



**IH cantabria**  
INSTITUTO DE HIDRÁULICA AMBIENTAL  
UNIVERSIDAD DE CANTABRIA

IH cantabria

**Copernicus Tools for Monitoring Global Change  
Effects in Rivers and Riparian Zones**

**(Cop.RIVER)**

**Deliverable 8: Development of terrestrial and aquatic  
remote sensing indicators**

## INDEX

INDEX.....	2
1 BACKGROUND .....	3
2 SELECTION OF RIVER BASINS .....	3
2.1 GENERAL DESCRIPTION OF THE REGION.....	3
2.2 DESCRIPTION OF THE STUDY RIVER BASINS.....	5
2.2.1 <i>The Pas basin</i> .....	5
2.2.2 <i>The Saja basin</i> .....	5
3 DEVELOPMENT OF SELECTED INDICATORS .....	6
3.1 TERRESTRIAL DOMAIN.....	7
3.1.1 <i>Land Use/ Land Cover</i> .....	7
3.1.2 <i>Imperviousness</i> .....	9
3.1.3 <i>Longitudinal connectivity</i> .....	11
3.1.4 <i>Vegetation height</i> .....	13
3.2 AQUATIC DOMAIN.....	17
3.2.1 <i>Eutrophication</i> .....	17
4 GROUND DATA FOR THE VALIDATION OF THE SELECTED INDICATORS .....	19
5 ACKNOWLEDGMENTS .....	20
6 REFERENCES.....	20

## 1 BACKGROUND

Cop.RIVER aims to promote the use of Earth Observation (EO) in applications and services related to the ecological status of riverscapes (*i.e.*, rivers and their associated alluvial plains, floodplains and riparian forests). The action will strengthen the Copernicus user uptake by supporting regional and national authorities in the implementation of the EU Biodiversity Strategy to 2020, the Habitats and Birds Directives and the Water Framework Directive by applying GAP analysis, to complement available Copernicus information on the state and characteristics of rivers and riparian zones.

This action will develop an innovative toolkit (*i.e.*, environmental knowledge and geo-information services) that will allow defining a selected set of standardized ecological indicators from both terrestrial and aquatic domains. This tool will enable achieving independent decision-making to assist on water resource management, restoration and conservation actions in these complex, fragile and valuable landscapes.

The action will also develop a benchmark for monitoring riparian processes and services (water quality, habitat conservation or urban planning) that will foster opportunities for European enterprises to provide innovative EO systems and services for a more sustainable management of riverscapes based on remote sensing data.

## 2 SELECTION OF RIVER BASINS

### 2.1 General description of the region

The selected river basins are situated within the central North Atlantic region of Spain (Figure 1), in Cantabria. This area is characterized by a humid oceanic temperate climate (Barquín *et al.*, 2011), marked by substantial rainfall. The average annual precipitation is approximately 1300 mm (Álvarez-Cabria *et al.*, 2016), with higher amounts occurring in the mountainous areas (Fernández *et al.*, 2023). Rainfall is relatively evenly distributed throughout the year, though peaks occur in spring and winter (Barquín *et al.*, 2011). The region experiences mild temperatures, averaging around 14°C, which decrease at higher altitudes due to both elevation and the reduced buffering effect of the Cantabrian Sea at greater distances from the coast (Alice Project, n.d.).

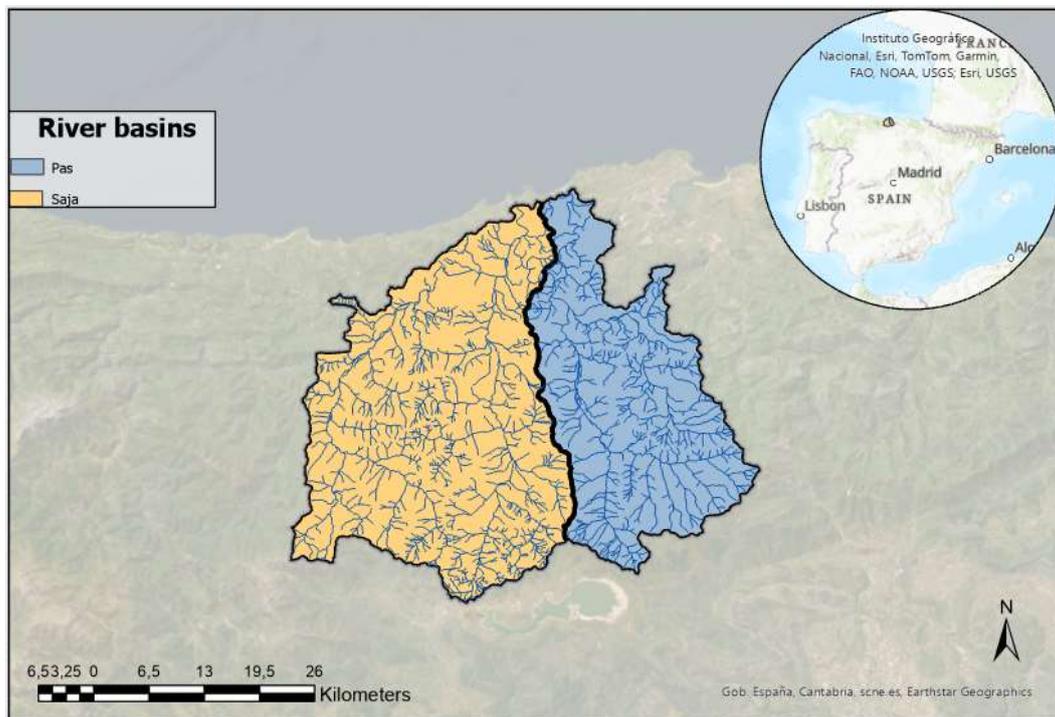


Figure 1. Map of the considered study basins.

Both the Pas and Saja river basins discharge into the Cantabrian Sea, and are managed by a single regional water agency, the Cantabrian Hydrographic Confederation (CHC) (Álvarez-Cabria *et al.*, 2016). These basins are bounded to the south by the Cantabrian Mountain range, where the rivers originate. The range extends from the west (Galicia) to the east (Basque Country), running parallel to the Cantabrian Sea coastline, with its highest peak, Torrecerredo, reaching 2648 meters (ALICE project, n.d.).

The climate and varied lithologies in the region support the predominance of deciduous Atlantic forests. However, human activities have led to the clearance of these forests in many areas, which have been replaced by pastures and eucalyptus plantations, with fewer instances of *Pinus radiata* plantations (ALICE project, n.d.). The dominant tree species in these deciduous forests include beech (*Fagus sylvatica*), oak species (mainly *Quercus robur* and *Quercus ilex*), ash (*Fraxinus excelsior*), chestnut (*Castanea sativa*), hazel (*Corylus avellana*), and elm (*Ulmus spp.*) (Barquín & Death, 2008; ALICE project, n.d.). At higher elevations, vegetation shifts to meadows, thickets, and heaths, with species such as broom (*Cytisus scoparius*), heather (*Calluna spp.*), and gorse (*Ulex spp.*) (Estevez *et al.*, 2017).

In the riparian zones, the characteristic tree species include alder (*Alnus glutinosa*), ash (*Fraxinus excelsior*), elm (*Ulmus glabra*), willow (*Salix atrocinerea*), hazel (*Corylus avellana*), and oak (*Quercus robur*) (Barquín & Death, 2008; Barquín *et al.*, 2011; ALICE project, n.d.).

A detailed description of the selected study basins is presented below.

## 2.2 Description of the study river basins

### 2.2.1 The Pas basin

The Pas River, originating from Castro Valnera, extends for 61 km and flows through the autonomous region of Cantabria, discharging into the Mogro estuary. It is flanked by the Miera River to the east and the Saja River to the west. The main tributaries of the Pas River are the Magdalena and Pisueña Rivers (CHCantábrico, n.d.-b).

The estimated catchment area of the Pas River basin covers 649 km<sup>2</sup>, characterized by a highly mountainous terrain (DMA Cantabria, n.d.-a). The entire catchment area, including the full course of the Pas River and its tributary, the Pisueña River, is designated as a Site of Community Importance (SCI) under the name Río Pas. At its estuary, there is an additional SCI known as "Dunas de Liencres and Estuario del Pas," located at the river's mouth (CHCantábrico, n.d.-b).

