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The longevity of blue zones: myth or reality

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The concept of Blue Zones (BZs) refers to regions characterized by an exceptionally high concentration of centenarians, many of whom maintain good health well into advanced age. To date, five such regions have been identified and validated: Sardinia (Italy), Okinawa (Japan), Nicoya (Costa Rica), Ikaria (Greece), and Martinique (a French overseas territory). Despite their widespread recognition, BZs have faced scrutiny over the reliability of demographic data, particularly regarding the accuracy of age reporting. Nevertheless, irrespective of their demographic authenticity, which, as discussed in the review, holds true for the majority of cases, the lifestyle patterns observed in these communities remain highly relevant for the promotion of healthy ageing. Their behavioural and environmental practices provide a robust framework for informing public health strategies aimed at strengthening resilience against non-communicable diseases. Interventions centred on environment and lifestyle and the encouragement of meaningful social engagement have the potential to markedly enhance population health. In fact, minimizing exposure to air pollution and ultra-processed foods, while supporting anti-inflammatory diets, consistent physical activity, and stress management, may significantly reduce the incidence of age-related chronic conditions. As urbanization and modernization continue to reshape daily life, preserving and adapting traditional health-promoting behaviours becomes increasingly important. Policies that support local food production, and enforce regulations to limit environmental degradation may be critical to sustaining the longevity benefits observed in BZs. Ultimately, the exceptional longevity observed in these communities underscores the need for prevention models based on personalized, context-sensitive approaches that integrate ecological and sociocultural factors.

Key words: blue zone, environment, genetics, healthspan, longevity

Abbreviations

BMI: body mass index
BZ: blue zone
CP: centenarian prevalence
CVD: cardiovascular diseases
ELI: extreme longevity index
GWAS: genome-wide association studies
LLI: long-lived individual

LIFE EXPECTANCY AND LONGEVITY

Life expectancy at birth is defined as the average number of years that

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a newborn could expect to live, if he or she were to pass through life exposed to the sex- and age-specific death rates prevailing at the time of his or her birth, for a specific year, in a given country, territory, or geographic area [1]. Life expectancy introduces the concept of longevity, which refers to individuals who surpass the population average life expectancy. A human being is generally considered long-lived individual (LLI) if he/she exceeds 90 years of age, though 100 years is commonly recognized as the threshold for exceptional longevity. Longevity is a relative concept that varies according to the country or population in question and must take into account differences in life expectancy influenced by genetic, historical, anthropological, and socio-economic factors. In absolute terms, longevity may be defined based on the maximum scientifically validated lifespan achieved [2,3]. At the global level, the longevity record belongs to Jeanne Calment, who died at the extraordinary age of 122 years [4]. Among men, the record is held by the Japanese supercentenarian Jiroemon Kimura, born in 1897 and deceased on 12 June 2013, at a validated age of 116 years and 54 days [5].

Chronological age, whether for living or deceased individuals, is typically defined as the time elapsed since birth. However, in addition to chronological age, parallel concepts have been introduced, such as biological age, based on biomarkers, and psychological age, estimated through cognitive parameters. Despite these developments, chronological age remains the only objective and universally applied parameter in aging research. Although age calculation is a precise operation, errors may occur due to age exaggeration or inaccuracies in administrative records. For this reason, age validation is a crucial step in the scientific study of longevity. In Italy, the age of a centenarian is certified by cross-referencing multiple data sources, such as identity documents and fiscal codes, and verifying consistency with information on offspring, marriages, and other family documents (e.g., birth and death certificates) [3,6].

Globally, the number of centenarians is estimated to range between 500,000 and 1,000,000, with an average ratio of five women for every man. The number of centenarians has increased over the course of history, but their existence has been documented only since the 18th century, following the introduction of parish records and, later, civil registration systems, which have enabled accurate assessments of age at the time of death [6].

POPULATION LONGEVITY

Population longevity is identified when the spatial distribution of centenarians is non-random and the proportion of individuals reaching advanced ages within a specific population exceeds that of surrounding areas. Investigating the determinants of such longevity typically focuses on characteristics and behaviours commonly shared within the population. This is grounded in the assumption that most individuals are born and raised in the same environment, thereby sharing genetic background, early-life conditions, and traditional habits, including diets based on locally sourced products [6,7].

Population longevity is generally inferred from an unusually high proportion of centenarians and nonagenarians. To compare longevity across populations, both scholars and media frequently employ centenarian prevalence (CP), a demographic indicator measuring the ratio of centenarians to the total population at a given time and location. CP is calculated as the number of individuals aged ≥ 100 years divided by the total population, multiplied by 10,000. This standardization facilitates comparative demographic analyses. However, CP presents limitations, particularly in contexts affected by migration or fertility shifts. For example, in populations experiencing demographic expansion or substantial youth immigration, CP may underestimate longevity by diluting the proportion of older individuals. Conversely, in depopulated areas with youth outmigration, CP may overestimate longevity. Consequently, CP may not always serve as a reliable metric for inter-population comparisons, despite its widespread use by gerontologists and policy institutions [6,7].

