San Juan and Sindempart sector, with a high density and a high proportion of social housing. The second growth center is along the urban boundary with La Serena, the Tierras Blancas sector, which exhibits a high density, particularly toward the sector's northeast. Between the two growth centers in Coquimbo, there are fragments of residential areas, with low density in the north, El Rosario, and high density in the south, La Cantera. Finally, there are two axes of low-density residential growth, along the bay's coast in both municipalities, and to the east of La Serena with very low-density fragments (Figure 2).

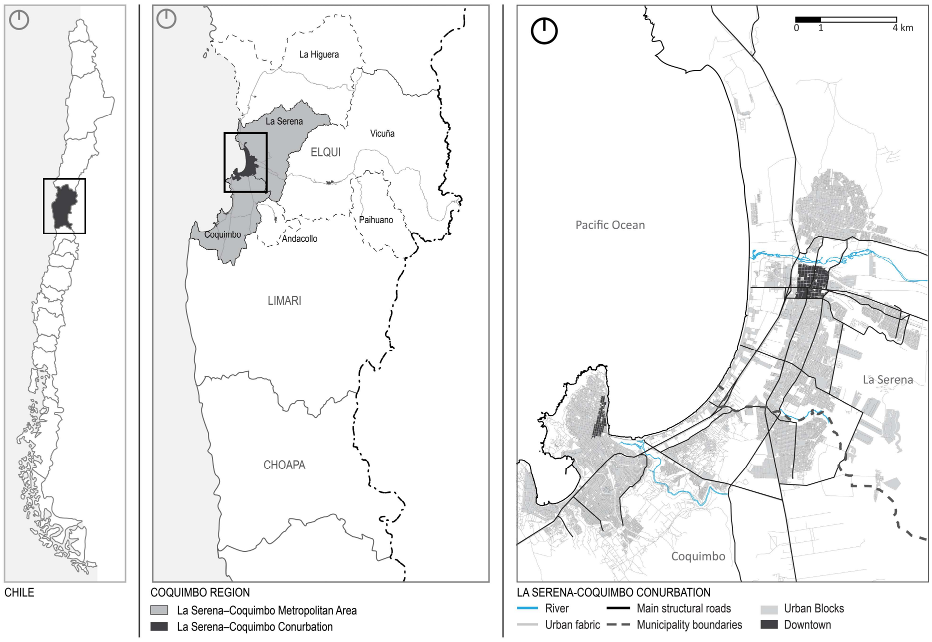

Figure 1. La Serena–Coquimbo conurbation.

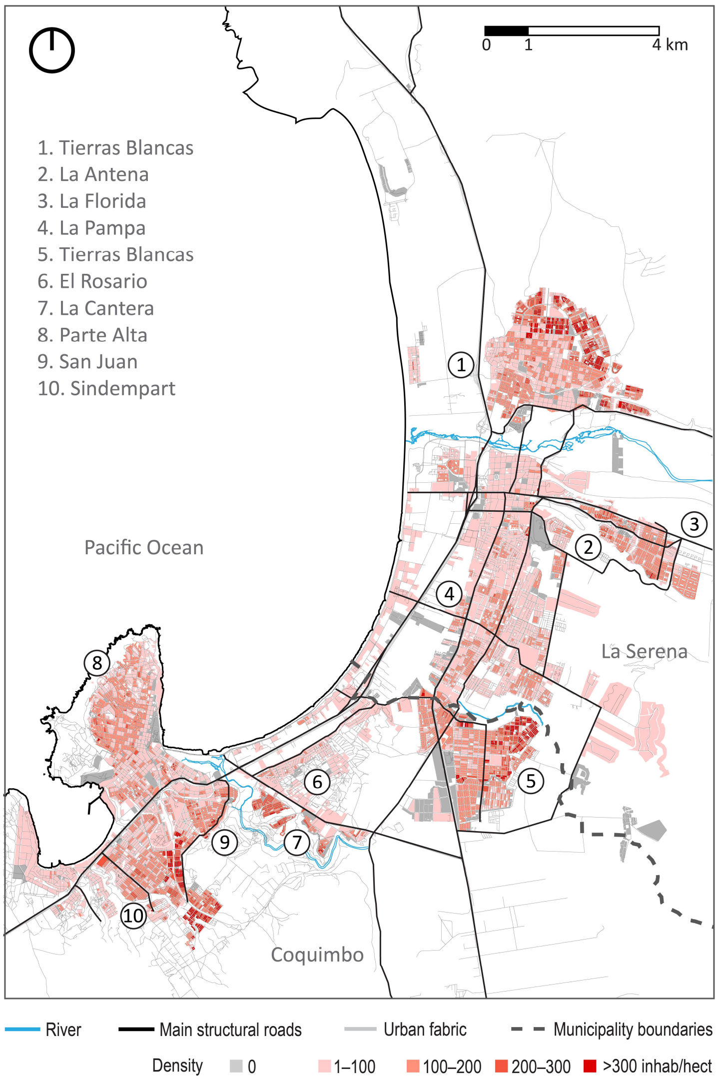

Figure 2. Population density in the La Serena–Coquimbo conurbation.