The geology of the region is predominantly composed of clays, sandstones, siltstones, and calcareous rocks (Derepasko *et al.*, 2021). Regarding land use, the most urbanized areas are concentrated in the lower reaches of the basin, while the upper reaches experience less anthropogenic pressure. The populations in the basin mainly rely on the tertiary sector, with the primary sector playing a relatively minor role compared to other river basins. Agricultural activity is most prominent in the upper part of the basin, with scattered cultivated areas in the middle and lower sections (DMA Cantabria, n.d.-a). Forested areas follow a similar distribution, although grasslands and scrublands are the dominant vegetation types in the basin (Natura Spain, n.d.-a).

In terms of pressures on the basin, there is relatively little infrastructure, such as dams or weirs, that significantly affects river flow (Derepasko *et al.*, 2021). However, one of the primary pressures is the stabilization of riverbanks along approximately one-third of the river's course. Additionally, industrial activities in the middle reaches of the basin pose further pressures (DMA Cantabria, n.d.-a).

### 2.2.2 The Saja basin

The Saja River, originating in the Sierra del Cordel, spans a length of 67 km and flows through the autonomous region of Cantabria, discharging into the estuary of San Martín de la Arena. It is bordered by the Pas River to the east and the Nansa River to the west (CHCantábrico, n.d.-c). The Besaya River, a key tributary of the Saja, runs 47 km from its source in Campoo de Enmedio, joining the Saja at Torrelavega (CHCantábrico, n.d.-a). Other important tributaries include the Argoza and Bayones Rivers (CHCantábrico, n.d.-c).

The estimated catchment area of the Saja basin is 1025 km<sup>2</sup>, characterized by steep topography (Peñas *et al.*, 2011). The headwaters of this basin include the Saja-Besaya Natural Park, the largest in Cantabria, and two Sites of Community Importance (SCI): Valles Altos del Saja y Nansa y Alto Campoo and Río Saja (CHCantábrico, n.d.-c).

Geologically, the basin is composed of clays, sandstones, siltstones, and calcareous rocks (DMA Cantabria, n.d.-b). In terms of land use, the most densely populated and urbanized areas are concentrated near the basin's outlet, while the headwater regions are sparsely populated. Economic

activities in the region are primarily centered around the secondary sector, including industry and construction, with a significant contribution from the tertiary sector. Agricultural and farming activities are minimal, reflecting the basin's transition away from primary sector reliance. Agricultural areas are found along the riverbanks in lowland regions, while wooded areas dominate the steeper areas, far from urban centers (DMA Cantabria, n.d.-b).

Within the wooded areas, mixed deciduous forests are the characteristic formation, both for the riparian forest and in the higher areas, with oak groves (*Quercus robur*) on the south-facing sunny slopes and the beech forests (*Fagus sylvatica*) on the shady slopes standing out, also having an important representation of holm oak trees (*Quercus ilex*) and chestnut trees (*Castanea sativa*). Other tree formations worth mentioning are the eucalyptus plantations, which are numerous in this basin (IHCantabria, 2020).

As the altitude increases, and as a result of the climatic characteristics, a vegetation succession is gradually formed, changing from wooded structures to scrubland formations. The natural meadows, meanwhile, show an irregular distribution, occurring both in the high mountain areas and in the coastal zone (IHCantabria, 2020).

The lower areas of the basin experience the highest levels of disturbance, largely linked to urbanization and industrialization. Although infrequent, the existing pressures are substantial, including floodplain occupation, riverbank stabilization, and wastewater discharges from major urban and industrial centers. Additionally, the basin contains 20 dams, representing a significant environmental pressure (DMA Cantabria, n.d.-b). In terms of invasive species, *Reynoutria japonica* and *Cortaderia selloana* are the most widespread, particularly in the lower river sections and around Torrelavega, where human disturbance is greatest (IHCantabria, 2020).

Regarding water quality, of the 16 water bodies within the basin, two do not meet the optimum status required by the Water Framework Directive (IHCantabria, 2020).

### 3 DEVELOPMENT OF SELECTED INDICATORS

One of the main objectives of Cop.RIVER is to develop a comprehensive set of remote sensing indicators pertinent to the management and monitoring of river and riparian ecosystems. The main indicators aligned with the reporting requirements for characterizing riverbank elements have been calculated.

As an example, the calculation of multiple variables for river and riparian zone characterization using different remote sensing indicators and Copernicus products is presented for the Saja and Pas basins, highlighting their utility for the reporting process in compliance with several European directives.

## 3.1 Terrestrial domain

### 3.1.1 Land Use/ Land Cover

This variable, included in the Land Use category, refers to the various land use types present within a catchment, with particular emphasis on distinguishing between anthropogenic uses (*e.g.*, cropland, buildings, roads) and land uses related to natural habitats (*e.g.*, grasslands, forests, wetlands).

The River Habitat Survey (RHS), a manual developed for conducting river habitat assessments in the UK and Ireland, and widely adopted across Europe, recommends the use of this attribute. First published in 1992 in preparation for the Water Framework Directive, the RHS demonstrates the practical relevance of this variable in fulfilling the reporting requirements of the Directive.

Furthermore, this parameter is included in the Explanatory Notes & Guidelines for the 2007-2012 period for assessment and reporting under Article 17 of the Habitats Directive (ETC/BD, 2011). The guidelines emphasize the necessity of differentiating natural soils from cultivated or ploughed soils, underscoring the importance of this variable in the context of the Habitats Directive.

At the national level, particularly within Spanish legislation, this parameter is essential for complying with the requirements of the Natural Heritage and Biodiversity Law, which mandates the identification of forest areas by land use and forest type. This highlights the broader applicability of this indicator in fulfilling both national and international environmental obligations.

Two Copernicus products provide a clear solution for this parameter: the *Corine Land Cover* (CLC) product and the *Riparian Zones* product. The CLC is a European-wide dataset, updated in 2000, 2006, 2012 and 2018, comprising 44 land cover classes with a minimum mapping unit of 25 hectares. By offering data on land uses across multiple years, it enables the analysis of changes over time. The most recent CLC data, from 2018, was derived using Sentinel-2 data alongside Landsat-8 data, with a geometric accuracy of 10 meters for the first time.

The *Riparian Zones* product, as the name suggests, is designed to provide an accurate and standardized land cover classification of riparian zones across Europe, representing the transition zones between terrestrial landscapes and rivers. This product, available for the years 2012 and 2018, facilitates the characterization of these often challenging-to-map areas, enabling the delineation of floodplains in response to various directives. The land cover and land use information within this product is derived from Very High Resolution (VHR) satellite data and other available sources and is harmonized with the CORINE Land Cover dataset. Additionally, there are other specific products related to land use, such as the *N2K Land Cover/Land Use* layer, the *Dominant Leaf Type* layer and the *Forest Type* product. While not used in this case, these could be applied if more specific data are required.

In this case, the *Riparian Zones* product from 2018 was used to represent the Land Use/Land Cover parameter in the riparian systems. The information provided by *Riparian Zones* in the two selected basins, the Saja (Figure 2) and Pas (Figure 3) basins, reveals a higher predominance of woodland and heathland in the headwaters, while areas closer to the river's mouth show a greater presence of urbanization and agricultural activity.

