



# Validation Report - CLCplus Backbone 2023

ESTABLISHMENT AND MAINTENANCE OF A  
CROSS-CUTTING VALIDATION  
FRAMEWORK FOR AND VALIDATION OF  
COPERNICUS LAND MONITORING SERVICE  
PRODUCTS



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## Executive Summary

This report presents the validation results for the Copernicus Land Monitoring Service (CLMS) raster product CLCplus Backbone 2023 (CLCplus BB). It comprises a raster inventory layer displaying the predominant land cover class out of 11 basic categories for the reference year 2023. The work was conducted under the framework service contract No EEA/DIS/R0/23/010. Thematic accuracy was assessed in a statistically sound approach using available reference and supportive data at different reporting units. It showed that at

- **EEA 38 + UK level: Results are good but fall short of the target >90% at the EEA38 + UK reporting level** with blind validation at 79.5% (0.6% Margin of Error) and plausibility validation at 88.6% (0.5% Margin of Error). Classes such as woody - broadleaved evergreen trees (4), low-growing woody plants (5), lichens and mosses (8) and non- and sparsely-vegetated (9) showed significant improvement during plausibility checks.
- **Biogeographical Regions level: there are some regional differences.** The Arctic, Atlantic, Continental, Macaronesia and Steppic regions achieve >90% accuracies, lowest accuracy is observed in the Tropical region (78.2%). The Mediterranean and Tropical regions show significant challenges distinguishing low-growing woody plants (5), permanent herbaceous (6) and periodically herbaceous areas (7).

A documentation review confirmed the availability of a comprehensive and detailed Product User Manual (PUM) and Algorithm Theoretical Basis Document (ATBD) for the investigated product. Both documents are comprehensive and clearly written, though they deviate from the CLMS template structure. The ATBD would benefit from a quality control chapter, improved map elements and clearer figure captions. The PUM is well-structured but should include a non-technical summary and chapter overview. Minor spelling and consistency issues were found in both documents.

# 1 Introduction

This report informs about the validation assessments and their results obtained for the CLCplus BB raster product 2023. The validation was conducted under the framework service contract No EEA/DIS/R0/23/010. The CLMS validation framework defines the validation methods applicable to the different CLMS products in a way to maximize synergies, yet also allow adaptations needed to product specific characteristics. Generally, the validation framework addresses the different validation elements referred to in the ISO19157:2023 standard, titled "Geographic information – Data quality," to investigate the CLMS product quality within the CLMS validation framework:

- **Completeness:** The presence and absence of features, their attributes, and relationships.
- **Logical consistency:** The degree of adherence to logical rules of data structure, attribution, and relationships (e.g., topological consistency).
- **Positional accuracy:** The accuracy of the position of features.
- **Temporal accuracy:** The accuracy of temporal attributes and the relationships of features with time.
- **Thematic accuracy:** The accuracy of attribute values and classifications.

In addition to the ISO19157 quality elements:

- **Usability:** Checks assess the quality and completeness of product documentation.

Completeness, logical consistency and positional accuracy are tested and validated as part of the CLMS production and delivery phase, mainly via the CLMS QC Tool (European Environment Agency 2025a) and are not replicated here. Temporal accuracy checks are only applied to CLMS product layers, where the relationships of product features to time are an implicit product criterion and are not applied to the CLCplus BB 2023 raster product.

## 2 Product Description

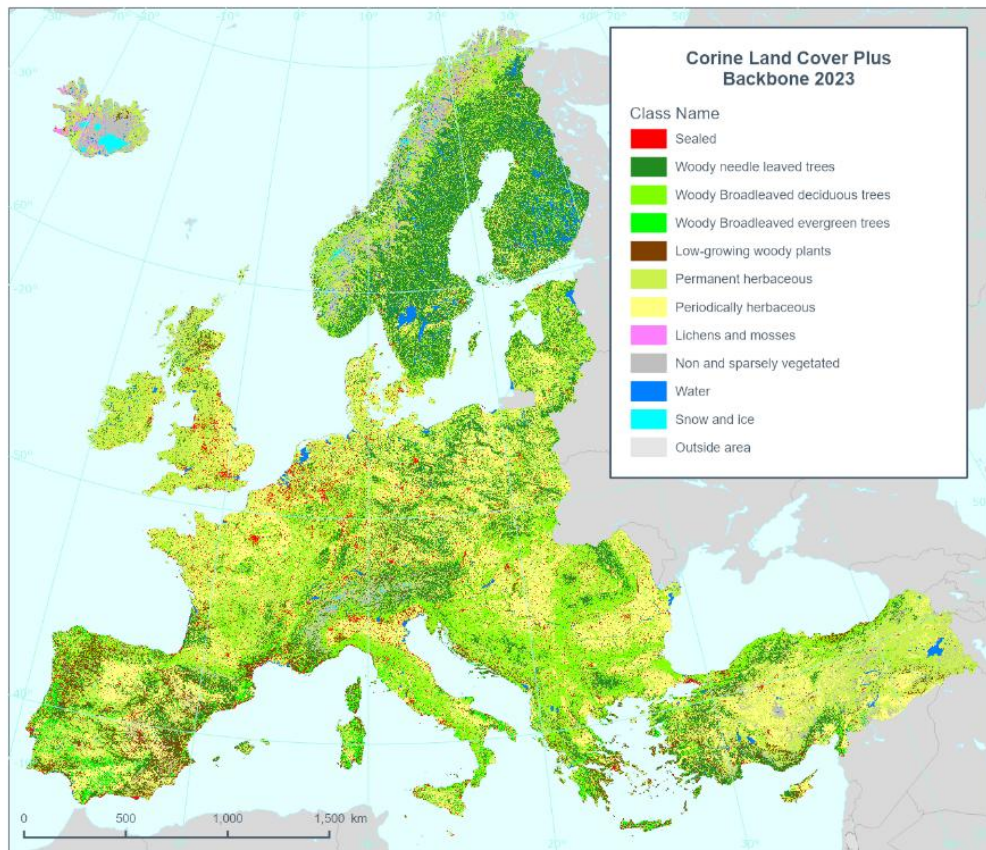
CLCplus BB is a detailed pan-European wall-to-wall land cover (LC) inventory layer. It is part of the CLCplus product suite. This validation report covers the CLCplus BB product generated for the reference years 2023 (Table 1). The product provides, as a 10m spatial resolution raster layer, 11 encoded LC classes according to a predefined product specification (Table 2).

**Table 1: CLMS product elements validated**

Product Name	Acronym	Version	Date Provided / Published
CLCplus-Backbone Raster	CLCplus BB 2023	V1_0	11.04.2025 (Publication)

**Table 2: CLCplus BB 2023 raster product characteristics (Copernicus Land Monitoring Service 2025b)**

Product Name		Acronym	Product family
CLCplus Backbone Raster Product 10m		CLCplus BB 2023	CLMS_CLCplus
Summary:	CLCplus BB is a spatially detailed, large scale, Earth-Observation-based land cover inventory. The CLCplus BB raster product is a 10m pixel-based land cover map based on Sentinel time series from October 2022 to March 2024 and auxiliary features. For each pixel it shows the dominant land cover among the 11 basic land cover classes.		
Reference year:	2023		
Geometric resolution	Pixel resolution 10m x 10m, fully conform with the EEA reference grid		
Coordinate Reference System:	European ETRS89 LAEA projection / WGS84 and the respective UTM zone for French DOMs		
Coverage:	6.002.105 km² (covering the full EEA38 + UK)		
Geometric accuracy (positioning scale):	Equals Sentinel-2 positional accuracy in 2023 (<9m at 95.5 % confidence level)		
Thematic accuracy:	90 % overall accuracy, not more than 15 % omission errors and 15 % commission errors per class (the amount of omission and commission errors for particular difficult classes such as Low-growing woody plants and Lichens and Moses might regionally exceed those thresholds)		
Data type:	8bit unsigned raster with LZW compression		
Minimum Mapping Unit (MMU):	Pixel-based (no MMU)		
Raster (thematic values)	coding pixel	1: Sealed 2: Woody – needle leaved trees 3: Woody – Broadleaved deciduous trees 4: Woody – Broadleaved evergreen trees 5: Low-growing woody plants (bushes, shrubs) 6: Permanent herbaceous 7: Periodically herbaceous 8: Lichens and mosses 9: Non- and sparsely-vegetated 10: Water 11: Snow and ice 253: Coastal seawater buffer 254: Outside area 255: No data	
Metadata:	XML metadata files according to INSPIRE metadata standards		
Delivery format:	Cloud optimized GeoTIFFs as 100x100km tiles incl. pyramids and embedded colour map (*.tif), attribute table (*.aux.xml), and INSPIRE-compliant metadata in XML format (*.xml)		



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO



**Figure 1: CLCplus BB 2023 for the EEA38 + UK (note: French DOMs are not shown) (Copernicus Land Monitoring Service 2025c).**



## 3 Validation Methodology and Analysis

The following chapters describe the specific methods to check the thematic accuracy and usability for the CLCplus BB product 2023.

### 3.1 Thematic accuracy

The CLMS validation approach for thematic accuracy compares the CLMS products with validation data in a sample-based approach, following established scientific practices (Congalton and Green 2008; Olofsson et al. 2014; Stehman and Foody 2019). The validation data is assumed to be more accurate than the product data. The level of agreement between validation and product data defines the thematic accuracy. The accuracy estimation methodology consists of three major components, explained in more detail in the following chapters: Sampling Design, Response Design and Accuracy Assessment.

#### 3.1.1 Sampling Design

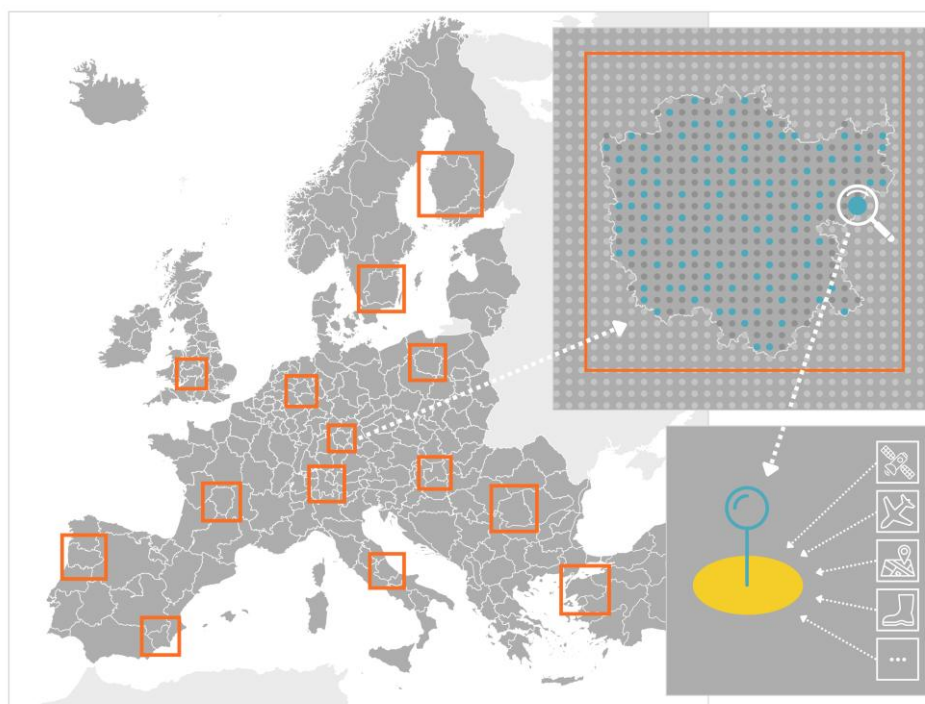
The sampling design involves the protocol for selecting the sample and determining the number of sample units. The sample is chosen using a probability approach, ensuring each element has a calculable chance of selection (sampling weights). This approach allows for extrapolation of accuracy from the sample to the entire study area. Stratification is used to effectively allocate samples to classes of interest or rare classes that might otherwise be underrepresented. Knowing the sampling probability (weights) is crucial to account for unequal probabilities and prevent bias in accuracy estimation. **The sampling design for the validation of thematic accuracy for the CLMS product consists of two elements** (Figure 2):

- **Validation Areas:** representing the smallest reporting unit and seamlessly covering EEA38 + UK territory as defined by the Copernicus EEA38 + UK boundary layer (European Environment Agency 2023).
- **Sampling Frame:** 2x2 km grid points covering all validation areas.

**The validation areas are primarily defined by NUTS2 administrative units**, which provide comprehensive and scalable coverage for the validation process. They are aligned with the CLMS production extent, including a buffer around the terrestrial territory. The validation areas are stratified by the Biogeographical Regions (BGR) dataset offered by EEA (European Environment Agency 2016). It contains the official delineations used in the Habitats Directive (92/43/EEC) and for the EMERALD Network set up under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). Each validation area is assigned to the BGR where most of the territory overlaps. During the generation of the validation areas, smaller NUTS2 units with fewer than 500 sample grid points were aggregated, and larger NUTS2 units were split to better align with the boundaries of the BGR.

**The sampling frame is represented by points along a 2x2 km-spaced grid** aligned with the Copernicus grid (European Environment Agency 2024) and LUCAS Master frame grid (European Commission: Eurostat et al. 2018). It was spatially enlarged to cover EEA38 + UK. Each point of the grid is stratified by the CLCplus Backbone raster product 2018 (Copernicus Land Monitoring Service 2023) into 11 classes, with the pixel northeast of the point used as a reference class for stratification. The points define the position of the sample unit. The final sample units for the accuracy assessment are then selected using both validation areas and sampling frame.