2.2. Data and Methods

The methodology consisted of operationalizing the pillars defined by the Food and Agriculture Organization (FAO) for food security, i.e., availability, accessibility, and stability, via a spatial approach to analyse urban food infrastructure and its contribution to urban food resilience.

For this, a cadastral survey of the location of markets and supermarkets in the urban space of the La Serena–Coquimbo Conurbation was conducted in 2024 by the authors. Information from Asof C.G. (National Trade Confederation of Flea Markets and Related Organizations) was used to map the street markets. Municipal registries and supermarket websites were used to locate supermarkets. The exact location and operational days were recorded for each cataloged infrastructure point. Site verification was conducted to confirm the location, and in the case of supermarkets, it was confirmed that they offered fresh fruits and vegetables; otherwise, they were excluded from the dataset. A total of 40 supermarkets were surveyed in the La Serena–Coquimbo Conurbation, 24 in La Serena, and 16 in Coquimbo. Regarding street markets, 13 are found in La Serena and 10 in Coquimbo (Figure 2). Population data were sourced from the 2017 census, the latest available dataset offering microdata at a block level.

The operationalization of the FAO's food security pillars was based on previous research that has attempted to systematize them both qualitatively [27] and quantitatively [47]. The former analyzed the implications for the four pillars from a cultural perspective, while the latter evaluated the impact of technology use in production and its effects on food security.

In this paper, the operationalization of the pillars was carried out as follows and synthetized in Table 1. Availability was defined as the diversity index. This analysed the spatial distribution of the diversity that urban food infrastructure provides to households. The service area method is used with ArcGIS Network Analyst [46,48,49] to determine the maximum distance of 1000 m from the centroid for supermarkets and the midpoint for street markets. Information was transferred to urban blocks and classified. A score of 0 was assigned for blocks without food access within a 1000 m, 0.5 when the block has access to just one food system, and 1 when it has access to both systems. Food access was materialised as the redundancy index. This analysed the redundancy of access that each food system provides through the urban food infrastructure to blocks. The coverage method was calculated from the centroid blocks with a maximum distance of 1000 m [46,50,51] using Network Analysis in ArcGIS. The number of food access points for each food system was calculated. In La Serena–Coquimbo, some blocks had access to five food points in the same system; however, taking this maximum as a ceiling for the index means that it demanded too much from the system. For this research, redundancy was understood as access to at least two food points in the same system. A score of 0 was assigned for blocks without food access or redundancy in any system, 0.5 when the block has redundant access to one food system, and 1 when it has redundant access to both systems. The economic dimension is excluded from this methodology because it is focused on the spatial dimension.

Table 1. Operationalization of the FAO's food security pillars.

FAO Pillar	Indicator	Method	Potential Scores	UFRI
Availability	Diversity index	Service area 1000 m	0.0 Food desert 0.5 Access to one system 1.0 Access to both systems	33%
Food access	Redundancy index	Coverage method 1000 m	0.0 Food desert 0.5 Redundancy in one system 1.0 Redundancy in both systems	33%
Stability	Short-term index	Coverage method 1000 m	0.0 Food desert 0.1–0.9 Equalization considering 1–6 days of the week 1.0 Food access every day of the week	33%

Stability is concretized as the short-term index. This analysed the weekly operation of the urban food infrastructure. The coverage method was calculated using ArcGIS Network Analysis from the centroid blocks with a maximum distance of 1000 m and was equalized according to the days of the week on which each food point is working, from 0 in food deserts to 1 with access to any food point 7 days per week. Long-term stability was discussed qualitatively in the discussion, considering previous disturbances of the systems, but it is not quantified in this paper. Finally, the Urban Food Resilience Index (UFRI) is calculated by weighting one-third of each of the three indexes: (1) diversity index, (2) redundancy index, (3) short-term stability index.

Analysis of the data is carried out using a dual approach: first, from a spatial dimension, identifying neighbourhoods with different levels in each index; second, from a quantitative dimension, analysing the amount of urban surface (ha), population, and density of population for each score of the index.

3. Results

3.1. Diversity Index

Figure 3 shows the spatial distribution of the points of sale points for each food system. While supermarkets are predominant, mainly located close to the main structural roads and present throughout the conurbation, street markets are strategically distributed and primarily located at the two northern and southern ends of the conurbation, distant from the main structural roads, and provide neighbourhoods with fresh food. The street markets' locations are directly related to social housing neighbourhoods.

Complementarily, some parts of the conurbation are not served by any of the food systems. These can be considered as food deserts and will be classified in the index as 0. There are two types: (1) social housing and informal neighbourhoods, (2) high socio-economic housing sectors along the coast and in isolated housing estates along main roads in the east.

The spatial analysis of the diversity index in Figure 4 shows the location of juxtaposition and complementary patterns between the two food systems, regardless of the number of points of sale.

