Journal of Population Ageing
https://doi.org/10.1007/s12062-026-09531-1

RESEARCH

Discovering Blue Zones in Colombia: Biodemographic Analysis Based on National Data of Areas With the Highest Rate of Centenarians, Semi-Supercentenarians and Supercentenarians

Ivan David Lozada-Martinez[1,2] · Karoll Arcos Navarro[3] · German Gallego[3] · Juan-Manuel Anaya[1,2] · J. Sebastián Ruiz-Santacruz[3]

Received: 10 May 2025 / Accepted: 2 February 2026

Abstract

The biodemographic evidence that integrates environmental and demographic variables to demonstrate the association between blue zones and extreme longevity, remains heterogeneous and limited. The aim of this study was to analyze the environmental and human characteristics of the geographic areas with the highest rates of centenarians in Colombia. This was an ecological study based on national census data. Rates of centenarians, semi-supercentenarians and supercentenarians were calculated. Sociodemographic and geoscientific variables related to the territorial areas with the highest rates of centenarians in general were analyzed. In 2018, Colombia had a total of 12,226 centenarians (5294 men vs. 6932 women), corresponding to 0.02% ($n = 12{,}226 / 44{,}164{,}417$) of the total population. The overall centenarian rate in Colombia was 2.80 per 10,000 inhabitants, with a higher rate observed among women compared to men (3.10 vs. 2.50). The national rate for centenarians (100–104 years old), semi-supercentenarians (105–109 years old) and supercentenarians (≥110 years old) were 1.59, 0.60, and 0.56 per 10,000 inhabitants, respectively. Twenty municipalities were identified with notably higher centenarian rates compared to the national average, ranging from 9.95 to 72.83, with higher frequency of male centenarians, as well as centenarians located in urban areas. A consistent pattern of proximity to agricultural areas, herbaceous vegetation, forests, and, in some cases, bodies of water was observed across all municipalities. In Colombia, there are territorial zones with centenarian rates notably higher than the national average, which may be considered potential "blue zones" for the study of healthy and extreme longevity.

Keywords Blue zones · Centenarians · Longevity · Demography · Health transition · Colombia

Extended author information available on the last page of the article

Published online: 07 March 2026

Introduction

Extreme longevity is an increasingly topic, given the accelerated aging of the global population and the notable rise in the proportion of octogenarians, nonagenarians, and centenarians (United Nations, 2023). According to the World Social Report 2023, the global population aged 65 years and older is growing faster than all younger age groups, and the number of centenarians worldwide is projected to exceed 3.7 million by 2050 (United Nations, 2023).

In high-income countries, such as Japan, centenarian rates have steadily increased during the last decades, reaching up to 159 per 10,000 inhabitants (The Asahi Shimbum, 2024). By contrast, in Latin America the phenomenon has been less documented, although countries such as Costa Rica and Cuba have reported emerging clusters of longevity that resemble the internationally recognized "blue zones" (Poulain & Herm, 2025).

In Colombia, available evidence is scarce; previous demographic reports estimated fewer than 10,000 centenarians in 2005, whereas the 2018 census registered over 12,000, suggesting a modest but progressive increase (Departamento Administrativo Nacional de Estadísticas, 2018). In epidemiological terms, this means that the national centenarian rate in Colombia rose from approximately 2.00 per 10,000 inhabitants in 2005 to 2.80 per 10,000 inhabitants in 2018, a 40% relative increase over thirteen years (Departamento Administrativo Nacional de Estadísticas, 2018). Although still lower than the prevalence observed in countries such as Japan, this upward trend indicates that extreme longevity is becoming a growing phenomenon in Colombia and deserves systematic investigation.

Aging models support that aging is a multilevel, multidimensional, and multidirectional process, in which various factors contribute significantly, though differently, to healthy aging (Machado et al., 2018). These factors are influenced by both interindividual and population variability (Nielsen et al., 2024). Social determinants of health and environmental factors play a critical role in shaping a specific aging phenotype (Nielsen et al., 2024).

Based on the above, it is hypothesized that the more favorable the interaction between humans and the environment in which they live their life cycle, the greater the probability of achieving healthy aging and reaching extreme longevity (Argentieri et al., 2025). This forms the basis of the well-known "blue zones," which are said to be characterized by unique traits that allow certain populations to enjoy prolonged healthy lifespan and extreme longevity (Lozada-Martinez & Anaya, 2024). This has been evidenced by higher rates of nonagenarians and centenarians compared to national averages (Lozada-Martinez & Anaya, 2024). Identifying potential blue zones has practical and scientific relevance. Beyond describing exceptional survival, these spatial patterns help prioritize the validation of extreme ages, guide follow-up studies linking environmental and social contexts with longevity, and inform place-based health and aging policies tailored to local conditions (Argentieri et al., 2025). Understanding where and under what circumstances individuals reach advanced ages can support demographic monitoring systems and the design of interventions that foster healthy longevity at the community level (Lozada-Martinez & Anaya, 2024).

However, the scientific evidence that integrates biological and demographic variables to demonstrate this association remains heterogeneous, fragmented, and limited (Addie et al., 2024); (Rattan, 2024). As a result, it is difficult to robustly identify the strongest protective factors that contribute to healthy and extreme longevity in specific populations.

Biodemography is an emerging branch of classical demography that seeks to explore the relationship between biological and demographic theories to understand life course processes in populations (Vaupel, 2010). Aging and longevity are two key challenges within biodemography, requiring the search for synergies, complementarities, and mutualism between data and plausible biological responses (Vaupel, 2010). Centenarians, as models of the most successful biological aging in humans, are of great interest to biodemography for studying longevity (Marcos-Pérez et al., 2021). In Colombia, the relationship between demographic and environmental determinants and their potential association with human development and the aging process of centenarians, as an example of an extreme longevity phenotype, has been poorly studied (Lozada-Martinez et al., 2024a); (Pérez-Molina et al., 2025).

The aim of this study was to compare the demographic distribution of centenarians and analyze the environmental and human characteristics of the geographic areas with the highest rates of centenarians in Colombia, in order to identify whether certain territories may be considered potential "blue zones" for extreme longevity research.

In this context, our spatial-ecological approach represents a practical extension of biodemographic inquiry, applying population-level data to reveal geographic patterns of extreme longevity. These territorial patterns generate testable hypotheses about how social structures and environmental exposures may shape biological aging processes, guiding future individual-level and mechanistic studies of longevity.

Methods

Study Design

Ecological exploratory study with a spatial focus, based on aggregated data from the 2018 Colombian National Population and Housing Census, which provides a nationwide demographic snapshot for that year.

Setting and Participants

The data were obtained from the 2018 National Population and Housing Census of Colombia (the most recent census conducted) (Departamento Administrativo Nacional de Estadísticas, 2018). This census is a publicly accessible, nationwide survey carried out by the National Administrative Department of Statistics (DANE) of Colombia (Departamento Administrativo Nacional de Estadísticas, 2018). Its purpose is to characterize the inhabitants, their distribution across the territory, and the living conditions of the population. As a government-led national survey, it adheres to strict technical and scientific standards. The population is categorized by geo-

graphic region, age group, sex, ethnicity, and other demographic variables of interest for population studies.

For this analysis, the entire Colombian centenarian population was considered, which was recorded in detail through specific age groups: (1) 100 to 104 years; (2) 105 to 109 years; (3) 110 to 114 years; (4) 115 to 119 years; and 5)≥120 years. In 2018, Colombia had a total population of 44,164,417 inhabitants, of which 22,593,924 (51.15%) were women.

These age categories were not defined by the authors but correspond exactly to those used by the DANE in the official 2018 National Population and Housing Census (Departamento Administrativo Nacional de Estadísticas, 2018). This classification was maintained to ensure consistency with national demographic standards and to preserve data fidelity. It is important to note that, while the census relies on in-person enumeration, potential age misreporting at extreme ages cannot be entirely excluded and should be considered when interpreting these results.

Variables

Basic sociodemographic data were collected, including sex, age, and the department and municipality where the centenarians reside. Additionally, centenarians were categorized into the following age subgroups: (1) Centenarians (100–104 years); (2) Semi-supercentenarians (105–109 years); and (3) Supercentenarians (≥110 years). Geoscientific data were obtained from a public geoportal provided by the same institution (DANE) to explore hydrographic, environmental, geographical, and economic variables related to the territorial area (Departamento Administrativo Nacional de Estadísticas, 2025d). The territorial zones were classified according to the definitions used by DANE (Departamento Administrativo Nacional de Estadísticas, 2025b). The urban area was defined as a geographic area delineated by an urban perimeter, with boundaries established by municipal council agreements (Departamento Administrativo Nacional de Estadísticas, 2025b). It corresponds to the location of a municipality's administrative headquarters. The populated area was defined as a concentration of at least twenty adjacent or closely located homes, situated in the rural area of a municipality (Departamento Administrativo Nacional de Estadísticas, 2025a). This concentration exhibits urban characteristics, such as the delineation of vehicular and pedestrian routes. The dispersed rural area was defined as a sparsely distributed arrangement of homes and agricultural operations (Departamento Administrativo Nacional de Estadísticas, 2025c). It lacks street grids or nomenclature for roads, highways, and avenues, and generally does not have public services or other urban amenities.