**Figure 2: Schematic example of sampling design: selection of validation area (orange squares), selected sampling locations (blue) within validation area (white outline) and sampling units (yellow) populated with existing reference information.**

The validation areas are selected from each BGR stratum using a random selection process, whereby larger validation areas are more likely to be selected. A minimum of one validation area per BGR is required, with an approximately proportional allocation of the remaining areas. Depending on the applied reporting level different numbers of validation areas are selected for the standard CLMS cross-cutting validations. For the EEA38 + UK wide assessment of CLCplus BB 2023, 40 validation areas are randomly selected from each BGR (Table 3) representing approximately 19% of EEA38 + UK territory. In addition to the previous CLCplus BB 2021 validation, two validation areas had been included, located in the Alpine and Atlantic regions.

**Table 3: Validation areas per BGR in EEA38 + UK**

BGR	EEA38 + UK	
	Total validation areas	Selected validation areas
Alpine (ALP)	21	4
Anatolian (ANA)	11	2
Arctic (ARC)	1	1
Atlantic (ATL)	73	7
Black Sea (BLS)	6	2
Boreal (BOR)	17	3
Continental (CON)	102	10
Macaronesia (MAC)	2	1
Mediterranean (MED)	60	6
Pannonian (PAN)	10	2
Steppic (STE)	1	1
Tropical (TRO)	3	1
<b>Total</b>	<b>307</b>	<b>40</b>

**Sample points are then drawn from the sampling frame within the selected validation areas.** The points are selected using a random stratified approach from each CLCplus BB 2018 strata. The number of sample units is determined based on two key considerations:

- Minimum number of sample units for accuracy reporting: A sufficient number of sample units is needed to report accuracy across all thematic classes at both the validation area and BGR levels. The number of sample units is guided by the product accuracy requirements and corresponding margin of error (MoE) of  $\pm 5\%$  at a 95% confidence interval. The underlying sample size calculation is presented in (Stehman and Foody 2019) and uses expected user's accuracy  $p$  and targeted MoE  $d$ , to estimate the required number of sample units per class  $n_h$ . The z-score  $z$  is set to 1.96 for a 95% confidence interval.

$$n_h = \frac{z^2 p(1 - p)}{d^2}$$

- Based on the assumption of a product per class user's accuracy of 85% and a target MoE of the UA of 5%, this would then require 200 sample units per class. The objective is to have a minimum number of sample units per class at the BGR level. For each selected validation area there should be a minimum of 30 samples per class. However, fewer samples may be acceptable for rare classes that are not well-covered in some BGRs or validation areas. For some classes, the selected sample size is thus below 200 per BGR because there are not enough sample units available within the standard 2x2 km sampling frame.
- A maximum number of sample units per validation area was defined, ranging from 500 to 800, depending on the number of validation areas per BGR. Larger BGRs were allocated fewer sample units per validation area, while smaller BGRs with fewer validation areas received more. Once the minimum number of sample units per validation area is met, the remaining units up to the maximum number are allocated proportionally. This approach targets enough sample units for all thematic classes across all reporting levels, while maintaining a representative character by allocating a part of the sample units proportionally.
- Shared sampling design: The overall CLMS validation framework foresees that one sample can be used for different CLMS products (cross-cutting efficiency). To achieve this, a sufficient number of sample units must be allocated across different thematic domains. The CLCplus BB 2018 classes (Copernicus Land Monitoring Service 2022) are used as the strata for guiding this allocation since its thematic classes cover most land cover types. To ensure adequate representation of rare classes, more sample units are included than typically required to achieve statistical robustness.

Sample weights are calculated for each sample unit combining the selection probabilities of the first stage and second stage sampling. The weights provide the information how many sample units each point represents in the total population of all possible sample points. It considers the different selection probabilities in both sampling stages and compensates for unequal number of samples per strata.

This general cross-cutting sampling approach foresees using the same validation areas and sample units for the validation of different CLMS products and reference years. Validation areas are not considered fixed but may be adjusted or changed in the course of later validation activities in order to consider the availability of existing and upcoming reference data, align with changing CLMS product extent or to better cover specific CLMS product classes.

**Adjustments are needed to this general sampling approach for the CLCplus BB validation** to ensure independence of validation data from production data. The LUCAS 2018 survey data has been used in the production of CLCplus BB 2018, 2021 and 2023 (Copernicus Land Monitoring Service 2025a), but is also an important reference data source for this CLMS validation. Therefore, to maintain independence from the training data, any point in the sampling frame

grid that coincided with LUCAS 2018-point locations has been replaced using the following procedure:

- Shift the points 1 km north. If the point remains within the same LC, it is kept in its new position.
- If the point does not remain in the same strata, shift the point 1 km east from the original position. If the point is within the same CLCplus BB 2018 strata, it is kept in its new position. If not, shift the point back to the northern position and accept the different strata.

**This procedure ensures the independence of validation data by avoiding bias from using training data and maintains an approximate share of the same LC strata.** Around 26% of the sample points selected were shifted spatially. For the 2023 validation, the same sampling design and exclusion rules were applied for newly selected validation areas. This approach preserves the independence of validation data from training data and ensures consistency across the time series of validation data from 2018, 2021, and 2023.

**The targeted sample size of 200 sample units is achieved for all thematic classes at the EEA38 + UK level** (Table 4). For some BGR, there are thematic classes with lower sample unit numbers, due to their limited occurrence, e.g. sparse vegetation (9) in the PAN region, broadleaved evergreen trees (4) in the BLS region, or sealed areas (1) in the ARC region.

**Table 4: Sample units per CLCplus BB 2023 class and BGR at EEA38 + UK**

	1	2	3	4	5	6	7	8	9	10	11	Total
ALP	169	530	474	1	286	669	178	72	367	103	124	2,973
ANA	132	155	154	10	161	400	240		198	49		1,499
ARC	46	26	58		96	156	8	87	105	99	100	781
ATL	326	354	571	187	416	1,527	632		222	250		4,485
BLS	93	141	357	10	139	289	263		110	71		1,473
BOR	231	417	290		203	401	261	92	204	147		2,246
CON	382	596	961		211	1,091	1,336		96	306		4,979
MAC	38	50	15	88	66	108	28		26	76		495
MED	223	358	433	612	791	919	688		238	226		4,488
PAN	166	163	228		152	254	394		26	105		1,488
STE	85	86	118		91	126	182		34	78		800
TRO	58			206	52	145	20		5	101		587
Total	1,949	2,876	3,659	1,114	2,664	6,085	4,230	251	1,631	1,611	224	26,294

1: Sealed

2: Woody – Needle leaved trees

3: Woody – Broadleaved deciduous trees

4: Woody – Broadleaved evergreen trees

5: Low-growing woody plants

6: Permanent herbaceous

7: Periodically herbaceous

8: Lichens and mosses

9: Non- and sparsely-vegetated

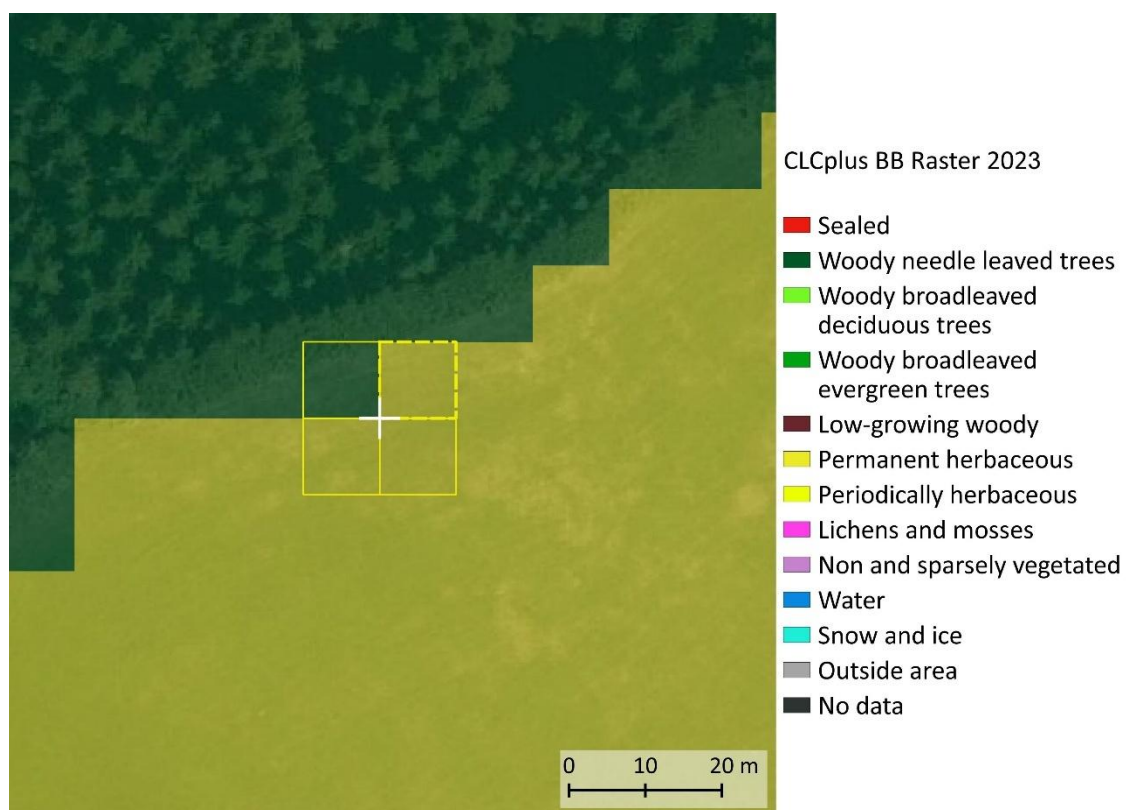
10: Water

11: Snow and ice

### 3.1.2 Response Design

The response design describes all steps to collect validation data at the sample sites and compare it with the product to be validated. It includes deciding on an appropriate type of sample unit and the protocol for collecting or preparing reference data to create a 1:1 spatial, thematic, and temporal match with the product data.

The sample unit for CLCplus BB 2023 consists of 4 pixels representing an area of 20x20 meters around the central sampling point (Figure 3). The north-eastern pixel is used as the main sample unit for land cover interpretation. Additionally, it is recorded if the other three units also belong to the same land cover. This enables further analyses, such as homogeneity assessments over the enlarged sample unit. In analogy to the CLCplus BB production process, a pixel is classified into a land cover class if that class covers more than 50% of the pixel. If no single class exceeds 50%, a relative majority is used, as detailed in the decision tree applied during the CLCplus BB 2023 production (Copernicus Land Monitoring Service 2025b).



**Figure 3: Sample units for the validation of CLCplus BB 2023. Central sampling point (white cross) and surrounding sample units (yellow) including the main North-Eastern sample unit (dashed line)**

In the standard approach, validation data is created by classifying samples according to the thematic classes of the products being validated. This process involves utilizing existing and suitable reference datasets. **Sample units are inspected or visually interpreted using Computer-Assisted Photointerpretation (CAPI) and existing high-quality reference and supporting data** (Table 5). The reference data serve as the primary source for visual interpretation, providing high-quality reference information from the same year. Supportive data, on the other hand, offer additional context or information to aid the decision-making process. Reference data from different years can be used to confirm stable classes/quantities from logical rules or to track and confirm change between CLMS product releases. E.g. Orthophotos showing needle leaved forest in pre-product dates and needle leaved forest in post-product years, imply that the same forested land cover was also present in the CLMS product reference year. In addition, NDVI time



series based on Sentinel-2 data are used at the sample location to support the identification of land cover classes through their temporal profile in the reference year (e.g. to confirm duration of snow coverage in the reference period). The checks and interpretation of the sample units are conducted in a Geographic Information System (GIS), employing dedicated data entry forms that incorporate a range of features including dropdown menus, checkboxes, comment text fields and the capacity for structured and guided data entry (Figure 4).



**Figure 4: Standard GIS layout for interpretation of CLCplus BB sample units. Customized attribute entry form (right) and multiple maps views with reference or supportive layers (left).**

To address possible discrepancies in temporal, thematic, or spatial comparability with validation data, two approaches are applied for validation:

- **Initial Blind Approach:** At this stage, validation data is created independently of the product. The interpreter is unaware of the CLMS product value or the sample strata to which it belongs during the classification process, ensuring an unbiased comparison. Alternatively, reference data from different sources can be compared directly to the map. This approach helps to maintain the objectivity of the validation process.
- **Plausibility Approach:** In this phase, "not matching" sample units are reviewed again with knowledge of the CLMS product value. This review helps to identify and rectify discrepancies due to factors such as border cases, ambiguous class definitions, or different minimum mapping units or issues related to positional shift between reference and map data (Table 6).

To account for geolocation differences between the reference data and the map, the plausibility assessment uses a reduced threshold for land cover class coverage. Instead of the >50% majority threshold defined in the CLCplus BB product specification and used in blind interpretation, a lower threshold of >25% LC coverage within the sample pixel is sufficient to confirm plausibility.

This approach results in two validation datasets, one from the initial blind approach and another after the plausibility review, thereby reducing errors in sample unit classification. The workflow ensures that the plausibility review is conducted only after the blind approach has been completed, and it is performed by a different operator, further enhancing the objectivity and accuracy of the validation process.