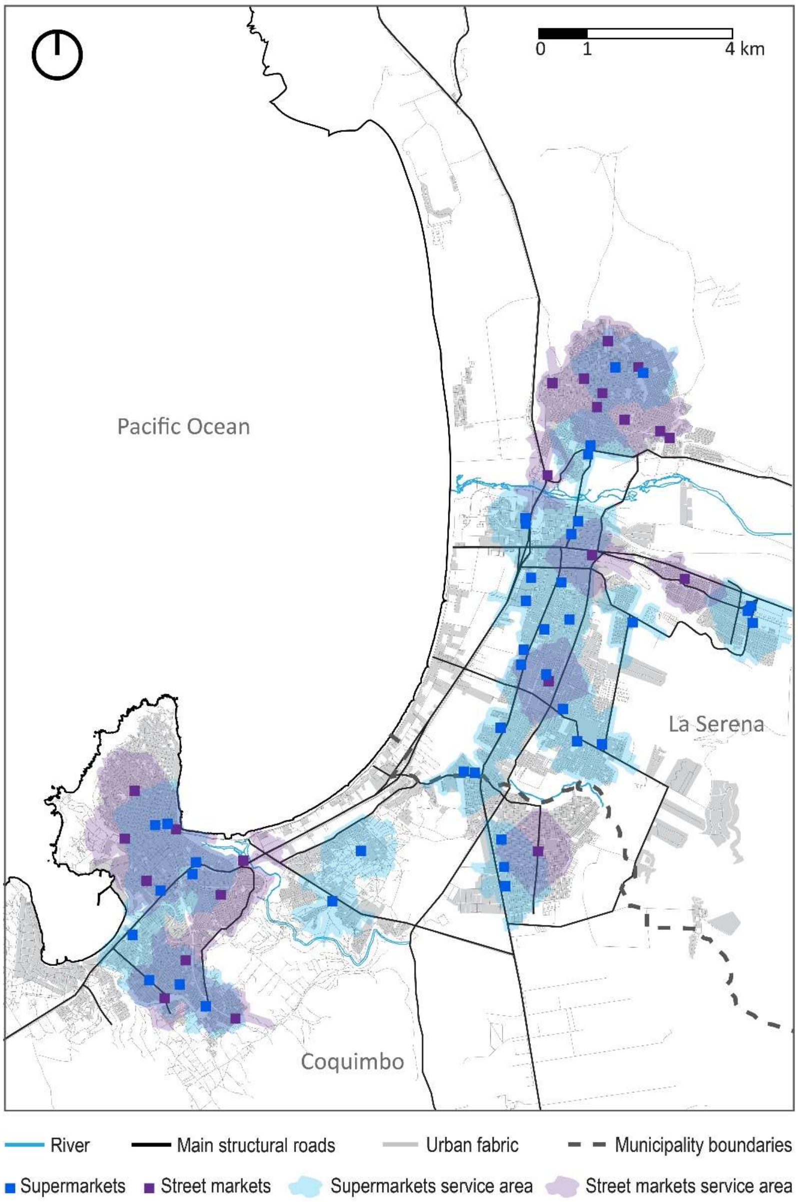

Figure 3. Services area of supermarkets and street markets in La Serena–Coquimbo conurbation.

The juxtaposition pattern occurs when two service areas of two different food systems overlap. It is related to value 1 and there are six spots along the conurbation: one on the north end—Las Compañías; two on the south end, Coquimbo Downtown and Sindempart Sector; and three in the central area, La Serena Downtown, La Pampa, and Tierras Blancas. Around these areas, there are others with complementary patterns that have coverage of only one of the systems. The value of the index in this case is 0.5. These areas serve as connections between the previous spots, just in the central area, and at the south end. Between La Serena and Coquimbo, there is an area with only supermarket coverage, which is an exception in the system.

Regarding the quantification of spatial data, Table 2 shows that 33.9% of the urban surface has no coverage, directly affecting 20% of the population. On the other hand, 40.7% of the surface has coverage from just one food system, with supermarket coverage 10% higher than street markets.