As underscored by Poulain and Herm [8], exceptional longevity in BZ populations is assessed using the Extreme Longevity Index (ELI). The ELI is defined as the proportion of individuals within a birth cohort who reach an advanced age, typically 100 years or more. In practical terms, it reflects the probability that a newborn will become a centenarian. To calculate the ELI, centenarians are identified based on their place of birth, and the number of live births in that location is determined for a specific historical period, typically a century or more earlier. The index is then computed by dividing the number of individuals born in a given municipality who reached age 100 or older by the total number of births in that municipality during the same period, and multiplying the result by 100. Cohorts born between 1860 and 1910 are often used to analyse long-term longevity trends. The ELI allows for the identification of geographical areas with exceptionally high concentrations of centenarians and is considered more robust than the CP indicator, as it is less affected by migration than CP. However, a limitation of the ELI is that it may slightly underestimate longevity if centenarians who emigrated are not accounted for due to unknown survival status or date of death. Fortunately, this underestimation is generally minimal, and, in

any case, the ELI remains a reliable metric for assessing exceptional longevity without the risk of significant overestimation. Another potential limitation is that the ELI is a relative measure, strongly influenced by the size and health status of the cohort under study, particularly in populations where only a small number of individuals reach extreme old age. Nevertheless, this issue is not relevant when applying the ELI to BZ populations. As with any measure of population longevity, rigorous age validation is essential to ensure accuracy, especially in small communities where even minor errors can lead to substantial distortions [6-8].

Sardinia offers a notable example of rigorous age validation. The process included: i) Cross-referencing civil and parish records (e.g., birth and baptism certificates); ii) Reconstructing complete genealogies from 1866 onward (the year civil registries were introduced); iii) Verifying the data using information on the siblings of centenarians [6,7].

Research on population longevity remains limited due to several challenges: i) Age validation is methodologically complex and often hampered by incomplete or inaccurate historical records; ii) Limited statistical power, as communities with exceptional longevity tend to be small and the number of extremely old individuals low; iii) The need for multidisciplinary approaches, as studies require expertise in demography, genetics, epidemiology, nutrition, and beyond. Methodologies are still evolving, and consensus on how to integrate cross-disciplinary data has yet to be reached.

Identifying the determinants of population longevity requires a detailed examination of the shared characteristics of LLIs. Since those born and raised in the same locality tend to share genetic, environmental, and behavioural factors, analysing these commonalities may help isolate variables associated with extended lifespan. Understanding the distribution of longevity across regions may ultimately yield insights into the biological and social drivers of long and healthy lives.

EARLY ATTEMPTS TO IDENTIFY AREAS OF LONGEVITY

At the beginning of the 20th century, the first potential longevity hotspots were claimed based on census-recorded centenarian prevalence and mortality rates. The U.S. Census Bureau compared the proportion of centenarians across various countries, highlighting exceptional cases such as Bolivia (7.5 centenarians per 10,000 inhabitants in 1900), Bulgaria (6 in 1905), and the Philippines (5.1 in 1903) [9]. In subsequent years, it became evident that such high prevalence was primarily the result of unreliable civil registration systems. To give a clearer picture, today in Italy, one of the countries with the highest longevity, the prevalence of centenarians is about 4 per 10,000 inhabitants [10].

In January 1973, Leaf reported that the prevalence of centenarians in Hunza (Pakistan), Abkhazia (then part of the Soviet Union), and Vilcabamba (Ecuador) was ten times higher than in most Western countries. He also noted that these populations lived in conditions of poor sanitation, high infant mortality, widespread infectious diseases, illiteracy, and lack of access to modern healthcare, factors that should make their alleged longevity even more remarkable [11]. In 1979, Mazess and Forman demonstrated that many individuals in Vilcabamba had exaggerated their ages, often to gain social prestige or to promote tourism [12]. By 1981, Leaf acknowledged that there was no reliable evidence to support the extraordinary ages claimed by the inhabitants of Vilcabamba and that no credible documentation existed for the Hunza or Abkhazians either [13].

Even today, reports occasionally emerge from remote areas of the world of individuals claiming to have reached 120 or even 130 years of age, often accompanied by the revelation of the secret to their longevity. Demographers routinely demonstrate that such claims are exaggerated and lack verifiable documentation. Studies such as that of Young et al. [14] have shown that in some mountainous societies of the Caucasus, age exaggeration, particularly among men, was used to enhance social status. To counter this phenomenon, rigorous age validation methods have been developed, including, as previously stated, cross-referencing of birth and death certificates, genealogical reconstruction, and triangulation across multiple independent sources [15].