For the study of spatial autocorrelation, the available layers from the National Geostatistical Framework (MGN) were used (Departamento Administrativo Nacional de Estadísticas, 2024). The geographical localization of centenarians in each municipality and department was carried out using data from the National Population and Housing Census – 2018 (Departamento Administrativo Nacional de Estadísticas, 2018). Additionally, to characterize land cover in the study area, the Corine Land Cover classification at level 2 was employed, conducted by IDEAM (Colombian Institute of Hydrology, Meteorology, and Environmental Studies) (Instituto de Hidrología, Meteorología y Estudios Ambientales, 2024) and based on Landsat 8

imagery from 2018. The layer of double drains was also included to observe how this component interacted, considering that the layer of single drains, due to its high volume and the scale being used, made it difficult to identify patterns. This combination of data sources provided valuable information regarding the relationships between the geographic variables utilized in the spatial analysis (Crimmins & Vasunilashorn, 2016); (Gavrilov & Gavrilova, 2015).

Environmental characteristics were defined according to the official land-cover classification used by the DANE (Departamento Administrativo Nacional de Estadísticas, 2024) and IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales, 2024). The following categories were considered: (a) bodies of water: areas occupied by permanent or semi-permanent surface water such as rivers, lakes, reservoirs, and wetlands; (b) agricultural zones: lands primarily dedicated to crop cultivation, agroforestry, or mixed agricultural activity, including seasonal and permanent crops; (c) grasslands: open areas covered predominantly by natural or cultivated grasses used for grazing or as natural vegetation cover; (d) herbaceous vegetation: territories dominated by non-woody plants, shrubs, or low vegetation that grow naturally outside of agricultural or forested areas (Departamento Administrativo Nacional de Estadísticas, 2024; Instituto de Hidrología, Meteorología y Estudios Ambientales, 2024). These environmental variables were extracted from the official spatial datasets and aggregated at the municipal level for consistency with the demographic data.

For the purposes of this study, the concept of "blue zones" was operationalized following a quantitative criterion. Specifically, any territorial unit (department or municipality) with an overall centenarian rate higher than the national average of 2.80 per 10,000 inhabitants (based on the 2018 census) was considered a potential "blue zone." This threshold allowed us to identify geographic areas with unusually high concentrations of centenarians in comparison to the national baseline.

Data Measurement

To determine the total frequency of the centenarian age subgroups (centenarians, semi-supercentenarians, and supercentenarians), the frequencies of the corresponding individual age groups (100–104 years, 105–109 years, and ≥110 years, respectively) were summed. Subsequently, the centenarian rates, both overall and by subgroup, were calculated and expressed per 10,000 inhabitants. The female-to-male (F/M) ratio among centenarians was calculated, as well as their distribution across territorial zones.

Statistical Methods

The centenarian rates were calculated based on available census data corresponding to the Colombian population in 2018. The following formula was used: ((centenarian frequency/total population in the territorial zone)*10,000). Qualitative variables were summarized using frequency and percentages.

For departmental and municipal analyses, denominators corresponded to the total population of each territorial unit, as reported in the 2018 census. For the urban, populated, and dispersed rural categories, denominators corresponded to the total popu-

lation residing in each area type within the respective territorial unit. This ensured that all reported centenarian rates were standardized per 10,000 inhabitants according to the appropriate population base.

Additionally, 95% confidence intervals (95% CI) were calculated for each estimate using the exact Poisson method. This procedure allows for the assessment of the precision of the rates and helps determine whether the observed differences between territories are statistically significant or may be attributed to chance, which is particularly relevant in municipalities with small numbers of centenarians.

In order to identify the existence of global spatial autocorrelation, Moran's I and Geary's C were calculated. For this, a weight matrix based on municipal neighborhoods was constructed and row-standardized. To assess local spatial autocorrelation, the Local Moran's statistic was calculated using permutations under the null hypothesis of randomness. Municipalities with a high centenarian rate surrounded by other municipalities with a high centenarian rate were identified, and p-values (hotspots) were computed.

The use of these spatial analysis techniques was justified by the study hypothesis, which sought to identify whether longevity in Colombia follows a random or clustered geographical distribution. First, Moran's I was applied to test the null hypothesis of spatial randomness and to detect whether global clustering of centenarians existed. Confirming a non-random distribution provided the rationale for subsequent spatial exploration. Second, rasterization and spatial relative risk estimation allowed us to move from global clustering to local identification of 'hotspots', i.e., municipalities with a significantly higher prevalence of centenarians. This multi-step approach ensured that the sociodemographic and environmental factors analyzed in the regression models were tested against spatially meaningful outcomes.

Additionally, point patterns were analyzed by calculating the Spatial Relative Risk using a fixed-bandwidth isotropic kernel with uniform edge correction. Contour lines were generated based on the p-values of the risk estimation, and raster images were created, considering only pixels where the p-value was less than 0.05.

The statistical analysis was conducted using the R software (Version 4.3.1) (https://www.r-project.org/).

Ethical Statement

This study was performed in compliance with Act 008430/1993 of the Ministry of Health of the Republic of Colombia, which classified it as minimal-risk research. The institutional review board of Universidad de la Costa approved the study design.

Results

National and Department Demographic Characteristics of Centenarians in Colombia

In 2018, Colombia had a total of 12,226 centenarians (5,294 men vs. 6,932 women), corresponding to 0.02% (n = 12,226/44,164,417) of the total population. Of these,

79.16% ($n=9,679$) lived in urban areas, while only 14.03% ($n=1,716$) lived in rural dispersed areas. The overall centenarian rate in Colombia was 2.80 per 10,000 inhabitants, with a higher rate observed among women compared to men (3.10 vs. 2.50). The highest overall rate was found in urban areas (2.83 per 10,000 inhabitants), followed by intermediate geographic zones (2.64 per 10,000 inhabitants) and rural dispersed areas (2.48 per 10,000 inhabitants). In these zones, the rate was higher in women compared to men.

When stratified by age subgroups, centenarians (100–104 years), semi-supercentenarians (105–109 years), and supercentenarians (≥110 years), it was identified that the national rate for the first group was 1.59 per 10,000 inhabitants (1.26 for men vs. 1.91 for women). The national rate for semi-supercentenarians and supercentenarians was 0.60 per 10,000 inhabitants (0.60 for both sexes) and 0.56 per 10,000 inhabitants (0.58 for men vs. 0.55 for women), respectively (Table 1).

Five departments were identified where the overall centenarian rate was notably higher compared to the national rate: (1) Bolívar (4.70 per 10,000 inhabitants); (2) Guaviare (4.50 per 10,000 inhabitants); (3) Chocó (4.00 per 10,000 inhabitants); (4) Atlántico (3.50 per 10,000 inhabitants); and (5) Risaralda (3.50 per 10,000 inhabitants). Interestingly, variations were observed between these departments when analyzing specific centenarian subgroups. Bolívar (2.38), Chocó (2.27), and Valle del Cauca (1.98) had the highest rates of centenarians aged 100–104 years, while Guaviare (3.42), Risaralda (1.22), and Bolívar (0.99) exhibited the highest rates of semi-supercentenarians. For supercentenarians, Vaupés (1.59), Bolívar (1.28), Chocó (0.78), and Vichada (0.78) recorded the highest rates (Table 1).

When incorporating the 95% CI, it was observed that Bolívar (4.36–4.98), Risaralda (3.09–3.90), and Valle del Cauca (2.96–3.32) presented more precise estimates, whereas Guaviare (3.11–6.34) showed a wide interval, reflecting greater uncertainty due to its smaller population. These findings suggest that, although absolute rates help identify territories with exceptional longevity, the width of the 95% CI should be taken into account when assessing the stability of the estimates.

The overall female/male ratio among centenarians was 1.30, with the highest ratio observed in urban areas (1.39) and the lowest in dispersed rural areas (0.94). For centenarians aged 100–104 years, the female/male ratio was 1.59, while for semi-supercentenarians and supercentenarians, the ratios were 1.03 and 0.98, respectively. In all three groups, the highest ratios were found in urban areas (1.73, 1.08, and 1.01, respectively), while the lowest were in dispersed rural areas (1.06, 0.81, and 0.81, respectively) (Table 2).

