https://doi.org/10.5194/essd-2025-793
Preprint. Discussion started: 16 January 2026

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Wetland Use Intensity (WUI) Dataset for European Wetlands in coastal zones

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Abstract

This paper presents the Wetland Use Intensity (WUI) dataset developed under the RESTORE4Cs project, which quantifies agricultural and other anthropogenic pressures within and surrounding European wetlands in coastal zones. The dataset provides the WUI for the year 2023 at 10 m spatial resolution based on Sentinel-2 and Sentinel-1 satellite time series, characterizing spatial patterns of land use intensity within wetland ecosystems. WUI supports the identification of restoration priority areas and supports EU policies through indicators for climate mitigation, biodiversity, and sustainable land management. The dataset follows FAIR principles and is publicly available via Zenodo under CC BY-NC 4.0: https://doi.org/10.5281/zenodo.17660102.

1 Introduction

Several European Union (EU) policies acknowledge the critical role of wetlands in achieving the EU's goals related to climate neutrality, biodiversity conservation, pollution reduction, flood regulation, and the circular economy. As a result, evaluating the current extent and condition of European wetlands, including their capacity for long-term mitigation through restoration and other conservation measures, is a top priority for the EU in addressing climate change. This priorisation is reflected by the EU funding of the four Horizon Europe sister projects RESTORE4Cs, REWET, ALFAwetlands and WET HORIZONS, all having the goals of enhancing protection and restoration of Europe's wetlands, improving the geospatial knowledge base of wetlands, evaluating the pathways of wetland restoration, supporting strategies on climate change mitigation and adaptation as well as supporting wetland management to optimise carbon uptake and promote biodiversity.

With increasing extreme weather events, sea level rise and intensified land use, especially coastal wetlands are playing an important role as buffer zones, offering a wide range of ecosystem services. Timely, reliable and sufficiently detailed data on wetlands are often lacking for decision-makers. As a result, there is increasing interest in using Earth Observation (EO) technologies to support wetland monitoring (Weise et al. 2020). The type and intensity of land use is a main driver of coastal wetland degradation and loss, making Earth observation-based data on land cover and land use effective indicators for wetland

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status. However, discrete land cover/use categories cannot reflect the wide variation of the actual wetland use intensity. For example, within the land use class permanent grassland, the intensity of grassland use (e.g. number of mowings) can vary greatly. Similarly in other land cover and land use types such as agriculture or forest, the intensity of agricultural land use or disturbances (such as fires or deforestation) have a major influence on the ecosystem. To complement the monitoring of wetlands with information beyond discrete land cover/use categories, time series of Sentinel-2 data were leveraged to derive the wetland use intensity at pan-European level.

Wetland use intensity (WUI) refers to the degree or extent to which wetlands are utilized for various purposes and indicates how wetlands are being impacted or exploited through various human activities which may affect the ecological health or function of the wetland (Steinbach et al. 2020). WUI differentiates intensively used wetland areas (e.g. arable cropping at different intensities) from less intensively used areas (such as grassland for livestock grazing or fodder production) as well as natural/semi-natural areas and permanent water. WUI represents the magnitude of changes in spectral properties of the land surface over a growing season. A high WUI, or a WUI that increases over time, can impact the health of the wetland, potentially leading to degradation, loss of biodiversity, and/or changes in the hydrological and biogeochemical functions of the ecosystem. Thus, knowledge about the WUI is fundamental for managing wetlands, prioritizing protection and restoration efforts and for maintaining the balance between human needs and ecological preservation. The WUI dataset developed in the EU Horizon Europe RESTORE4Cs project provides a standardized, high-resolution assessment of land use intensities within and around wetlands across Europe's coastal zones. This paper describes the dataset production workflow and data structure.

2 Data description

Spatial coverage: European Coastal Zones; Temporal coverage: 2023; Spatial resolution: 10 m; Format: GeoTIFF (incl. vrt).

The Wetland Use Intensity (WUI) dataset for the year 2023 quantifies land use intensity within wetland areas across European coastal zones. The dataset is derived from multi-temporal Sentinel-2 imagery using a modified version of the Mean Absolute Spectral Dynamics (MASD) algorithm (Franke et al., 2012), adapted for consistent time-series analysis. The dataset expresses wetland use intensity as continuous values between 400 and 3000 (to be divided by 100 to retrieve mean daily MASD values). Areas and pixels with an insufficient time series availability are labelled by the value 1. To account for the permanent and regular seasonal flooding of wetlands, the WUI dataset is complemented with a surface water dynamics layer, identifying areas that are flooded more than 60% of the time (assigned the fix value 400 in the WUI dataset). This layer was generated based on a Sentinel-1 time series from 2023, following a methodology described in Tøttrup et al. (2022; described as model E). The Surface Water Dynamics Layer was used to account for hydrological variability within wetland areas. Each WUI raster is provided in GeoTIFF format at 10 m spatial resolution, in Lambert Azimuthal Equal Area projection (EPSG:3035), tiled to the EEA 100 km reference grid. Since the dataset is meant as a complementary information to existing wetland datasets, the WUI datasets are provided in three layers that show the wetland use intensity within the boundaries of:

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1. EEA's Extended Wetland Ecosystems Layer (https://www.eea.europa.eu/en/datahub/datahubitem-view/b9399908-557a-47a8-954a-958dabeaf1b6 - last access 17.12.2025)
2. RAMSAR Site Boundaries (https://rsis.ramsar.org/?__goaway_challenge=meta-refresh&__goaway_id=1813d84476fafa4821b05cf5debe5930 - last access 17.12.2025)
3. ALFAwetlands' European Wetland Map (Tegetmeyer et al. 2025) (https://zenodo.org/records/15302184 - last access 17.12.2025)

3 Methods

The WUI is based on an algorithm for time series analysis, the Mean Absolute Spectral Dynamics (MASD), developed by Franke et al. (2012). The MASD algorithm assesses the average spectral change (absolute magnitude) in selected spectral bands across timesteps during a growing season. A timestep is the time between two Sentinel-2 observations/scenes, for which spectral change is measured. Ideally, all timesteps are four weeks long, with the first scene capturing the start of the growing season and the last one the end of the growing season. The scene selection logic is illustrated in Figure 1. For the cloud-based processing of the pan-European coastal WUI layer, an automatic Sentinel-2 image selection procedure was developed following this logic, operating on an average tile area of about 6km x 6km. To define the onset, peak and end of the growing season, standardized growing seasons for Northern, Central and Southern Europe were established based on the approach described by Van Oijen et al. (2014). The three growing seasons are defined as May-Oct for latitudes above 55 degrees, Mar-Oct for latitudes below 45 degrees and Apr-Oct for latitudes between 45 and 55 degrees. For each defined growing season region, the 6km x 6km tile-based scene selection logic was applied. Areas with persistent cloud cover, in which the time series did not meet the minimum requirement of 4 coverages per season, were indicated as such and assigned as insufficient data areas in the final WUI layer.

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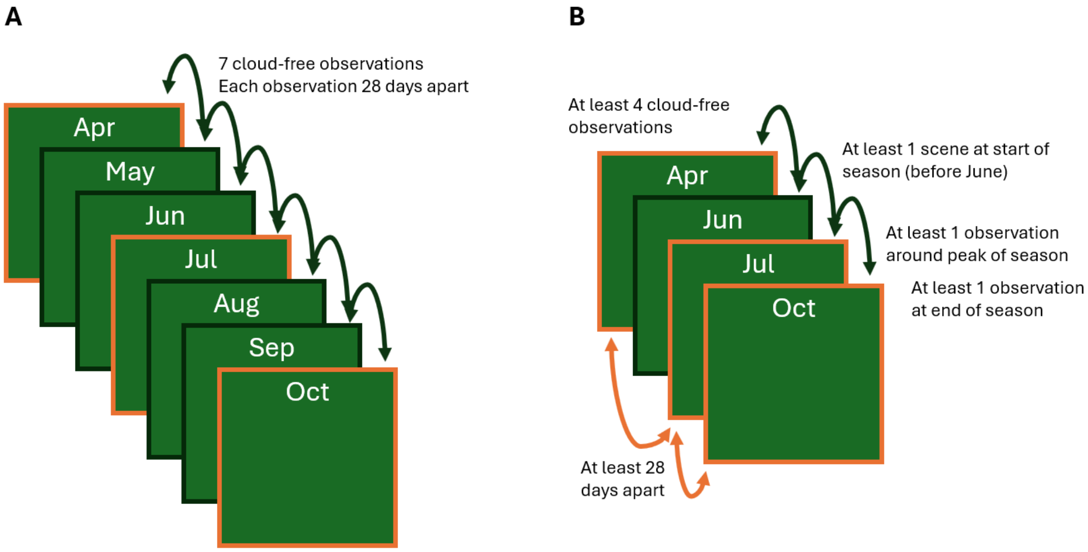

Figure 1: Schematic representation of A) the ideal scene selection for Central Europe, and of B) the minimum required scene scenario. Orange outlines indicate start, peak and end of season observations.