THE FIRST BLUE ZONE (BZ)

In the late 1990s, a group of Italian researchers initiated a study on longevity in Sardinia. The Sardinian population, characterized by relative geographic isolation and reduced genetic diversity, offered a unique opportunity to investigate the genetic and environmental factors influencing lifespan. The project was named AKEA, an acronym for A Kent'Annos, a traditional Sardinian expression meaning "may you live to be one hundred". The findings were remarkable: the distribution of centenarians across the island was not uniform but instead clustered notably in the mountainous region of Ogliastra.[16] Even more unusual was the sex ratio among centenarians; whereas women typically far outnumber men among the oldest-old, in Ogliastra the male-to-female ratio was nearly equal (see the end of paragraph) [17].

In 1999, Pes, one of the researchers involved in the study, presented the data at a demography conference

in Montpellier, where it was met with scepticism from many experts. Among the most critical was James Vaupel, a leading demographer, who suggested that the high number of centenarians was likely due to errors in the civil registration system rather than genuine exceptional longevity [18]. Also present was Michel Poulain, a Belgian demographer renowned for his work in age validation, who was subsequently invited to verify the authenticity of the data. Over the following six months, Pes and Poulain visited around 40 municipalities in Ogliastra, interviewing centenarians and examining official documents. Poulain confirmed that this area of Sardinia did indeed exhibit extraordinary longevity. In 2004, the team published the results of their study, identifying the first BZ of human longevity, a term coined from the blue ink used to circle villages with high concentrations of centenarians on the map. To verify that the geographic distribution of centenarians in Sardinia was not random, a deterministic spatial model was employed. The results confirmed the existence of an area with an exceptionally high prevalence of centenarians: in 15 villages located between Ogliastra and Barbagia, surrounding the Gennargentu massif, 91 individuals (47 men and 44 women) out of 18,000 people born between 1880 and 1900 had reached 100 years of age, a figure three times higher than the Sardinian average. Two main hypotheses were proposed to explain this exceptional longevity: (1) the population long-standing geographic isolation, which may have stabilized the gene pool, and (2) the preservation of specific sociocultural and anthropological characteristics [19].

A BZ was defined as a geographically limited and demographically homogeneous area in which residents share a common lifestyle, environment, and likely genetic background, and where longevity significantly exceeds that of surrounding regions. These zones are typically characterized by low environmental pollution, traditional lifestyles marked by low stress, strong familial and community support, a natural diet, and high levels of physical activity sustained even into old age [6]. To date, no specific genetic markers have shown significant differences from the general population, leaving the role of specific alleles in Sardinian longevity unresolved. However, numerous studies have highlighted the crucial role of physical activity and nutrition, suggesting that sociocultural context plays a significant role [18]. The traditional Sardinian diet is largely composed of pasta, sourdough bread, vegetables, legumes, whole grains, red wine, and the traditional minestrone, prepared with onions, fennel, carrots, legumes (beans, fava beans, peas), potatoes, and pancetta [20-22].

To confirm the persistence of the BZ, in 2023 Michel Poulain, supported by Italian National Institute of Statistics and international experts, reanalysed Sardinian demographic data. Using spatial interpolation techniques, the new mapping showed that the BZ had expanded beyond Ogliastra to include villages west and south of the Gennargentu. Additional longevity hotspots were identified in northern Sardinia, in Gallura, and in the south, around Teulada. A person born in a village within the newly defined BZ has twice the probability of reaching 100 years of age compared to someone born in other parts of Sardinia. In conclusion, the most recent investigation not only confirms that the mountainous regions of Sardinia continue to represent an area of exceptional longevity, but also shows that the zones of longevity have expanded [7].

Concerning the male-female ratio mentioned at the beginning of the paragraph, the most evident difference in medicine between men and women concerns life expectancy. In Western countries, women live on average 5–6 years longer than men. Among centenarians, 85% are female. At the national level, the male-to-female ratio among centenarians is approximately 1:4.54, exhibiting a geographic north-south gradient: in northern regions, the ratio increases to about 1:7, whereas in southern regions it progressively decreases. However, in isolated areas such as the Sardinian BZ, the ratio is close to 1:1, due to the high prevalence of male centenarians [3,19].

It remains debated whether the greater female longevity is attributable to gender-related factors or biological sex, i.e., cultural versus biological influences. Since females outlive males in other animal species as well, it is unlikely that this phenomenon is exclusively linked to cultural behaviours. Biological factors, such as differences in hormone production or the presence of two X chromosomes, must contribute at least partially to female longevity [23,24].