Demographic Characteristics of Municipalities With Higher Rate of Centenarians in Colombia

Twenty municipalities were identified with notably higher centenarian rates compared to the national average, ranging from 9.95 to 72.83 centenarians per 10,000 inhabitants. The department with the highest number of municipalities in this group is Boyacá, which accounts for 7 municipalities. Among the subgroups of centenarians, the most frequently observed in these areas are centenarians (9 municipalities), followed by semi-supercentenarians (7 municipalities) (Table 3). Differences in rates

Table 1 Aging index and demographic distribution of centenarians and subgroups in Colombia

Department	Aging index to 2021	Rate of overall centenarians (per 10,000 inhabitants)			Rate of centenarians (100–104 years old) (per 10,000 inhabitants)			Rate of semi-supercentenarians (105–109 years old) (per 10,000 inhabitants)			Rate of supercentenarians (≥ 110 years old) (per 10,000 inhabitants)		
		Total	Men	Women	Total	Men	Women	Total	Men	Women	Total	Men	Women
National	60	2.80	2.50	3.10	1.59	1.26	1.91	0.60	0.60	0.60	0.56	0.58	0.55
Antioquia	72	3.10	2.80	3.40	1.82	1.48	2.13	0.71	0.76	0.66	0.55	0.54	0.56
Atlántico	49.70	**3.50**	2.80	4.10	**1.93**	1.42	2.43	0.78	0.74	0.81	**0.76**	0.61	0.90
Bogotá, D.C.	72	2.70	2.50	2.90	1.39	1.05	1.70	0.60	0.60	0.59	0.69	0.81	0.58
Bolívar	45.50	**4.70**	3.90	5.40	**2.38**	1.69	3.06	**0.99**	1.02	0.96	**1.28**	1.20	1.36
Boyacá	76.30	2.40	2.20	2.70	1.32	1.07	1.57	0.65	0.66	0.64	0.46	0.48	0.45
Caldas	108.50	2.20	2.10	2.20	1.47	1.22	1.70	0.37	0.46	0.29	0.30	0.35	0.25
Caquetá	35.80	1.90	1.80	2.00	0.91	0.82	1.01	0.22	0.10	0.33	0.75	0.82	0.67
Cauca	60.70	2.50	1.90	3.20	1.65	1.13	2.16	0.49	0.37	0.60	0.36	0.35	0.38
Cesar	29	1.80	1.60	2.00	1.14	0.97	1.31	0.30	0.31	0.28	0.35	0.29	0.41
Córdoba	48.70	3.00	3.00	3.10	1.74	1.54	1.94	0.86	0.92	0.80	0.43	0.49	0.37
Cundinamarca	64.80	2.30	1.90	2.70	1.33	1.06	1.60	0.44	0.37	0.50	0.50	0.43	0.58
Chocó	33.50	**4.00**	3.30	4.70	**2.27**	1.85	2.67	**0.91**	0.75	1.08	**0.78**	0.66	0.90
Huila	50.80	1.90	2.10	1.80	1.23	1.36	1.10	0.30	0.29	0.31	0.38	0.41	0.35
La Guajira	15.90	2.70	2.30	3.10	1.63	1.21	2.04	0.50	0.47	0.54	0.54	0.61	0.47
Magdalena	40.10	3.00	2.80	3.20	1.60	1.31	1.90	0.89	0.93	0.85	0.46	0.50	0.42
Meta	49.10	1.90	1.90	2.00	0.99	0.92	1.05	0.51	0.51	0.50	0.42	0.45	0.39
Nariño	73.40	2.30	1.80	2.80	1.35	0.96	1.73	0.47	0.41	0.54	0.49	0.45	0.52
Norte de Santander	47.90	2.10	2.00	2.30	1.21	1.08	1.34	0.46	0.39	0.52	0.46	0.54	0.39
Quindío	99.90	2.60	2.90	2.30	**1.84**	1.87	1.81	0.29	0.44	0.15	0.47	0.56	0.37
Risaralda	94.10	**3.50**	3.30	3.60	1.51	1.04	1.94	**1.22**	1.49	0.98	0.73	0.77	0.70
Santander	56.10	2.30	1.80	2.80	1.60	1.10	2.08	0.34	0.34	0.34	0.39	0.37	0.41
Sucre	47.80	2.70	2.40	3.00	1.81	1.63	2.00	0.57	0.41	0.74	0.32	0.36	0.27
Tolima	81.20	2.30	2.00	2.50	1.49	1.21	1.77	0.34	0.34	0.35	0.43	0.44	0.41
Valle del Cauca	68	3.10	2.80	3.40	**1.98**	1.57	2.36	0.60	0.62	0.58	0.54	0.61	0.48

Table 1 (continued)

Department	Aging index to 2021	Rate of overall centenarians (per 10,000 inhabitants)			Rate of centenarians (100–104 years old) (per 10,000 inhabitants)			Rate of semi-supercentenarians (105–109 years old) (per 10,000 inhabitants)			Rate of supercentenarians (≥110 years old) (per 10,000 inhabitants)		
		Total	Men	Women	Total	Men	Women	Total	Men	Women	Total	Men	Women
Arauca	30.40	1.40	1.60	1.20	0.79	0.49	1.09	0.20	0.41	0	0.37	0.66	0.08
Casanare	33.20	1.30	0.90	1.80	0.94	0.57	1.33	0.21	0.15	0.26	0.18	0.20	0.15
Putumayo	33.80	1.70	1.30	2.10	1.09	0.69	1.49	0.35	0.27	0.42	0.28	0.34	0.21
Archipiélago de San Andrés, Providencia y Santa Catalina	62.80	2.70	2.10	3.20	1.65	0.85	2.40	0.41	0.85	0	0.62	0.42	0.80
Amazonas	23.40	1.70	1.70	1.60	0.90	1.16	0.63	0.45	0.29	0.63	0.30	0.29	0.31
Guainía	14.60	1.80	1.70	1.90	1.12	0.86	1.41	0	0	0	0.67	0.86	0.47
Guaviare	27.90	**4.50**	5.40	3.50	0.82	1.27	0.29	**3.42**	3.58	3.23	0.27	0.51	0
Vaupés	21.50	2.10	1.00	3.40	0	0	0	0.53	0	1.11	**1.59**	1.01	2.23
Vichada	16.60	2.10	2.20	1.90	0.39	0	0.83	**0.91**	1.47	0.27	**0.78**	0.73	0.83

Table 2 Female/male ratio of centenarians and subgroups in Colombia

Department	Overall F/M ratio of centenarians				F/M ratio of centenarians (100–104 years old)			F/M ratio of semi-supercentenarians (105–109 years old)			F/M ratio of supercentenarians (≥ 110 years old)		
	Total	Urban area	Populated areas	Dispersed Rural Area	Total	Urban area	Dispersed Rural Area	Total	Urban area	Dispersed Rural Area	Total	Urban area	Dispersed Rural Area
National	1.30	1.39	1.22	0.94	1.59	1.73	1.06	1.03	1.08	0.81	0.98	1.01	0.81
Antioquia	1.28	1.40	1.21	0.72	1.53	1.70	0.82	0.93	1.02	0.43	1.10	1.13	1
Atlántico	1.56	1.6	1.07	0.60	1.77	1.80	1	1.15	1.17	1	1.55	1.63	0
Bogotá, D.C.	1.26	1.26	0	0.50	1.76	1.76	0.50	1.07	1.07	0	0.77	0.07	0
Bolívar	1.39	1.48	1.28	0.77	1.83	2	0.61	0.95	1.01	0.64	1.14	1.15	1.25
Boyacá	1.24	1.59	1	0.93	1.51	1.82	1.08	1	1.33	0.92	0.96	1.21	0.69
Caldas	1.16	1.32	1	0.63	1.47	1.77	0.70	0.60	0.66	0.50	0.75	0.69	0.66
Caquetá	1.12	1.2	0	0.83	1.20	1.55	0.50	3	3	3	0.80	0.70	0.80
Cauca	1.72	2.18	2.30	1.21	1.94	2.46	1.39	1.65	1.88	1.25	1.09	1.60	0.63
Cesar	1.30	1.19	1.63	1.66	1.37	1.32	1.30	0.94	0.84	2	1.43	1.15	2.50
Córdoba	1.06	1.15	0.97	0.92	1.26	1.43	1	0.87	0.80	1.06	0.76	0.94	0.57
Cundinamarca	1.46	1.52	2	1.19	1.54	1.60	1.25	1.36	1.42	1.09	1.36	1.45	1
Chocó	1.45	1.73	1.91	1.03	1.47	1.88	0.83	1.47	2	0.87	1.40	1	1.83
Huila	0.85	1.10	0.50	0.57	0.81	1.05	0.52	1.06	1.62	0.40	0.85	0.92	1
La Guajira	1.38	1.30	1.14	1.52	1.75	1.61	2.27	1.21	1.28	1.16	0.80	0.69	0.60
Magdalena	1.15	1.20	1.20	0.60	1.44	1.52	1	0.91	0.95	0	0.84	0.90	0
Meta	1.01	1.15	7	0.37	1.11	1.18	0.45	0.95	1.42	0.22	0.85	0.88	0.50
Nariño	1.59	1.57	2.10	1.50	1.87	2.23	1.32	1.37	0.93	2.50	1.20	1.05	1.20
Norte de Santander	1.15	1.17	0.75	1.08	1.27	1.30	1.33	1.38	1.50	0.75	0.75	0.72	1
Quindío	0.87	0.83	3	1	1.04	0.95	3	0.36	0.40	0	0.71	0.76	0
Risaralda	1.19	1.48	1.16	0.76	2.02	2.02	2.80	0.71	1.19	0.43	1	0.90	1
Santander	1.62	1.81	1.57	0.94	1.96	2.16	1.15	1.02	1.08	0.87	1.16	1.32	0.63

Table 2 (continued)