Since the MASD is sensitive to the observation lengths and observation density of the satellite time series, it was modified to minimize the impact of varying time series inputs. Each MASD of an observation pair (consecutive selected scenes) is divided by the number of days of the observation lengths to retrieve interpolated daily MASD values. These daily MASD values are averaged over the growing season and thus provided more temporally stable values that allowed for a scale up and for more comparable WUI values across regions. Since the aim was to assess WUI mainly in vegetated wetland areas, only vegetation-sensitive bands were selected to calculate the MASD. To account for a balance between the spectral ranges and the spatial resolution of the Sentinel-2 bands, the green and red band in the visual spectrum, two bands from the red-edge and near infrared (NIR) and two bands in the short-wave infrared (SWIR) were used. The average daily MASD for each pixel in a time series is calculated following the equations:

$$daily\ MASD_{ox} = \frac{1}{d_{obs}}\frac{1}{n}\sum_{i=b1}^{bn}\left|p_i^t - p_i^{t+1}\right| \tag{1}$$

where, ox = individual satellite image pixel pair with valid cloud-free observations, d*obs* = observation lengths in days between image pixel pair, n = no. of spectral bands, b = spectral band, p = pixel reflectance and t = observation date

All *daily MASD tx* over a growing season are then averaged per pixel:

$$daily\ MASD_{avg} = \frac{1}{m}\sum_{i=1}^{m} daily\ MASD_{ox\ i} \tag{2}$$

m = no. of individual observation pairs with valid observations

In order to generate a WUI layer that is focusing on wetlands and which is spatially coherent to other existing wetland information layers, it was processed within areas that are likely to be wetland habitats. Therefore, three different "wetland masks" were used: 1) EEA's Extended Wetland Ecosystems Layer 2) RAMSAR Sites (Ramsar Sites Information Service) and

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3) ALFAwetlands' European Wetland Map (EWM) (Tegetmeyer et al. 2025). Since the RAMSAR as well as the EWM boundaries include some urban areas, these were additionally masked using the High Resolution Layer (HRL) Imperviousness layer from the Copernicus Land Monitoring Service (https://land.copernicus.eu/en/products/high-resolution-layer-imperviousness?tab=datasets - last access 17.12.2025).

Since seasonally inundated areas in the wetlands cause large spectral changes and high MASD values that can cause confusion in the WUI interpretation through high MASD values, the surface water dynamics in the coastal wetlands for the same year (2023) was considered complementary to the WUI. All Sentinel-1 scenes acquired in 2023 were used to assess the surface water dynamics, following an approach described in Tøttrup et al. (2022, described as model E). This approach is fully automated and uses dynamic thresholds to classify individual Sentinel-1 ground range detection data in VV polarization from the ascending orbit. In opposite to a fixed threshold, this statistical approach allows for the definition of dynamic classification thresholds for each scene, accounting for variations in backscatter caused by various factors. The individually classified scenes were then combined to monthly surface water composites, informing on the frequency of water occurrence in 2023. Areas with a surface water occurrence above 60% were classified as "regularly inundated" (value 400 in the WUI dataset). Figures 2-5 show examples of the WUI layer for four different wetlands in coastal zones, while Figure 6 demonstrates the differences between the three WUI layers that have been generated for the three existing spatial references.