A study of the community of Villagrande Strisaili, located in the heart of the BZ, found that men from this town have life expectancies equivalent to those of women and that the number of male centenarians is virtually equal to that of females. The absence of a survival gap is attributed to an extraordinary male resilience, with survival curves around age 60 exceeding those of the rest of Italy for men born between 1881 and 1920. Certain genetic factors have been hypothesized as determinants of male longevity, but current evidence does not support the notion that specific genetic polymorphisms are responsible for this trait. Mitochondrial DNA has also been investigated for its potential role in sex differences in longevity. In particular, haplogroup J was identified at more than twice the frequency among male centenarians compared to the rest of the island (18.3% versus 6.7%), suggesting a possible role in reduced male mortality [8,25,26].

Additional factors to consider include anthropometric differences between men and women. In this BZ, the average height gap between sexes may be less pronounced,

while women may have a relatively higher body mass index (BMI). If these differences are confirmed, they could favour male longevity, since there is an inverse correlation between height, BMI, and lifespan. Analyses of military conscripts indicate that men from the BZ tend to be shorter than their peers from other Sardinian areas, although comparable data for women are lacking, limiting further exploration of this hypothesis [8,27-29].

Lifestyle-related factors may also contribute to male longevity in this BZ. Potential differences in diet and physical activity levels between men and women, linked to distinct social roles, could play a key role [27,28]. Although specific studies on gender differences in the Sardinian diet are lacking, it is hypothesized that greater wine consumption by men, combined with their physical activity as shepherds or farmers, may have positively influenced their longevity. The Sardinian BZ is situated in a mountainous area, which may have increased daily energy expenditure in adult men, further supporting their survival. Socio-cultural aspects may also impact male longevity. Central Sardinian society was traditionally matriarchal until industrialization in the 1950s. While men worked in agriculture and shepherding, women managed households and preserved moral values, which may have generated higher stress levels among women and consequently higher female mortality. Certain social norms and family dynamics may further favour male survival. In the BZ, married men often have younger spouses, reducing the risk of widowhood, a condition associated, especially among men, with reduced life expectancy. Indeed, data from Villagrande show a higher proportion of married men among the oldest individuals compared to the rest of Sardinia and Italy, with most of these men married to younger women. This phenomenon favours their survival, as does the tendency of older men to live with an unmarried daughter following the loss of a spouse, whereas older women are more likely to live alone [25].

Finally, fertility and reproductive history may influence female longevity. Traditionally, Sardinian women had high birth rates and gave birth at advanced ages, factors that could have increased pregnancy-related complications and reduced exposure to oestrogens, hormones known for their protective cardiovascular effects. Certain gender stereotypes and related social conventions in the BZ may have favoured male longevity. In these communities, older men receive a high degree of care and support both from family and society, which may contribute to prolonging their lives [8,25].

THE OTHER BZS

Following the identification of the Sardinian BZ, a process of age validation for centenarians was also initiated in Okinawa (Japan), already renowned for the exceptional longevity of its inhabitants. The results confirmed this characteristic, officially granting the region BZ status. The concept of BZs gained further recognition the year after the scientific publication on Sardinia, when National Geographic journalist Dan Buettner popularized the term in an article highlighting three regions, Okinawa (Japan), Loma Linda (California), and Sardinia, where research had shown that people live significantly longer and healthier lives than average [18,21]. Longevity and well-being of these populations was attributed to specific lifestyle factors: individuals in these regions tended to follow a diet rich in fruits and vegetables, engaged in regular physical activity, prioritized family and community, and avoided smoking. Other factors included moderate alcohol consumption, calorie moderation, effective stress management, a sense of purpose, religious involvement, and favourable genetics [8,18]. After Sardinia and Okinawa, two additional BZs were identified: Nicoya (Costa Rica) and Ikaria (Greece) (see below).

With regard to Loma Linda, it is important to note that this community has never been subjected to the same level of demographic scrutiny as the other BZs. Despite its frequent inclusion in media narratives, no formal validation study has confirmed its status as a BZ. Instead, longitudinal studies have shown that members of this community live, on average, four to seven years longer than other Californians, an outcome attributed to conscious lifestyle choices rooted in the Seventh-day Adventist faith. Adventists adhere to a health-conscious lifestyle, characterized by a predominantly vegetarian diet, abstention from alcohol and tobacco, regular physical activity, and a strong sense of community and spirituality. Unlike the BZs, longevity in Loma Linda does not stem from favourable environmental conditions or ancestral traditions, but from religiously motivated behavioural choices, rather than from any spatial demographic clustering [30].