TERRESTRIAL AND AQUATIC REMOTE SENSING INDICATORS

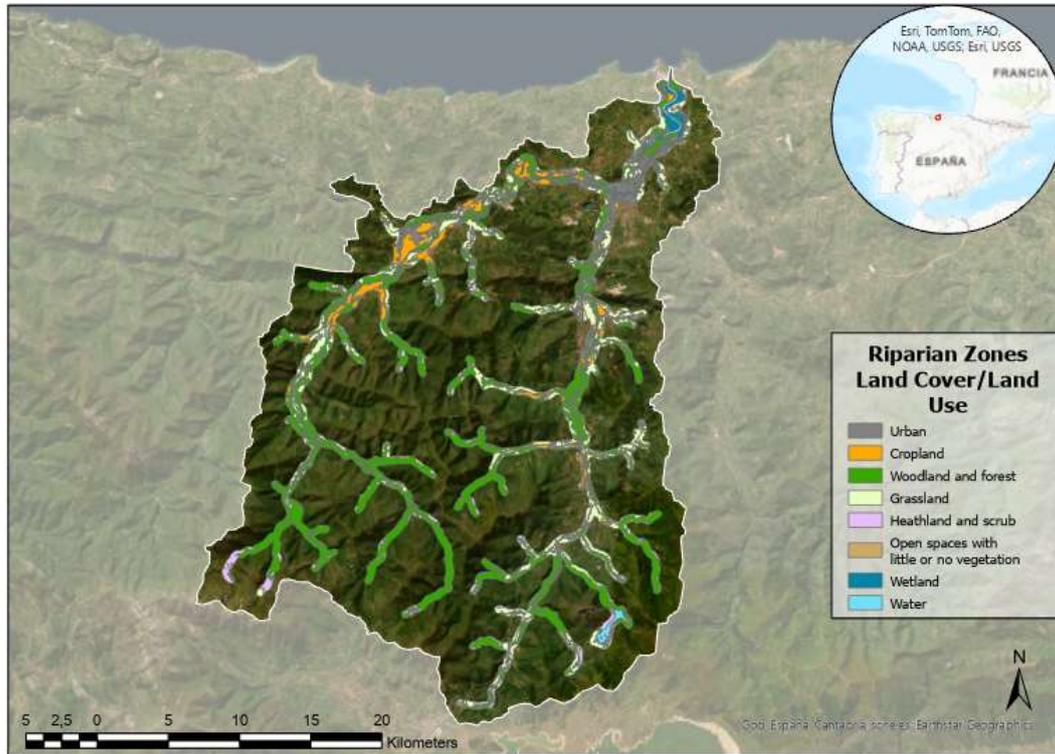


Figure 2. Land use categories in the Saja basin obtained from the Riparian Zones product.

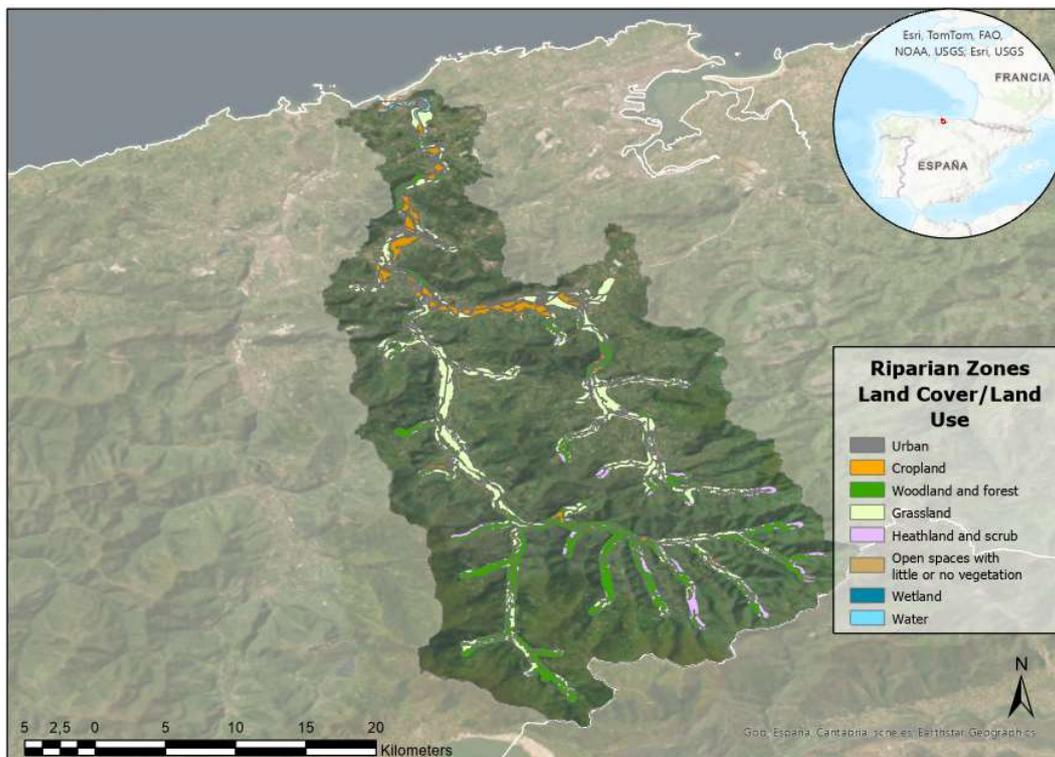


Figure 3. Land use categories in the Pas basin obtained from the Riparian Zones product.

Besides the great spatial coverage provided by *Riparian Zones*, it is clear that only the main water courses are represented by this product. Moreover, land cover categories have a medium level resolution; *e.g.*, only broad ecosystem types are depicted. This challenge could be solved by gathering ground data and developing land cover and habitat models for the entire river network (Pérez-Silos *et al.*, 2019). This issue will be tackled in the last year of the project by carrying out a GAP analysis.

### 3.1.2 Imperviousness

This variable, included in the “Disturbances” category, represents artificially sealed areas that create impermeable barriers, limiting groundwater recharge. Such areas encompass roads and buildings; *i.e.*, any structures that involve paving and subsequently alter the soil's permeability.

This metric is recognized as a key indicator in monitoring programs aligned with the Water Framework Directive for assessing the status of inland water bodies (such as rivers, lakes, and reservoirs) and for determining their ecological status. Furthermore, this parameter can be employed to evaluate the effectiveness of a Nature-based Solution (NbS), as described by Burdon *et al.* (2020).

The most straightforward approach to characterize this variable is through the *Copernicus High Resolution Layer Imperviousness* product, which provides information on the spatial distribution and temporal changes of artificially sealed surfaces. This product is available for the reference years 2006, 2009, 2012, 2015 and 2018, with the 2018 dataset being utilized in this analysis due to its recency and 10-meter spatial resolution.

Within the *Imperviousness* product Copernicus, the *Imperviousness Density* was used, which provides pixel-level data on sealing density, ranging from 0% to 100%. To represent this layer in the riparian zones, the *Riparian Zones* product was used to delimit the area of interest.

For the two selected basins, higher percentages of imperviousness were observed in the major population centers. This is particularly marked in the Saja basin in the downstream reaches (Figure 4), and to a lesser extent in the Pas basin (Figure 5).

TERRESTRIAL AND AQUATIC REMOTE SENSING INDICATORS

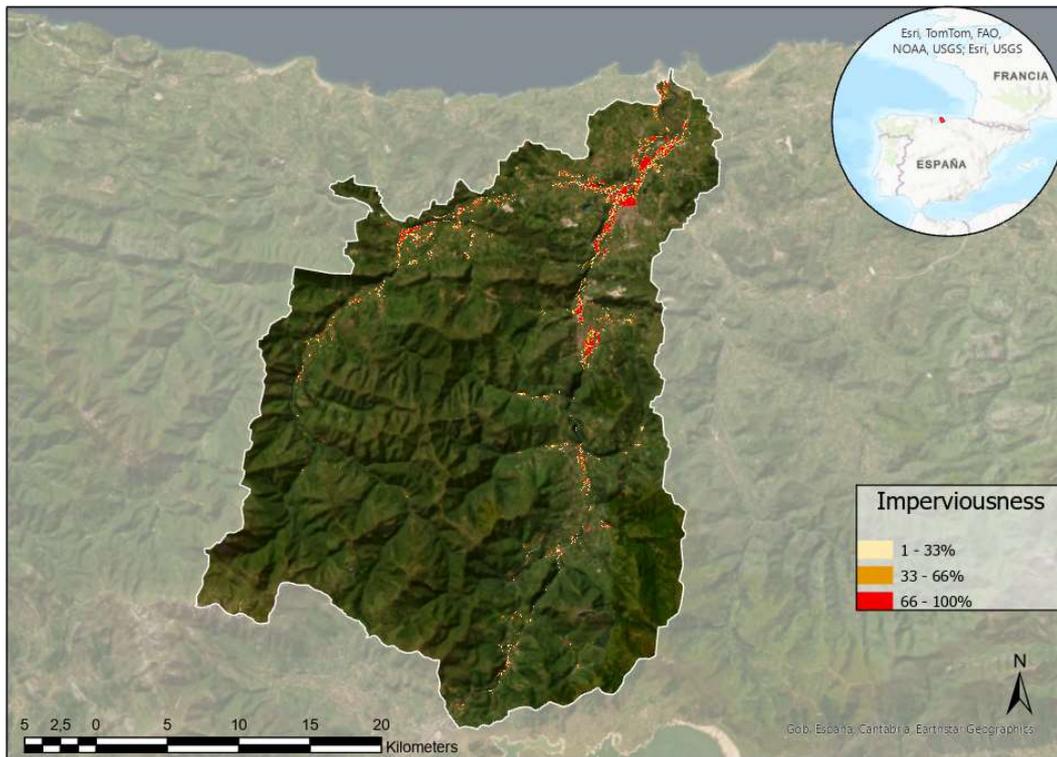


Figure 4. Imperviousness Density in the riparian zones of the Saja basin.

