Bayesian Spatially-Adjusted Gini Index Using Poverty Rates for Fine-Grained Inequality Mapping

Xavier Perafita[1,2], Alba Tarres[1], Angi Vila[1], David Solano2, Manuel A. Moreno[2,3,4], Diana S. Antonio[2], Wendy S García-Peñuela[2], Marta Solans[2], Maria A. Barceló[2,4], Marc Saez[2,4]

1 Observatori—Organisme Autònom de Salut Pública de la Diputació de Girona (Dipsalut), Girona, Spain

2 Research Group on Statistics, Econometrics and Health (GRECS), University of Girona, Spain

3 CIBER of Epidemiology and Public Health (CIBERESP), Madrid, Spain

4 Unitat de Suport a la Recerca de la Catalunya Central, Foundation for Research in Primary Health Care Jordi Gol i Gurina, Sant Fruitós de Bages, Spain

METMA 2025 - LATAM II

Introduction

Life expectancy (LE) is a key indicator of population health, but traditional estimates—based on national or large regional aggregates, mask local variability and become unstable in small municipalities; these highly volatile values in very small areas hinder LE analysis and limit the design of tailored public health policies. To address this, we propose developing a Bayesian framework to produce continuous LE estimates in very small areas of Catalonia (even those with fewer than 100 inhabitants), disaggregated by sex and nationality to capture intersectional health inequalities, and to assess the feasibility and temporal stability of these estimates in order to inform more precise municipal health policies.