Okinawa, an archipelago of about 160 islands located in the southernmost part of Japan, is one of the country 47 prefectures and is home to over 1,000 centenarians among its 1.37 million residents. Since 1976, the Okinawa Centenarian Study has investigated the causes of this remarkable longevity, attributing it to a combination of genetic, dietary, climatic, cultural, and social factors. Okinawans exhibit distinct genetic traits compared to the broader Japanese population, suggesting a degree of genetic isolation that may contribute to increased longevity. Numerous studies have explored the link between diet and longevity in Okinawa, hypothesizing that low caloric intake may be a key factor in extending life expectancy by reducing the incidence of cardiovascular disease, diabetes, and cancer. Traditional

Okinawan cuisine included, instead, tofu, vegetables, purple sweet potatoes; champuru (a stir-fry made with bitter melon, cabbage, bamboo shoots, and kombu seaweed); nbushi (watery vegetables like daikon, luffa, carrots, or pumpkin, cooked with miso); and irichi, a sautéed mix of slow-cooked vegetables including burdock, dried daikon, green papaya, and seaweed [31,32].

The population of the Nicoya Peninsula in north-western Costa Rica exhibits a longevity advantage over the national average, with an overall mortality rate approximately 20% lower. Scientific studies have found that Nicoyans are, on average, taller than the general Costa Rican population but have lower BMI and fewer physical and mental disabilities. Environmental factors may play a role: the region drinking water is high in calcium, which may offer protection against cardiovascular disease and age-related osteoporosis. Older adults in Nicoya experience particularly low stress levels, as reflected in various social indicators, including reduced suicide rates. Longevity in Nicoya is also supported by improved socioeconomic conditions, an effective social security system, and government-guaranteed access to free healthcare. Traditional Nicoyan diets include beans, squash, and corn (the "three sisters"); rosquillas; tortillas; tropical fruits like mango and papaya; and gallo pinto, a mix of rice and black beans often served with corn tortillas [20,22].

Ikaria, a Greek island in the Aegean Sea with just over 8,000 inhabitants, boasts one of the highest life expectancies in Greece and an unusually balanced ratio of older women to men. Most Ikarians follow a traditional lifestyle that includes a localized version of the Mediterranean diet, vigorous physical activity, and low stress levels. The most striking feature of Ikarians is their ability to live free from stress, as demonstrated by their well-known indifference to wealth and material goods. Afternoon napping is also a common practice, and some research suggests it may lower the risk of coronary mortality. Their diet includes olive oil, vegetables, fruits, legumes, local products, red wine, herbal teas, and honey; and soufiko, a stew of eggplants, yellow peppers, potatoes, green beans, tomatoes, onions, garlic, zucchini, crushed chili, olive oil, and red wine [7,20,33].

Martinique, an overseas department of France located in the West Indies, is known for its banana plantations, rum, and idyllic beaches. With a population of 350,000, the island is marked by a strong *joie de vivre*, despite having one of the highest median ages among French regions due to significant youth emigration to mainland France. As early as 2007, French demographers had noted an unusually high presence of supercentenarians (people aged 110 and older) in Martinique and Guadeloupe. Eight such individuals were identified, whereas statistically, only one would have been expected [34].

Beginning in December 2019, efforts emerged to have Martinique officially recognized as a BZ. Despite pandemic-related delays, results finalized in February 2023 confirmed significant findings: as of January 1, 2023, the island was estimated to have over 400 centenarians, twice the national average. Additionally, the probability of reaching 100 years of age is twice as high for residents of Martinique compared to mainland France. Interestingly, older Martiniquans tend to live longer if they remain on the island, compared to those who emigrate to France. Based on rigorous scientific validation, Martinique has now been recognized as a BZ by Michel Poulain [7]. However, there is an apparent contradiction between the reported longevity and other health indicators [35-37] (see below for a possible explanation). Vallin [34] hypothesizes that the high prevalence of supercentenarians in Guadeloupe and Martinique, as opposed to another French overseas territory, La Réunion, may be linked to a genetic selection process rooted in the history of slavery, particularly the deadly Atlantic crossing, during which only the most resilient individuals survived and reproduced. Compared to La Réunion, where slavery was less widespread and less brutal, this could partly explain the longevity differential. However, this hypothesis does not account for why only Martinique, and not Guadeloupe, is classified as a longevity hotspot. In any case, definitive conclusions would require genetic studies [34].

In Italy, there are also areas where longevity exceeds expectations (so-called longevity hotspots), although ongoing studies have not yet confirmed them as official BZs, such as Cilento and certain mountain villages in Sicily located in the Sicani and Madonie ranges [20,38-41].

Lessons from BZs

The concept of BZs has significantly advanced our understanding of the determinants of exceptional longevity. Populations residing in these regions appear to share not only certain genetic traits (see next paragraph for a discussion of the role of genetics in longevity), but also longstanding cultural traditions, comparable early-life experiences, consistent exposure to local environmental conditions, and a diet predominantly composed of regional, minimally processed foods. According to Michel Poulain [7], research conducted within these zones has yielded seven core principles associated with extended lifespan and improved healthspan: i) Engage in Natural Physical Activity; ii) Practice Nutritional Moderation; iii) Minimize Chronic Stress; iiii) Prioritize Familial Relationships; iiiii) Foster Community Integration; iiiiii) Maintain Environmental Harmony; iiiiiii) Sustain a Sense of Purpose [7]. Collectively, these principles not only contribute to increased lifespan but also enhance the quality of life, highlighting the intricate interplay

between individual behaviours, social cohesion, and environmental stewardship in the pursuit of healthy ageing. Adherence to these principles not only fosters extended lifespan but also enhances quality of life, reinforcing the interdependence of individual and communal well-being. Table I presents some of the previously mentioned factors and their potential mechanisms in promoting healthy ageing.