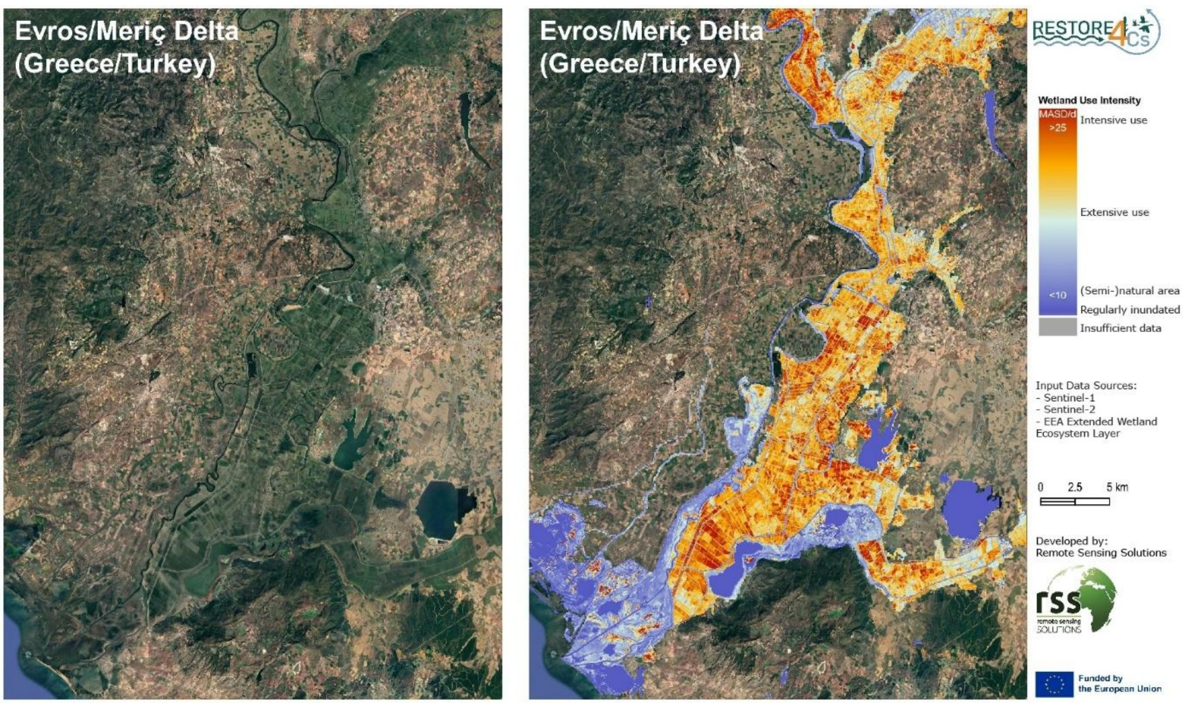

Figure 2: Example of the 2023 WUI layer for the Evros/Meriç Delta within the EEA Extended Wetland Ecosystem Layer boundary, with a mix of intensively and extensively used areas as well as semi-natural areas near the coastline. Map data © 2015 Google.

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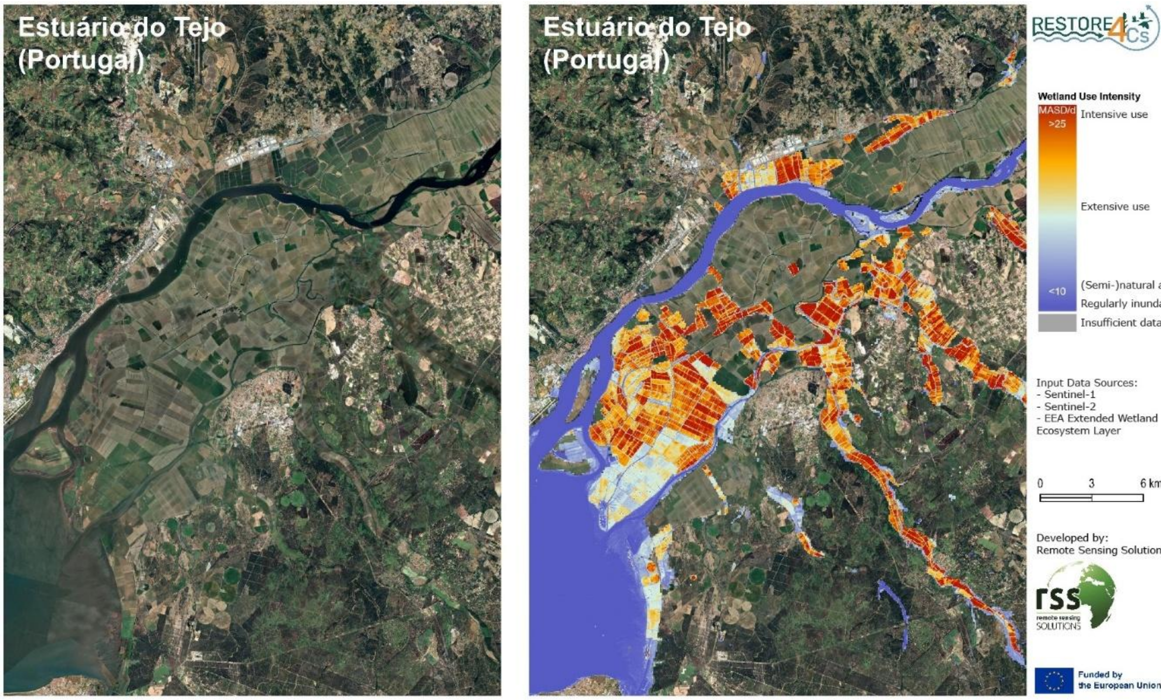

Figure 3: Example for the Tejo Delta within the EEA Extended Wetland Ecosystem Layer boundary, with a mix of high wetland use intensity in agricultural plots, extensively used areas as well as semi-natural areas near the coastline. Map data © 2015 Google.