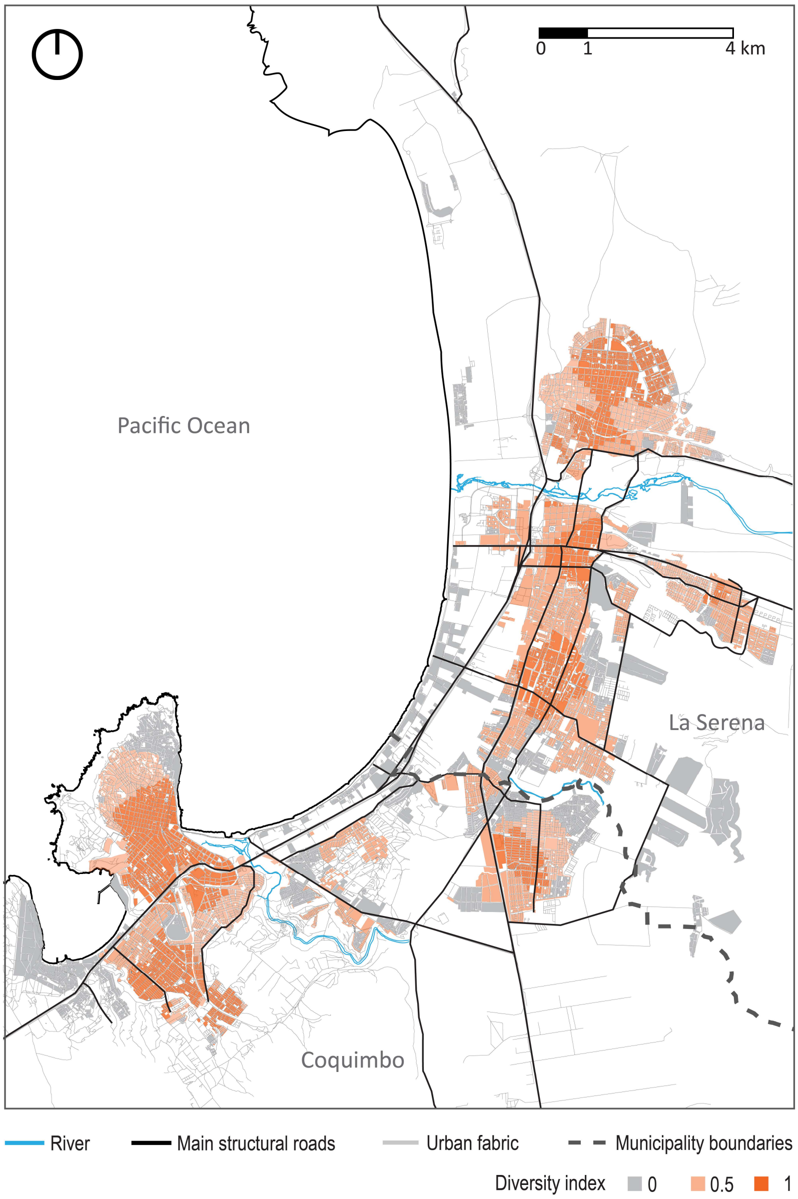

Figure 4. Spatial dimension of the diversity index in La Serena–Coquimbo conurbation.

Table 2. Quantification of the diversity index in La Serena–Coquimbo Conurbation.

Index Score	Description	Urban Surface		Population		Density (Inhabit/ha)	
0.0	Without service area	33.9%		20%		136.6	
0.5	Served only by street market Served only by supermarkets	15.6% 26.0%	40.7%	22.4% 22.2%	44.6%	160.8 104.9	131.9
1.0	Served by both systems	25.4%		35.4%		158.4	

For the population, this value directly impacts almost 46% of the population; conversely, the spatial distribution is equivalent for both systems. This is due to the difference in population density, which is denser in areas with street market coverage.

Finally, the area with coverage from both food systems is the lowest at 25%, directly impacting just over 35% of the population. This means that areas with a diversity index of 1 are the most densely populated in the conurbation. Areas with a diversity index of 1 have a high density. This means that those areas served by street markets are the most densely populated in the conurbation.

In general terms, the diversity index per inhabitant is 0.57, which is considered medium–high and represents the operationalization of the FAO's first pillar: availability.

3.2. Redundancy Index

The spatial analysis of the redundancy index in Figure 5 maps the number of points of sale accessible to each block. In this index, maximum redundancy is found in only three spots, located at both ends of the conurbation. In the south, the historical centre of Coquimbo, along with some nearby neighbourhoods, has a high rate of redundancy, surrounded by a medium level of redundancy. In the north, the social neighbourhood holds an important spot with a high score for redundancy. As at the southern end, its surrounding area is covered by an area of medium resilience. Moreover, the historical centre of La Serena and the central area of the conurbation only possess medium resilience scores. This contrasts with the high values for the diversity index of this central area of the conurbation.