**Table 5: Reference (r) and supportive data (s) used for the validation of CLCplus BB 2023**

Coverage	Use	Product name	Reference type	Reference year	Access mode	Provider
EEA39	s	EEA39_VHR_2018	Orthoimagery	2018	WMS / WMTS	EEA/CLMS
EEA39	s	EEA39_VHR_2021	Orthoimagery	2021	WMS / WMTS	EEA/CLMS
EEA38 + UK	s	EEA39_VHR_2024	Orthoimagery	2022-2024	Download	EEA/CLMS
EEA38 + UK	r	Sentinel-2 Mosaic (summer - autumn)	Orthoimagery	2023	Download	EEA/CLMS
EEA38 + UK	r	Sentinel-2 Mosaic (winter - spring)	Orthoimagery	2023	Download	EEA/CLMS
EEA38 + UK	s	Sentinel-2 Mosaic (summer - autumn)	Orthoimagery	2022	Download	EEA/CLMS
EEA38 + UK	s	Sentinel-2 Mosaic (winter - spring)	Orthoimagery	2022	Download	EEA/CLMS
EEA38 + UK	s	Sentinel-2 Mosaic (summer - autumn)	Orthoimagery	2024	Download	EEA/CLMS
EEA38 + UK	s	Sentinel-2 Mosaic (winter - spring)	Orthoimagery	2024	Download	EEA/CLMS
EEA38 + UK	r	Sentinel-2 NDVI time series 2021-2024	Vegetation index time series	2021-2024	Download	EEA/CLMS
Global	s	Bing maps	Orthoimagery	unknown	WMS / WMTS	Bing
Global	s	Google Maps	Orthoimagery	unknown	WMS / WMTS	Google
EU22+UK	s	LUCAS 2009	Field data / PI	2009	Download	Eurostat
EU26+UK	s	LUCAS 2012	Field data / PI	2012	Download	Eurostat
EU27+UK	s	LUCAS 2015	Field data / PI	2015	Download	Eurostat
EU27	s	LUCAS 2022	Field data / PI	2022	Download	Eurostat
EU27	s	LUCAS 2022 Copernicus Polygons	Field data	2022	Download	Eurostat
EU27+UK	s	LUCAS Master Strata	PI	<2017	Download	Eurostat
National / regional	s	Harmonized IACS inventory	IACS / LPIS	2019-2024	Download	EuroCrops / Europe-LAND
National / regional	s	Orthoimagery, Aerial photos	Orthoimagery	Most recent	WMS / WMTS or Download	Various
National / regional	r	Orthoimagery, Aerial photos	Orthoimagery	2023	WMS / WMTS or Download	Various
National / regional	s	Land Cover / Land Use or Vegetation Maps from different Regions, incl. French DOM	Land Cover Map	Most recent available	WMS / WMTS or Download	Various

**Table 6: Possible causes for implausibility of CAPI blind results**

Cause for blind CAPI not plausible	Explanation
Border case	Mixed pixels commonly found in transition zones between land cover types. Determining the precise coverage of a LC class is difficult. In such cases, the sample unit is classified "in favour" of the map.
Qualitatively limited reference data	The limitations of the reference data prevent an unambiguous classification. These limitations can be due to shift, tilt, shadow, low resolution, or partial missing data.
Difficult class elements for photointerpretation	LC difference cannot be directly interpreted. For example, the height of the woody plants distinguished CLCplus BB class 2/3/4 vs. 5. This attribute cannot be clearly determined from 2D image data.
Error in blind approach	Incorrect interpretation during blind approach.
Other/unclear	All other cases. Requires explanatory comment.

### 3.1.3 Accuracy Assessment

The product's thematic accuracy is assessed by comparing the validation data and the product map data using a statistical approach, with the results presented in a confusion matrix. Sample weights are used to compensate for the unbalanced selection probabilities of individual sample units in the stratified sampling approach. Several accuracy measures are calculated to assess the thematic accuracy of the CLMS product. These reporting measures include:

- **User's Accuracy (per product class, UA):** Indicates the probability that a sample unit classified as a certain class in the product actually belongs to that class on the ground.
- **Producer's Accuracy (per product class, PA):** Indicates the probability that a sample unit belonging to a certain class on the ground is correctly classified in the product.
- **Overall Accuracy (OA):** Indicates the proportion of correctly classified sample units across all classes.
- **Margin of Error (MoE):** The margin of error, representing the standard deviation at a 95% confidence level, is calculated for user's accuracy, producer's accuracy, and overall accuracy. This provides an estimate of the uncertainty associated with the accuracy measures.

$$MoE = z \times SE$$

*SE* is the Standard Error of the accuracy estimate, and *z* is the z-score corresponding to the desired confidence level, approximately 1.96 for 95% confidence level.

- **F1 Score (per product class *i*):** The F1 Score is a harmonic mean of user's accuracy and producer's accuracy for each product class. It provides a single measure of accuracy that balances the trade-off between both accuracies.

$$F1\ Score = 2 \times \frac{UA_i \times PA_i}{UA_i + PA_i}$$

Since the CLMS validation framework uses the same sample units for different CLMS products, the strata and the mapped classes are not necessarily the same. Standard stratified estimators as described by (Olofsson et al. 2014) are not suitable for calculation of overall, user's and producer's accuracy. Instead, indicator functions and stratified estimators as described by (Stehman 2014) are used here to calculate accuracies and their variances. These indicator functions account for the fact that the sample units were selected from strata that differ from the map classes. The indicator function for overall accuracy is defined as follows:

$$y_u = \begin{cases} 1 & \text{if unit } u \text{ is classified correctly} \\ 0 & \text{if unit } u \text{ is classified incorrectly} \end{cases}$$



Overall accuracy is then calculated as a sample mean using a stratified estimator (Stehman 2014):

$$\hat{\bar{Y}} = \sum_{h=1}^H N_h^* \bar{y}_h / N$$

Where

$$\bar{y}_h = \sum_{u \in h} y_u / n_h^*$$

is the sample mean of the  $y_u$  values in stratum  $h$ ,  $u \in h$  indicates that sample unit  $u$  was selected from stratum  $h$  and  $H$  denotes the number of strata.  $N$  is the number of all possible units in the sample frame (population),  $N_h^*$  is the number of possible units and  $n_h^*$  the selected sample units in stratum  $h$ . An estimator for the variance of  $\hat{\bar{Y}}$  is provided in (Stehman 2014) Equation 25 and 26.

User's accuracy and producer's accuracy require different indicator functions for  $y_u$  and  $x_u$ .

For user's accuracy:

$$y_u = \begin{cases} 1 & \text{if unit } u \text{ is classified correctly and is map class } k \\ 0 & \text{otherwise} \end{cases}$$

and

$$x_u = \begin{cases} 1 & \text{if unit } u \text{ is map class } k \\ 0 & \text{otherwise} \end{cases}$$

for producer's accuracy:

$$y_u = \begin{cases} 1 & \text{if unit } u \text{ is classified correctly and has class } k \text{ in the validation data} \\ 0 & \text{otherwise} \end{cases}$$

and

$$x_u = \begin{cases} 1 & \text{if unit } u \text{ has class } k \text{ in the validation data} \\ 0 & \text{otherwise} \end{cases}$$

User's and producer's accuracies are then calculated using a combined ratio estimator (Stehman 2014) Equation 27:

$$\hat{R} = \frac{\sum_{h=1}^H N_h^* \bar{y}_h}{\sum_{h=1}^H N_h^* \bar{x}_h}$$

where  $\bar{y}_h$  and  $\bar{x}_h$  are the sample means of  $y_u$  and  $x_u$  in the stratum  $h$ . The variance estimator for  $\hat{R}$  is provided in (Stehman 2014) Equation 28.

In addition to accuracy metrics based on the weighted confusion matrix, unweighted confusion matrices with raw sample unit counts are provided. These offer insights into inter-class confusion, especially for rare classes with low sample weights and where the actual performance may not be well reflected in the weighted result. To avoid confusion with the statistical correct weighted accuracy metrics, the producer's and user's accuracy based on the unweighted confusion matrix are labelled additionally as "Unweighted" and calculated as:

$$\text{Unweighted UA} = \frac{\text{Number of sample units correctly classified and with map class } k}{\text{Total number of sample units classified as map class } k}$$

$$\text{Unweighted PA} = \frac{\text{Number of sample units correctly classified and with validation class } k}{\text{Total number of sample units with validation data class } k}$$

## 3.2 Usability

The CLMS validation approach for usability assessment is done by conducting a structured review of the Product User Manuals (PUM) and Algorithm Theoretical Basis Documents (ATBD). The document review was carried out following the standard approach defined within the CLMS validation framework, which incorporates principles of usability checks. The methodology focused on evaluating the ATBD and PUM for the CLCplus BB 2023 against the CLMS template structures.

The review process involved systematically checking each section of the available ATBD (Copernicus Land Monitoring Service 2025a) and PUM (Copernicus Land Monitoring Service 2025b) to assess their alignment with the expected content, structure, proofreading, and level of detail prescribed by the templates. Key aspects examined included the clarity and completeness of sections on product purpose, methodology, technical specifications, user guidance, and supporting visuals such as tables and figures. A scoring system was applied to indicate the extent to which each element met the criteria, ranging from well-aligned to requiring significant improvement.

In addition, the methodology included qualitative comments to highlight strengths, identify areas needing clarification or expansion, and suggest specific enhancements. This structured approach ensured a consistent, transparent assessment of the documentation's quality and usability.

## 4 Results

### 4.1 Thematic Accuracy

The thematic accuracy results are described at the two reporting levels: EEA38 + UK and BGR.

#### 4.1.1 EEA38 + UK

The thematic accuracy evaluation shows an **OA of the CLCplus BB 2023 raster layer of 88.6% (0.5% MoE) for the plausibility approach** and 79.5% (0.6%) for the blind validation approach (Table 7). **The targeted OA of the CLCplus BB raster of >90% could thus not be confirmed.**

**Table 7: Overall thematic accuracy results at EEA38 + UK level**

Method	OA [%]	MoE [%]
Blind validation approach	79.5%	0.6%
Plausibility validation approach	88.6%	0.5%

**Accuracies improve during the plausibility checks, with more classes approaching or exceeding the requested 85% class accuracy** (Table 8). The class-specific accuracies of the water (10) and snow and ice (11) have UA and PA higher than the required 85% in the blind validation results. The classes woody – needle leaved trees (2) and periodically herbaceous (7) have UA higher than 85% and PA slightly below 85%. Especially, woody – broadleaved evergreen trees (4), low-growing woody plants (5), lichens and mosses (8) and non- and sparsely-vegetated (9) improved considerably during the plausibility checks. The higher UA compared to PA for the classes periodically herbaceous (7), lichens and mosses (8) and non- and sparsely-vegetated (9) indicate that those classes are underestimated in the CLCplus BB 2023. The lower PA indicates that the number of missed pixels in these classes is higher than the number of falsely classified pixels in the map. The MoE is below the targeted 5% for all classes except lichens and mosses (8), which relates to the combination of lower accuracy and lower number of sample units.

**The confusion matrix shows the number of samples per class** (Table 9). It provides more information on the main class confusions identified during the plausibility analysis. The green diagonal line indicates the matches between CLMS product and validation sample. As already noted in the CLCplus BB 2021 validation, one unexpected confusion is between sealed (1) and permanent herbaceous areas (6). The very high PA (unweighted) of 91.6% for the class sealed (1) is in contrast to the lower UA (unweighted) of 73.4%. There are many areas where well classified small urban structures and surrounding landscape are very well captured (Figure 5). However, visual data checks showed, that this reported confusion is often caused by fragmented urban settlements or linear infrastructures like roads, which are

difficult to capture at 10m spatial resolution and the strong spectral response from sealed surfaces (Figure 6). There are good examples of differentiation between small adjacent areas of broadleaved and coniferous forest, and the transition to herbaceous areas (Figure 7). Still, high confusion occurs among some vegetation-related classes. Low growing woody plants (5) show confusion with larger growing deciduous trees (3) and permanent herbaceous areas (6) (Figure 8 and Figure 9). Sparse vegetation (9) also contributes to misclassifications with sealed (1) and

