



PROGRAMME OF
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Copernicus Land Monitoring Service – High Resolution Layer – Tree Cover & Forests

HRL TREE COVER & FORESTS - PRODUCT USER MANUAL



Date: 2025-11-03

Doc. Version : 2.3

Content ID: D1.12 HRL TC&F





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Document Control Information:

Document Title	D1.12 HRL Tree Cover and Forests - Product User Manual
Project Title	Copernicus Land Monitoring Service – High Resolution Layer - Vegetated Land Cover Characteristics
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Document Code	D1.12 HRL TC&F
Document Version	2.3
Distribution	Public
Date	2025-11-03

1 Executive summary

Copernicus is the European Union's Earth Observation Programme. It offers information services based on satellite Earth observation and in situ (non-space) data. These information services are freely and openly accessible to its users through six thematic Copernicus services (Atmosphere Monitoring, Marine Environment Monitoring, Land Monitoring, Climate Change, Emergency Management and Security).

The **Copernicus Land Monitoring Service (CLMS)** provides geographical information on land cover and its changes, land use, vegetation state, water cycle and earth surface energy variables to a broad range of users in Europe and across the world in the field of environmental terrestrial applications.

CLMS is jointly implemented by the **European Environment Agency (EEA)** and the European Commission's **DG Joint Research Centre (JRC)**.

The **High Resolution Layer (HRL)** vegetated land cover characteristics are a set of harmonised yearly maps dedicated to the thematic themes **Tree Cover & Forests**, **Grasslands** and **Croplands**. These include a rich suite of raster products mapping the yearly status of those land cover types at a spatial resolution of 10 metres and change layers at 3-yearly interval and 20-metre resolution. HRL vegetated land cover characteristics extends the time-series of the existing HRL's Tree Cover & Forests and Grasslands and complements the CLMS portfolio with new layer dedicated to the mapping of crop types and agricultural practices such as mowing, harvest and cover crops.



2 Background of the document

2.1 Scope

This Product User Manual is the primary document that users are recommended to read before using the product. It provides a description of the product characteristics, production methodologies and workflows, and information about the product quality of the annual provision of **HRL Tree Cover & Forests**. Furthermore, it gives information on the terms of use and product technical support. More detailed information on the methodologies and processing workflows that were used to produce the products can be found in the Algorithm Theoretical Baseline Document (ATBD) [7].

2.2 Content and structure

In more detail, the document is structured as follows:

- Chapter 3 provides an overview of the lineage of the products in relation to previous HRL productions;
- Chapter 4 contains a review of user requirements;
- Chapter 5 provides an overview of what is included in the High Resolution Layers Vegetated Land Cover Characteristics and how the comprised products relate to each other;
- Chapter 6 presents potential application areas and example use cases;
- Chapter 7 provides a description of the products including the nomenclature and class definitions, file naming, spatial resolution format(s), etc.;
- Chapter 8 summarizes the quality assessment, validation procedure and the results;
- Chapter 9 provides information about product access and use conditions as well as the technical product support.

3 Lineage of HRL Tree Cover and Forests, Grasslands, and Croplands

High Resolution Layers (**HRL**) on **Tree Cover & Forests** had already been established in the **Copernicus Land Monitoring Service (CLMS)** portfolio since the reference years 2012 producing initially a **Dominant Leaf Type (DLT)**, a **Tree Cover Density (TCD)**, and a **Forest Type (FTY)** map at a spatial resolution of 20 metres (Figure 3-1). Change layers and reference datasets were included with the reference year 2015. At the same time the accuracy targets were raised towards at least 90% user's and producer's accuracy for the DLT and TCD status layers. A further important step followed with the first production for the reference years 2018 (further referred to as **Historic HRL Forest 2018**) where the spatial resolution of the status layers was raised to 10 metres, the implementation of the change layers was partially reconsidered and target accuracies of 90% user's and producer's accuracy for the change layers were defined. In addition, new aggregated layers depicting the density of coniferous and broadleaved tree cover were introduced. With the **HRL Tree Cover & Forests** starting from the reference year 2018 the product specifications have been kept largely in line with the definitions used for the **Historic HRL Forest 2018** [8] whereas major changes concerned in particular the move to a yearly update



cycle for the status layers and changes to some confidence layers (not shown in Figure 3-1). The new HRL Tree Cover & Forests therefore replace and extend the *Historic HRL Forest 2018*. This does not include an update of the change layer 2015 – 2018; the new status layers for 2018 are therefore not consistent with the original change layers 2015 – 2018.