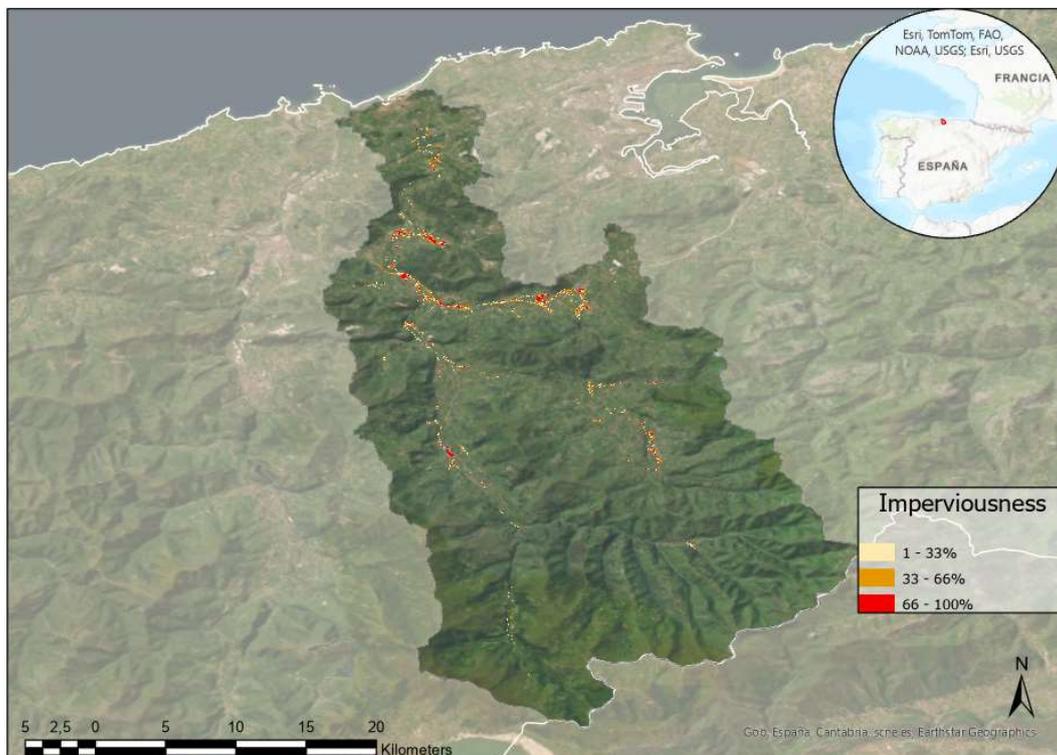


Figure 5. Imperviousness Density in the riparian zones of the Pas basin.

### 3.1.3 Longitudinal connectivity

This variable, included in the “Connectivity” category, reflects the unnatural breaks in a particular riparian forest or riparian habitat type. Specifically, this parameter shows the proportion of a river reach where the vegetation formation is absent. This variable is widely used, as it provides insight on other aspects of interest, such as the area of vegetation adjacent to the riverbank or the extent of a specific vegetation type relative to its potential coverage area.

Various methodological approaches for assessing the riverbank ecological status, as required by the Water Framework Directive, includes this parameter. For example, the Riparian Quality Index (RQI) evaluates the longitudinal continuity of woody vegetation alongside six other parameters to provide a comprehensive assessment of riverbank ecological status and to identify potential environmental issues. Also, the Morphological Quality Index (MQI), developed in Italy, assesses the morphological quality of streams in the context of the Water Framework Directive.

This parameter is also considered in proposals for characterizing habitat types under the Habitats Directive, such as the methodological guidelines for monitoring the conservation status of habitats by Spain’s Ministry for Ecological Transition and the Demographic Challenge. In the context of the Habitats Directive, forest continuity is assessed not at the level of riparian forests as a whole but at the level of individual riparian habitat types, given the directive’s focus on independently evaluating the conservation status of each habitat type.

Thus, the longitudinal connectivity can be assessed either at the riparian zone level (*i.e.*, for the many habitats conforming the riparian forest *sensu lato*), aligning with the Water Framework Directive, or for specific habitat types, in accordance with the Habitats Directive. Given this distinction, a specific habitat type was selected to calculate the indicator addressing the variable connectivity, thereby demonstrating its utility for the Habitats Directive reporting. This contrasts with previous indicators calculated here, which were applied to riparian zones without distinguishing habitat typologies. Although the analysis in this case focuses on a particular habitat type, the same methodology can be applied to evaluate the connectivity of riparian forests as a whole system.

When focusing on a specific habitat, the first step is to determine the area it occupies. In this case, we used a habitat model based on ground truth points identified by botanists. This model predicts local area occupancy, representing the probability of a habitat's presence in each pixel within the study area. These probability values are then converted into actual habitat occupancy by overlaying the probability data for each habitat type with concurrence layers, selecting the habitat type with the highest probability for each pixel (Pérez-Silos *et al.*, 2019).

For this analysis, the selected habitat type was 91E0 (Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)) as it is one of the most prevalent riparian forests in the study area.

To assess the longitudinal connectivity of the 91E0 habitat, the river network was divided into functional segments using the NetMap software (Pérez-Silos *et al.*, 2019), which were further subdivided into 10-meter sections. For each section, 100-meter buffers were created on both the left and right banks. The presence of the 91E0 habitat within each section was determined using the information provided by the habitat distribution model.

Longitudinal connectivity was assessed by counting the number of polygons within each functional segment that contained the habitat. This approach enabled the calculation of the percentage of the river segment where the riparian habitat formation is continuous for each habitat polygon.

Based on the results for this parameter, and applying the value ranges established by Lara *et al.* (2019) to assess the habitat conservation status, a strong relationship was found between connectivity and habitat coverage in the Saja (Figure 6) and Pas (Figure 7) basins, as expected. This parameter also provides insight into whether the habitat is distributed across both sides of the river. Since each riverbank is evaluated independently, high habitat coverage on one bank does not necessarily indicate high longitudinal connectivity, which could be as low as 50% if the habitat is absent from the opposite bank.

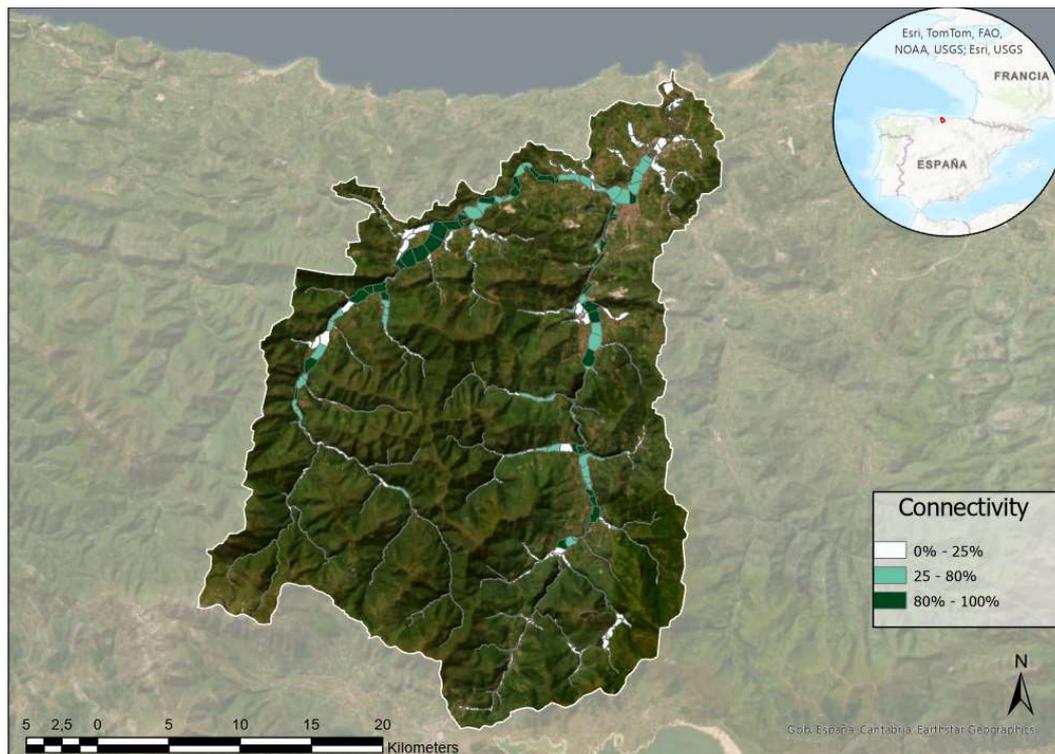


Figure 6. Longitudinal Connectivity of the 91E0 habitat in the Saja basin.