#### CLCplus BB product classes

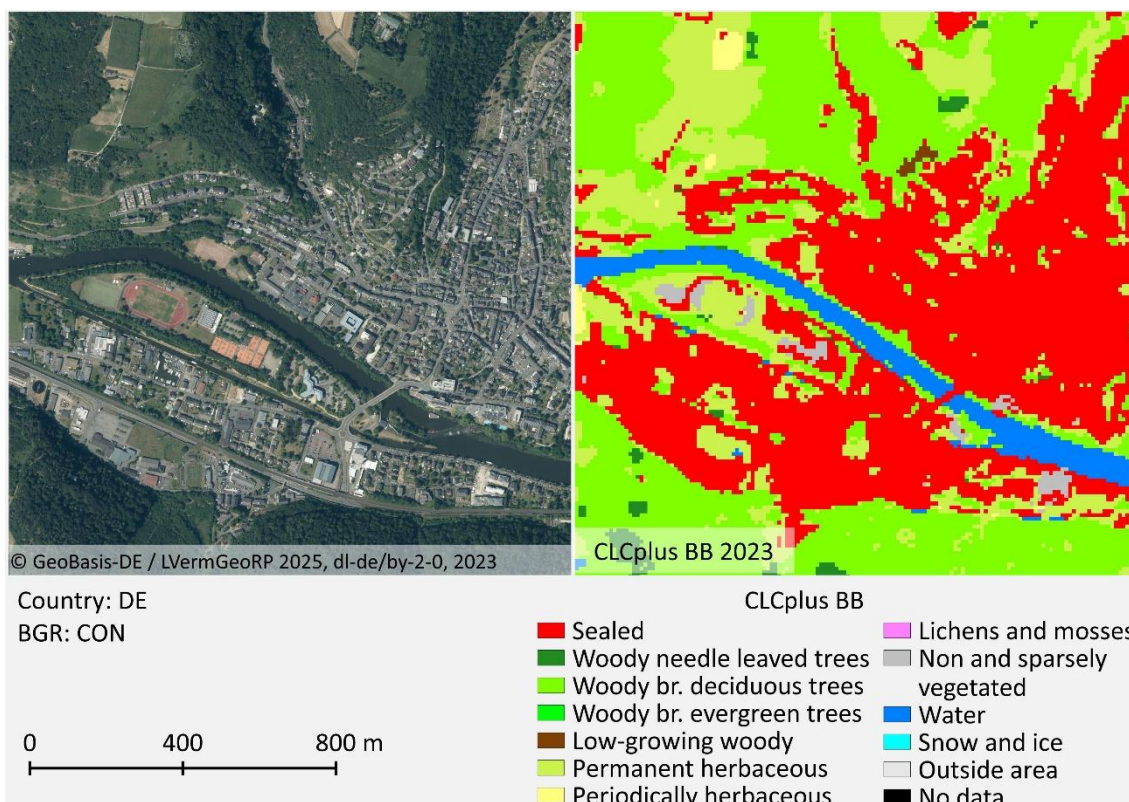
- 1: Sealed
- 2: Woody – needle leaved trees
- 3: Woody – Broadleaved deciduous trees
- 4: Woody – Broadleaved evergreen trees
- 5: Low-growing woody plants
- 6: Permanent herbaceous
- 7: Periodically herbaceous
- 8: Lichens and mosses
- 9: Non- and sparsely-vegetated
- 10: Water
- 11: Snow and ice

permanent herbaceous (6). Permanent herbaceous (6) has confusions with all other classes, except snow and ice (11). Lichens and mosses (8) are especially confused with permanent herbaceous vegetation (6) and non- and sparsely-vegetated (9) areas. Lichens and mosses often grow in complex patterns with rocks, grasses, dwarf shrubs, difficult to assess using satellite image pixels and the class is often even difficult to map without further ancillary information from very high-resolution images (Figure 10). Other classes such as water (10) and snow and ice (11) have very high classification accuracy, showing minimal confusion.

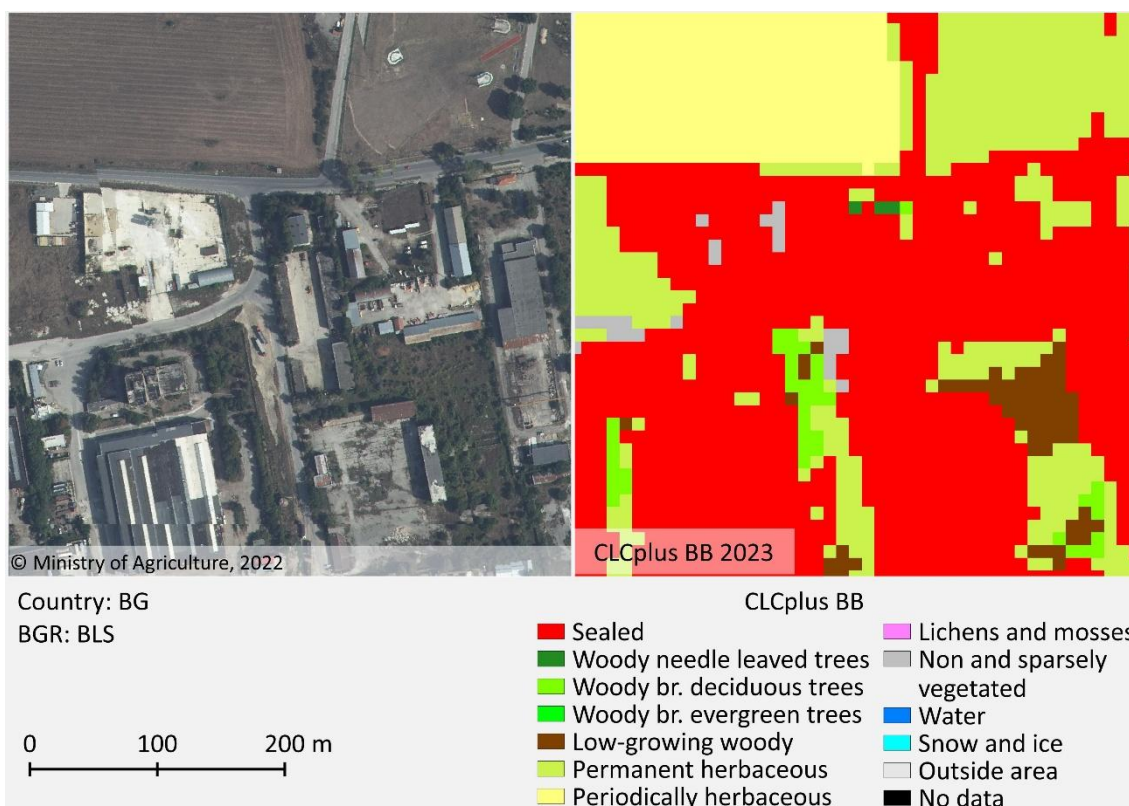
**Table 8: Thematic accuracy per class at EEA38 + UK**

Product Class	Blind Validation approach					Plausibility validation approach				
	UA [%]	MoE [%]	PA [%]	MoE [%]	F1 Score [%]	UA [%]	MoE [%]	PA [%]	MoE [%]	F1 Score [%]
1	69.6	2.6	75.0	3.5	72.2	75.0	2.4	82.8	3.3	78.7
2	85.2	1.8	84.8	1.3	85.0	91.3	1.4	94.0	0.8	92.6
3	80.3	1.5	82.1	1.4	81.2	90.6	1.0	90.7	1.1	90.7
4	59.3	3.1	70.2	2.8	64.3	86.5	2.2	89.0	1.7	87.8
5	66.2	2.3	55.4	2.0	60.3	82.1	1.5	81.9	1.9	82.0
6	74.4	1.2	82.1	1.0	78.0	85.5	1.0	88.9	0.8	87.2
7	93.2	0.8	84.5	1.2	88.7	94.7	0.8	87.9	1.1	91.2
8	59.4	10.3	33.3	6.9	42.7	83.1	8.7	44.4	7.3	57.9
9	70.4	2.9	56.2	3.1	62.5	81.0	2.4	71.4	3.3	75.9
10	97.8	0.7	94.7	1.6	96.2	98.4	0.7	95.9	1.5	97.1
11	94.8	3.0	96.3	3.0	95.6	95.6	2.6	99.6	0.8	97.6

Green = higher than CLMS product target accuracies (85%), Yellow = within 5% of target accuracy, Red = MoE >5%

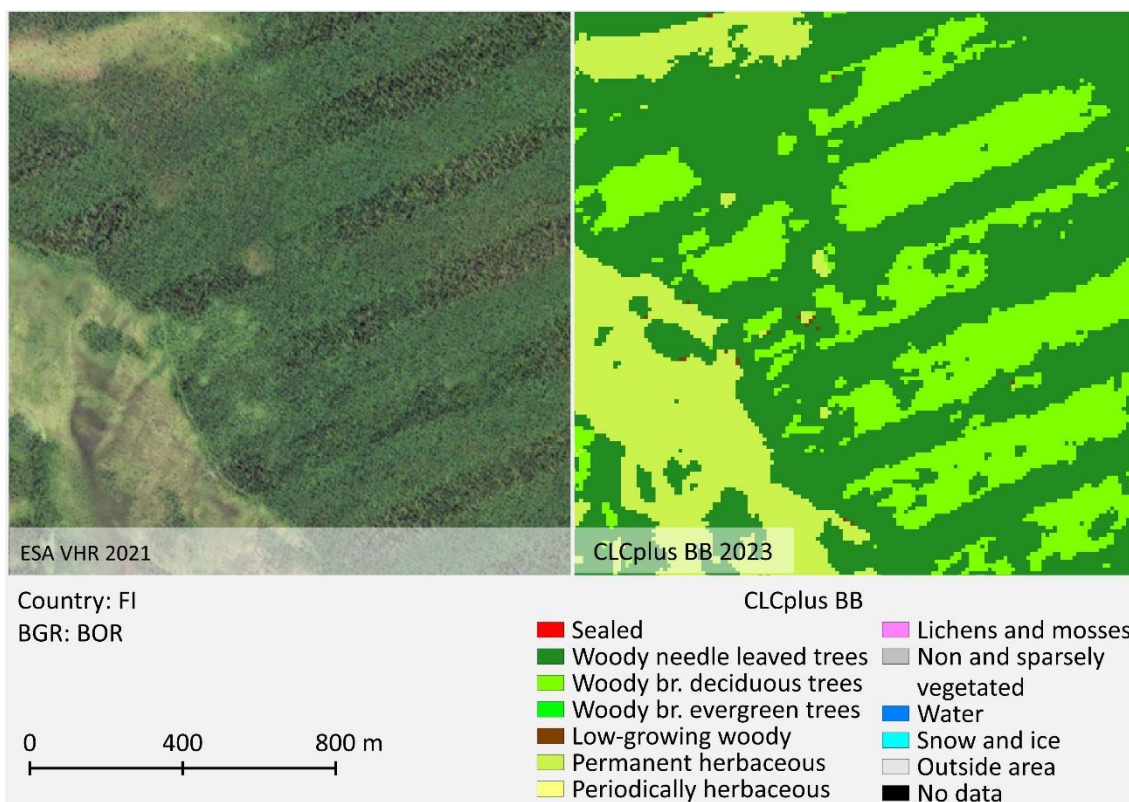


**Figure 5: Example of well classified small urban structures and surrounding landscape in Germany.**

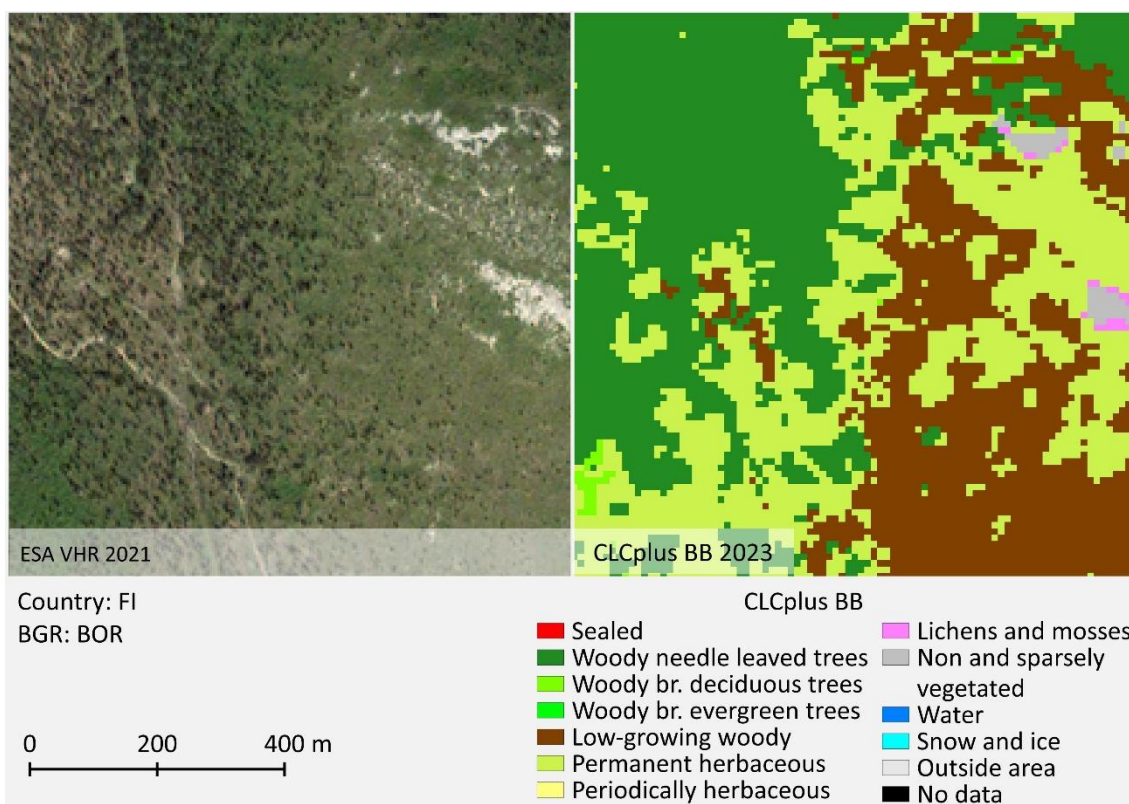


**Figure 6: Example of confusion between sealed areas, herbaceous vegetation and woody vegetation in fragmented urban settlements in Bulgaria.**