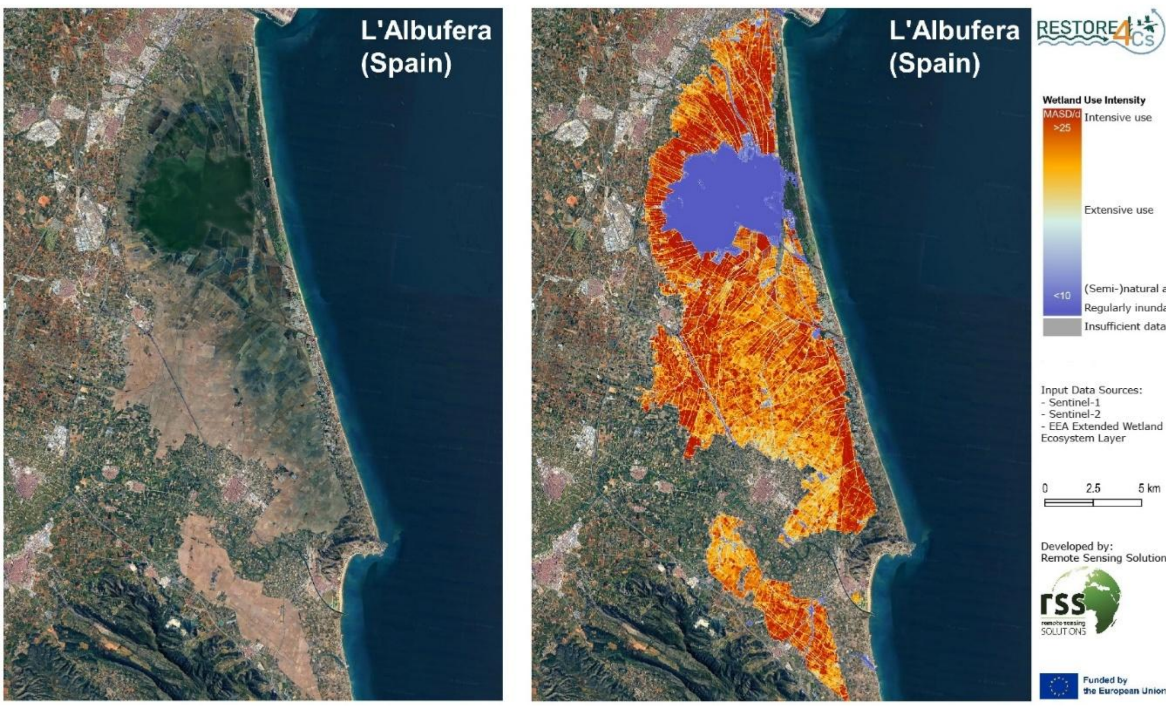

Figure 4: Example of the 2023 WUI layer for L'Albufera within the EEA Extended Wetland Ecosystem Layer boundary, dominated by agricultural areas (seasonally flooded rice paddies) and a high wetland use intensity. Map data © 2015 Google.

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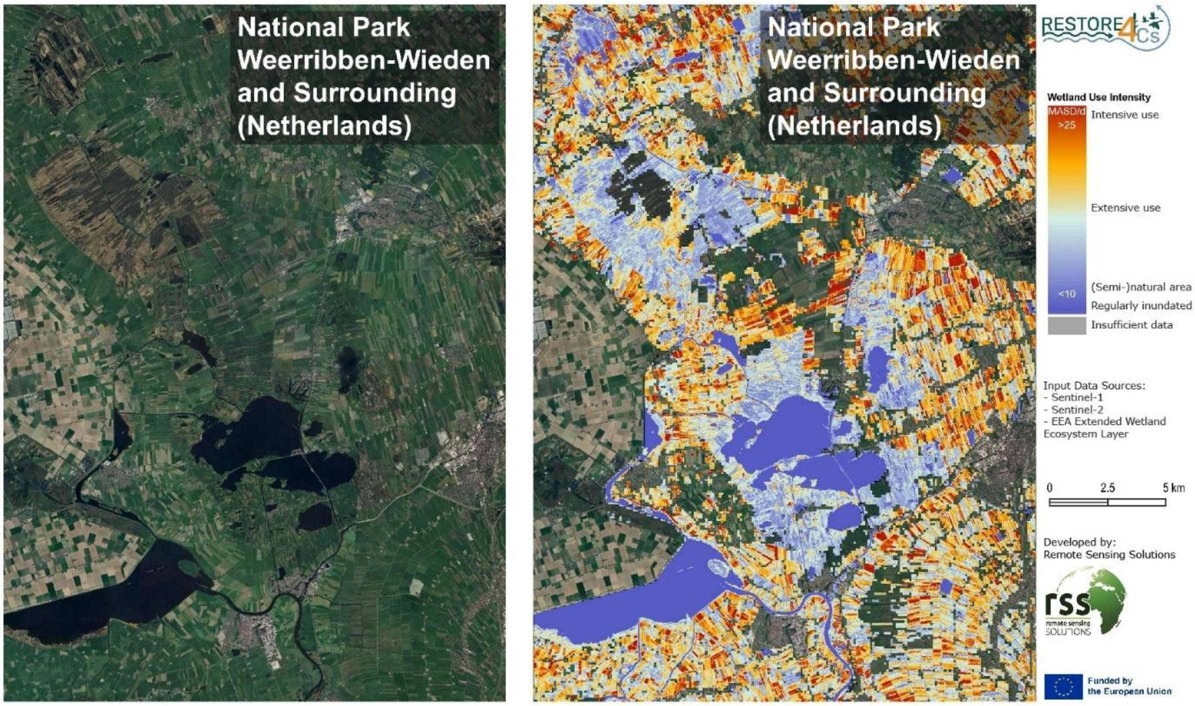

