

Supplementary Material 3

Data description

S3.1 IST-SDM spatio-temporal predictions and anomalies

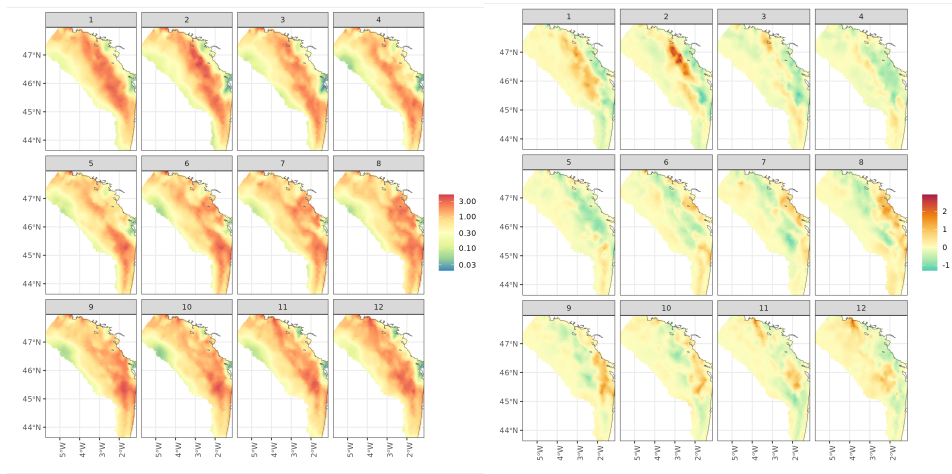


Fig. S3.1: IST-SDM predictions. (left) Monthly spatial predictions for sole in the log-scale $\log S(x, t)$. (right) Monthly anomalies of the spatial predictions $S^*(x, t)$. Each panel corresponds to the average anomalies for a month over the period 2008 - 2018.

S3.2 Satellite NDVI data

For NDVI data, we use the one kilometer monthly product available through MODIS (Busetto and Ranghetti, 2016). These are satellite observations data, which provide high-resolution information of the Earth's surface. By capturing reflected light in various spectral bands, these data are used to compute Normalized Difference Vegetation Index (NDVI), a key indicator

of vegetation health and density. NDVI values range from -1 to 1, with higher values indicating healthier and denser vegetation. This index is particularly useful for monitoring changes in vegetation over time, assessing drought conditions, and understanding ecosystem dynamics. We filter the data over France and aggregate the data on a grid cell with a 10 km resolution (grid with 3980 cells). These data range from 2000 to 2023 with a monthly time step and consist of 288 maps.

NDVI spatio-temporal variability is strongly related to temperature and precipitation, with significant heterogeneity in these relationships across regions (Piao et al., 2003; Vicente-Serrano et al., 2013). Consequently, the seasonal cycle is expected to have a strong influence on NDVI through fluctuations in both precipitation and temperature, with possible heterogeneity depending on local climatic conditions (Eisfelder et al., 2023). Specifically in France, as noted by Eastman et al. (2013), the main pattern should exhibit higher NDVI values during spring, summer, and early autumn, corresponding to higher temperatures during these periods and increased precipitation in spring and early autumn. In contrast, NDVI is expected to be lower in late autumn and winter due to lower temperatures and vegetation senescence.

S3.3 Species distribution model predictions

For the IST-SDM, we use monthly spatio-temporal predictions for three key species in the Bay of Biscay (common sole, *Solea solea* - squids, *Loligo vulgaris* - whiting, *Merlangius merlangus*) spanning a decade from 2008 to 2018 (Figure S3.1). These predictions were derived from a hierarchical model that integrates data from fishers' declarations and scientific surveys (Alglave, Rivot, et al., 2022; Alglave, Vermard, et al., 2023). These spatio-temporal predictions consist of 132 spatial fields over time defined over a 3537 grid cell.