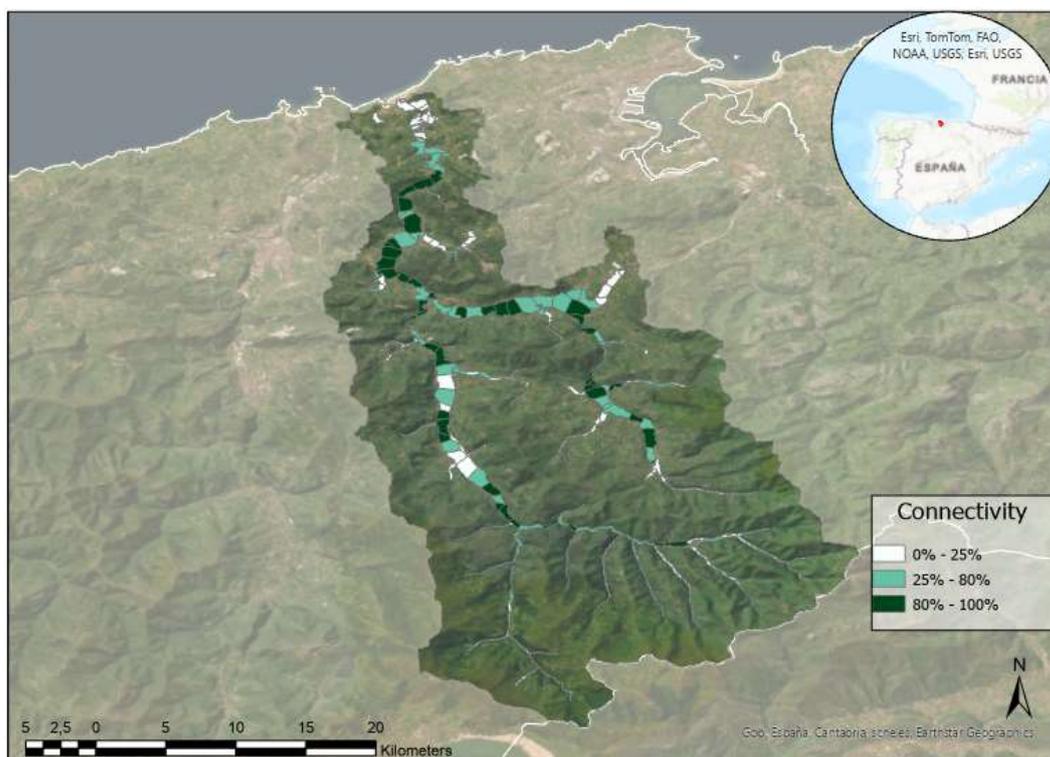


Figure 7. Longitudinal connectivity of the 91E0 habitat in the Pas basin.

### 3.1.4 Vegetation height

This variable, included in the “Dendrometry” category, usually refers to woody vegetation or, mainly, to trees. Although it is a simple and straightforward variable, easily understood, it has numerous variants, such as the number of height classes, the dominant height, the average height or the modal height.

Regarding the riparian vegetation, this variable is particularly relevant for the reporting needs of the Habitats Directive. Besides being proposed in the methodological proposals of several European countries (Ercole *et al.*, 2016; Lara *et al.*, 2019), it is also included in the Explanatory Notes & Guidelines for the 2007-2012 period for assessment and reporting under the Article 17 of the Habitats Directive (ETC/BD, 2011).

In addition, this variable may also be interesting in the development of conservation and restoration strategies. For example, vegetation high can be an easy-to-measure indicator of the effectiveness of NbS implementation (*e.g.*, Kettenhuber *et al.*, 2023).

For the estimation of the vegetation height, we used the *Normalized Digital Surface Model (NSDM)* available as part of the National Aerial Orthophotography Plan (PNOA) in Spain. This model, created from a point cloud, allows the calculation of the height of different structures, including vegetation and buildings (separated into two different categories). Points that do not belong to vegetation or buildings categories, such as a bridge, are included in the No Data category. Data processing includes

the use of the NDVI for establishing a threshold to determine whether any of the points classified as vegetation should be reclassified as buildings. The PNOA project is carried out every 6 years, starting in 2008 and covering the entire national territory. In this case, the second coverage, carried out between 2015 and 2021, with a mesh pitch of 2.5m was used.

In both the Saja (Figure 8) and Pas (Figure 9) basins, higher mean height values can be observed in the headwaters compared to lower values found in the areas closer to the mouth of the river.

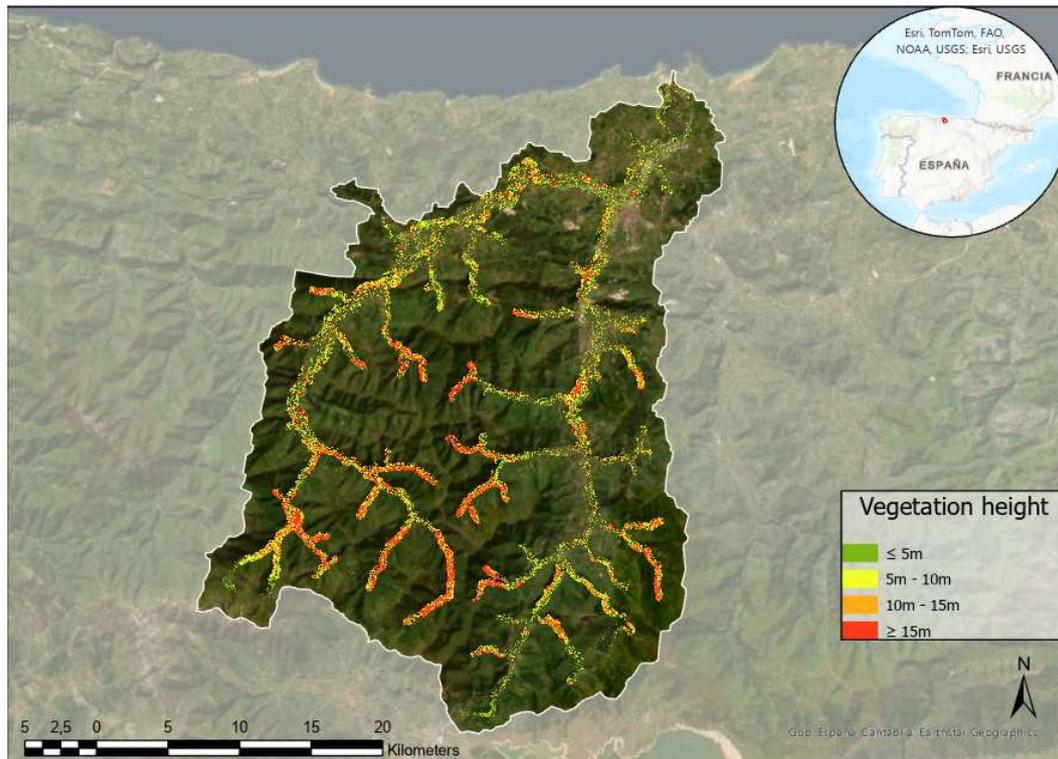


Figure 8. Mean vegetation height in the Saja basin.