BZs and genetics

Coming back to genetics of longevity, it has become clear that longevity does not depend solely on genetics. This message was widely reported following a collaborative study by statisticians from Ancestry and Calico Life Sciences, which analysed the genealogies of 400 million individuals, incorporating birth and death dates, locations, and family relationships, and concluded that genetic factors account for less than 10 percent of lifespan variation [42]. Although this large-scale investigation assessed the influence of genes on lifespan, it did not specifically examine exceptional longevity, since only a few families with centenarians were included. Conversely, compelling evidence indicates that a healthy lifestyle can substantially increase life expectancy in the general population [43]. A study published last year of over 276,000 U.S. veterans found that adoption of eight healthy behaviours could extend life by up to 24 years. These behaviours included adhering to a balanced diet, engaging in regular physical activity, obtaining sufficient sleep, managing stress effectively, cultivating strong social relationships, and avoiding smoking, opioid misuse, and excessive alcohol consumption [44]. According to the authors, veterans who practiced all eight behaviours might expect to live to approximately 87 years, nearly a decade longer than the average U.S. life expectancy [44].

In contrast, an investigation of a cohort of Ashkenazi Jews living in community settings, defined as exceptionally LLIs by their ability to survive independently to age 95 or older [45], showed that, within this ethnic group, individuals with exceptional longevity did not differ from the general population in lifestyle factors. This finding suggests that such individuals may interact differently with environmental influences. It is important to consider the unique genetic history of this population, which has experienced repeated bottlenecks due to pogroms in various European countries. Bottlenecks reduce genetic diversity and amplify the effects of genetic drift, a stochastic process altering allele frequencies over time; as a result, some alleles may become fixed or lost by chance. This phenomenon has contributed both to increased frequencies of certain rare genetic disorders, such as Tay–Sachs disease, and, potentially, to the spread of alleles with beneficial effects [46].

More generally, centenarians exhibit lower incidence rates of age-related diseases, including cardiovascular disease, cancer, and dementia, as demonstrated by a recent registry-based study of all individuals aged over 60 born between 1912 and 1922 in the Stockholm region of Sweden (n = 170,787). Using historical records, participants were followed prospectively from 1972 to 2022 and classified by age at death [47]. The study found that centenarians, across all age bands, had lower incidence rates for almost all diseases compared to controls who did not reach 100. Individuals with exceptional longevity may therefore carry genetic factors that mitigate the effects of unhealthy behaviours. Supporting this hypothesis, studies of centenarian offspring have shown that parental exceptional longevity is associated with reduced cardiovascular disease prevalence, independent on lifestyle, socioeconomic status, and diet, highlighting a potential genetic contribution to disease-free survival among offspring of LLIs [48].

As discussed above, during the first eight decades of life, lifestyle exerts a greater influence on health and survival than genetics. However, beyond age 80, genetic factors appear increasingly important in maintaining health and longevity. Among centenarians, genetic contribution is estimated at up to 33 percent in women and 48 percent in men [49]. Recent reviews of longevity genetics have consistently identified only alleles of Apolipoprotein E and Forkhead box O3A, both associated with cardiovascular protection, across multiple studies [50,51]. This consistency likely reflects the dynamic nature of genetic determinants of longevity, which are shaped by a population unique environmental history. It is thought that population-specific genes play a larger role in achieving exceptional longevity than variants shared across populations, underscoring the complex interplay of genetic and environmental factors in determining individual healthspan and lifespan [48,49,52].

In general, the effect sizes of identified longevity-associated genes are small, implying that longevity, as with other complex traits, is influenced by many loci of modest effect. Consequently, genome-wide association studies (GWAS) have yielded few replicated associations between common variants and longevity. By aggregating data from diverse populations, GWAS may overlook the ecological context of longevity, potentially diluting the impact of population-specific genetic factors [51]. This may explain the lack of strong genetic associations observed among centenarians in BZs.

CRITIQUES OF THE BZS: THE NEWMAN CONTROVERSY

The concept of BZs has been the subject of critique by Saul Newman, an Australian researcher affiliated with

Table I. The science of longevity: BZs and Italian longevity hotspots as model of healthy ageing.