When the method is univariate (single species) we only retain sole for the analysis. Sole spatio-temporal distribution is strongly structured by reproduction phenology (Arbault, Camus, and Bec, 1986; Alglave, Olmos, et al., 2024). Sole migrates offshore during reproduction from January to March and then returns to nearshore areas for feeding. It is expected that reproduction will be reflected through EOFs. Also, one could constrain EOFs with steady seasonality to better emphasize such process.

In some scenarios, multiple ecological variables must be analyzed together to identify shared dynamics. In such cases, EOFs must be tailored to multivariate data to infer the common patterns shaping these species (Thorson et al., 2015). To illustrate this, we consider several species in the Bay of Biscay, including sole, whiting, and squids. These species live in

relatively coastal areas and share similar ecological niches (Alglave, Vermard, et al., 2023). Consequently, they are expected to exhibit shared spatio-temporal patterns, such as synchronous reproductive periods from January to March (Moreno et al., 2002; Arbault, Camus, and Bec, 1986; Houise, 1993). Our objective is to identify and quantify these patterns using multivariate EOFs.

References

- Alglave, Baptiste, Maxime Olmos, et al. (2024). “Investigating fish reproduction phenology and essential habitats by identifying the main spatio-temporal patterns of fish distribution”. In: *ICES Journal of Marine Science*, fsae099.
- Alglave, Baptiste, Etienne Rivot, et al. (2022). “Combining scientific survey and commercial catch data to map fish distribution”. In: *ICES Journal of Marine Science* 79.4, pp. 1133–1149.
- Alglave, Baptiste, Youen Vermard, et al. (2023). “Identifying mature fish aggregation areas during spawning season by combining catch declarations and scientific survey data”. In: *Canadian Journal of Fisheries and Aquatic Sciences* 80.5, pp. 808–824.
- Arbault, Par Suzanne, P Camus, and C le Bec (1986). “Estimation du stock de sole (*Solea vulgaris*, Quensel 1806) dans le Golfe de Gascogne à partir de la production d’oeufs”. In: *Journal of applied ichthyology* 2.4, pp. 145–156.
- Busetto, Lorenzo and Luigi Ranghetti (2016). “MODISstsp: an R package for preprocessing of MODIS Land Products time series”. In: *Computers & Geosciences* 97, pp. 40–48. issn: 0098-3004. doi: 10.1016/j.cageo.2016.08.020. url: <https://github.com/ropensci/MODISstsp>.
- Eastman, J Ronald et al. (2013). “Global trends in seasonality of normalized difference vegetation index (NDVI), 1982–2011”. In: *Remote Sensing* 5.10, pp. 4799–4818.
- Eisfelder, Christina et al. (2023). “Seasonal Vegetation Trends for Europe over 30 Years from a Novel Normalised Difference Vegetation Index (NDVI) Time-Series—The TIMELINE NDVI Product”. In: *Remote Sensing* 15.14, p. 3616.
- Houise, Christophe (1993). *Etude de la population du merlan (*Merlangius merlangus* L.) du golfe de Gascogne*. Tech. rep.
- Moreno, A et al. (2002). “Biological variation of *Loligo vulgaris* (Cephalopoda: Loliginidae) in the eastern Atlantic and Mediterranean”. In: *Bulletin of Marine Science* 71.1, pp. 515–534.
- Piao, Shilong et al. (2003). “Interannual variations of monthly and seasonal normalized difference vegetation index (NDVI) in China from 1982 to 1999”. In: *Journal of Geophysical Research: Atmospheres* 108.D14.
- Thorson, James T et al. (2015). “Spatial factor analysis: a new tool for estimating joint species distributions and correlations in species range”. In: *Methods in Ecology and Evolution* 6.6, pp. 627–637.
- Vicente-Serrano, Sergio M et al. (2013). “Response of vegetation to drought time-scales across global land biomes”. In: *Proceedings of the National Academy of Sciences* 110.1, pp. 52–57.