Multifactor Simulation and Evaluation of Future Land-Use in the Atlanticas Islands (NW Spain) with a Temporal–Spatial Fusion Network (TSFN)

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Abstract: Land cover change (LULC) in the Atlánticas Islands of Galicia (NW Spain) is reshaping biodiversity and local livelihoods. We apply a Temporal Spatial Fusion Network (TSFN) to hindcast 2015–2020 and forecast 2020–2040 land use and cover under 3 policy scenarios: Benchmark (BS), Development Priority (DPS) and Ecological Priority (EPS). TSFN reaches κ 0.99 in BS, κ 0.97 in DPS and κ 0.99 in EPS, outperforming an ANN-CA baseline at κ 0.90. Although the overall mosaic shifts by <5 %, 2 clear trajectories emerge. Cropland, with its food production service, dropped 6 % during 2005–2020 and is set to fall another 14 % by 2040 as scrub expands. Regulating and cultural services also weaken water supply −45 %, waste treatment −43 %, climate regulation −27 %, recreation −40 % and biodiversity protection −38 % in DPS. EPS cushions ≈25 % of these losses but cannot halt cropland decline. By ingesting near real time multispectral data, TSFN provides detailed multiscenario maps that give park managers a solid basis to balance tourism, resource extraction and conservation in this oceanic reserve.
Keywords: Land use/land cover (LULC) forecasting, Multiscenario modelling, Ecosystem service valuation (ESV), Remote sensing (RS), Spatial planning.

1. Introduction

Land-use and land-cover change (LULCC) affects about 75 % of the global land surface and accelerates biodiversity loss and the decline of ecosystem services (ES) (Fang et al.,2022). Tourist islands are especially vulnerable because of limited space, seasonal population peaks and intense infrastructure demand increase soil sealing, freshwater stress and habitat fragmentation (Roy et al., 2022). Yet most island studies focus on past change and rarely translate future land trajectories into service impacts (Wang et al., 2022).
This work applies a deep-learning model, the Temporal Spatial Fusion Network (TSFN), in the Atlánticas Islands of Galicia National Park, a 1,200 ha oceanic archipelago under strong tourism and resource-extraction pressure. A built-in data generator streams satellite imagery and socioeconomic layers directly to the network, so full rasters never need to reside in memory. Projections for 2020–2040 reveal three main risks: continued cropland loss that erodes food production, drops of 40 %–45 % in water-supply and recreation value, and declining climate-regulation capacity. The resulting scenario maps and quantified service indicators give park managers a solid basis for balancing tourism, resource use and conservation within this Atlantic reserve.

2. Materials and methods

2.1. Study area

Atlánticas Islands National Park spans 8,480 ha (7,285 ha marine and 1,195 ha land) and includes the Cíes, Ons, Sálvora and Cortegada archipelagos off Galicia, NW Spain. Rainfall rises from about 1,000 mm yr^{-1} in Cíes to almost 2,000 mm yr^{-1} in Cortegada, with mean temperatures of 13 – 15 °C (MITECO, 2025).The park hosts Spain's largest colony of European shag, roughly 700 – 1,000 pairs, alongside thousands of yellow-legged gulls. Visitation reached 509,000 people in 2024; summer quotas limit entry to 1,800 visitors d^{-1} in Cíes and 1,300 in Ons, managed through an online permit syst. Management follows the 2019 zoning plan that designates core, buffer and regulated-use areas.

Figure 1. Location of Atlánticas Islands National Park on the coast of Galicia, north-west Spain.

2.2. Method summary

All layers were resampled to a 30 m grid restricted restricted to the Atlantic Islands National Park extent.
The core layer was land-use/land-cover (LULC); auxiliary rasters included topography (elevation, slope), climate normals, wind speed, vegetation indices (NDVI), net primary productivity, soil classes, carbon flux, socio-economic variables (population density, GDP), Natura 2000 polygons, and OpenStreetMap-derived distance rasters to roads, buildings, railways and water bodies. After standardisation, the full stack of bands was reduced to four principal components explaining ≥ 95 % of the total variance.
The TSFN ingests 5 x 5 cell patches in three temporal sequences (2000 – 2005 – 2010, 2005 – 2010 – 2015 and 2010 – 2015 – 2020). A ConvLSTM, a gated Transformer and an LSTM are trained with a Keras generator that applies class weighting, early stopping and a learning-rate schedule. Model skill is evaluated with overall accuracy (OA), kappa (κ), producer (PA) and user accuracy (UA), Figure of Merit (FoM) and area under the curve (He et al., 2018) and is benchmarked against an ANN-CA baseline.
Outputs are generated for the BS, EPS and DPS scenarios. ESV in €/ha follows the coefficients of Costanza et al. (1997), and spatial clusters of gains and losses are identified with the Getis Ord statistics.

3. Results and discussion

TSFN gives κ 0.997 in 2015 and 2020 for the BS; DPS and EPS stay solid at κ 0.97. OA, PA and UA all exceed 0.95. The model raises κ from 0.90 to almost 1.00 relative to the ANN CA baseline. Change matrices show 97 % class stability from 2000 to 2020; cropland is the main exception, already down 6 % and projected to fall another 14 % by 2040. Forecast maps for 2040 are almost identical across scenarios: terra firma vegetation dominates, and built-up land is negligible. Service valuation highlights large declines by 2040: water supply −45 %, waste treatment −43 %, recreation −40 %, and about −27 % in both climate regulation and soil formation. Even small land-cover shifts could therefore erode key benefits, making TSFN's 30 m outputs a sound guide for safeguarding cropland, freshwater resources and visitor capacity in future park planning.

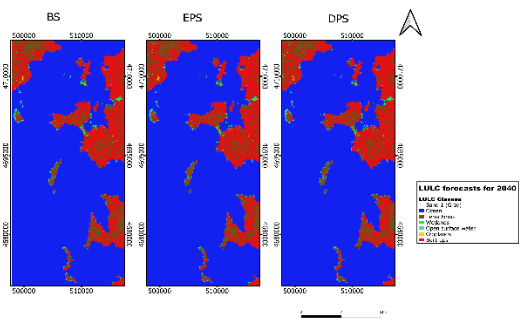

Figure 2. Atlánticas Islands LULC forecasts for 2040 under BS, EPS and DPS scenarios.

4. Conclusions

TSFN reaches κ 0.997 and keeps OA, PA and UA > 0.95 when validated against 2020 reference maps. Change detection shows 97 %-pixel stability from 2000–2020; cropland is the exception, dropping 6 % in that period and projected to lose another 14 % by 2040, mostly replaced by scrub. This contraction drives sharp ES losses for 2040: water-supply capacity −45 %, waste-treatment potential −43 %, recreation value −40 %, climate regulation −27 % and soil formation −27 %. Built-up area stays ≈0 % under all scenarios, confirming effective zoning. Because TSFN ingests 30 m data through an internal generator, it produces high-resolution, scenario-based maps without external LULC layers or heavy preprocessing. The outputs give managers numeric targets for cropland retention, freshwater protection and daily visitor caps, while the model's modest computation load makes it a practical tool for evidence-based planning in small, biodiversity-rich archipelagos.

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