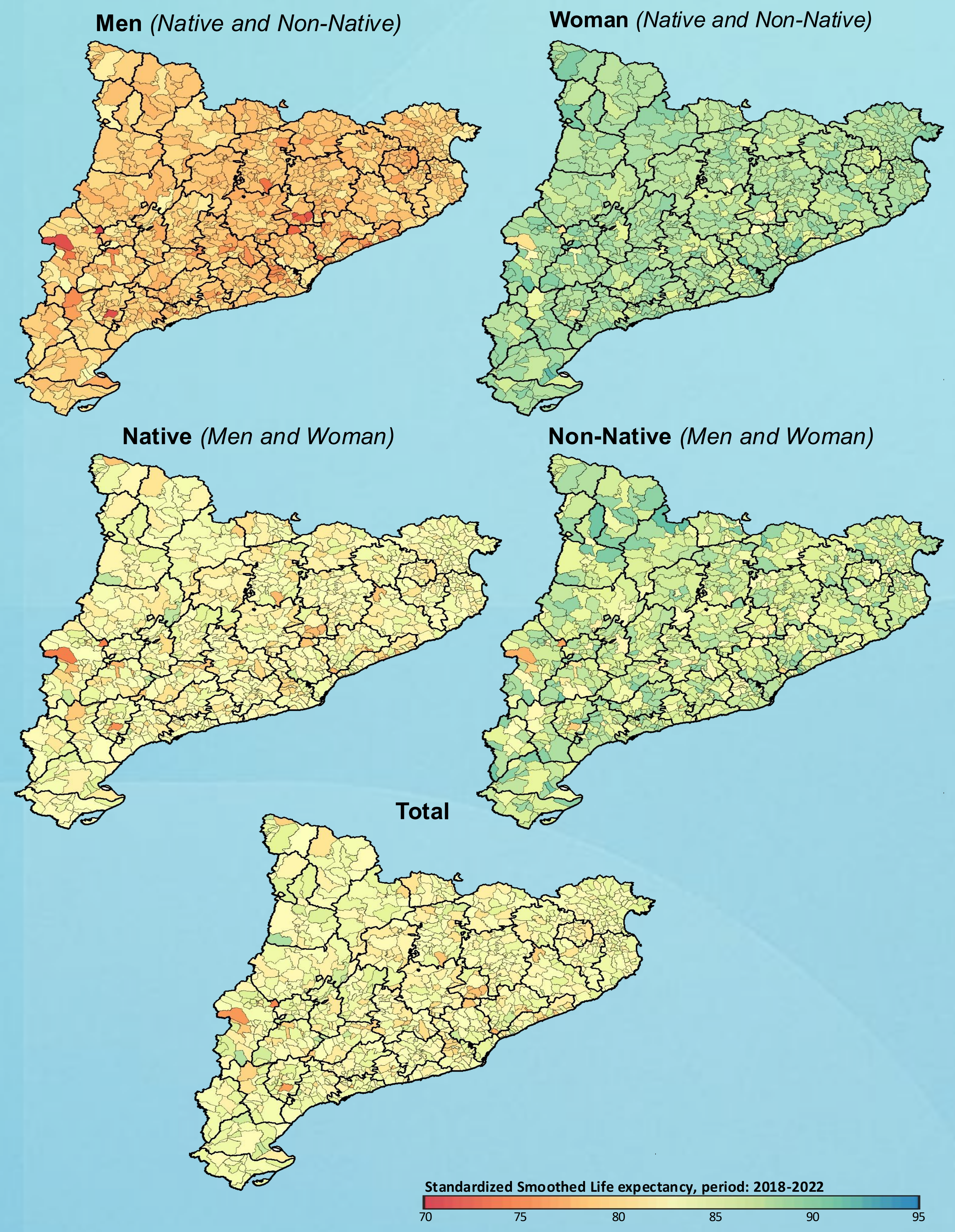
Methods

We conducted a **longitudinal ecological study** using data from approximately **1,000 municipalities** in Catalonia, covering **nearly 1.5 million deaths** between 2000 and 2022. Our main outcome was **life expectancy at birth**, **stratified by sex and nationality**. To estimate it, we derived **life tables** from **standardized mortality ratios** and **relative risks**, which were obtained through a **Bayesian spatiotemporal mixed-effects model**.

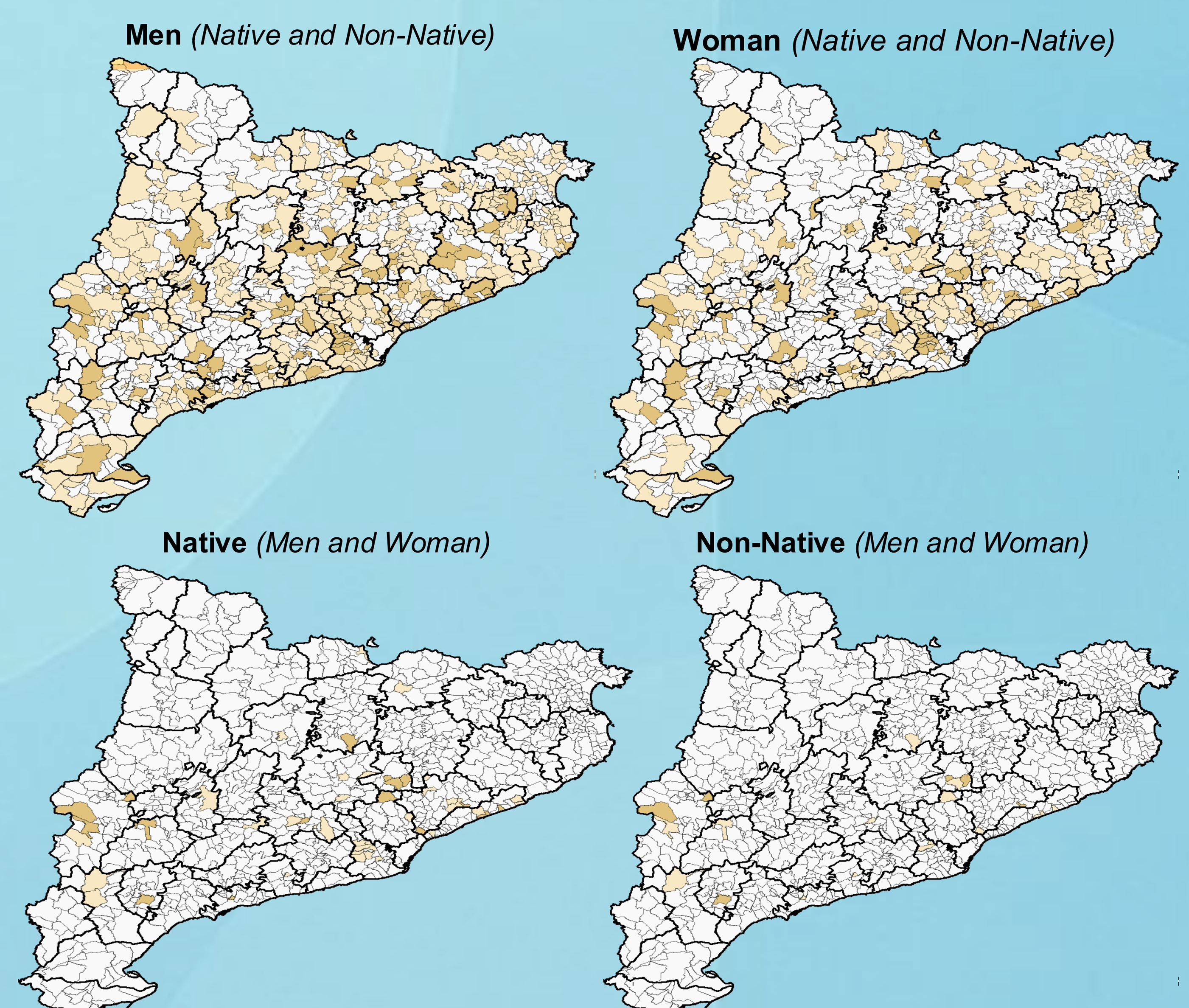
The model incorporated **both observed and unobserved heterogeneity by** including **spatially structured and unstructured random effects**, as well as separable and non-separable spatial and temporal components. Age-specific mortality risks were modeled with **interactions between sex, nationality, and age groups**, allowing for nuanced estimation of disparities. To explore contextual influences on longevity, we performed additional ecological analyses using municipal-level covariates. All inferences were made in a **Bayesian framework** using the **Integrated Nested Laplace Approximation (INLA)** approach, with **complexity-penalizing priors** to control model flexibility and avoid overfitting.