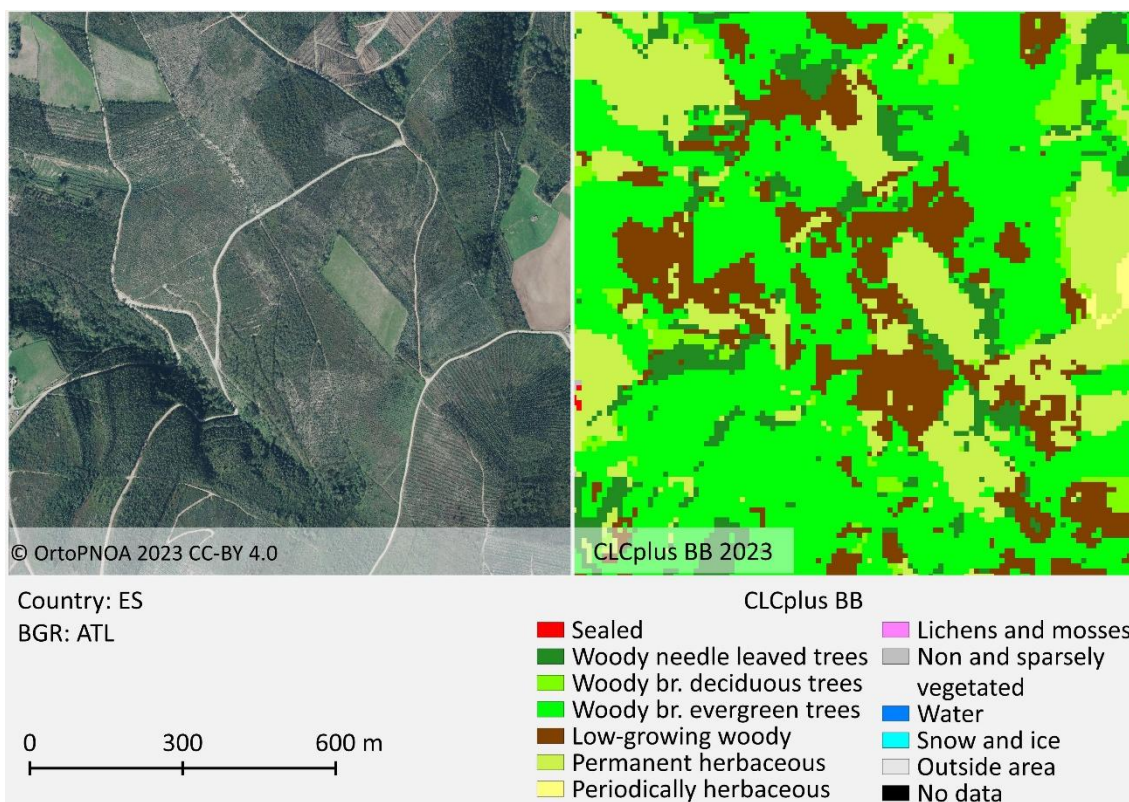


**Figure 7: Example of well classified adjacent broadleaved and coniferous forest areas and transition to herbaceous areas in Finland.**

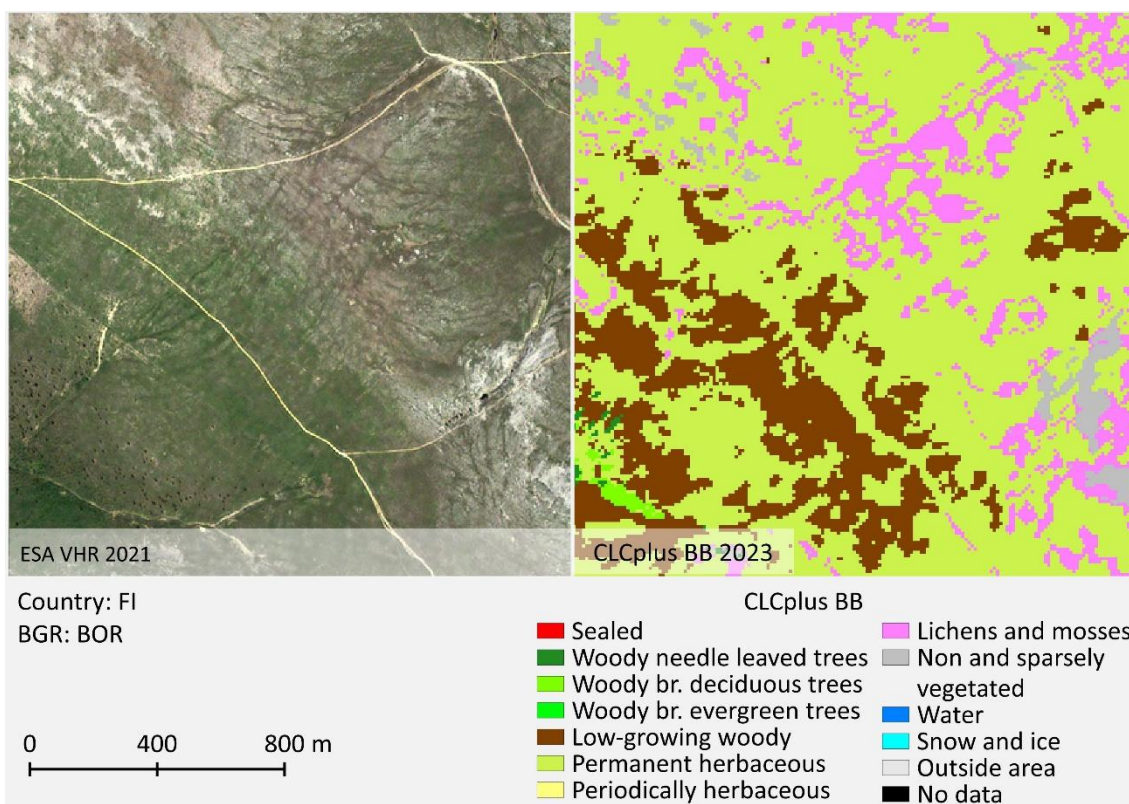


**Figure 8: Example of confusion in complex situation of woody vegetation, low-growing woody plants and permanent herbaceous vegetation in Finland.**





**Figure 9: Example of confusion in complex situation of woody vegetation, low-growing woody plants and permanent herbaceous vegetation in Spain.**



**Figure 10: Example of confusion in complex situation of lichens and mosses, low-growing woody plants and permanent herbaceous vegetation in Finland.**



**Table 9: Unweighted confusion matrix (sample counts) at EEA38 + UK - plausibility approach**

			Validation data												
			1	2	3	4	5	6	7	8	9	10	11	Total	UA Unweight.
CLCplus BB 2023	1	Sealed	1,430	10	49	11	20	300	15	0	107	7	0	1,949	73.4%
	2	Woody – needle leaved trees	4	2,543	129	4	55	119	0	0	22	0	0	2,876	88.4%
	3	Woody – Broadleaved deciduous trees	7	134	3,228	14	99	158	8	0	9	2	0	3,659	88.2%
	4	Woody – Broadleaved evergreen trees	6	2	13	973	20	76	10	0	14	0	0	1,114	87.3%
	5	Low-growing woody plants	10	72	172	49	1,851	400	46	11	47	6	0	2,664	69.5%
	6	Permanent herbaceous	52	36	125	60	130	5,088	429	45	103	17	0	6,085	83.6%
	7	Periodically herbaceous	8	3	13	12	19	158	3,981	0	34	2	0	4,230	94.1%
	8	Lichens and mosses	0	5	0	0	2	11	0	218	15	0	0	251	86.9%
	9	Non- and sparsely-vegetated	42	20	6	2	42	170	32	47	1,238	31	1	1,631	75.9%
	10	Water	2	1	7	1	2	15	2	1	15	1,565	0	1,611	97.1%
	11	Snow and ice	0	0	0	0	0	0	0	0	30	0	194	224	86.6%
Total			1,561	2,826	3,742	1,126	2,240	6,495	4,523	322	1,634	1,630	195	26,294	
PA Unweighted			91.6%	90.0%	86.3%	86.4%	82.6%	78.3%	88.0%	67.7%	75.8%	96.0%	99.5%		84.8%

#### 4.1.2 BGR

The OA per BGR shows regional variation (Table 10). Accuracies above 90% were achieved in the plausibility approach in five regions (ARC, ATL, CON, MAC, STE). Four regions are slightly below 90% (BLS, BOR, MED, PAN). The ALP and ANA regions are slightly lower than 85%. Only one region falls below 80% OA (78.2% in TRO). The MoE is equal or below 5% for all BGRs, which indicates robust accuracy estimates.

The accuracies per class (Table 11) show a similar picture at BGR level as for the EEA38 + UK. The F1 Score for sealed (1) is below 70% in three of the twelve BGRs (ALP, ANA, BOR), each with a high MoE. Low-growing woody plants (5) achieve F1 Scores below 50% in four BGRs, all with MoE values greater than 5%, and exceed both PA and UA of 85% only in the MAC and MED regions. The rare class lichens and mosses (8) occurs in three BGRs, with F1 Scores ranging from 25.3 to 81.7%. Water (10), woody – needle leaved trees (2) and periodically herbaceous (7) have the highest accuracies, with F1 Scores above 95% in at least two regions, and PA and UA above 85% in the majority of the BGRs. Periodically herbaceous areas (7) are well detected in most BGRs, with both UA and PA above 85%, except in ALP, BOR, MAC and TRO. The regions ARC, ATL, CON, MAC and MED have very good accuracy results, each with five or more classes F1 Scores above 85%. Within the TRO region, only water (10) reaches an F1 Score above 85%.

The confusion matrix with sample counts (Table 12) shows similar class confusions in the BGRs as already observed at EEA38 + UK level. Noteworthy is the high number of sample units identified as sealed (1) in the validation data that were correctly classified as sealed in most BGRs. The unweighted PA for this class exceeds 90% in most BGR (Table 12) and is considerable higher than the weighted PA (Table 11). This difference is due to the confusion with classes that have much higher sampling weights, particularly the large permanent herbaceous class (6). Confusion between low-growing woody plants (5), permanent herbaceous (6) and periodically herbaceous (7) is evident in several regions (ALP, BOR, CON, MED) indicating the difficulty to distinguish between these classes.

**Table 10: Overall thematic accuracy per BGR**

BGR	Blind		Plausibility	
	OA [%]	MoE [%]	OA [%]	MoE [%]
Alpine (ALP)	80.3	1.7	83.8	1.5
Anatolian (ANA)	80.1	2.6	84.4	2.3
Arctic (ARC)	83.4	3.9	94.0	2.5
Atlantic (ATL)	79.2	1.3	91.9	0.9
Black Sea (BLS)	85.6	1.9	88.4	1.8
Boreal (BOR)	81.5	1.9	88.0	1.5
Continental (CON)	86.0	1.0	91.4	0.8
Macaronesia (MAC)	62.3	5.0	91.3	2.9
Mediterranean (MED)	68.1	1.4	86.5	1.0
Pannonian (PAN)	85.6	1.6	88.9	1.5
Steppic (STE)	88.8	2.1	90.8	2.0
Tropical (TRO)	72.9	3.2	78.2	3.0

Green = 90% or higher, Yellow = 85-89.9%

**Table 11: Thematic accuracy per class and BGR - plausibility approach**

BGR	Class	Name	UA [%]	MoE [%]	PA [%]	MoE [%]	F1 Score [%]
ALP	1	Sealed	67.0	10.1	57.9	15.2	62.1
	2	Woody – needle leaved trees	88.8	2.7	93.3	1.8	91.0
	3	Woody – Broadleaved deciduous trees	83.2	3.4	93.9	2.6	88.2
	4	Woody – Broadleaved evergreen trees	n.a.	n.a.	n.a.	n.a.	n.a.
	5	Low-growing woody plants	59.9	8.0	43.1	6.9	50.1
	6	Permanent herbaceous	83.2	2.9	86.5	2.3	84.8
	7	Periodically herbaceous	89.1	7.2	67.4	9.9	76.7
	8	Lichens and mosses	81.2	11.6	14.9	3.4	25.3
	9	Non- and sparsely-vegetated	79.9	4.4	83.9	4.4	81.9
	10	Water	93.7	5.4	98.0	2.3	95.8
	11	Snow and ice	80.0	10.2	97.8	4.3	88.0
ANA	1	Sealed	81.0	6.7	50.6	22.3	62.3
	2	Woody – needle leaved trees	84.5	5.8	88.7	6.0	86.5
	3	Woody – Broadleaved deciduous trees	74.3	6.8	69.6	14.7	71.9
	4	Woody – Broadleaved evergreen trees	n.a.	n.a.	n.a.	n.a.	n.a.
	5	Low-growing woody plants	57.3	9.3	53.7	15.0	55.4
	6	Permanent herbaceous	83.9	3.7	91.8	1.7	87.7
	7	Periodically herbaceous	95.3	3.0	86.0	4.6	90.4
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.
	9	Non- and sparsely-vegetated	71.4	6.9	63.5	8.6	67.3
	10	Water	97.2	2.7	70.8	14.9	82.0
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
ARC	1	Sealed	82.6	11.1	100	0.0	90.5
	2	Woody – needle leaved trees	92.3	10.4	100	0.0	96.0
	3	Woody – Broadleaved deciduous trees	54.7	12.9	94.0	8.1	69.2
	4	Woody – Broadleaved evergreen trees	n.a.	n.a.	n.a.	n.a.	n.a.
	5	Low-growing woody plants	69.7	9.3	69.4	12.9	69.5
	6	Permanent herbaceous	91.6	5.1	97.1	2.7	94.3
	7	Periodically herbaceous	n.a.	n.a.	n.a.	n.a.	n.a.
	8	Lichens and mosses	82.5	12.4	74.9	13.5	78.5
	9	Non- and sparsely-vegetated	97.9	2.9	95.2	3.7	96.5
	10	Water	99.1	1.8	100	0.0	99.5
	11	Snow and ice	100	0.0	100	0.0	100
ATL	1	Sealed	77.8	5.0	91.2	4.6	84.0
	2	Woody – needle leaved trees	84.4	4.0	91.3	3.7	87.7
	3	Woody – Broadleaved deciduous trees	94.6	1.8	89.0	2.3	91.7
	4	Woody – Broadleaved evergreen trees	94.9	3.2	90.6	6.4	92.7
	5	Low-growing woody plants	93.8	2.1	80.2	4.3	86.4
	6	Permanent herbaceous	91.1	1.4	95.7	0.9	93.4
	7	Periodically herbaceous	97.9	1.2	92.7	2.2	95.2
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.
	9	Non- and sparsely-vegetated	82.6	7.3	64.8	9.7	72.7
	10	Water	97.5	2.8	93.7	4.3	95.6
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
BLS	1	Sealed	77.0	9.5	70.0	17.2	73.3
	2	Woody – needle leaved trees	88.3	5.4	93.4	3.9	90.8
	3	Woody – Broadleaved deciduous trees	91.0	2.9	96.1	1.7	93.4