Department	Overall F/M ratio of centenarians				F/M ratio of centenarians (100–104 years old)			F/M ratio of semi-supercentenarians (105–109 years old)			F/M ratio of supercentenarians (≥110 years old)		
	Total	Urban area	Populated areas	Dispersed Rural Area	Total	Urban area	Dispersed Rural Area	Total	Urban area	Dispersed Rural Area	Total	Urban area	Dispersed Rural Area
Sucre	1.23	1.49	0.93	0.94	1.21	1.57	0.90	1.77	1.33	3.50	0.75	1.28	0.16
Tolima	1.29	1.61	0.55	0.68	1.48	1.97	0.70	1.04	1.14	1	0.96	1.10	0.42
Valle del Cauca	1.35	1.43	0.87	1.09	1.66	1.80	1.06	1.03	0.97	1.60	0.87	0.92	0.90
Arauca	0.73	0.80	0.66	0.66	2.16	1.40	4	0	0	0	0.12	0.25	0
Casanare	1.83	2.27	0	0.85	2.27	3	1	1.66	1.33	0	0.75	1.50	0
Putumayo	1.57	1.77	2.5	1.12	2.10	1.66	1.75	1.50	2	1	0.60	2	0
Archipiélago de San Andrés, Providencia y Santa Catalina	1.60	1.33	1.5	0	3	1.50	0	0	0	0	2	1	0
Amazonas	0.83	1	1	0.66	0.50	1	0	2	0	0	1	0	0
Guainía	1	0	0	1.50	1.50	0	2	0	0	0	0.50	0	1
Guaviare	0.57	0.60	0	0.36	0.20	0	0.25	0.78	0.85	0.42	0	0	0
Vaupés	3	0	1	4	0	0	0	0	0	0	2	0	3
Vichada	0.77	0	0	1.40	0	0	0	0.16	0	0.25	1	0	3

F/M Female/Male

Table 3 Municipalities with the highest rate of centenarians overall in Colombia per 10,000 inhabitants

Department	Municipality	Frequency of centenarians					Rate of centenarians			Most frequent centenarian subgroup
		Total	Men	Women	Urban area*	Dispersed Rural Area	Total	Men	Women	
Risaralda	La Celia	45	32	13	1	44	72.83	98.49	44.38	Semi-supercentenarians
Antioquia	Ciudad Bolívar	132	89	43	98	34	56.50	76.18	36.81	Semi-supercentenarians
Magdalena	El Piñón	58	37	21	58	0	33.51	40.96	25.37	Semi-supercentenarians
Boyacá	Ventaquemada	37	24	13	2	35	26.45	34.59	18.44	Semi-supercentenarians
Amazonas	Miritί – Paraná	2	1	1	0	2	19.55	17.60	21.97	Semi-supercentenarians/Supercentenarians
Casanare	Sácama	3	1	2	0	3	17.91	11.60	24.60	Centenarians
Boyacá	Sutatenza	6	3	3	2	4	17.13	17.54	16.75	Centenarians
Valle del Cauca	La Victoria	18	12	6	14	4	16.27	22.78	10.35	Centenarians
Chocó	Medio Atrato	15	10	5	3	12	14.79	19.12	10.18	Centenarians
Boyacá	El Espino	4	1	3	4	0	14.73	7.02	23.23	Centenarians
Boyacá	Macanal	5	1	4	2	3	14.01	5.54	22.68	Centenarians/Supercentenarians
Boyacá	Berbeo	2	1	1	0	2	13.76	13.55	13.98	Centenarians
Boyacá	San Eduardo	2	0	2	2	0	12.72	0	26.45	Centenarians
Guainía	Puerto Colombia	2	0	2	0	2	12.17	0	25.60	Centenarians/Supercentenarians
Boyacá	Panqueba	2	1	1	0	2	12.16	12.36	11.97	Supercentenarians
Cundinamarca	Chaguaní	4	1	3	2	2	12.03	5.47	20.02	Centenarians/Supercentenarians
Bolívar	Córdoba	17	12	5	5	11	11.32	15.05	7.10	Semi-supercentenarians
Bolívar	Maria La Baja	51	25	26	46	5	11.25	10.89	11.61	Centenarians
Chocó	Sipí	3	2	1	3	0	10.83	13.43	7.81	Semi-supercentenarians
Casanare	Chámeza	2	1	1	2	0	9.95	9.58	10.35	Centenarians

*The urban area was defined as including the centenarian population located both in the urban zone and in populated areas

were observed regarding sex, as well as territorial zones. La Celia, located in the department of Risaralda, has the highest overall centenarian rate (72.83), while the municipality of Ciudad Bolívar (Antioquia department) reports the highest number of centenarians ($n = 132$) in this group. Despite differences in the frequencies reported across regions, a pattern emerged indicating a higher frequency of male centenarians, as well as centenarians located in urban areas (Table 3).

Human and Environmental Characteristics Between the Departments and Municipalities With the Highest Rate of Centenarians in Colombia

Among the departments with the highest centenarian rates in Colombia (Figs. 1A-F), it was identified that the distribution of centenarians in four departments is closely related to proximity to bodies of water, agricultural zones, grasslands, and herbaceous vegetation (Fig. 1A, B, C and E). In the cases of the department of Chocó (Fig. 1C) and Guaviare (Fig. 1F), the concentration of centenarians was predominantly associated with proximity to grasslands and forests. In the department of Risaralda (Fig. 1D) and Valle del Cauca (Fig. 1E), the centenarian population distribution was more notably linked to proximity to agricultural zones and artificially greened areas.

Among the municipalities noted for having high centenarian rates, a consistent pattern of proximity to agricultural areas, herbaceous vegetation, forests, and, in some cases, bodies of water were observed across all municipalities (Figs. 2-AF). In the cases of La Celia (Fig. 2-C) and Ciudad Bolívar (Fig. 2-A), the municipalities with the highest centenarian rates in the country (72.83 and 56.50 per 10,000 inhabitants, respectively), this pattern of proximity to agricultural zones and areas with herbaceous vegetation was evident. In both municipalities, the frequency of centenarians is higher among men. However, in La Celia, centenarians are predominantly located in dispersed rural areas compared to urban areas (44 vs. 1 centenarian) (Fig. 2-C), whereas in Ciudad Bolívar, centenarians are primarily concentrated in urban areas (98 vs. 34 centenarians) (Fig. 2-A).

Overall, agricultural zones were also prominent, notably in Risaralda (61%) and Bolívar (23.40%) (Table 4). Open areas with sparse vegetation and grasslands collectively accounted for 13.50% of total hotspot land, while wetlands and water bodies remained marginal. Urbanized areas represented only 1% of the total territory, underscoring the rural nature of longevity hotspots. Risaralda and Atlántico showed relatively higher urban percentages (16.60% and 4.10%, respectively), yet remained minor compared to forest and agricultural coverage (Fig. 3). Mining and dumping zones were minimal (0.60%) (Fig. 3).

To complement the descriptive findings, 95% CI were calculated for all territorial centenarian rates. These intervals, presented in Tables 5 and 6, provide a measure of precision for each estimate and allow readers to assess whether the observed differences between departments and municipalities may reflect chance variation or meaningful patterns.

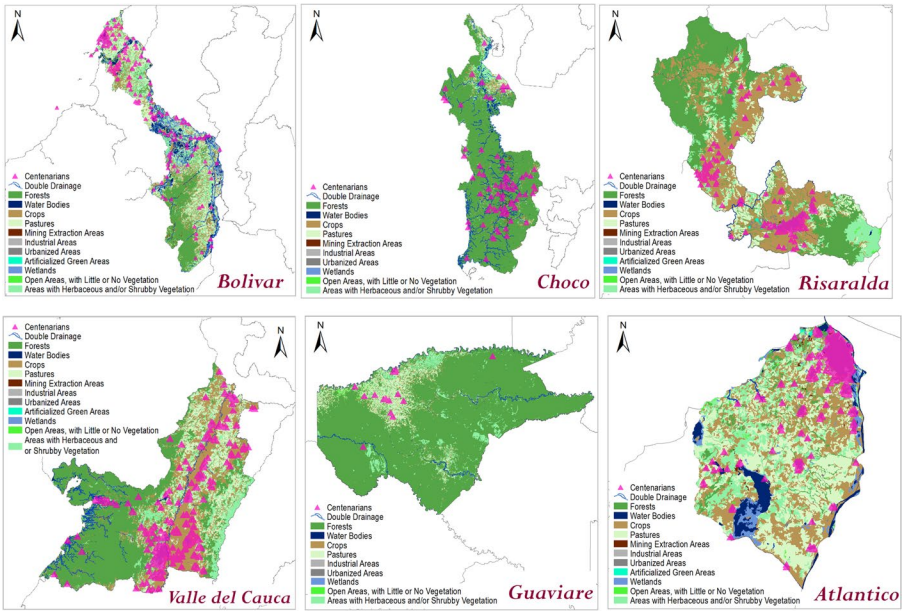

Fig. 1 Geographical and human activity characteristics of the departments with the highest rate of centenarians in Colombia. (**A**) Bolívar department. (**B**) Chocó department. (**C**) Risaralda department. (**D**) Valle del Cauca department. (**E**) Guaviare department. (**F**) Atlántico department. The pink triangles represent the distribution of centenarians in the territory

Discussion

This study offers a novel window into the biodemographic dynamics of longevity in Colombia, a country marked by profound ecological diversity and social heterogeneity (Ministerio de Cultura de Colombia, 2024). By identifying spatial clusters of centenarians and analyzing their distribution through both demographic and environmental lenses, the research contributes novel insights to the ongoing conversation about aging and human development.