Figure 5: Example of the 2023 WUI layer for the National Park Weerribben-Wieden (dominated by low wetland use intensity) and its surrounding area within the EEA Extended Wetland Ecosystem Layer boundary. Map data © 2015 Google.

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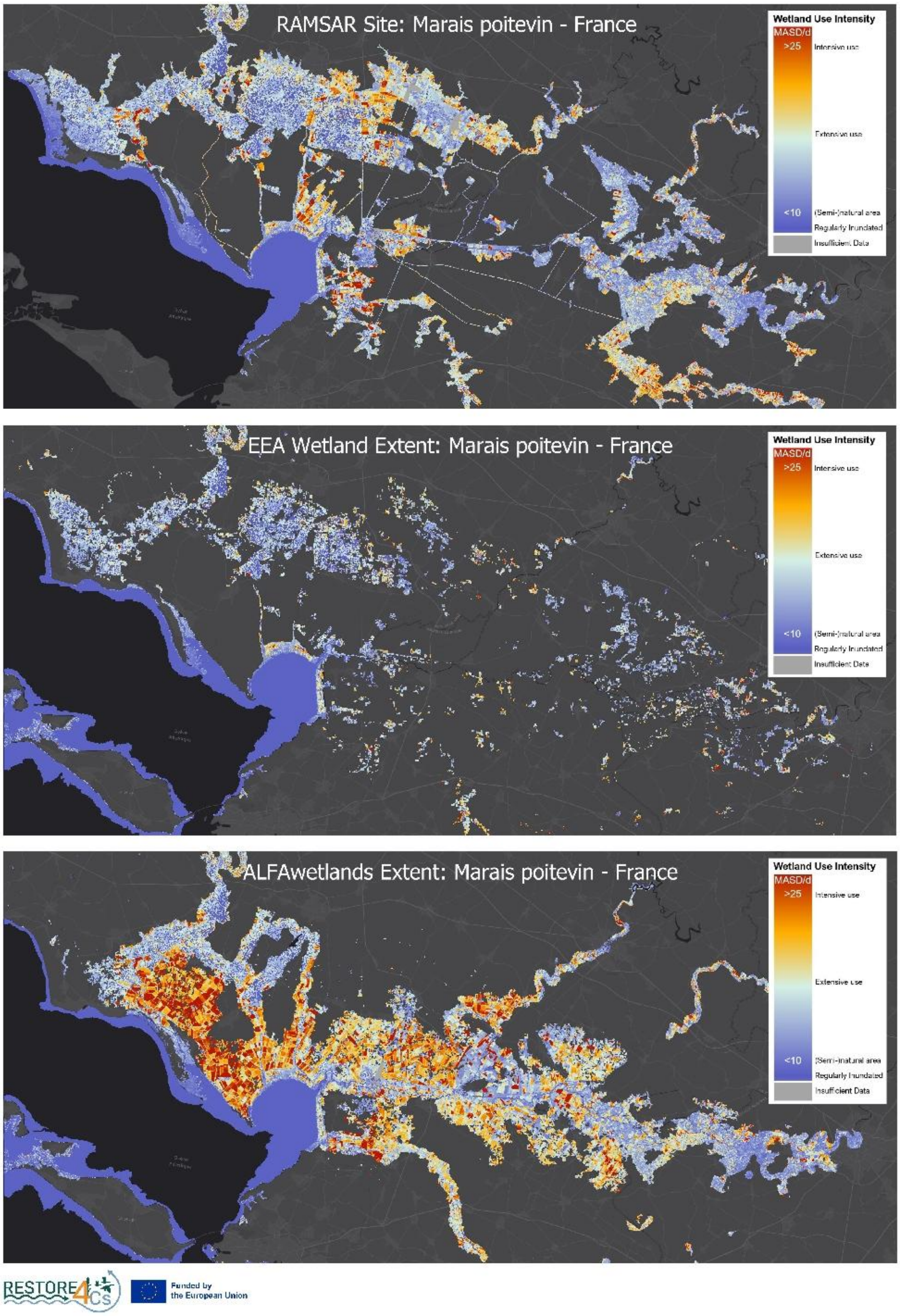

Figure 6: Example for Marais Poitevin in France of the three different WUI layer versions, using the Ramsar site boundary (top), and the wetland delineations from EEA (center) and ALFAwetlands (bottom). Please see the individual layer descriptions of the data provider for interpreting the differences in wetland delineations. Map data 2025 ESRI | Powered by Esri.