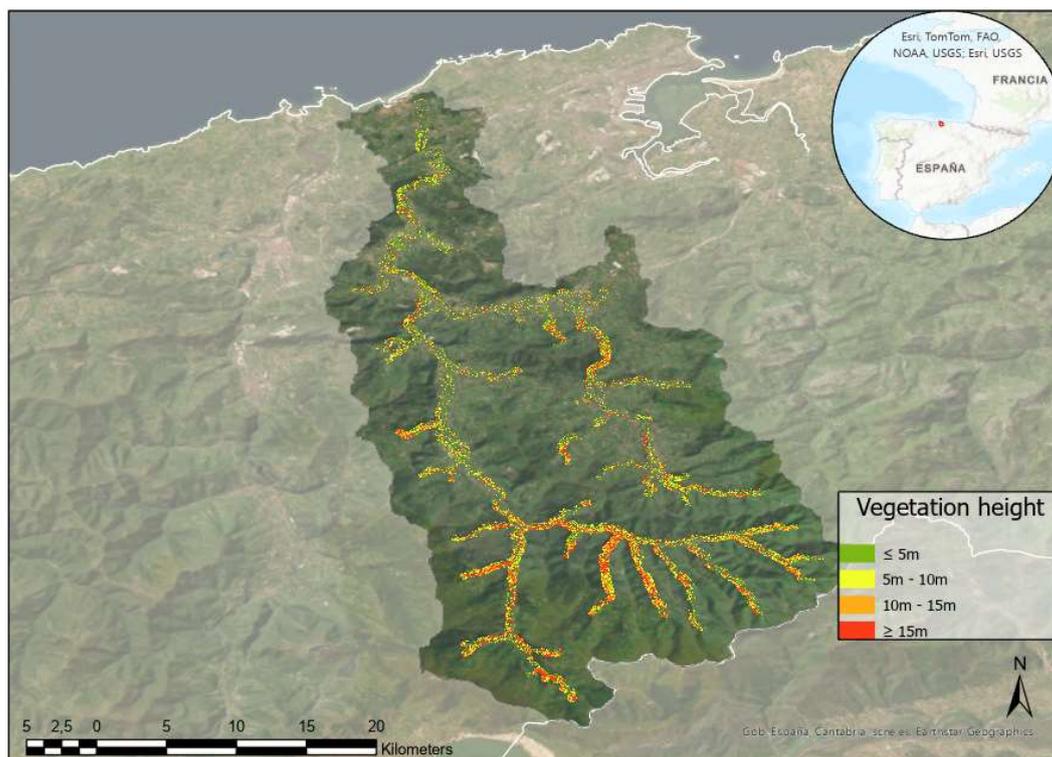


Figure 9. Mean vegetation height in the Pas basin.

The Normalized Digital Surface Model (PNOA) also allows calculating other indicators related to the vegetation height, such as the modal height. The modal height refers to the central tendency in the representation of height intervals or, in other words, the height or height interval that is most repeated within a tile. This indicator cannot be measured at the pixel level, and it is necessary to select a sampling unit. In this case, functional units were selected as the sampling units to represent the modal height.

Functional units were generated by the NetMap software (Pérez-Silos *et al.*, 2019), and can be defined as morphostructural river segments and their contributing area that can compartmentalize the physical environment in a homogeneous way at the functional level. Within these functional units, the vegetation modal height values have been calculated for each patch of the habitat 91E0, obtained from the habitat model described in the previous section.

The individual height values were divided into three ranges based on whether they were low, medium or high according to the ranges established in Lara *et al.* (2019) to determine the habitat conservation status. Based on the number of values assigned to each of these ranges of values, it was determined which of these ranges was the most abundant, thus assigning the modal height. In case the highest rank is set as the mode, this will indicate a better conservation status than those functional units where the mode is the lowest rank.

A greater abundance of tiles with a higher modal height, representing a favourable conservation status, were observed in the Saja basin (Figure 10) compared to the Pas basin (Figure 11).

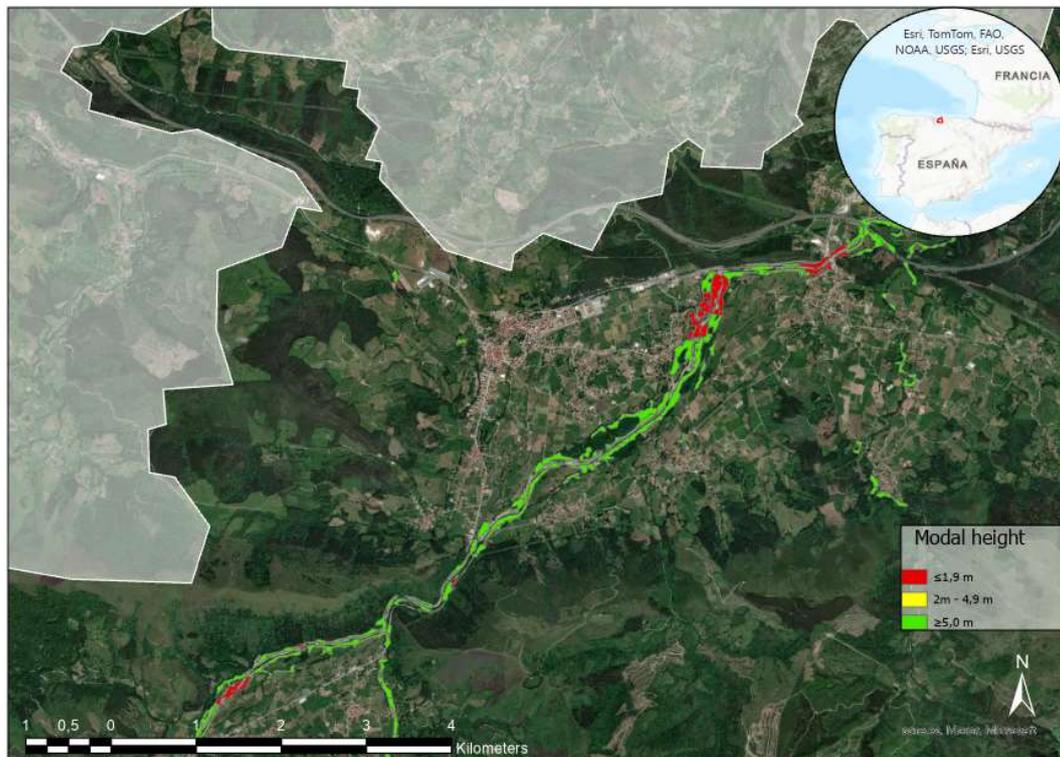


Figure 10. Example of the Modal height at the functional unit level in the Saja basin.

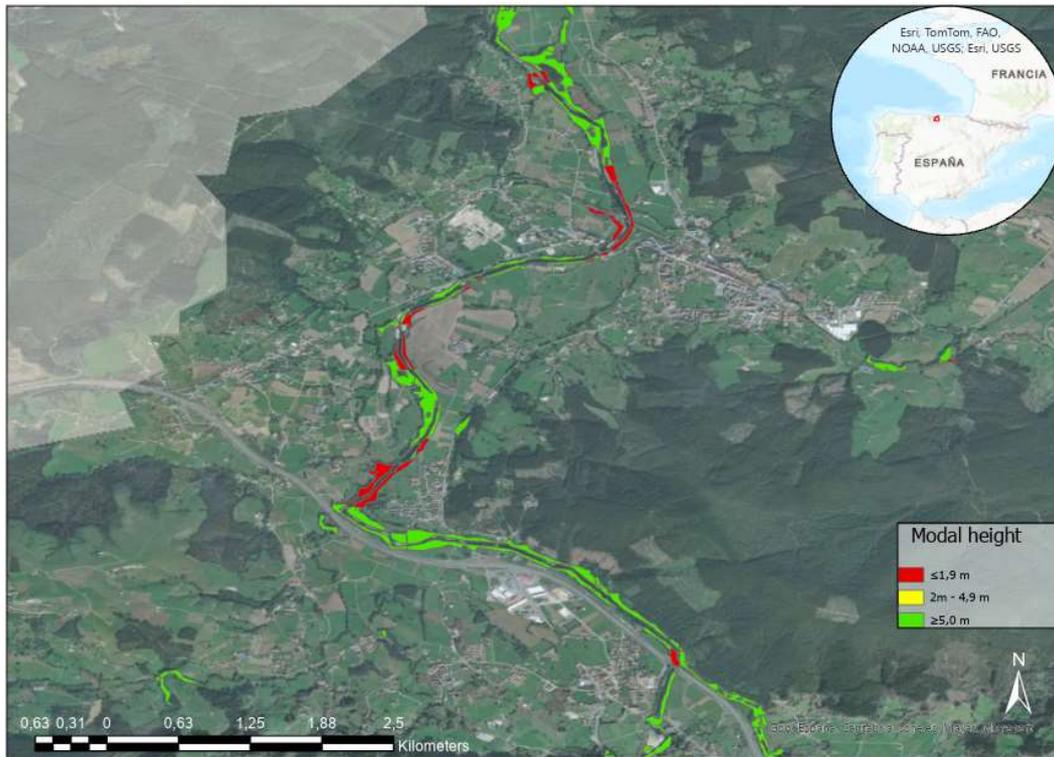


Figure 11. Example of the Modal height at the functional unit level in the Saja basin.