The presence of over 12,000 centenarians, while modest in relative terms, is significant in absolute numbers, particularly considering the country's middle-income status and the limited representation of similar nations in global longevity research (Lozada-Martinez et al., 2024b). Beyond demographics, what gives these findings depth is their alignment with a growing body of evidence suggesting that longevity is not only a biological phenomenon but a reflection of multilevel and multidimensional interactions between individuals and their environments (Friedman et al., 2024). Social determinants of health, mental health, and cardiometabolic risks all have a substantial impact on healthy aging (Santamaría-Garcia et al., 2023).

Although the census data do not allow testing biological mechanisms directly, the observed geographic patterns of longevity can be conceptually framed within biodemographic and geroscientific models. Theories such as inflammaging, epigenetic modulation, and adaptive metabolic pathways provide plausible biological hypotheses to explain how environmental and social conditions might interact with intrinsic

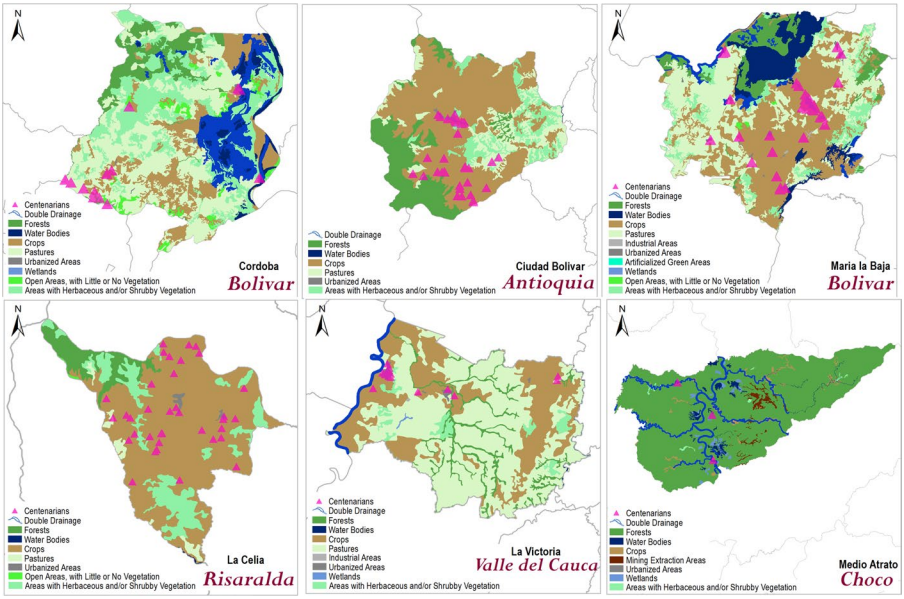

Fig. 2 Geographic and human activity characteristics of the municipalities with the highest centenarian rates within the departments with the highest rates in Colombia. (**A**) Municipality of Ciudad Bolívar. (**B**) Municipality of María La Baja. (**C**) Municipality of La Celia. (**D**) Municipality of Córdoba. (**E**) Municipality of La Victoria. (F) Municipality of Medio Atrato. Pink triangles represent the distribution of centenarians in the territory

aging processes (Anaya et al., 2024; Dugan et al., 2024; van Sleen et al., 2023). These hypotheses are not inferred from the data themselves but are proposed as guiding frameworks for future multidisciplinary research linking population-level indicators with individual health, molecular, and environmental data (Anaya et al., 2024; Dugan et al., 2024; van Sleen et al., 2023).

Additionally, epigenetic mechanisms may play a role (Wang et al., 2022). Environmental factors such as diet, physical activity, exposure to microbiota, and psychosocial stress influence the expression of genes involved in aging and age-related diseases (Wang et al., 2022). In rural, agriculturally active zones like Risaralda or Bolívar, dietary patterns rich in plant-based, locally grown food and low in ultra-processed products might support favorable epigenetic profiles (Yuan et al., 2023). This offers a biological basis for the observed rural longevity and the patterns of healthy aging seen in centenarian hotspots.

Although certain environmental characteristics, such as agricultural activity or proximity to water bodies, have been proposed as potential correlates of longevity, the census data used here do not provide information on individual-level behaviors, diet, or social factors that could mediate these associations (Wang et al., 2022). As such, the relationships identified should be interpreted as ecological and hypothesis-generating, rather than explanatory. Future biodemographic studies linking environmental exposure data with health and lifestyle indicators will be essential to test these hypotheses empirically.

Table 4 Geographical characteristics of the hotspots with the highest Spatial relative risk of centenarians in Colombia

Land Cover	Department						
	Atlántico	Bolívar	Chocó	Risaralda	Guaviare	Valle del Cauca	Total
	Km^2 (%)						
Open areas with little or no vegetation	143 (13.60)	1020 (21.40)	1549 (6.30)	44 (10.40)	789 (5.20)	251 (5.80)	**3796 (7.50)**
Agricultural areas	350 (33.20)	1117 (23.40)	1506 (6.10)	257 (61.00)	203 (1.30)	924 (21.50)	**4357 (8.60)**
Wetlands	25 (2.40)	244 (5.10)	261 (1.10)	0	7 (0.10)	0	**538 (1.10)**
Forests	59 (5.60)	851 (17.80)	20,168 (81.80)	79 (18,80)	13,364 (87.80)	2609 (60.70)	**37,130 (73.60)**
Water bodies	39(3.60)	219 (4.60)	386 (1.60)	1 (0.30)	76 (0.50)	78 (1.80)	**799 (1.60)**
Grasslands	258 (24.50)	1185 (24.90)	513 (2.10)	38 (90)	780 (5.10)	252 (5.90)	**3027 (6.00)**
Mining and dumping sites	6 (0.60)	8 (0.20)	260 (1.10)	0	0	5 (0.10)	**279 (0.60)**
Urbanized zones	175 (16.60)	125 (2.60)	23 (0.10)	2 (0.40)	0	177 (4.10)	**502 (1.00)**
Total	**1055 (100)**	**4768 (100)**	**24,667 (100)**	**421 (100)**	**15,220 (100)**	**4297 (100)**	**50,429 (100)**

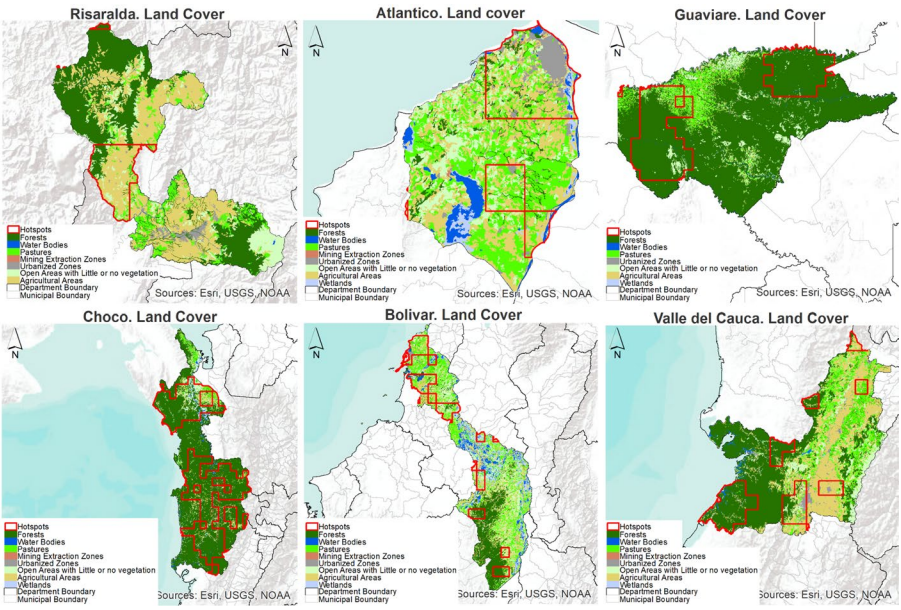

Fig. 3 Geographical characteristics of the hotspots with the highest spatial relative risk of centenarians in Colombia. (**A**) Risaralda department. (**B**) Atlántico department. (**C**) Guaviare department. (**D**) Chocó department. (**E**) Bolivar department. (**F**) Valle del Cauca department

Table 5 Centenarian rates per 10,000 inhabitants and CI 95% in municipalities with the highest rates, Colombia, 2018

Department	Municipality	Centenarian rate	95% CI Lower	95% CI Upper
Risaralda	La Celia	72.80	53.12	97.46
Antioquia	Ciudad Bolívar	56.50	47.27	67.00
Magdalena	El Piñón	33.50	25.44	43.32
Boyacá	Ventaquemada	26.50	18.62	36.46
Amazonas	Mirití – Paraná	19.60	2.36	70.62
Casanare	Sácama	17.90	3.69	52.34
Boyacá	Sutatenza	17.10	6.28	37.30
Valle del Cauca	La Victoria	16.30	9.64	25.72
Chocó	Medio Atrato	14.80	8.27	24.39
Boyacá	El Espino	14.70	4.01	37.72
Boyacá	Macanal	14.00	4.55	32.70
Boyacá	Berbeo	13.80	1.66	49.72
Boyacá	San Eduardo	12.70	1.54	45.95
Guainía	Puerto Colombia	12.20	1.47	43.97
Boyacá	Panqueba	12.20	1.47	43.94
Cundinamarca	Chaguaní	12.00	3.27	30.82
Bolívar	Córdoba	11.30	6.59	18.13
Bolívar	Maria La Baja	11.30	8.37	14.79
Chocó	Sipí	10.80	2.23	31.67
Casanare	Chámeza	10.00	1.20	35.96

When contrasted with prior literature, these findings show both similarities and divergences (Poulain & Herm, 2025). In Japan and Italy, for example, national centenarian rates already reaching up to 159 per 10,000 inhabitants, but the spatial clustering in rural or semi-rural territories mirrors what we observed in Colombia (Poulain & Herm, 2025). In Costa Rica's Nicoya Peninsula, one of the most recognized "blue zones," the role of agricultural environments and plant-based diets has been emphasized as protective factors (Gómez Salas et al., 2024), parallels that can be drawn with Colombian municipalities such as La Celia or Ciudad Bolívar. Conversely, the predominance of male centenarians in certain Colombian hotspots contrasts with global trends of female survival advantage, pointing to potentially unique local dynamics that deserve further study (Poulain & Herm, 2025).