Factor	BZs	Cilento	Mountain villages of Sicily	Biological mechanisms and health benefits
Diet	Mediterranean-style diet rich in polyphenols, legumes, nuts, and olive oil (only in Ikaria and Sardinia); low in red meat and processed foods	Traditional Mediterranean diet, rich in extra virgin olive oil, vegetables, whole grains; low in red meat and refined sugars	Mediterranean diet with rural traditions, high consumption of legumes, wild herbs, seasonal vegetables, extra virgin olive oil; low in processed foods	Antioxidant and anti-inflammatory effects, protects against CVD, T2D, neurodegenerative disorders
Environmental quality	Low pollution, clean air, pure water sources.	Low pollution, minimal industrial exposure, high environmental purity.	Low pollution, mountains climate with clean air, and natural water sources.	Reduces oxidative stress, supports mitochondrial function, prevents vascular ageing.
Natural rhythms and sleep	Exposure to natural light, daily naps (siestas), low artificial light at night	Strong alignment with natural rhythms and a culture of frequent napping	Balanced natural rhythms due to rural lifestyle, frequent afternoon rest, low exposure to artificial light	Improves sleep quality, lowers cortisol, enhances cognitive function
Physical activity	Daily natural movement (walking, farming, household activities)	Active lifestyle with regular walking, gardening, and outdoor activities	High physical activity through farming, walking, walking on hilly terrain, manual labour, and traditional crafts	Reduces obesity risk, maintains cardiovascular health, enhances mitochondrial biogenesis
Social cohesion and purpose	Strong community ties, family-centred lifestyle, "Ikigai" (sense of purpose), Plan de Vida	Multigenerational living, strong social bonds, "La Bella Vita" philosophy	Strong community ties, high family involvement, spiritual traditions, and social cohesion in small villages	Lowers stress, improves mental resilience, enhances longevity
Stress and inflammation	Low chronic stress due to relaxed lifestyle and strong social support	Low stress, strong community engagement	Low stress due to rural environment, close-knit communities, and traditional spiritual practices	Decreases systemic inflammation, lowers risk of age-related diseases
Age-related diseases	Low incidence of cardiovascular diseases (CVD), type 2 diabetes, and alzheimer's diseases	Low incidence of CVD, cognitive decline, and metabolic disorders	Lower prevalence of CVD, metabolic syndrome, and cognitive disorders due to traditional diet and lifestyle	Prolonged healthspan, lower morbidity, better quality of life

Bibliography in reference [38].

University College London. Although he lacks formal training in gerontology or demography, Newman has recently concentrated on challenging longevity research, highlighting what he considers methodological shortcomings. He argues that many reported centenarians may not be genuine and points out that BZs are often located in economically disadvantaged and geographically remote regions, where civil registration systems may be incomplete or unreliable [53,54]. Newman also challenges the alignment between lifestyle characteristics attributed to BZ populations and epidemiological indicators. He cites Okinawa as an example, noting that it ranks first among Japan's 47 prefectures in BMI, second in beer consumption, and fourth in suicide rates among individuals over 65 [53,54]. However, this critique omits key contextual details.

Indeed, a group of researchers from diverse backgrounds, but all involved in the study of BZs, has responded to Newman's criticisms, amplified by mainstream media, which attempt to discredit the BZs through a series of unfounded arguments [53,54]. These arguments, the researchers write [55], were advanced by a critic lacking any academic training or expertise in demography, gerontology, or geriatrics, and without a single peer-reviewed publication in these fields. His manuscripts have never been published in any scientific journal subject to peer review. After describing the general procedures for identifying BZs, outlined earlier in

this paper, the researchers provide concrete examples of how fieldwork was conducted. For instance, Sardinia, one of the most studied BZs, is situated in a G7 country with a robust civil registration infrastructure dating back to the 19th century. In Sardinia, civil records are further corroborated by baptismal certificates, as nearly all infants were traditionally baptized. These ecclesiastical documents provide an independent means of age verification, reinforcing the credibility of reported longevity. So, a complete genealogical reconstructions of village inhabitants from 1866 onward was performed. Not only were the birth and death dates of each centenarian verified, but also those of their siblings, allowing for the exclusion of identity substitution. This rigorous process led to the removal of a single false supercentenarian from the Sardinian database [56]. So, the exceptional longevity observed in these regions is well-documented and grounded in methodologically sound research. Newman claims that the high number of centenarians and supercentenarians in certain non-BZ areas is due to errors in demographic records, a point that is sometimes valid. However, he fails to acknowledge that this does not apply to the BZs, where ages have been rigorously validated using modern and reliable demographic methods, as previously stated. He also argues that BZ records exhibit signs of “age heaping". Yet such phenomena are absent in the validated BZ datasets, which show no anomalous distribution of birth dates. Furthermore, examples of fraudulent death registrations in Japan and the United States are entirely irrelevant to the BZs, where each data point has been meticulously verified and every suspicious case excluded. Another assertion, that BZs coincide with areas of high illiteracy, poverty, and crime, is misleading. Although some BZs have experienced delays in socioeconomic development [57], such factors do not influence longevity rate calculations. For instance, in 2005, Okinawa had the highest rate of centenarians from age 70 onward, far surpassing the Japanese average [58]. It is true that the increase in life expectancy in Okinawa has slowed compared to other prefectures. However, this is attributable to factors such as the spread of Western diets and the development of infrastructure discouraging physical activity, not to poverty or crime (see below). Japan, in fact, has one of the lowest crime rates in the world. Longevity is also not a static phenomenon and may change in response to shifts in lifestyle (see conclusions). The use of crime and poverty statistics from the whole of Sardinia to discredit the BZs is equally misleading. The Sardinian BZ is a small rural area of about 50,000 inhabitants distributed across six mountain villages, whereas the total population of Sardinia is approximately 1.6 million, mostly residing in urban centres such as Sassari and Cagliari. In conclusion, the ages of individuals in officially recognized BZs have been rigorously validated, and their exceptional longevity is well documented. The critic preprints are ethically and scientifically irresponsible. Their dissemination through mainstream media and popular science media [59,60] constitutes an insult to both the scientific community and the BZ populations, who proudly celebrate their lder adults and the culture of longevity [55].