Results

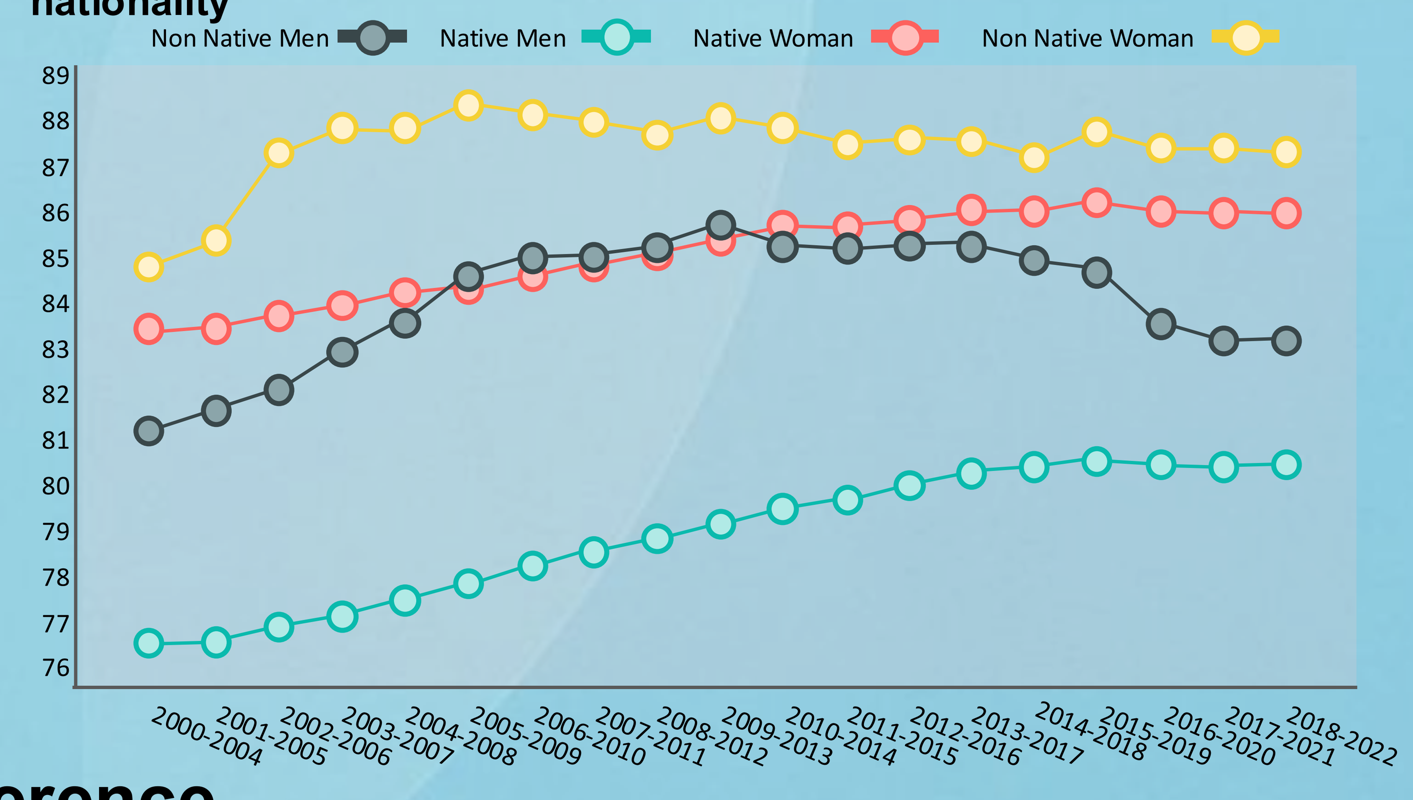
Life expectancy calculated by sex and nationality (2018-2022)



Median exceedance probability maps of mortality rates by sex and nationality (2018-2022)



Life expectancy at birth standardized and intersected by sex and nationality



Conclusions

- The **Bayesian model** provides highly reliable LE estimates in very small, low-density areas, ensuring **consistent results over time** and facilitating precise identification of high-risk municipalities.
- **Standardization** is essential: it **reveals inequalities**—particularly between native and non-native populations—that unstandardized estimates tend to mask (e.g., the widened LE gap during the Spanish economic crisis).
- Identifying these **high-risk areas** enables the design of **targeted**, **territory-specific interventions**, fostering more equitable and efficient public health responses.
- Analyses of **tiny or minority populations** require careful disaggregation to avoid biased conclusions; **calculating native-only LE may help mitigate distortion** introduced by heterogeneous non-native groups.

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Dipsalut Diputació de Girona
GRECS
Universitat de Girona
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