The female/male ratios observed in our study also provide insights for understanding sex-differentiated aging. Although women generally live longer and exhibit higher centenarian rates (Ostan et al., 2016), the predominance of men in certain Colombian hotspots challenges conventional assumptions. From a public health perspective, this suggests that local environmental, cultural, or occupational factors may modulate sex-specific longevity patterns (Lemaître et al., 2020). For example, reduced exposure to urban occupational hazards, sustained engagement in agricultural work, and strong community ties could favor male survival into advanced ages (Lemaître et al., 2020). These findings highlight the need for sex-sensitive approaches in aging research and policy, as determinants of extreme longevity may operate differently for men and women depending on their social and ecological context (Lemaître et al., 2020).

Table 6 Centenarian rates per 10,000 inhabitants and CI 95% by department, Colombia, 2018

Department	Centenarians	Population	Centenarian rate	95% CI Lower	95% CI Upper
Antioquia	1847	5,974,788	3.10	2.95	3.23
Atlántico	815	2,342,265	3.50	3.24	3.72
Bogotá, D.C.	1932	7,181,469	2.70	2.57	2.81
Bolívar	891	1,909,460	4.70	4.36	4.98
Boyacá	278	1,135,698	2.40	2.16	2.75
Caldas	199	923,472	2.20	1.86	2.47
Caquetá	68	359,602	1.90	1.46	2.39
Cauca	313	1,243,503	2.50	2.24	2.81
Cesar	198	1,098,577	1.80	1.56	2.07
Córdoba	474	1,555,596	3.00	2.77	3.33
Cundinamarca	639	2,792,877	2.30	2.11	2.47
Chocó	182	457,412	4.00	3.42	4.60
Huila	195	1,009,548	1.90	1.66	2.22
La Guajira	222	825,364	2.70	2.34	3.06
Magdalena	375	1,263,788	3.00	2.67	3.28
Meta	177	919,129	1.90	1.65	2.23
Nariño	311	1,335,521	2.30	2.07	2.60
Norte de Santander	289	1,346,806	2.10	1.90	2.40
Quindío	133	509,640	2.60	2.18	3.09
Risaralda	292	839,597	3.50	3.09	3.90
Santander	472	2,008,841	2.30	2.14	2.57
Sucre	235	864,036	2.70	2.38	3.09
Tolima	280	1,228,763	2.30	2.01	2.56
Valle del Cauca	1187	3,789,874	3.10	2.95	3.31
Arauca	33	239,503	1.40	0.94	1.93
Casanare	51	379,892	1.30	0.99	1.76
Putumayo	49	283,197	1.70	1.28	2.28
Archipiélago de San Andrés, Providencia y Santa Catalina	13	48,299	2.70	1.43	4.60
Amazonas	11	66,056	1.70	0.83	2.97
Guainía	8	44,431	1.80	0.77	3.54
Guaviare	33	73,081	4.50	3.10	6.34
Vaupés	8	37,690	2.10	0.91	4.18
Vichada	16	76,642	2.10	1.19	3.39

One hypothesis is that certain social and environmental conditions, particularly in rural or semi-urban communities, reduce typical male-associated risk behaviors (e.g., substance use, high-risk labor) and foster protective routines (Pinho-Gomes et al., 2022). For instance, involvement in community agriculture, lower stress from urban labor markets, and stronger social ties may be particularly beneficial for men who reach later life stages (Pinho-Gomes et al., 2022). These observations pave the way for new sex-informed hypotheses in longevity research.

The spatial analysis also underscores the importance of ecosocial theories of health, which suggest that health outcomes emerge from dynamic interactions between biological systems and broader social and environmental structures (Krieger, 2024). In

the municipalities of La Celia and Ciudad Bolívar, for example, we see two distinct models of longevity: one deeply rural and environmentally immersed, the other more urban but potentially enriched by access to healthcare and community cohesion. Both demonstrate that the paths to aging well are diverse, shaped by local histories, geographies, and cultures (Krieger, 2024).

The spatial distribution of centenarian rates across Colombian departments indeed reveals contrasting patterns. Departments such as Bolívar and Risaralda, with relatively favorable socioeconomic and health indicators, coexist with others like Chocó and Guaviare, characterized by limited infrastructure and historical vulnerability. At first glance, these discrepancies may seem paradoxical and could raise questions about data quality or contextual plausibility. However, such variation is consistent with Colombia's marked demographic, environmental, and cultural heterogeneity and underscores the need to interpret longevity patterns beyond purely structural explanations.

These regional patterns should not be interpreted through a unidimensional socioeconomic lens. The coexistence of high centenarian rates in departments such as Bolívar, Risaralda, Chocó, and Guaviare reflect the complex interplay between environment, social structures, and biological adaptation rather than a simple gradient of development. According to multidimensional and multidirectional models of aging, longevity may arise from synergistic or compensatory mechanisms that allow individuals and communities to maintain resilience even under adverse socioeconomic or infrastructural conditions (Anaya et al., 2025; Christensen et al., 2009; Poulain et al., 2013; Vaupel, 2010). In this sense, these apparent paradoxes do not undermine the findings but rather reinforce the biodemographic premise that exceptional longevity is a heterogeneous phenomenon shaped by diverse ecological and social determinants (Christensen et al., 2009; Poulain et al., 2013; Vaupel, 2010). Further research combining demographic data with health and lifestyle indicators will be essential to explore these mechanisms in depth.

Importantly, these findings help address gaps in global aging research. First, they introduce empirical evidence from a Latin American country, a region frequently underrepresented in geroscience literature (Lozada-Martinez et al., 2024b). Second, they offer a methodology that integrates open-access census data with geospatial and ecological indicators, making it feasible for other resource-limited settings to explore similar questions. Third, they hint at synergistic protective factors that may not be fully appreciated in high-income countries, where aging research often focuses on biomedical technologies and individualized interventions.

From the perspective of geroscience, this study broadens the scope of what it means to "age successfully." It reminds us that longevity cannot be fully understood without considering the lifelong biological adaptation to social and ecological environments (Ferrucci et al., 2024). This analysis underscores the value of spatial analysis for identifying human longevity patterns, offering scalable tools to detect emerging blue zones and inform place-based health interventions.

From a biodemographic standpoint, the geographic distribution of centenarians in Colombia supports the view that longevity is not solely a demographic outcome but a multifactorial process shaped by the interaction between biology, environment, and society (Ferrucci et al., 2024). The identification of potential longevity hotspots across heterogeneous ecological and socioeconomic contexts reflects the adaptability

of human aging, consistent with the biodemographic premise that survival to extreme ages emerges from complex and nonlinear dynamics rather than uniform demographic transitions. In this sense, the findings contribute to expanding the empirical scope of biodemography toward diverse population settings and reinforce its integrative perspective on human longevity.

The interpretation of these findings must also be viewed within the Latin American context, where demographic data on centenarians remain limited and often affected by under-registration and age misreporting (Poulain et al., 2013; Poulain & Herm, 2025). Despite these challenges, several regional analyses have shown similar spatial heterogeneity in survival to advanced ages, suggesting that localized longevity clusters may exist even in settings with data constraints (Poulain et al., 2013; Poulain & Herm, 2025). By providing this nationwide ecological assessment of centenarian distribution in Colombia, this study contributes to addressing a significant regional gap and lays the groundwork for future comparative biodemographic research as data quality in Latin America continues to improve.

There are limitations to consider in this study. First, the cross-sectional design precludes the establishment of causal relationships between environmental exposures and longevity. The study period is limited to the year 2018, as this corresponds to the most recent national census in Colombia. We cannot determine whether individuals lived their entire lives in the locations where they were counted, or whether they migrated there later in life, a factor that could confound interpretations of environmental influence. Second, while the census provides a comprehensive demographic snapshot, it does not capture critical variables such as comorbidities, lifestyle behaviors, psychosocial factors, or genetic profiles. These dimensions are central to understanding the mechanisms behind extreme longevity but remain outside the scope of the current dataset.