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4 Data records

Each annual WUI map is stored as a GeoTIFF raster with metadata describing projection, year, spatial resolution and reference boundary. All layers are provided in 100km tiles that are aligned with the EEA reference grid and Lambert Azimuthal Equal Area (LAEA, EPSG: 3035) projection. In addition, a stylefile for the visualisation of the data in QGIS is provided.

5 Technical validation

The WUI dataset was visually validated against independent datasets. MASD values cannot be quantitatively validated directly. Instead, a plausibility check was done by comparing the resulting WUI categories with actual use intensities in RESTORE4Cs pilot wetlands (Aveiro in Portugal, Moros in Spain, Camargue in France, Danube Delta in Romania, Curonian Lagoon in Lithuania and Grevelingen in The Netherlands), as documented by photos and field-observed management practices. For each pilot wetland, checks were done for multiple sites and use intensity classes (e.g. cropland, grassland, horticulture, natural land) and for multiple years. Based on the validity checks, the WUI category thresholds (based on MASD values) were adjusted to better reflect actual use intensities.

6 Usage notes

Understanding the spatial and temporal dynamics of wetland use intensity is essential for protecting, restoration and sustainable sustainably managing wetlands. The WUI dataset provides insights into wetland use and status beyond classic land use categories. It is intended to be a complementary dataset for wetland ecosystem assessments and to deepen the understanding of pressures and threads facing wetlands. The layer supports finding priority areas for restoration actions and protection enforcement within wetlands. Being produced annually, the WUI can identify trends and continuously monitor the effectiveness of ongoing restoration activities.

Users should consider the seasonality and specific circumstances of local agriculture when interpreting the WUI layer. Generally, the layer provides continuous averaged daily MASD values, which can also be converted into WUI categories using local knowledge for defining thresholds for such categories. Through site-specific validation and knowledge, the thresholds of the WUI categories can be adjusted to better reflect the local situation.

While every effort has been made to prepare this dataset using appropriate scientific standards, the data may nonetheless contain errors, omissions or inaccuracies for varying reasons. Inaccuracies are often found in areas that are inundated for short periods in the growing season, such as very shallow water bodies and along their lakesides. A short presence of surface water (which may not be captured by the surface water dynamics layer) results in high spectral change and thus high MASD values (example given in Figure 7). The dataset contains large areas with insufficient data coverage due to persistent cloud cover, where the minimum number of cloud-free observations have been below a certain threshold. This is particularly common in

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high rainfall zones and in regions with short growing seasons, such as along the West Coast of Norway, Iceland and the West coast of Great Britain and Ireland (Example given in Figure 8).