HRL's on **Grasslands** had already been established in the Copernicus Land Monitoring Service (CLMS) portfolio since the reference years 2015 initially producing a status layer on the absence / presence of grassland (Figure 3-1) with a target Overall Accuracy of 85%. With the reference year 2018, the spatial resolution of the status layers was increased to 10 metres and a change layer with a target Overall Accuracy of 80% was introduced. With the **HRL Grasslands** starting from the reference year 2017, the product specifications have been largely maintained to ensure consistency with the definitions used for the *Historic HRL Grassland 2018* [9]. In particular, the **HRL Grassland (GRA)** layer has been transitioned to an annual update cycle for the status layers, complemented by an additional yearly **Herbaceous Cover** layer that also includes temporary grassland in the reference year. A further methodological enhancement concerns the removal of the Minimum Mapping Unit (MMU) from both the **PLOUGH** and **GRA** layer starting from 2022. This adjustment was introduced to improve the current consistency between the **GRA**, **HER**, and **PLOUGH** layers and to eliminate artificial gains and losses resulting from MMU-induced filtering. While this change enhances the internal coherence and spatial detail of the current **HRL Grassland** layers, it may lead to minor differences when compared to **historic layers** (years before 2022) where MMU thresholds were still applied. Consequently, users should be aware that actual small-area grassland changes may be partly mixed with technical changes resulting from the removal of the MMU. New layers on the count and timing of Grassland Mowing (Minimum Mapping Unit of 0.25 ha) and changes to some confidence layers (not shown in detail in Figure 3-1) are introduced. The new **HRL Grasslands** therefore replaces and extends the *Historic HRL Grassland 2018*. This does not include an update of the change layer 2015 – 2018; the new status layers for 2018 are therefore not consistent with the original change layers 2015 – 2018.

The **HRL Croplands** is a new set of layers dedicated to agriculture and comprises several yearly layers mapping crop types (10-metre spatial resolution) and agricultural practices such as harvest, fallow land and secondary crops (10-metre spatial resolution, Minimum Mapping Unit of 0.25 ha).