On the other hand, the results show that although several departments and municipalities present centenarian rates that far exceed the national average, the inclusion of 95% CI allows for a more nuanced interpretation of these findings. Departments such as Bolívar, Risaralda, and Valle del Cauca exhibited relatively narrow intervals, suggesting greater precision in the estimates. In contrast, Guaviare showed a particularly wide interval, reflecting statistical instability due to a small absolute number of centenarians within a limited population. This finding underscores the importance of considering the inherent variability of the rates, avoiding categorical conclusions based solely on point estimates.

At the municipal level, this situation becomes even more pronounced, as municipalities with smaller populations tend to display extreme rates accompanied by wide 95% CI. This necessitates cautious interpretation of the results, since high values do not necessarily imply greater population longevity but may instead reflect random fluctuations in small counts.

Additionally, it is important to emphasize the temporal limitation of our study. The analyses were based on the 2018 Colombian National Census, and therefore the sociodemographic and environmental conditions influencing longevity may have changed during the subsequent years. Factors such as climate change, migration dynamics, health system transformations, and lifestyle transitions could modify the prevalence and distribution of centenarians, which must be considered when interpreting the current findings.

As with any census-based analysis, the possibility of age misreporting, particularly among individuals aged 110 years and above, cannot be fully ruled out. Although these data were collected through standardized, in-person enumeration by DANE, future studies should aim to validate extreme ages through linkage with vital registration and individual-level verification.

Our classification identifies potential blue zones rather than definitive "blue zones." More advanced approaches (e.g., Empirical Bayes/Poisson-Gamma smoothing or spatial scan statistics) should be prioritized once individual-level validation and vital registration linkages are available. Until then, a transparent national-baseline criterion, together with uncertainty quantification and clustering tests, offers a prudent first stage for screening territories that merit demographic validation and targeted follow-up.

Despite these limitations, the study is grounded methodological strengths. It leverages a national census with high population coverage, reducing selection bias. The integration of land cover and spatial risk analysis provides an innovative ecological lens rarely applied in longevity research. Furthermore, by focusing on patterns rather than isolated cases, the study offers valuable insights into the broader contextual drivers of longevity. Data presented correspond to centenarians from a geographic area characterized by racial and cultural mixing (Martschenko et al., 2023), providing valuable information for subsequent analyses. These strengths support the validity of our observations and lay the groundwork for more targeted, longitudinal, and multidimensional investigations.

Existence of Potential Blue Zones in Colombia?

The geographic and environmental patterns revealed in this study provide compelling evidence that certain regions of Colombia may be potential "blue zones", territories where a combination of biological, social, and ecological conditions favor exceptional longevity (Lozada-Martinez & Anaya, 2024). The clustering of centenarians in municipalities with abundant forest cover, agricultural activity, and low levels of urbanization is not random. Rather, it suggests a confluence of factors that echo the conditions observed in internationally recognized blue zones.

These findings call for deeper, interdisciplinary exploration. To understand the true nature of these Colombian longevity hotspots, future studies should combine biodemographic analysis with fieldwork, health records, biomarker data, and ethnographic insights. In doing so, we may uncover not only new blue zones but also new models of aging, rooted in culture, land, and community, that can inform aging policy and health promotion strategies across diverse contexts.

Beyond their academic value, these findings have practical implications. From a public health perspective, identifying municipalities with unusually high centenarian rates underscores the need to strengthen demographic monitoring systems and integrate them with health and social data to better track longevity trends (Argentieri et al., 2025). For research, these areas represent natural laboratories for studying protective factors, biological, environmental, and cultural, that contribute to extreme longevity (Argentieri et al., 2025). For territorial planning and policy, the evidence suggests opportunities to design context-specific strategies that support healthy aging, such as

improving access to healthcare in rural areas, preserving ecological environments, and fostering community-based social networks (Crimmins & Vasunilashorn, 2016).

From a policy perspective, mapping these areas can guide the validation and improvement of vital registration and census systems, support the targeted allocation of health and social programs for older adults, and inform territorial planning that accounts for regional differences in aging trajectories. Such evidence-based strategies can help integrate local environmental and social factors into national healthy-aging policies, aligning with the World Health Organization's Decade of Healthy Ageing framework (World Health Organization, 2020).

Future research should extend this ecological approach by integrating age-specific mortality data and analyzing demographic structures across regions. Linking census information with vital registration and mortality records would make it possible to determine whether areas identified as potential longevity hotspots are truly characterized by reduced mortality and survival advantages across the life course. Such analyses will be crucial to confirm the demographic foundations of longevity patterns observed in this study.

Conclusions

In Colombia, the 2018 census documented 12,226 centenarians, corresponding to a national rate of 2.80 per 10,000 inhabitants. Our analysis identified departments such as Bolívar, Guaviare, Chocó, Atlántico, and Risaralda, and twenty municipalities, where centenarian rates were notably higher than the national average. While women predominated overall, several hotspots revealed a relative predominance of men, suggesting context-specific sex dynamics. Similarly, although most centenarians lived in urban areas, some municipalities displayed concentrations in dispersed rural settings, highlighting the diversity of demographic patterns across the territory.

These areas, characterized by proximity to agricultural zones, herbaceous vegetation, forests, and, in some cases, bodies of water, may be considered potential "blue zones" for the study of healthy and extreme longevity. Centenarians and semi-supercentenarians were the most common subgroups within these zones.

This study not only demonstrates the geographic and demographic distribution of centenarians but also underscores the interaction between environmental and human characteristics that may shape extreme longevity. These findings highlight the importance of strengthening demographic monitoring and integrating ecological, health, and policy approaches to better understand and address the determinants of longevity. They also provide evidence that may guide aging policy planners, decision-makers, and researchers in designing targeted strategies to promote healthy aging in diverse territorial contexts.

Acknowledgements None.

Author Contributions All authors contributed to the study conception and design, data analysis and writing the manuscript. All authors read and approved the final manuscript.

Funding Open Access funding provided by Colombia Consortium.

Data Availability The dataset generated and analyzed is available and provided on request.

Declarations

Ethical Approval The institutional review board of Universidad de la Costa approved the study design.

Competing interests The authors declare no competing interests.

References

Addie, S., Kohanski, R., Ferrucci, L., Carter, C., & Carrington-Lawrence, S. (2024). Considering the future of geroscience: Goals and opportunities stemming from the fourth Geroscience Summit. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences, 79*(9), Article glae179. https://doi.org/10.1093/gerona/glae179

Anaya, J. M., Alpi, S. V., Castelblanco-Toro, S. M., Lozada-Martínez, I. D., & Salazar-Uribe, J. C. (2025). Quality of life and well-being in Colombian centenarians. *Scientific Reports, 15*, Article 32071. https://doi.org/10.1038/s41598-025-18137-0

Anaya, J. M., Lozada-Martínez, I. D., Torres, I., & Shoenfeld, Y. (2024). Autoimmunity in centenarians: A paradox. *Journal of Translational Autoimmunity, 8*, Article 100237. https://doi.org/10.1016/j.jtauto.2024.100237

Argentieri, M. A., Amin, N., Nevado-Holgado, A. J., Sproviero, W., Collister, J. A., Keestra, S. M., Kuilman, M. M., Ginos, B. N. R., Ghanbari, M., Doherty, A., Hunter, D. J., Alvergne, A., & van Duijn, C. M. (2025). Integrating the environmental and genetic architectures of aging and mortality. *Nature Medicine, 31*(3), 1016–1025. https://doi.org/10.1038/s41591-024-03483-9

Christensen, K., Doblhammer, G., Rau, R., & Vaupel, J. W. (2009). Ageing populations: The challenges ahead. *Lancet*, *374*(9696), 1196–1208. https://doi.org/10.1016/S0140-6736(09)61460-4

Crimmins, E. M., & Vasunilashorn, S. M. (2016). Biodemography: Adding biological insight into social, economic, and psychological models of population and individual health change with age. In L. K. George & K. F. Ferraro (Eds.), *Handbook of aging and the social sciences* (8th ed., pp. 55–75). Academic Press. https://doi.org/10.1016/B978-0-12-417235-7.00003-2

Departamento Administrativo Nacional de Estadíísticas. (2018). Censo Nacional de Poblacióón y Vivienda 2018. https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/censo nacional-de-poblacion-y-vivenda-2018

Departamento Administrativo Nacional de Estadísticas. (2024). Marco Geoestadístico Nacional (MGN) 2024. https://geoportal.dane.gov.co/geovisores/territorio/mgnmarco-geoestadistico-nacional/

Departamento Administrativo Nacional de Estadísticas. (2025a). *Basic concepts*. https://www.dane.gov.co/files/inf_geo/4Ge_ConceptosBasicos.pdf

Departamento Administrativo Nacional de Estadísticas. (2025b). *Censo Nacional de Población y Vivienda 2018*. https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/censo-nacional-de-poblacion-y-vivenda-2018

Departamento Administrativo Nacional de Estadísticas (2025c). *Geoportal*. https://geoportal.dane.gov.co

Departamento Administrativo Nacional de Estadísticas. (2025d). *Marco Geoestadístico Nacional (MGN) 2024*. https://geoportal.dane.gov.co/geovisores/territorio/mgn-marco-geoestadistico-nacional/

Dugan, A., Prskawetz, A., & Raffin, N. (2024). The environment, life expectancy, and growth in overlapping generations models: A survey. *Journal of Economic Surveys*, *38*(5), 1593–1621. https://doi.org/10.1111/joes.12602