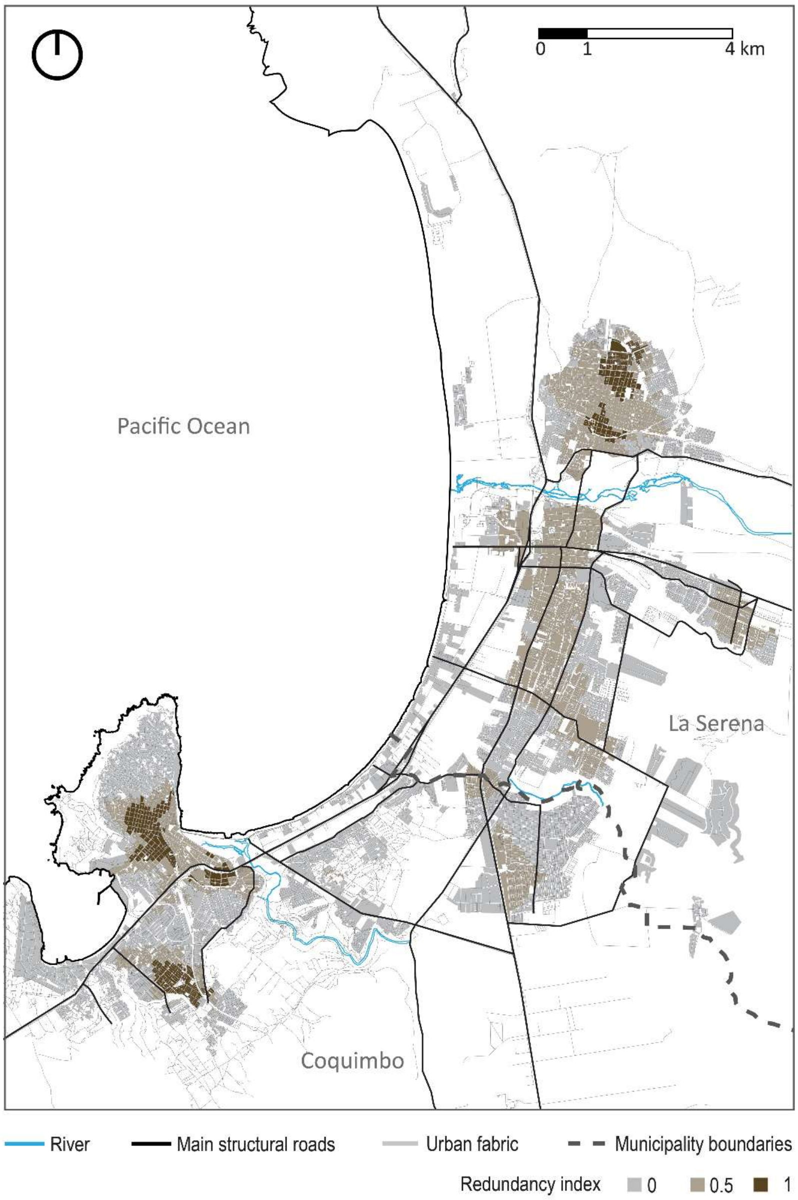

Figure 5. Spatial dimension of the redundancy index in La Serena–Coquimbo conurbation.

Regarding the quantification of spatial data, Table 3 shows that the urban surface with the lowest score is 63% directly affecting nearly 60% of the population, where two-thirds are non-redundant. On the other hand, the highest redundancy only covers 5.6% of the urban surface, affecting only 8.2% of the population. However, this small group has the highest density in La Serena–Coquimbo.

Table 3. Quantification of the redundancy index in La Serena–Coquimbo Conurbation.

Index Score	Description	Urban Surface		Population		Density (Inhabit/ha)	
0	Without access Without redundancy	33.9% 29.1%	63.0%	20.0% 37.8%	57.8%	136.6 154.5	148.8
0.5	Redundancy in only one food system	31.4%		34.0%		126.5	
1.0	Redundancy in both systems	5.6%		8.2%		163.4	

In general terms, the redundancy index per inhabitant is 0.25, which is considered low and represents the operationalization of the FAO's second pillar: accessibility.

3.3. Short-Term Stability Index

The spatial analysis of the short-term stability index in Figure 6 shows that a large area of the urban blocks (52.1%) has access to fresh food at least 6 days per week. There are lower ratios with access between one and three days per week in five spots of the conurbation. There are sectors with high density (Table 4) and with a high presence of social housing. One is located in the extreme north—Tierras Blancas; one east of the downtown of La Serena—La Antena; one in the center of the Conurbation—Tierras Blancas; and two near the downtown sector of Coquimbo—San Juan and Parte Alta.

Table 4. Quantification of the short-term stability index in La Serena-Coquimbo Conurbation.

Index Score	Description	Urban Surface	Population	Density (Inhabit/ha)
0	Without access	33.9%	20.0%	136.6
0.01–0.25	One day of the week	6.2%	10.4%	172.0
0.26–0.50	Two or three days of the week	6.5%	9.4%	154.6
0.51–0.75	Four or five days of the week	1.3%	1.4%	129.0
0.76–1.00	Six or seven days of the week	52.1%	58.8%	137.6

As for the quantification of spatial data, Table 4 shows that 20% of the population lacks access. On the other hand, almost 60% of the people have access every day. This is related to the large number and distribution of supermarkets that open 6–7 days a week. However, nearly 20% depend on a diverse number of street markets within walking distance. A significant percentage, 10.4%, have access just one day a week and live in the denser areas.

In general terms, the short-term index per inhabitant is 0.63, which is considered medium-high and represents the operationalization of the FAO's fourth pillar: stability.