BGR	Class	Name	UA [%]	MoE [%]	PA [%]	MoE [%]	F1 Score [%]
	4	Woody – Broadleaved evergreen trees	n.a.	n.a.	n.a.	n.a.	n.a.
	5	Low-growing woody plants	72.5	7.5	56.8	11.8	63.7
	6	Permanent herbaceous	79.6	4.6	86.1	3.9	82.8
	7	Periodically herbaceous	97.2	2.1	87.4	3.2	92.0
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.
	9	Non- and sparsely-vegetated	84.3	7.6	41.3	12.6	55.5
	10	Water	99.6	0.8	98.8	1.4	99.2
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
BOR	1	Sealed	60.1	7.6	75.2	18.0	66.8
	2	Woody – needle leaved trees	92.8	2.5	94.3	1.2	93.6
	3	Woody – Broadleaved deciduous trees	83.8	3.6	82.3	4.8	83.0
	4	Woody – Broadleaved evergreen trees	n.a.	n.a.	n.a.	n.a.	n.a.
	5	Low-growing woody plants	32.0	6.8	46.8	18.7	38.0
	6	Permanent herbaceous	80.8	4.0	85.1	3.4	82.9
	7	Periodically herbaceous	89.9	3.7	77.8	5.8	83.4
	8	Lichens and mosses	88.0	6.7	76.1	8.0	81.7
	9	Non- and sparsely-vegetated	72.1	9.2	40.5	17.9	51.9
	10	Water	99.6	0.6	97.5	2.3	98.5
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
CON	1	Sealed	72.7	4.9	88.6	5.5	79.9
	2	Woody – needle leaved trees	91.5	2.3	94.4	2.1	92.9
	3	Woody – Broadleaved deciduous trees	94.6	1.4	94.0	1.3	94.3
	4	Woody – Broadleaved evergreen trees	n.a.	n.a.	n.a.	n.a.	n.a.
	5	Low-growing woody plants	67.5	6.9	47.5	9.3	55.8
	6	Permanent herbaceous	85.5	2.1	91.6	1.4	88.5
	7	Periodically herbaceous	97.5	0.8	90.3	1.6	93.8
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.
	9	Non- and sparsely-vegetated	45.6	12.4	28.6	11.3	35.2
	10	Water	96.2	2.7	94.4	3.9	95.3
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
MAC	1	Sealed	92.1	8.7	78.8	17.5	84.9
	2	Woody – needle leaved trees	98.0	3.9	100	0.0	99.0
	3	Woody – Broadleaved deciduous trees	n.a.	n.a.	n.a.	n.a.	n.a.
	4	Woody – Broadleaved evergreen trees	92.3	6.3	97.0	3.1	94.6
	5	Low-growing woody plants	92.6	6.3	89.7	11.4	91.1
	6	Permanent herbaceous	89.0	5.8	94.1	3.6	91.4
	7	Periodically herbaceous	n.a.	n.a.	n.a.	n.a.	n.a.
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.
	9	Non- and sparsely-vegetated	n.a.	n.a.	n.a.	n.a.	n.a.
	10	Water	98.7	2.6	100	0.0	99.3
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
MED	1	Sealed	84.3	4.8	78.8	6.9	81.5
	2	Woody – needle leaved trees	92.6	2.7	95.3	2.4	93.9
	3	Woody – Broadleaved deciduous trees	84.9	3.5	91.4	2.7	88.0
	4	Woody – Broadleaved evergreen trees	84.4	2.8	92.0	2.1	88.0
	5	Low-growing woody plants	87.2	2.0	91.8	1.8	89.4
	6	Permanent herbaceous	86.7	2.1	79.4	2.2	82.9
	7	Periodically herbaceous	85.9	2.8	85.1	2.9	85.5
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.

BGR	Class	Name	UA [%]	MoE [%]	PA [%]	MoE [%]	F1 Score [%]
	9	Non- and sparsely-vegetated	79.6	5.6	67.1	6.0	72.8
	10	Water	99.1	1.0	95.1	3.9	97.0
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
PAN	1	Sealed	65.5	8.1	84.2	11.3	73.7
	2	Woody – needle leaved trees	82.1	6.3	92.8	6.0	87.1
	3	Woody – Broadleaved deciduous trees	94.3	2.9	88.4	2.9	91.2
	4	Woody – Broadleaved evergreen trees	n.a.	n.a.	n.a.	n.a.	n.a.
	5	Low-growing woody plants	38.6	8.1	60.4	15.9	47.1
	6	Permanent herbaceous	73.2	5.7	83.5	4.1	78.0
	7	Periodically herbaceous	98.0	1.3	92.7	1.7	95.3
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.
	9	Non- and sparsely-vegetated	n.a.	n.a.	n.a.	n.a.	n.a.
	10	Water	93.8	4.5	98.0	2.7	95.8
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
STE	1	Sealed	76.5	9.1	78.3	22.0	77.4
	2	Woody – needle leaved trees	94.2	5.0	86.3	15.2	90.1
	3	Woody – Broadleaved deciduous trees	92.1	4.9	92.6	3.1	92.4
	4	Woody – Broadleaved evergreen trees	n.a.	n.a.	n.a.	n.a.	n.a.
	5	Low-growing woody plants	46.6	10.8	51.4	16.2	48.9
	6	Permanent herbaceous	78.2	7.3	89.4	4.8	83.4
	7	Periodically herbaceous	98.9	1.3	94.4	2.2	96.6
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.
	9	Non- and sparsely-vegetated	73.5	15.0	49.0	28.3	58.8
	10	Water	97.4	3.5	89.1	13.5	93.1
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.
TRO	1	Sealed	60.5	12.8	87.5	11.3	71.5
	2	Woody – needle leaved trees	n.a.	n.a.	n.a.	n.a.	n.a.
	3	Woody – Broadleaved deciduous trees	n.a.	n.a.	n.a.	n.a.	n.a.
	4	Woody – Broadleaved evergreen trees	93.2	3.5	77.0	3.5	84.4
	5	Low-growing woody plants	n.a.	n.a.	n.a.	n.a.	n.a.
	6	Permanent herbaceous	61.2	7.9	79.7	7.0	69.2
	7	Periodically herbaceous	n.a.	n.a.	n.a.	n.a.	n.a.
	8	Lichens and mosses	n.a.	n.a.	n.a.	n.a.	n.a.
	9	Non- and sparsely-vegetated	n.a.	n.a.	n.a.	n.a.	n.a.
	10	Water	98.3	3.3	100	0.0	99.1
	11	Snow and ice	n.a.	n.a.	n.a.	n.a.	n.a.

Green = 85% or higher, Yellow = 80-84.9%, Red = MoE >5%

n.a.= number of sample units <30, accuracy measures are not calculated

**Table 12: Unweighted confusion matrix (sample counts) per BGR - plausibility approach**

			Validation data											Total	UA Unweighted
			1	2	3	4	5	6	7	8	9	10	11		
ALP	1	Sealed	116	2	6	0	3	37	1	0	3	1	0	169	68.6%
	2	Woody – needle leaved trees	4	451	14	0	21	35	0	0	5	0	0	530	85.1%
	3	Woody – Broadleaved deciduous trees	1	47	381	0	21	24	0	0	0	0	0	474	80.4%
	4	Woody – Broadleaved evergreen trees	0	0	0	0	1	0	0	0	0	0	0	1	n.a.
	5	Low-growing woody plants	1	12	4	0	159	99	0	2	9	0	0	286	55.6%
	6	Permanent herbaceous	5	9	9	0	29	534	31	30	22	0	0	669	79.8%
	7	Periodically herbaceous	2	0	0	0	2	10	163	0	1	0	0	178	91.6%
	8	Lichens and mosses	0	3	0	0	0	4	0	61	4	0	0	72	84.7%
	9	Non- and sparsely-vegetated	2	6	0	0	7	18	0	35	296	2	1	367	80.7%
	10	Water	1	0	1	0	0	1	0	1	3	96	0	103	93.2%
	11	Snow and ice	0	0	0	0	0	0	0	0	30	0	94	124	75.8%
		Total	132	530	415	0	243	762	195	129	373	99	95	2,973	
		PA Unweighted	87.9%	85.1%	91.8%	n.a.	65.4%	70.1%	83.6%	47.3%	79.4%	97.0%	98.9%		79.1%
ANA	1	Sealed	106	0	1	0	1	15	0	0	9	0	0	132	80.3%
	2	Woody – needle leaved trees	0	131	8	0	2	13	0	0	1	0	0	155	84.5%
	3	Woody – Broadleaved deciduous trees	1	1	114	0	13	22	2	0	1	0	0	154	74.0%
	4	Woody – Broadleaved evergreen trees	0	0	4	0	1	4	1	0	0	0	0	10	n.a.
	5	Low-growing woody plants	0	9	12	0	93	33	0	0	14	0	0	161	57.8%
	6	Permanent herbaceous	3	0	5	0	8	332	26	0	26	0	0	400	83.0%
	7	Periodically herbaceous	1	0	0	0	0	9	229	0	1	0	0	240	95.4%
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	1	0	0	0	0	39	5	0	141	12	0	198	71.2%
	10	Water	0	0	0	0	0	1	0	0	3	45	0	49	91.8%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	112	141	144	0	118	468	263	0	196	57	0	1,499	
		PA Unweighted	94.6%	92.9%	79.2%	n.a.	78.8%	70.9%	87.1%	n.a.	71.9%	78.9%	n.a.		79.5%

			Validation data												
			1	2	3	4	5	6	7	8	9	10	11	Total	UA Unweighted
ARC	1	Sealed	38	0	0	0	0	5	0	0	3	0	0	46	82.6%
	2	Woody – needle leaved trees	0	24	0	0	2	0	0	0	0	0	0	26	n.a.
	3	Woody – Broadleaved deciduous trees	0	0	32	0	20	5	0	0	1	0	0	58	55.2%
	4	Woody – Broadleaved evergreen trees	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	5	Low-growing woody plants	0	0	0	0	67	28	0	1	0	0	0	96	69.8%
	6	Permanent herbaceous	0	0	2	0	3	136	0	13	2	0	0	156	87.2%
	7	Periodically herbaceous	0	0	0	0	0	0	8	0	0	0	0	8	n.a.
	8	Lichens and mosses	0	0	0	0	1	2	0	76	8	0	0	87	87.4%
	9	Non- and sparsely-vegetated	0	0	0	0	0	1	0	1	103	0	0	105	98.1%
	10	Water	0	0	0	0	0	0	0	0	1	98	0	99	99.0%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	100	100	100%
		Total	38	24	34	0	93	177	8	91	118	98	100	781	
		PA Unweighted	100%	n.a.	94.1%	n.a.	72.0%	76.8%	n.a.	83.5%	87.3%	100%	100%		87.3%
ATL	1	Sealed	265	1	11	0	4	33	2	0	9	1	0	326	81.3%
	2	Woody – needle leaved trees	0	303	25	0	9	13	0	0	4	0	0	354	85.6%
	3	Woody – Broadleaved deciduous trees	1	8	537	0	4	19	0	0	1	1	0	571	94.0%
	4	Woody – Broadleaved evergreen trees	0	0	0	178	4	3	0	0	2	0	0	187	95.2%
	5	Low-growing woody plants	1	2	5	1	372	31	1	0	3	0	0	416	89.4%
	6	Permanent herbaceous	8	7	36	8	35	1381	39	0	8	5	0	1,527	90.4%
	7	Periodically herbaceous	2	1	2	0	1	8	616	0	2	0	0	632	97.5%
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	4	3	0	0	10	9	5	1	186	4	0	222	83.8%
	10	Water	0	0	1	0	0	2	0	0	1	246	0	250	98.4%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	281	325	617	187	439	1,499	663	1	216	257	0	4,485	
		PA Unweighted	94.3%	93.2%	87.0%	95.2%	84.7%	92.1%	92.9%	n.a.	86.1%	95.7%	n.a.		91.1%