Ferrucci, L., Wilson, D. M., III., Donega, S., & Montano, M. (2024). Enabling translational geroscience by broadening the scope of geriatric care. *Aging Cell, 23*(1), Article e14034. https://doi.org/10.1111/acel.14034

Friedman, E., Franks, M., Teas, E., & Thomas, P. A. (2024). Social connectedness, functional capacity, and longevity: A focus on positive relations with others. *Social Science & Medicine, 340*, Article 116419. https://doi.org/10.1016/j.socscimed.2023.116419

Gavrilov, L. A., & Gavrilova, N. S. (2015). New developments in the biodemography of aging and longevity. *Gerontology, 61*(4), 364–371. https://doi.org/10.1159/000369011

Gómez Salas, G., Arriola Aguirre, R., Vindas Meza, L., Pinto Tomás, A., Cordero Solís, J. J., Barrientos Calvo, I., & Pérez Carvajal, A. M. (2024). Dietary diversity, anthropometric status and biochemical profile of centenarians of the Nicoya Peninsula, Costa Rica, and their offspring. *Revista Española de Geriatría y Gerontología, 59*(6), Article 101513. https://doi.org/10.1016/j.regg.2024.101513

Instituto de Hidrología, Meteorología y Estudios Ambientales. (2024). *Metodología Corine Land Cover*. https://www.ideam.gov.co/web/ecosistemas/metodologia-corine-land-cover

Krieger, N. (2024). Theorizing epidemiology, the stories bodies tell, and embodied truths: A status update on contending 21st c CE epidemiological theories of disease distribution. *International Journal of Social Determinants of Health and Health Services*, *54*(4), 331–342. https://doi.org/10.1177/27551938241269188

Lemaître, J. F., Ronget, V., Tidière, M., Allainé, D., Berger, V., Cohas, A., Colchero, F., Conde, D. A., Garratt, M., Liker, A., Marais, G. A. B., Scheuerlein, A., Székely, T., & Gaillard, J. M. (2020). Sex differences in adult lifespan and aging rates of mortality across wild mammals. *Proceedings of the National Academy of Sciences, 117*(15), 8546–8553. https://doi.org/10.1073/pnas.1911999117

Lozada-Martínez, I. D., & Anaya, J. M. (2024). What are blue zones? An argument in favor of its definition based on the most successful model of biological aging. *Aging Medicine, 7*(4), 446–448. https://doi.org/10.1002/agm2.12343

Lozada-Martínez, I. D., Diazgranados-García, M. C., Castelblanco-Toro, S., & Anaya, J. M. (2024a). Global research on centenarians: A historical and comprehensive bibliometric analysis from 1887 to 2023. *Annals of Geriatric Medicine and Research, 28*(2), 144–155. https://doi.org/10.4235/agmr.24.0043

Lozada-Martínez, I. D., Marín, J. S., Castelblanco-Toro, S. M., Mazenett-Granados, E. A., Suárez, J. F., Sarmiento, M., et al. (2024b). Demographics and clinical characteristics of a new population of centenarians in Colombia: The COOLCEN cohort. *Archives of Gerontology and Geriatrics - Plus*, 100006. https://doi.org/10.1016/j.aggp.2024.100006

Machado, A., Barroso, J., Molina, Y., Nieto, A., Díaz-Flores, L., Westman, E., & Ferreira, D. (2018). Proposal for a hierarchical, multidimensional, and multivariate approach to investigate cognitive aging. *Neurobiology of Aging*, *71*, 179–188. https://doi.org/10.1016/j.neurobiolaging.2018.07.017

Marcos-Pérez, D., Saenz-Antoñanzas, A., & Matheu, A. (2021). Centenarians as models of healthy aging: Example of REST. *Ageing Research Reviews, 70*, Article 101392. https://doi.org/10.1016/j.arr.2021.101392

Martschenko, D. O., Wand, H., Young, J. L., & Wojcik, G. L. (2023). Including multiracial individuals is crucial for race, ethnicity and ancestry frameworks in genetics and genomics. *Nature Genetics, 55*(6), 895–900.

Ministerio de Cultura de Colombia. (2024). *Diversidad cultural*. https://oibc.oei.es/uploads/attachments/464/Cartilla_Diversidad_Cultural.pdf

Nielsen, L., Marsland, A. L., Hamlat, E. J., & Epel, E. S. (2024). New directions in geroscience: Integrating social and behavioral drivers of biological aging. *Psychosomatic Medicine, 86*(5), 360–365. https://doi.org/10.1097/PSY.0000000000001320

Ostan, R., Monti, D., Gueresi, P., Bussolotto, M., Franceschi, C., & Baggio, G. (2016). Gender, aging and longevity in humans: An update of an intriguing/neglected scenario paving the way to a gender-specific medicine. *Clinical Science*, *130*(19), 1711–1725. https://doi.org/10.1042/CS20160004

Pérez-Molina, C. J., Chavarro-Bermeo, F. E., Gutiérrez-Fernández, L. F., Galvis-Villamizar, S., Arias Ortiz, W. A., Cabezas-Pinzón, L., & Escobar-Roa, C. F. (2025). Colombian centenarians: A geohealth approach to longevity study. *PLoS ONE, 20*(2), Article e0311690. https://doi.org/10.1371/journal.pone.0311690

Pinho-Gomes, A. C., Vassallo, A., Carcel, C., Peters, S., & Woodward, M. (2022). Gender equality and the gender gap in life expectancy in the European Union. *BMJ Global Health, 7*(2), Article e008278. https://doi.org/10.1136/bmjgh-2021-008278

Poulain, M., & Herm, A. (2025). Blue zone, a demographic concept and beyond. *American Journal of Lifestyle Medicine, 28*, Article 15598276251342502. https://doi.org/10.1177/15598276251342502

Poulain, M., Herm, A., & Pes, G. (2013). The blue zones: Areas of exceptional longevity around the world. *Vienna Yearbook of Population Research, 11*, 87–108. https://doi.org/10.1553/populationyearbook2013ss005

Rattan, S. I. S. (2024). Seven knowledge gaps in modern biogerontology. *Biogerontology, 25*(1), 1–8. https://doi.org/10.1007/s10522-023-10089-0

Santamaria-Garcia, H., Sainz-Ballesteros, A., Hernandez, H., Moguilner, S., Maito, M., Ochoa-Rosales, C., Corley, M., Valcour, V., Miranda, J. J., Lawlor, B., & Ibanez, A. (2023). Factors associated with healthy aging in Latin American populations. *Nature Medicine*, *29*(9), 2248–2258. https://doi.org/10.1038/s41591-023-02495-1

The Asahi Shimbum. (2024). *Japan's centenarian population hits new record high*. https://www.asahi.com/ajw/articles/15429644

United Nations. (2023). *Leaving no one behind in an ageing world: World social report 2023*. https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2023/01/2023wsr-chapter2.pdf

van Sleen, Y., Shetty, S. A., van der Heiden, M., Venema, M. C. A., Gutiérrez-Melo, N., Toonen, E. J. M., van Beek, J., Buisman, A. M., van Baarle, D., & Sauce, D. (2023). Frailty is related to serum inflammageing markers: Results from the VITAL study. *Immunity & Ageing, 20*(1), Article 68. https://doi.org/10.1186/s12979-023-00391-3

Vaupel, J. W. (2010). Biodemography of human ageing. *Nature, 464*(7288), 536–542. https://doi.org/10.1038/nature08984

Wang, K., Liu, H., Hu, Q., Wang, L., Liu, J., Zheng, Z., Zhang, W., Ren, J., Zhu, F., & Liu, G. H. (2022). Epigenetic regulation of aging: Implications for interventions of aging and diseases. *Signal Transduction and Targeted Therapy, 7*(1), Article 374. https://doi.org/10.1038/s41392-022-01211-8

World Health Organization. (2020). *WHO's work on the UN Decade of Healthy Ageing (2021–2030)*. https://www.who.int/publications/m/item/decade-of-healthy-ageing-plan-of-action

Yuan, L., Jiang, Q., Zhai, Y., Zhao, Z., Liu, Y., Hu, F., Qian, Y., & Sun, J. (2023). Association between plant-based diet and risk of chronic diseases and all-cause mortality in centenarians in China: A cohort study. *Current Developments in Nutrition, 8*(1), Article 102065. https://doi.org/10.1016/j.cdnut.2023

Authors and Affiliations

Ivan David Lozada-Martinez[1,2] · Karoll Arcos Navarro[3] · German Gallego[3] · Juan-Manuel Anaya[1,2] · J. Sebastián Ruiz-Santacruz[3]

✉ Ivan David Lozada-Martinez
ilozada@cuc.edu.co

✉ Juan-Manuel Anaya
anayajm@gmail.com

Karoll Arcos Navarro
kaarcosn@dane.gov.co

German Gallego
gallegovega@yahoo.com

J. Sebastián Ruiz-Santacruz
sebastianruizsantacruz@gmail.com

[1] Universidad de la Costa, Barranquilla, Colombia

[2] Alianza Centenarios, Bogotá, Colombia

[3] Departamento Administrativo Nacional de Estadísticas, Bogotá, Colombia