### 3.2 Aquatic domain

#### 3.2.1 Eutrophication

This variable, included in the “Disturbances” category, represents a process closely associated with pollution, characterized by an increase in primary production within aquatic environments. This phenomenon occurs when photosynthetic microorganisms, such as algae, proliferate beyond normal levels due to an excessive availability of nutrients. As these microorganisms multiply, they create an anoxic environment, often forming a dense layer that inhibits light penetration. This significantly alters the physical and chemical characteristics of the water, leading to severe ecological imbalances.

The assessment of eutrophication is not only critical for evaluating one of the most significant impacts on water quality, but also serves as an indirect indicator of nutrient enrichment and elevated chlorophyll-a concentrations. In fact, eutrophication can often be estimated based on nutrient levels or chlorophyll-a concentrations in the water, particularly the latter.

This parameter is particularly relevant in the assessment of riparian habitat conservation status under the Habitats Directive, as noted in Bundesamt für Naturschutz (2017). Furthermore, its significance is recognized in the EU-wide methodology to map and assess ecosystem condition as part of the EU Biodiversity Strategy 2030. Indirectly, it also addresses the requirements of the Water Framework

Directive, which, while not explicitly including eutrophication, mandates the evaluation of nutrient status and the pollution caused by specific substances.

When calculating a parameter in water bodies, the first step is to accurately define the locations of water-containing areas. For this purpose, a water mask was created, based on photo-interpreted training points representing various coverage categories, including deep and shallow water and with time series of spectral indices. Using the water pixels identified in the mask, water polygons were generated through a random forest classification model, excluding urban and artificial areas to reduce noise.

In this case, chlorophyll concentration was used as a proxy to assess eutrophication. This approach, proposed by Fedonenko *et al.* (2022), utilizes the Surface Algal Bloom Index (SABI) to estimate chlorophyll-a concentration in water. This value is then employed to calculate the Trophic State Index (TSI), which classifies water bodies into different trophic states. Lower TSI values correspond to an oligotrophic state, while higher values indicate a eutrophic state.

The TSI, divided into five distinct ranges, allows the visualization of the trophic state of the rivers. Rivers in the Saja (Figure 12) and Pas (Figure 13) basins are predominantly classified as mesotrophic or eutrophic. However, the eutrophic levels observed are not sufficiently elevated to qualify as hypereutrophic, a condition that is only observed in a few specific areas.

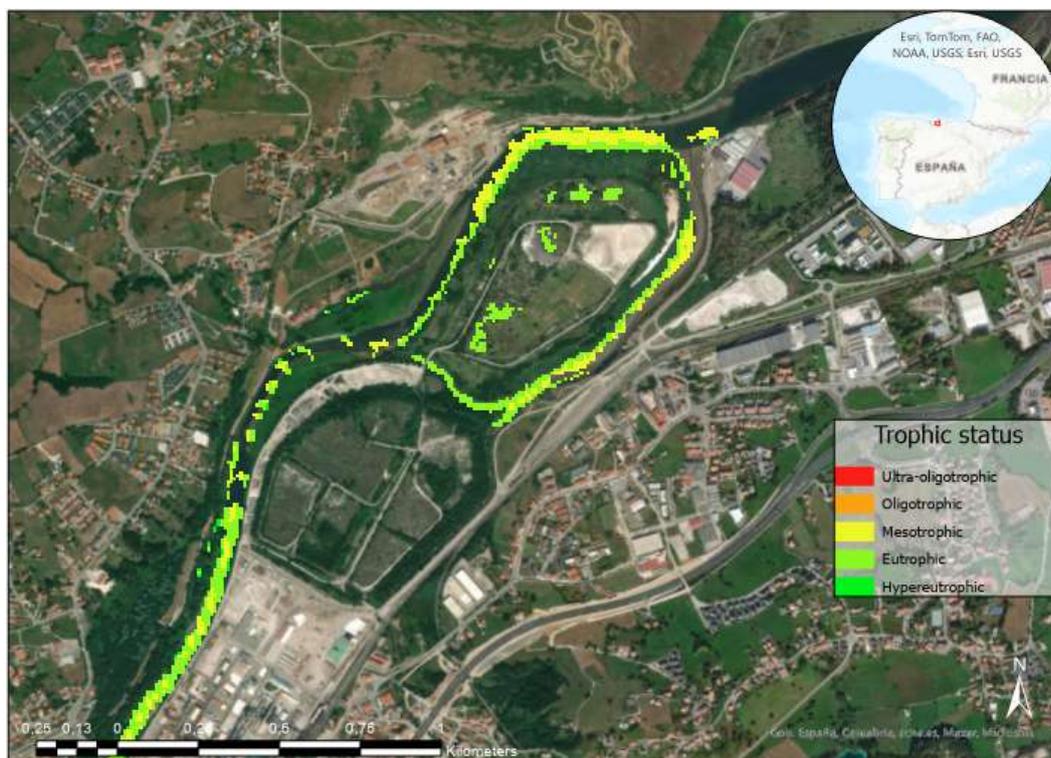


Figure 12. Example of the TSI following Fedonenko *et al.* (2022) in the Saja basin.

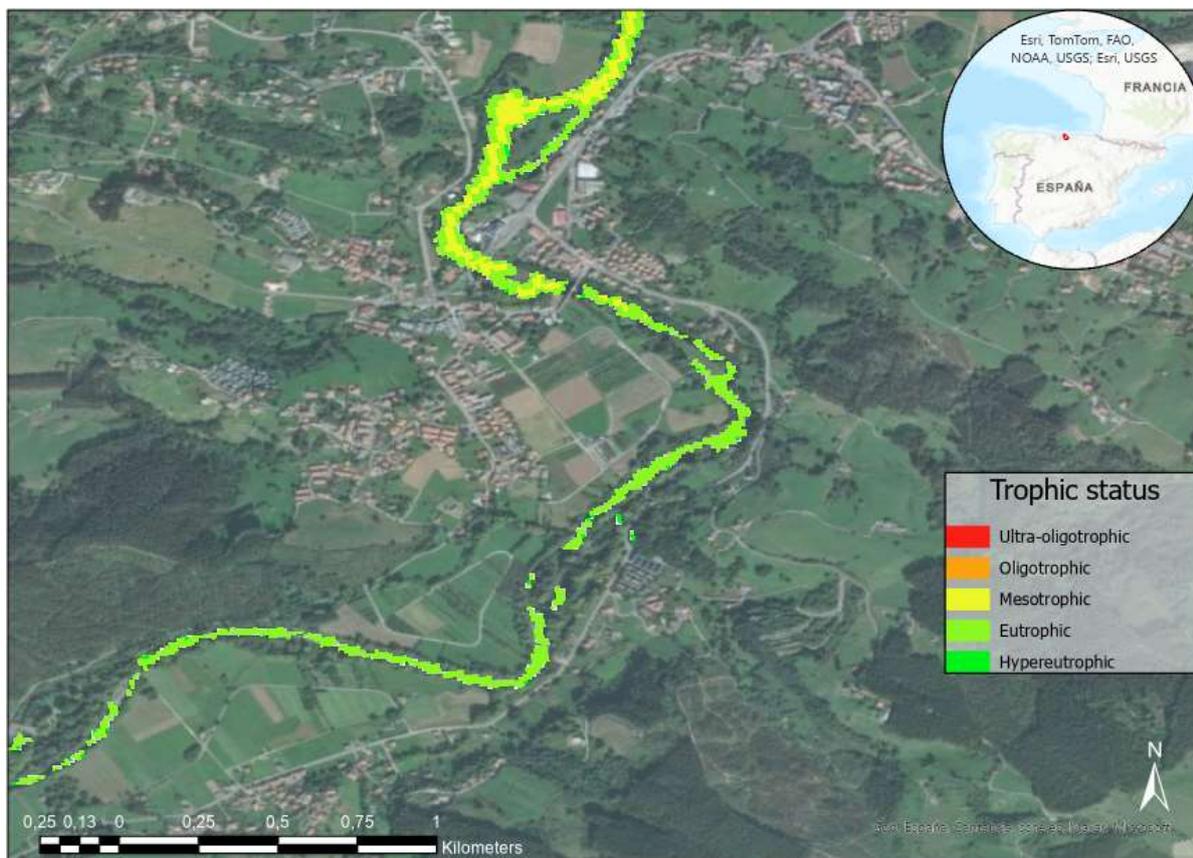


Figure 13. Example of the TSI following Fedonenko *et al.* (2022) in the Pas basin.