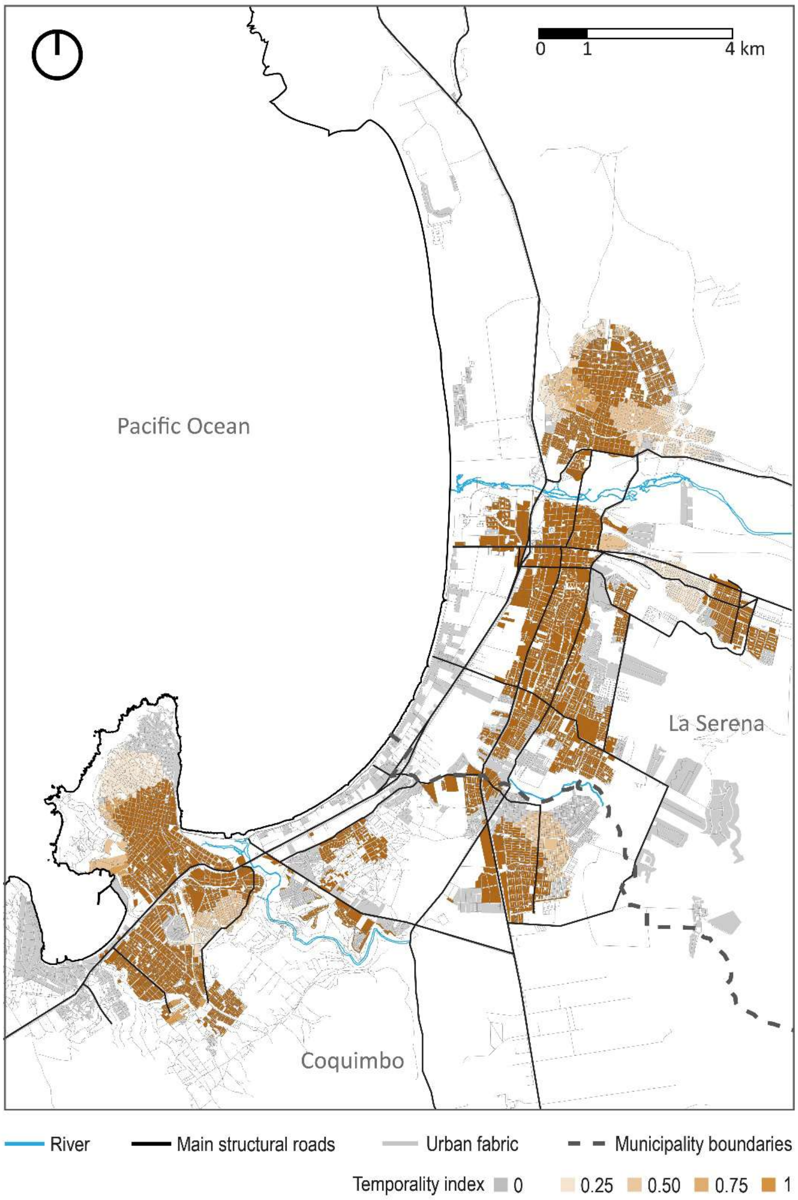

Figure 6. Spatial dimension of the short-term stability index in La Serena-Coquimbo conurbation.

3.4. Urban Food Resilience Index

The spatial analysis of the Urban Food Resilience Index (UFRI) in Figure 7 shows the distribution of different values throughout the La Serena–Coquimbo Conurbation. The higher scores of the index (1.0) coincide with the six high-value hotspots in the diversity index. They are equally distributed throughout the conurbation: one at the north end—Las Compañías; two at the south end—Downtown Coquimbo; and three in the central area—Downtown La Serena, La Pampa, and Tierras Blancas. A new hotspot also emerges in an extension of the urbanisation of the eastern zone—La Florida. The medium score is mainly found for narrow buffer areas around the higher rates, apart from the connecting area between the hotspot located in the historical centre of La Serena and that immediately to the south. The low-rate areas, in general, enlarge the medium score areas as an oil stain. They seek to link hotspots, such as the two located in the southern end or the two in the central area. Finally, areas with a very low UFRI score are quite concentrated in a few cold spots. They are mainly found on the urban edge of both ends of the conurbation: the northern urbanization of the southern end, Parte Alta; and around the entire urbanization of the northern endTierras Blancas. This also appears at the connection between the hotspot located in historical downtown La Serena and on the eastern side in La Antena.