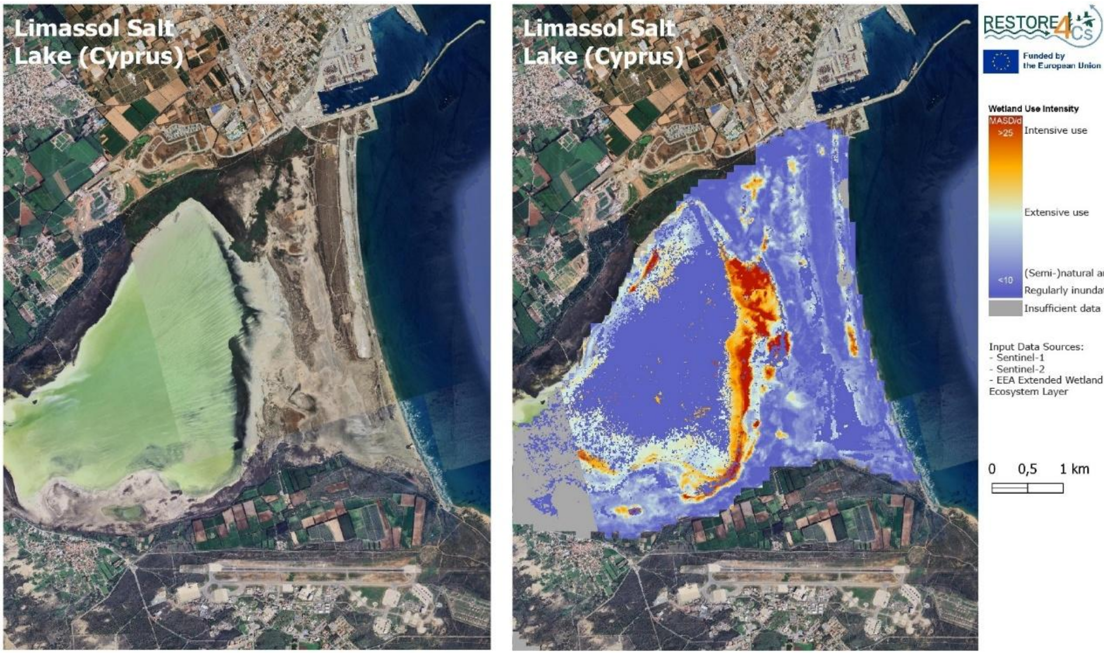

Figure 7: Inaccuracies showing high WUI values in very shallow lakes and lakesides due to short periods of inundation. Map data © 2015 Google.

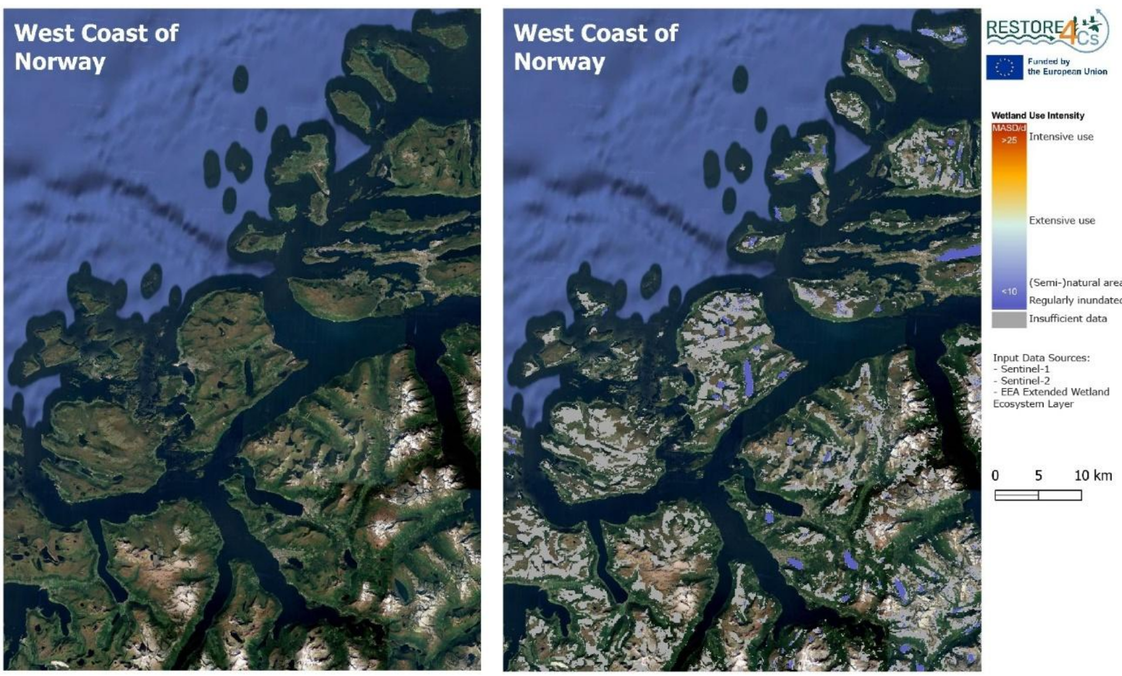

Figure 8: Areas with insufficient data coverage due to short growing seasons with persistent cloud cover. Map data © 2015 Google.

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Disclaimer:

The data is provided as is without warranty of any kind, either express or implied, including but not limited to fitness for a particular purpose. This dataset covers wetland use intensity for the year 2023 within European coastal zones using satellite imagery and derived metrics. The values therefore reflect conditions and methodology for that specific year and region. They may not be representative of other years. The dataset is not intended to replace in-field measurements or detailed site-specific assessments. Users relying on the data for decision-making, mapping, modelling, or policy should conduct their own validation or ground-truthing as appropriate. Use of the data is at the user's own risk.

7 Data availability

The dataset is publicly accessible on Zenodo (https://doi.org/10.5281/zenodo.17660102) under a CC BY-NC 4.0 licence (Remote Sensing Solutions, 2025).

Author contribution

JF: Conceptualization, Methodology, Supervision, Visualization, Writing; KK: Formal Analysis, Software; MS: Methodology, Validation, Project Administration; SK: Software; JH: Formal Analysis; IA: Formal Analysis; MS: Methodology

Competing interests

The authors declare that they have no conflict of interest.

Acknowledgments

This work was carried out as part of the HORIZON EUROPE project RESTORE4Cs (Grant Agreement No. 101056782). The authors acknowledge contributions from project partners.

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