			Validation data												
			1	2	3	4	5	6	7	8	9	10	11	Total	UA Unweighted
BLS	1	Sealed	66	0	4	0	0	6	0	0	17	0	0	93	71.0%
	2	Woody – needle leaved trees	0	123	9	0	2	7	0	0	0	0	0	141	87.2%
	3	Woody – Broadleaved deciduous trees	0	8	326	0	8	13	1	0	1	0	0	357	91.3%
	4	Woody – Broadleaved evergreen trees	0	1	6	0	3	0	0	0	0	0	0	10	n.a.
	5	Low-growing woody plants	0	3	10	0	98	23	3	0	2	0	0	139	70.5%
	6	Permanent herbaceous	5	0	4	0	6	221	42	0	10	1	0	289	76.5%
	7	Periodically herbaceous	1	0	0	0	2	3	256	0	1	0	0	263	97.3%
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	2	0	0	0	0	14	0	0	92	2	0	110	83.6%
	10	Water	0	0	0	0	0	0	0	0	1	70	0	71	98.6%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	74	135	359	0	119	287	302	0	124	73	0	1,473	
		PA Unweighted	89.2%	91.1%	90.8%	n.a.	82.4%	77.0%	84.8%	n.a.	74.2%	95.9%	n.a.		85.0%
BOR	1	Sealed	126	5	9	0	4	61	1	0	24	1	0	231	54.5%
	2	Woody – needle leaved trees	0	383	12	0	0	16	0	0	6	0	0	417	91.8%
	3	Woody – Broadleaved deciduous trees	0	44	232	0	2	11	0	0	0	1	0	290	80.0%
	4	Woody – Broadleaved evergreen trees	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	5	Low-growing woody plants	0	30	31	0	86	41	0	8	7	0	0	203	42.4%
	6	Permanent herbaceous	4	8	20	0	6	318	34	2	6	3	0	401	79.3%
	7	Periodically herbaceous	0	2	0	0	0	41	217	0	1	0	0	261	83.1%
	8	Lichens and mosses	0	2	0	0	1	5	0	81	3	0	0	92	88.0%
	9	Non- and sparsely-vegetated	4	10	3	0	4	32	3	10	132	6	0	204	64.7%
	10	Water	0	0	0	0	0	2	0	0	0	145	0	147	98.6%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	134	484	307	0	103	527	255	101	179	156	0	2,246	
		PA Unweighted	94.0%	79.1%	75.6%	n.a.	83.5%	60.3%	85.1%	80.2%	73.7%	92.9%	n.a.		76.6%

			Validation data												
			1	2	3	4	5	6	7	8	9	10	11	Total	UA Unweighted
CON	1	Sealed	277	1	8	0	6	69	3	0	15	3	0	382	72.5%
	2	Woody – needle leaved trees	0	539	30	0	3	22	0	0	2	0	0	596	90.4%
	3	Woody – Broadleaved deciduous trees	2	19	906	0	7	23	2	0	2	0	0	961	94.3%
	4	Woody – Broadleaved evergreen trees	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	5	Low-growing woody plants	2	9	33	0	124	31	7	0	1	4	0	211	58.8%
	6	Permanent herbaceous	7	4	26	0	15	925	109	0	2	3	0	1,091	84.8%
	7	Periodically herbaceous	0	0	7	0	4	26	1297	0	2	0	0	1,336	97.1%
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	15	1	2	0	5	24	6	0	40	3	0	96	41.7%
	10	Water	1	0	3	0	1	6	0	0	2	293	0	306	95.8%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	304	573	1,015	0	165	1,126	1,424	0	66	306	0	4,979	
		PA Unweighted	91.1%	94.1%	89.3%	n.a.	75.2%	82.1%	91.1%	n.a.	60.6%	95.8%	n.a.		88.4%
MAC	1	Sealed	35	0	0	0	0	2	0	0	1	0	0	38	92.1%
	2	Woody – needle leaved trees	0	49	0	0	1	0	0	0	0	0	0	50	98.0%
	3	Woody – Broadleaved deciduous trees	0	0	13	0	0	2	0	0	0	0	0	15	n.a.
	4	Woody – Broadleaved evergreen trees	1	0	0	82	0	5	0	0	0	0	0	88	93.2%
	5	Low-growing woody plants	0	0	1	2	61	1	1	0	0	0	0	66	92.4%
	6	Permanent herbaceous	2	0	1	2	1	89	13	0	0	0	0	108	82.4%
	7	Periodically herbaceous	0	0	1	0	0	0	26	0	1	0	0	28	n.a.
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	2	0	0	0	2	3	0	0	19	0	0	26	n.a.
	10	Water	0	0	0	0	0	0	0	0	1	75	0	76	98.7%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	40	49	16	86	65	102	40	0	22	75	0	495	
		PA Unweighted	87.5%	100%	n.a.	95.3%	93.8%	87.3%	65.0%	n.a.	n.a.	100%	n.a.		90.7%

			Validation data												
			1	2	3	4	5	6	7	8	9	10	11	Total	UA Unweighted
MED	1	Sealed	187	1	2	4	1	19	0	0	8	1	0	223	83.9%
	2	Woody – needle leaved trees	0	328	2	4	15	6	0	0	3	0	0	358	91.6%
	3	Woody – Broadleaved deciduous trees	1	3	366	14	18	27	1	0	3	0	0	433	84.5%
	4	Woody – Broadleaved evergreen trees	4	1	3	521	6	57	9	0	11	0	0	612	85.1%
	5	Low-growing woody plants	2	4	14	13	674	63	11	0	9	1	0	791	85.2%
	6	Permanent herbaceous	12	6	12	13	15	776	62	0	20	3	0	919	84.4%
	7	Periodically herbaceous	2	0	2	9	10	48	591	0	24	2	0	688	85.9%
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	7	0	0	2	11	22	8	0	187	1	0	238	78.6%
	10	Water	0	1	0	0	1	0	1	0	0	223	0	226	98.7%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	215	344	401	580	751	1,018	683	0	265	231	0	4,488	
		PA Unweighted	87.0%	95.3%	91.3%	89.8%	89.7%	76.2%	86.5%	n.a.	70.6%	96.5%	n.a.		85.9%
PAN	1	Sealed	113	0	6	0	1	35	3	0	8	0	0	166	68.1%
	2	Woody – needle leaved trees	0	131	25	0	0	6	0	0	1	0	0	163	80.4%
	3	Woody – Broadleaved deciduous trees	1	2	213	0	2	8	2	0	0	0	0	228	93.4%
	4	Woody – Broadleaved evergreen trees	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	5	Low-growing woody plants	1	3	42	0	60	30	13	0	2	1	0	152	39.5%
	6	Permanent herbaceous	3	1	8	0	6	192	40	0	4	0	0	254	75.6%
	7	Periodically herbaceous	0	0	1	0	0	7	385	0	1	0	0	394	97.7%
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	3	0	1	0	3	2	3	0	13	1	0	26	n.a.
	10	Water	0	0	1	0	0	3	1	0	2	98	0	105	93.3%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	
		Total	121	137	297	0	72	283	447	0	31	100	0	1,488	
		PA Unweighted	93.4%	95.6%	71.7%	n.a.	83.3%	67.8%	86.1%	n.a.	41.9%	98.0%	n.a.		81.0%

			Validation data												
			1	2	3	4	5	6	7	8	9	10	11	Total	UA Unweighted
STE	1	Sealed	65	0	2	0	0	8	5	0	5	0	0	85	76.5%
	2	Woody – needle leaved trees	0	81	4	0	0	1	0	0	0	0	0	86	94.2%
	3	Woody – Broadleaved deciduous trees	0	2	108	0	4	4	0	0	0	0	0	118	91.5%
	4	Woody – Broadleaved evergreen trees	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	5	Low-growing woody plants	2	0	20	0	44	15	10	0	0	0	0	91	48.4%
	6	Permanent herbaceous	2	1	2	0	6	97	14	0	2	2	0	126	77.0%
	7	Periodically herbaceous	0	0	0	0	0	4	178	0	0	0	0	182	97.8%
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	1	0	0	0	0	6	2	0	25	0	0	34	73.5%
	10	Water	0	0	1	0	0	0	0	0	1	76	0	78	97.4%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	70	84	137	0	54	135	209	0	33	78	0	800	
		PA Unweighted	92.9%	96.4%	78.8%	n.a.	81.5%	71.9%	85.2%	n.a.	75.8%	97.4%	n.a.		84.3%
TRO	1	Sealed	36	0	0	7	0	10	0	0	5	0	0	58	62.1%
	2	Woody – needle leaved trees	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	3	Woody – Broadleaved deciduous trees	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	4	Woody – Broadleaved evergreen trees	1	0	0	192	5	7	0	0	1	0	0	206	93.2%
	5	Low-growing woody plants	1	0	0	33	13	5	0	0	0	0	0	52	25.0%
	6	Permanent herbaceous	1	0	0	37	0	87	19	0	1	0	0	145	60.0%
	7	Periodically herbaceous	0	0	0	3	0	2	15	0	0	0	0	20	n.a.
	8	Lichens and mosses	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
	9	Non- and sparsely-vegetated	1	0	0	0	0	0	0	0	4	0	0	5	80.0%
	10	Water	0	0	0	1	0	0	0	0	0	100	0	101	99.0%
	11	Snow and ice	0	0	0	0	0	0	0	0	0	0	0	0	n.a.
		Total	40	0	0	273	18	111	34	0	11	100	0	587	
		PA Unweighted	90.0%	n.a.	n.a.	70.3%	n.a.	78.4%	44.1%	n.a.	n.a.	100%	n.a.		76.1%

n.a. = number of sample units <30, accuracy measures are not calculated

## 4.2 Usability

The CLMS validation approach for usability assessment is done by conducting a structured review of the CLCplus BB 2023 product documentation. The review found that both the ATBD and PUM for the CLCplus BB 2023 are well structured and mostly align with the CLMS template. Regarding the ATBD, the document covers the key areas of background, methodology, product specifications and user guidance effectively, however, it is missing the mandatory chapter “Quality control and production verification” (Chapter 4). The document version was also missing from the footer. Other issues related to readability could be improved such as page breaks at first-level chapters and consistency with abbreviations.

Addressing the PUM, consistency within the document should be guaranteed with figure captions (e.g. figures 7 to 15) in terms of font size as well as their reference appearing in text beforehand as to guide the reader and provide context. The inclusion of a “Non-technical summary” is also recommended for this document as it can serve as an introduction to those not familiar with the product. As such, the use of abbreviations and acronyms is not encouraged for this chapter. Finally, species names should be italicised to follow scientific and editorial conventions.

Both documents present some consistency issues with table formatting and colour that should be addressed to conform to CLMS templates. Furthermore, in text consistency should also be assured, for example the term “EEA38 + UK” appears both with and without space. It is recommended that one format is chosen. Finally issues with abbreviations should be addressed where they should be spelled out on first use in the text as well as their inclusion in the final table. Addressing these points will help ensure the documentation meets quality expectations, supports user needs, and remains fully aligned with CLMS standards.

## 5 Conclusions and Recommendations

### 5.1 Thematic Accuracy

The new CLMS validation framework methods and tools are used here to validate the CLCplus BB raster product for 2023. The validation areas defined within the framework are applied to generate validation data for CLCplus BB in a synergistic blind and plausibility approach. Thematic accuracies are calculated in the new CLMS Validation System Environment (VSE) software. **Thematic accuracy is assessed using a statistically sound methodology, leveraging available reference and supportive data across different reporting units.** It was essential that usage of LUCAS data in the CLMS productions was recorded (including LUCAS sample locations used) and provided to the validation process to enable independent validation uptake of this data. **Due to the heavy usage of LUCAS 2018 in the CLCplus BB production process, any point in the sampling frame that was part of the LUCAS 2018 survey has been replaced.** Future validations efforts could be minimized if LUCAS reference data is not used in the CLCplus BB production as was the case for LUCAS 2022, which could then be utilized for 2023 validation.

**The VHR image data 2021 and 2024 is used in the visual validation process.** It provides VHR multispectral products (with a spatial pixel resolution from 2 to 4 meters) for the CLMS reference years 2021 and 2024. Especially for regions without aerial orthophoto imagery this data set is the prime image reference. However, due to the applicable spatial resolution it has limitations for the analysis of land cover class relevant features. For some regions higher resolution data (<2m) could support the validation process, especially for regions with poor or no access to digital aerial photography as alternative very high image data source. Notably, no VHR product was available for the reference year 2023, creating a gap in high-resolution reference data for that year.