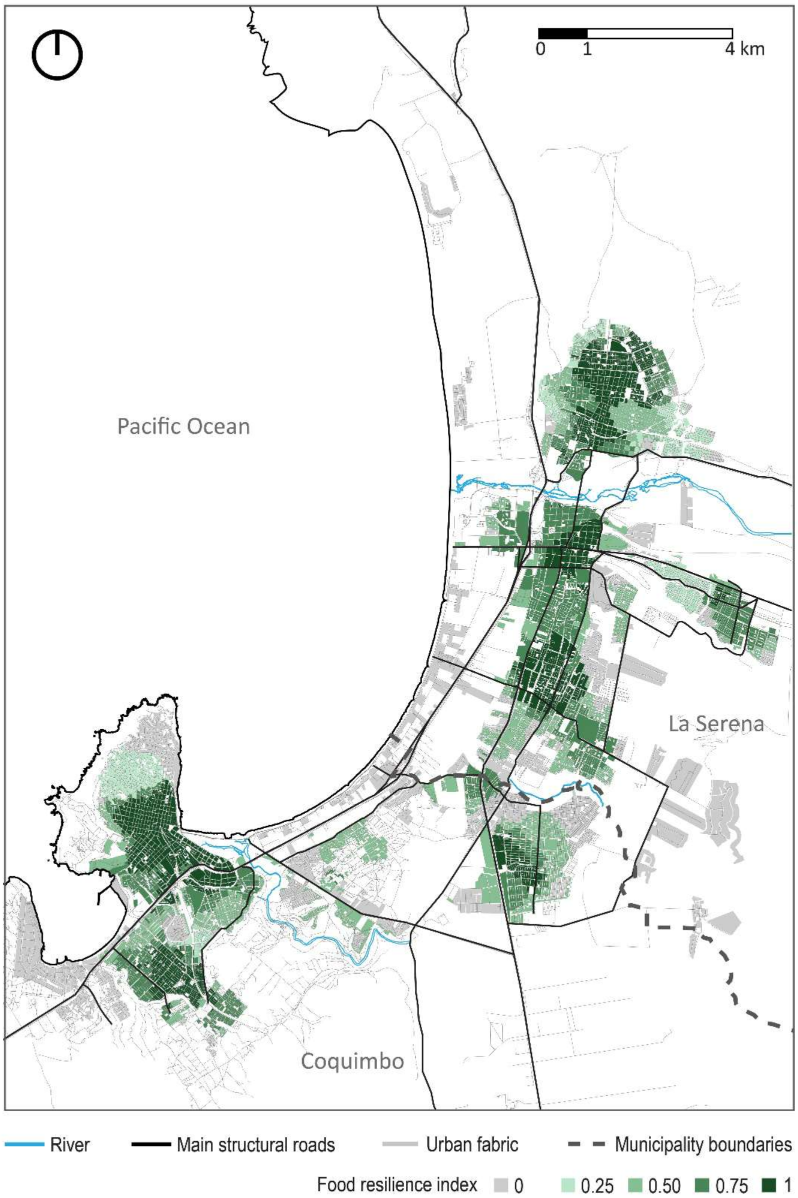

Figure 7. Spatial dimension of the Urban Food Resilience Index (UFRI) for La Serena–Coquimbo conurbation.

In terms of quantifying the spatial data, Table 5 shows the population that lives under the five different gradients of the UFRI. A fraction of 25% of the population has a high index, with a similar medium percentage (24.4%), while half the population falls into the levels of low, very low, or none. The highest density is found in the very low UFRI, with 10.4% of the population, followed by the sectors with the highest UFRI. This allows for the interpretation of two opposing trends. The first is that sectors with high UFRI are associated with consolidated areas of the urban system, which, along with higher population density, tend to develop commercial sub-centralities. The second is that peripheral growth areas with a high concentration of social housing tend to have very low UFRI, due to the almost non-existent supermarket coverage and the dependence on only one day per week of street markets. In general terms, the UFRI index per inhabitant is 0.49, which is considered medium and represents the operationalization of the built composite index.

Table 5. Quantification of the UFRI in La Serena–Coquimbo Conurbation.

Index Score	Description	Urban Surface	Population	Density (Inhabit/ha)
0	None	33.9%	20.0%	136.3
0.01–0.25	Very low	6.2%	10.4%	172.0
0.26–0.50	Low	19.4%	20.2%	130.4
0.51–0.75	Medium	21.0%	24.4%	137.9
0.76–1.00	High	19.5%	25.0%	149.0

4. Discussion

The proposed UFRI is conceived as a composite index built from the spatial dimension and distribution of the urban food infrastructure. This allows contrasting spatial analysis with quantitative data such as population, urban surface, and density to enrich the analysis and identify priority areas for intervention. In the La Serena–Coquimbo conurbation, a very low UFRI index is associated with high-density and social housing neighbourhoods. These results coincide with international accessibility studies that correlate low socioeconomic rates with low accessibility [48]. The Chilean census has multiple limitations, and it cannot enrich research with high-needs data. However, the potential application in other contexts could explore interrelationships between low UFRI and specific groups, including older adults, children, people lacking a vehicle, single parents, or those who are unemployed, such as via accessibility research [49,52,53].