Moreover, researchers engaged in Okinawan longevity studies have already addressed these apparent inconsistencies pointed out by Newman. Following World War II, local dietary patterns underwent significant Westernization, influenced in part by the introduction of American-style meals to schoolchildren by U.S. military forces. This shift contributed to a broader transformation in lifestyle, leading to Okinawa’s decline in national life expectancy rankings. Mortality data reveal a generational divide: pre-war cohorts maintain favourable mortality profiles, whereas post-war generations show markedly higher mortality relative to the national average [32].

A similar argument can be made regarding the apparent contradictions between longevity and general health status observed in Martinique, as this island has also undergone a nutritional transition that has contributed to the rise in chronic diseases [36]. In Nicoya, also, socioeconomic and cultural transitions have eroded its distinctiveness over time. A recent study has shown that the longevity advantage among Nicoyan men is diminishing. While Nicoyan males born in 1905 had 33% lower adult mortality rates than other Costa Ricans, those born in 1945 had 10% higher rates. The geographic area originally identified as the “Nicoya BZ” has since contracted to a small region in the southern peninsula. Nonetheless, Nicoyan men born before 1930 who are still alive continue to exhibit exceptionally high longevity, a characteristic not observed in more recent cohorts [61].

CONCLUSIONS

Critical scrutiny is a cornerstone of scientific inquiry and should be actively encouraged. Age validation, while inherently provisional, remains a vital methodological process. The convergence of rigorous verification procedures and the extraordinary prevalence of centenarians in BZs supports, with reasonable confidence, the assertion that such regions of exceptional longevity do indeed exist. However, BZs are not immutable geographical entities; they are dynamic ecosystems shaped by the evolving interplay between tradition and modernity. These communities emerge, develop, and may eventually decline, depending on how effectively their core values and practices adapt to changing socio-cultural

(lifestyle and exposome) and demographic conditions. A BZ represents a favourable phase in a community trajectory, where traditional elements such as strong social networks, simple local diets, regular physical activity, and a sense of purpose coexist with beneficial modern features, including basic healthcare, improved sanitation, education, and selective technological integration. When these elements align, they create optimal conditions for longevity and well-being. Over time, communities may reach a stable state characterized by high life expectancy and low incidence of age-related diseases. However, maintaining this equilibrium requires proactive stewardship, through sound policies, education, and a commitment to preserving both cultural heritage and healthy modernization. Without such efforts, the balance may deteriorate, as evidenced by the decline seen in Okinawa, and potentially in other BZs.

However, irrespective of whether these regions were ever fully "authentic" from a demographic standpoint, the lifestyle patterns associated with the BZ paradigm remain central to the promotion of healthy ageing. Their behavioural and environmental practices provide a valuable framework for informing public health strategies aimed at enhancing resilience against non-communicable diseases. Effectively translating such empirical insights into comprehensive public health policies and preventive care models is essential for extending healthspan and delaying the onset of age-related pathologies. Strategic interventions, such as reducing exposure to environmental pollutants, expanding urban green infrastructure, improving dietary quality, and implementing community-based wellness programs, combined with the promotion of anti-inflammatory diets, regular physical activity, and stress reduction, hold considerable promise for advancing healthy ageing on a population-wide, and potentially global, scale. As urbanization and modernization continue to reshape daily life, preserving and adapting traditional health-supporting behaviours becomes increasingly important. Ultimately, the exceptional longevity observed in these communities highlights the value of personalized, context-sensitive approaches that integrate ecological and sociocultural factors, in contrast to one-size-fits-all prevention models.

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