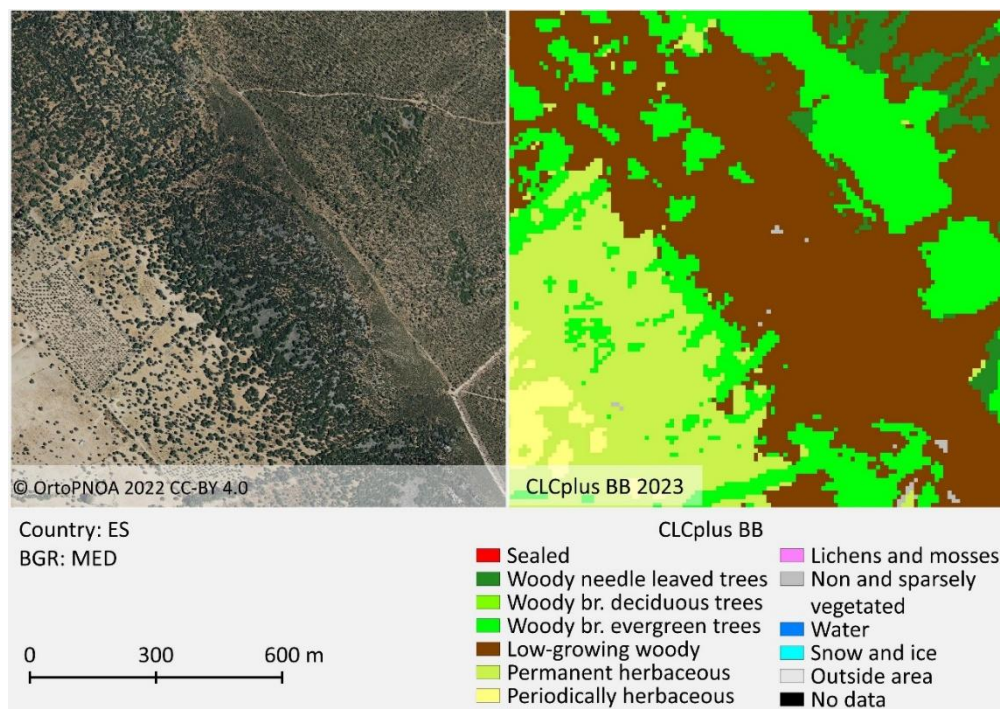
**Sentinel-2 based NDVI time series** (2021–2024) at the sample location, are used to provide seasonal context and support the interpretation of temporally defined classes such as snow or vegetation cover duration. Additionally, **Sentinel-2 temporal image mosaics** for summer/autumn and winter/spring of the reference year 2023 were used to provide additional information and confirm land cover classes or detect land cover changes, such as new constructions or forest clear-cuts. However, their effectiveness is limited by cloud-related data gaps and mixed-pixel effects causing ambiguous spectral profiles.

**The thematic validation results show good results approaching but not reaching the required target OA of >90% at EEA38 + UK level. All classes show significant improvement in plausibility checks** as compared to the blind validation. The class-specific accuracies show the expected confusion between low-growing woody plants (5), permanent herbaceous (6) as well as periodically herbaceous areas (7), especially in natural environments. **These land cover classes are difficult to map due to similar spectral behaviour and their temporal/seasonal dynamics make the visual interpretation of reference data challenging.** Such classes can be better assessed if a priori map class information is considered during the visual interpretation. The class-specific accuracies also show the expected confusion between the woody broadleaved classes (3, 4) low-growing woody plants (5) and permanent herbaceous (6) as well as non and sparsely vegetated areas (9), which are difficult to distinguish, especially in natural environments. This may also contribute to the regional differences at the BGR level. **Weaker classification results are seen within the regional assessments of the ALP, ANA, BOR, MED and TRO BGRs, which show challenges distinguishing certain classes,** especially low-growing woody plants (5) and permanent herbaceous (6) (Figure 11 and Figure 12).

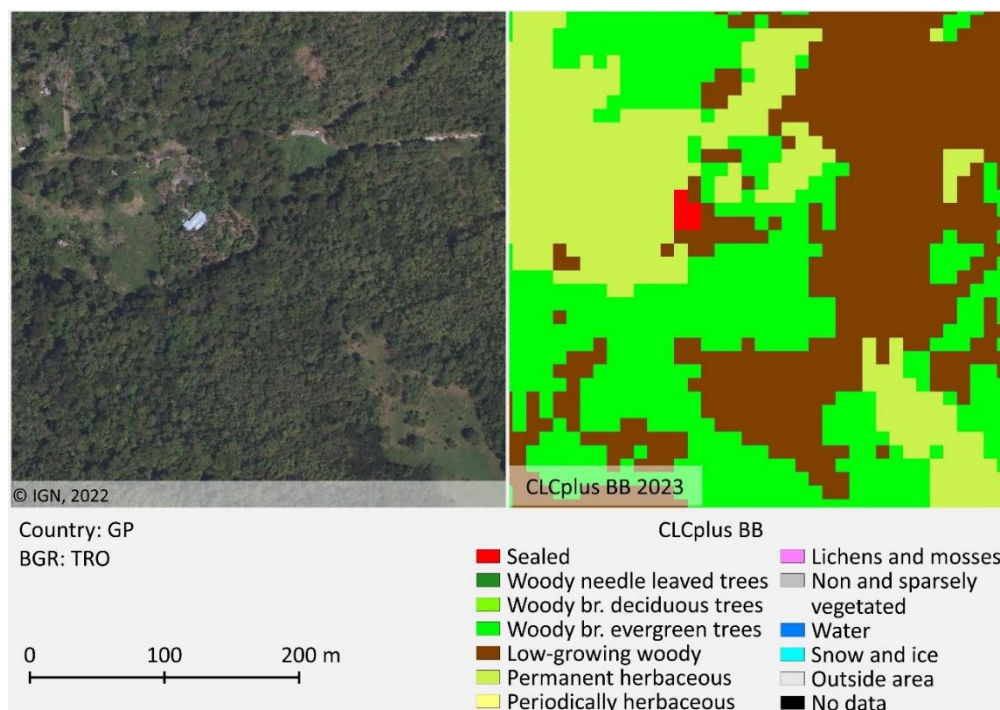
Although no formal consistency check was conducted, **CLCplus BB 2021 and 2023 show similar accuracy patterns, with overall higher accuracies in 2023.** This improvement is likely due to better thematic map quality, enhanced validation workflows, and the use of additional



reference data, which improved agreement already during the blind assessment. The reduced coverage threshold introduced in the 2023 plausibility approach further contributed to the increase in accuracy compared to 2021.



**Figure 11: Example of challenges in distinguishing low-growing woody plants from broadleaved forests in Spain.**



**Figure 12: Example of structurally similar ground cover with different CLCplus BB 2023 classes in Guadeloupe: low-growing woody vegetation versus woody broadleaved evergreen trees.**



## 5.2 Usability

To support user uptake and ensure the CLCplus BB 2023 product meets key expectations for usability, a structured assessment was carried out. This evaluation focuses on the check of product documentation.

**The ATBD is a well-structured document, but does not follow the standard CLMS ATBD template,** however the content is still present within differently named chapters. The review found that the chapter on “Quality control and product verification” is missing and the relevant information was not present within the other chapters. The inclusion of the section would benefit this product by providing a transparent view of internal quality control. Furthermore, harmonization in language, figure layouts and captions as well as table formatting could further enhance the usability and functionality of the product.

**The PUM review highlights the document’s detailed and comprehensive nature yet points out the need for improvement in areas such as clarity, consistency, and user guidance.** Key recommendations include adopting a structured chapter layout as specified in the CLMS PUM template, simplifying overly technical sections, standardizing terminology and formatting, and enhancing document navigation. Moreover, incorporating non-technical summaries, FAQ sections, and glossaries could make the document more accessible to a broader audience, including non-experts. These changes will ensure that the PUM aligns better with industry standards and user expectations, improving its overall usability and functionality.

## 6 References

- Congalton, Russell G., and Kass Green. 2008. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. 2nd ed. Boca Raton: CRC Press/Taylor & Francis. <https://doi.org/10.1201/9781420055139>.
- Copernicus Land Monitoring Service. 2022. *CLC+ Backbone Product Specification and User Manual*. Copenhagen: European Environment Agency (EEA). Product Specification and User Manual. <https://land.copernicus.eu/en/technical-library/clc-backbone-product-user-manual/@download/file> (February 10, 2025).
- Copernicus Land Monitoring Service. 2023. 'CLCplus Backbone 2018 (Raster 10 m), Europe, 3-Yearly, Feb. 2023'. doi:<https://doi.org/10.2909/cd534ebf-f553-42f0-9ac1-62c1dc36d32c>.
- Copernicus Land Monitoring Service. 2025a. *CLC+ Backbone 2023 Algorithm Theoretical Basis Document (ATBD)*. European Environment Agency (EEA). <https://land.copernicus.eu/en/technical-library/algorithm-theoretical-basis-document-clcplus-backbone-2023/@download/file> (September 11, 2025).
- Copernicus Land Monitoring Service. 2025b. *CLC+ Backbone 2023 Product User Manual (PUM)*. European Environment Agency (EEA). <https://land.copernicus.eu/en/technical-library/product-user-manual-clcplus-backbone-2023/@download/file> (July 1, 2025).
- Copernicus Land Monitoring Service. 2025c. 'CLCplus Backbone 2023 (Raster 10 m), Europe, 2-Yearly, May 2025'. doi:<https://doi.org/10.2909/b0bd43c6-1fa1-4d88-9c45-98b13a95d0b2>.
- Copernicus Land Monitoring Service. 2025d. 'Technical Library'. *Technical Library*. <https://land.copernicus.eu/en/technical-library> (September 9, 2025).
- European Commission: Eurostat, Barcaroli, G., Ballin, M., Masselli, M., and Scarnó, M. 2018. *Redesign Sample for Land Use/Cover Area Frame Survey (LUCAS) 2018 - 2018 Edition*. LU: Publications Office. <https://data.europa.eu/doi/10.2785/132365> (November 17, 2021).
- European Environment Agency. 2016. 'Biogeographical Regions'. <https://www.eea.europa.eu/en/datahub/datahubitem-view/11db8d14-f167-4cd5-9205-95638dfd9618> (December 9, 2024).
- European Environment Agency. 2023. 'Copernicus EEA38 Boundary Layer with 250 m Buffer (Raster 10m), Version 2, Nov. 2023'. <https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/a14e9739-089d-4f63-8f83-a184e1e8b906> (December 9, 2024).
- European Environment Agency. 2024. 'EEA Reference Grid for Europe (50km), Jun. 2024'. doi:<https://doi.org/10.2909/aac8379a-5c4e-445c-b2ef-23a6a2701ef0>.
- European Environment Agency. 2025a. 'CLMS QC Tool'. [https://github.com/eea/copernicus\\_quality\\_tools](https://github.com/eea/copernicus_quality_tools) (February 10, 2025).

European Environment Agency. 2025b. *Validation Report - CLCplus Backbone 2018*. . Doc. Version: 1.2. <https://land.copernicus.eu/en/technical-library/validation-report-clcplus-backbone-2018/@@download/file>.

European Environment Agency. 2025c. *Validation Report - CLCplus Backbone 2021*. . Doc. Version: 1.2. <https://land.copernicus.eu/en/technical-library/validation-report-clcplus-backbone-2021/@@download/file>.

Olofsson, Pontus, Giles M. Foody, Martin Herold, Stephen V. Stehman, Curtis E. Woodcock, and Michael A. Wulder. 2014. 'Good Practices for Estimating Area and Assessing Accuracy of Land Change'. *Remote Sensing of Environment* 148: 42–57. doi:10.1016/j.rse.2014.02.015.

Stehman, Stephen V. 2014. 'Estimating Area and Map Accuracy for Stratified Random Sampling When the Strata Are Different from the Map Classes'. *International Journal of Remote Sensing*, 35(13), 4923–4939. <https://doi.org/10.1080/01431161.2014.930207>.

Stehman, Stephen V., and Giles M. Foody. 2019. 'Key Issues in Rigorous Accuracy Assessment of Land Cover Products'. *Remote Sensing of Environment* 231: 111199. doi:10.1016/j.rse.2019.05.018.

## List of abbreviations

Abbreviation	Name
ALP	Alpine
ANA	Anatolian
ARC	Arctic
ATBD	Algorithm Theoretical Basis Document
ATL	Atlantic
BB	Backbone
BGR	Biogeographical Regions
BLS	Black Sea
BOR	Boreal
CAPI	Computer-Assisted Photo Interpretation
CLC	CORINE Land Cover
CLCplus BB	CORINE Land Cover Plus Backbone
CLMS	Copernicus Land Monitoring Service
CON	Continental
DOI	Digital Object Identifier
DOM	Départements d'Outre-Mer, French Overseas Territories
EEA	European Environment Agency
EEA38	Member and cooperating countries of the European Environment Agency network, Eionet
EUROSTAT	Statistical Office of the European Union
EU	European Union
FAIR	Findability, Accessibility, Interoperability, and Reusability
GeoTIFF	Georeferenced Tagged Image File Format
GIS	Geographic Information System
HRL	High Resolution Layer
IACS	Integrated Administration and Control Systems
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO	International Organization for Standardization
LAEA	Lambert azimuthal equal-area projection
LC	Land Cover
LPIS	Land Parcel Information System
LU	Land Use
LUCAS	Land Use and Coverage Area frame Survey from Eurostat
LULUCF	Land use, land-use change and forestry
LZW	Lempel-Ziv-Welch
MAC	Macaronesia
MED	Mediterranean
MMU	Minimum Mapping Unit
MoE	Margin of Error
MS	Member State
NUTS	Nomenclature of territorial units for statistics
OA	Overall Accuracy



PAN	Pannonian
PI	Photo Interpretation
PUM	Product User Manual
QC	Quality Control
STE	Steppic
TRO	Tropical
UA	User's Accuracy
UAT	User Acceptance Testing
UK	United Kingdom
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
UTM	Universal Transverse Mercator
VHR	Very High Resolution
VSE	CLMS Validation System Environment
XML	Extensible Markup Language
WGS84	World Geodetic System 1984
WMS	Web Map Service
WMTS	Web Map Tile Service