UFRI complements previous indexes that qualitatively and quantitatively evaluate urban food resilience, REF. In contrast to these, this indicator specifically concentrates on analysing the spatial distribution of the urban food infrastructure at the urban level. This enables a deeper assessment of its capacity to offer the population access to healthy food through diverse, redundant, and stable points of sale over time, providing food security under system perturbations. It aims to identify areas of low resilience thoroughly and to identify the factors driving it. The results show how the spatial visualization of data in the city and the quantification of its impact on the population and urban space enhances comprehension [54] and may provide a foundation for public policy-making and urban planning. On the other hand, incorporating urban food resilience as a factor in urban planning and management instruments helps to ensure food security, guide the urban food system toward more sustainable practices [16], and anticipate and adapt to risks [55] and climate change [56]

The methodology is based on previous research that identifies that supermarkets and street markets are the food systems providing food security to Chilean intermediate cities [22–24]. However, there are other food systems that provide fresh food to the city [57], albeit with a lower contribution, and potentially could contribute to the availability and access pillars. Accessibility studies have already explored how alternative food systems, such as grocers, farmers' markets, and community gardens [52,58], contribute to urban food security and resilience. However, to evaluate and plan urban food resilience, it is important to consider optimal redundancy [33]. Redundancy, understood as an overlap of food systems' coverage, acts as a buffer against perturbations and shocks, both for managers and for actors within the system. Nevertheless, introducing a larger number of food systems, increasing the standard, can reduce efficiency because it would require an investment in infrastructure that may not be necessary under regular scenarios [59]. Hence, the standard of redundancy should be adapted to the contextual reality of the urban food system. In the case of Chile, there have been two main food systems.

In relation to the fourth pillar of stability, this analysis has focused on the short-term continuity of the system. Engaging in long-term foresight in response to disturbances and shocks entails dealing with highly uncertain and unpredictable scenarios. Research dealing with perturbances usually address retrospective analysis of the system, such as a study on how urban planning has impacted the urban food system from farmland to access [5], how the urban availability of urban food infrastructure has evolved in a city or district to understand the dynamics and changeovers of foodscape environments for healthy living [39], or how a particular socio-natural or anthropical event has affected the food system [60]. However, a proper long-term index with a resilient approach should address a retrospective analysis of how all the shocks that had befallen a period had transformed the availability, accessibility, and stability of the system and to quantify this. In Chile, events such as the social uprising, the COVID-19 pandemic, earthquakes, or wildfires have altered the food security map of cities over the last few decades.

Regarding reliability, the UFRI relies on publicly available data, whose collection and processing involve minimal researcher interpretation. While this reduces the likelihood of divergent results, it also tends to make the indicator less flexible. In terms of validity, this study relies on the two food systems previously validated in the literature as the primary contributors to food security in Chilean cities [23,24]. As noted earlier, applying the index in a different context would require a reassessment of the food systems' availability. Concerning sensibility, the indicator can be readily recalculated with the addition, removal, or relocation of food access points, allowing for the ongoing monitoring of urban food resilience over time. Finally, in relation to the interpretability of UFRI results, resilience variations are associated with the spatial distribution of food systems and the temporal intermittency of street markets. As a composite indicator, it facilitates disaggregated analysis by component, enabling a clearer understanding of the final score assigned to a specific block within a neighbourhood.

As a final point, it is worth highlighting that the UFRI is conceived under a social–ecological mode of thinking where resilience is not synonymous with resistance to existing structures, i.e., engineering resilience [61,62], but is a concept closer to flexibility, i.e., ecological resilience [2,7,21,34]. Therefore, in contrast to the more static urban food systems of the Global North, which are based on supermarkets and groceries, Southern systems are more informal, alternative, and flexible [63]. The Chilean urban food systems are based on street markets and have a dual connotation regarding flexibility: adaptable and transformative [62]. Street markets can be adaptive because they can be easily adjusted in location or operation to respond to perturbances in areas with low UFRI rates. Because of this, the food system has the potential to be transformative in governance, public policy, and urban planning spheres, improving the adaptive results and reshaping the original system when it is unsustainable or unequal.

5. Conclusions

This article develops an innovative index to study food systems and evaluate urban food resilience. UFRI is designed as a composite index that combines the three pillars of food security and operationalizes them from an urban food resilience approach. It comprises the spatial dimension and distribution of the urban food infrastructure, which allows generation of spatial and quantitative data for informed urban planning decision-making. It is also conceived from a Latin American context, where access to data is usually challenging, so the operationalization of the pillars is made as straightforward as possible.

This paper uses a Chilean case study, where the combination of the two main food systems allows analysis of how the spatial and temporal juxtaposition and complementary patterns, redundancy, and short-term stability create urban food resilience in intermediate

Chilean cities. Due to the similarity of this dual food system in many Latin American cities, the methodology could be replicable. However, the potential application of this methodology to other contexts requires adaptation to the provision of food security and adjustment of the redundancy standards.

Finally, this methodology has the limitation that it does not address the economic dimension. It should be applied to both the offer side, analysing the range of supermarkets and other food systems, and to the demand side, analysing the socioeconomic level of neighbourhoods with accessibility to each food system. Future research including this economic dimension would allow diagnosis of food vulnerability and identification of neighbourhoods to prioritize multidimensional public policy interventions, including urban planning.

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