## 4 GROUND DATA FOR THE VALIDATION OF THE SELECTED INDICATORS

To validate remote sensing data, it is essential to have field data from various sources. This will allow the evaluation of the performance of the estimates derived from Copernicus products, as well as calculations based on Sentinel-2 or LiDAR data, compared to actual parameters values. In cases where discrepancies are identified, these data can be used to refine and improve the methods for greater accuracy.

One of the available ground truth datasets consists of field data collected by botanists identifying vegetation formations in the riparian zones. These data will be used to validate the land use data obtained from the Copernicus products.

In terms of riparian forest dasometry data, the primary validation dataset is the National Forest Inventory. This resource provides a range of parameters that can be extracted to validate and calibrate the models derived from the PNOA project, thereby enhancing their accuracy.

Regarding aquatic ground data, the most significant database originates from the Monitoring Programmes (including surveillance and operational control) established to assess water status in

accordance with national and European regulations. This monitoring system, referred to as the Automatic Water Quality Information System (SAICA), is managed by the General Directorate for Water Quality. SAICA operates through approximately 200 monitoring stations designed to detect various pollutants and other parameters. The network continuously collects water quality data across different river basins in Spain, allowing for the observation of trends in the measured parameters. Besides, IHCantabria has been regularly measuring several water quality parameters, including chlorophyll concentrations, in multiple rivers in Cantabria, which provides with critical information to validate the eutrophication calculations.

## 5 ACKNOWLEDGMENTS

This work is supported by the European Union's Caroline Herschel Framework Partnership Agreement on Copernicus User Uptake under grant agreement No FPA 275/G/GRO/COPE/17/10042, project FPCUP (Framework Partnership Agreement on Copernicus User Uptake), Action 2021-1-2 "Copernicus Tools for Monitoring Global Change Effects in Rivers and Riparian Zones" (SPECIFIC AGREEMENT N°19 - 2022/S12.879177 /19).

## 6 REFERENCES

- ALICE Project (n.d.). Improving the management of Atlantic Landscapes: accounting for biodiversity and ecosystem services. <https://alice.ihcantabria.com/>
- Álvarez-Cabria, M., Barquín, J., & Peñas, F. J. (2016). Modelling the spatial and seasonal variability of water quality for entire river networks: Relationships with natural and anthropogenic factors. *Science of the Total Environment*, 545, 152-162.
- Barquín, J., & Death, R. G. (2009). Physical and chemical differences in karst springs of Cantabria, northern Spain: do invertebrate communities correspond?. *Aquatic Ecology*, 43, 445-455.
- Barquín, J., Fernández, D., Álvarez-Cabria, M., & Peñas, F. (2011). Riparian quality and habitat heterogeneity assessment in Cantabrian rivers. *Limnetica*, 30(2), 0329-346.
- Bundesamt für Naturschutz (Ed.), (2017). Bewertungsschemata für die Bewertung des Erhaltungsgrades von Arten und Lebensraumtypen als Grundlage für ein bundesweites FFH-Monitoring. Teil II: Lebensraumtypen nach Anhang I der FFH-Richtlinie (mit Ausnahme der marinen und Küstenlebensräume). Bonn, Germany: Bundesamt für Naturschutz.
- Burdon, F. J., Ramberg, E., Sargac, J., Forio, M. A. E., de Saeyer, N., Mutinova, P. T., Moe, T. F., Pavelescu, M. O., Dinu, V., Cazacu, C., Witing, F., Kupilas, B., Grandin, U., Volk, M., Rîsnoveanu, G., Goethals, P., Friberg, N., Johnson, R. K., & McKie, B. G. (2020). Assessing the benefits of forested riparian zones: a qualitative index of riparian integrity is positively associated with ecological status in European streams. *Water* 12 (4), 1178.
- Confederación Hidrográfica del Cantábrico (CHCantábrico, n.d.-a). Río Besaya. <https://www.chcantabrico.es/las-cuencas-cantabricas/marco-fisico/hidrologia/rios/besaya>

- Confederación Hidrográfica del Cantábrico (CHCantábrico, n.d.-b). Río Pas.  
<https://www.chcantabrico.es/las-cuencas-cantabricas/marco-fisico/hidrologia/rios/pas>
- Confederación Hidrográfica del Cantábrico (CHCantábrico, n.d.-c). Río Saja.  
<https://www.chcantabrico.es/las-cuencas-cantabricas/marco-fisico/hidrologia/rios/saja>
- Derepasko, D., Peñas, F. J., Barquín, J., & Volk, M. (2021). Applying optimization to support adaptive water management of rivers. *Water*, 13(9), 1281.
- Directiva Marco del Agua (DMA) Cantabria (n.d.-a). Cuenca del Pas.  
<https://dmacantabria.cantabria.es/visorWeb/pdf/RIOS/Pas.pdf>
- Directiva Marco del Agua (DMA) Cantabria (n.d.-b). Cuenca del Saja-Besaya.  
<https://dmacantabria.cantabria.es/visorWeb/pdf/RIOS/SAJA.pdf>
- Ercole, S., Giacanelli, V., Bacchetta, G., Fenu, G., & Genovesi, P. (2016). Manuali per il monitoraggio di specie e habitat di interesse comunitario (Direttiva 92/43/CEE) in Italia: specie vegetali.
- Estevez, E., Rodríguez-Castillo, T., Álvarez-Cabria, M., Penas, F. J., González-Ferreras, A. M., Lezcano, M., & Barquín, J. (2017). Analysis of structural and functional indicators for assessing the health state of mountain streams. *Ecological indicators*, 72, 553-564.
- Fedonenko, E. V., Kunakh, O. M., Chubchenko, Y. A., & Zhukov, O. V. (2022). Application of remote sensing data for monitoring eutrophication of floodplain water bodies. *Biosystems Diversity*, 30(2), 179-190.
- Fernández, M. A. V., Fernández, M. M., Pardo, J. F. J., & Matesanz, D. C. (2023). Study of the access routes to the Castilian plateau through the Sella River valley (Asturias, Spain) during the end of the Upper Palaeolithic. *Journal of Archaeological Science: Reports*, 47, 103792.
- IHCantabria (2020). Plan de gestión ambiental integrada de cuencas hidrográficas a escala local 2020. Caso piloto: cuenca Saja-Besaya.
- Kettenhuber, P. L. W., dos Santos Sousa, R., Dewes, J. J., Rauch, H. P., Sutili, F. J., & Hörbinger, S. (2023). Performance assessment of a soil and water bioengineering work on the basis of the flora development and its associated ecosystem processes. *Ecological Engineering*, 186, 106840.
- Lara, F., Calleja, J. A., & Garilleti, R. (2019). Selección y descripción de variables que permitan diagnosticar el estado de conservación del parámetro 'Estructura y función' de los diferentes tipos de hábitat de bosque y matorral de ribera. Serie "Metodologías para el seguimiento del estado de conservación de los tipos de hábitat". Ministerio para la Transición Ecológica. Madrid. 57 pp.
- Natura Spain (n.d.-a). Zona LIC de río Pas. <http://www.naturaspain.com/zona-lic-rio-pas.html>
- Pérez-Silos, I., Álvarez-Martínez, J. M., & Barquín, J. (2019). Modelling riparian forest distribution and composition to entire river networks. *Applied Vegetation Science*, 22, 508-521.