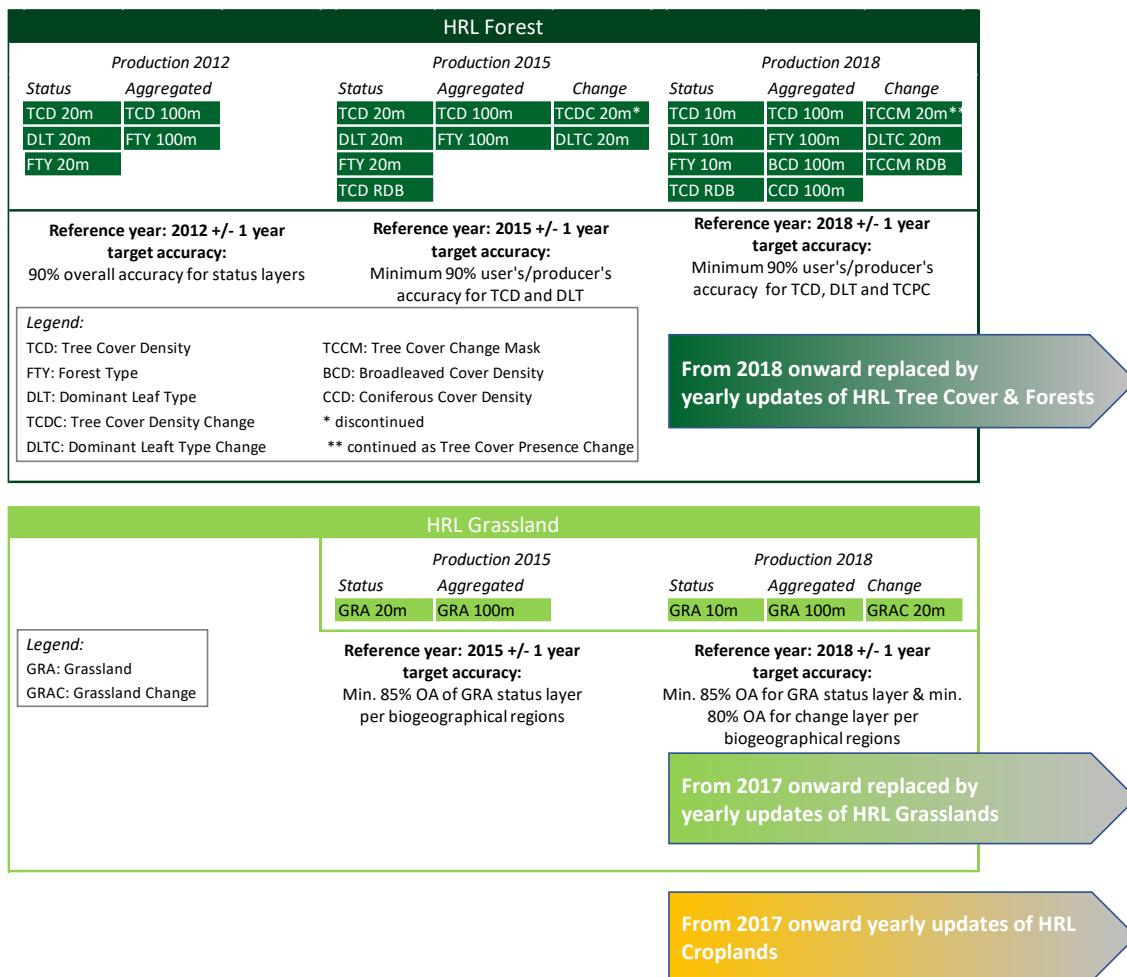


Figure 3-1 Evolution of HRL Forest and Grassland towards the three product groups HRL Tree Cover & Forests, HRL Grasslands, HRL Croplands.

4 Review of User Requirements

In the frame of the **Horizon 2020 (H2020)** project **ECoLaSS** a survey [5] of key stakeholders has been performed in order to evaluate the user requirements towards the evolution of existing and future **Copernicus** products. This survey made also use of the results from the Nextspace User Study [6] and revealed that **HRL** users like European institutions, service industry, research and academia, national agencies, regional administrations, NGOs or private users would in general appreciate:

- High thematic quality/meaningful and application-oriented product definitions;
- Sufficient spatial and timely resolution concerning both, status layer and change layer;
- Short update cycles;
- Change monitoring;
- Free and open access;
- High technical quality;
- Standardized and comparable nomenclature;
- Transparent and scientific workflows and state-of-the-art methodology;
- Detailed documentation of these workflow and the respective methodology;
- Consistency of the Pan-European products enabling synergistic use of all products;



- Streamlining the pan-European product with global ones;
- Availability of historic data and compatibility of time series;
- Open access to the original Copernicus Sentinel data;
- Sophisticated product presentation and visualisation possibilities in an online viewer on the Copernicus platform;
- **IPCC** -compliant land-use categories..

While many of these requirements had already been satisfied with previous HRL reference years some could only be implemented within the current update:

- A long-standing thematic gap in the European **CLMS** portfolio concerning the monitoring of agriculture has been addressed through new products on crop types and agricultural activities. This also improves the separation between grassland and cropland and the **IPCC** conformity;
- Yearly update cycle for status layer;
- Grassland use intensity (or the dynamics of intensification/ extensification) is partially addressed through a new product on Grassland mowing.

Further requirements that remain to be considered for future updates are for example:

- More fine-grained differentiation among species-rich (extensively used) and separation from species-poor (intensively used) and managed grassland;
- Tree-species compositions and shifts between extensive and intensive management;
- Increased timeliness of availability of the products: The mid-term goal is a product provision at latest 12 months after the end of the reference year.

5 Product structure - What are the High Resolution Layers?

The **High Resolution Layers (HRL)** vegetated land cover characteristics portfolio consists of **Tree Cover & Forests**, **Grasslands** and **Croplands** products (Figure 5-1), which together cover most of what is defined as the Biotic component of the **EAGLE** Land Cover Components¹. More specifically, the mapping is focused on surfaces with a vegetation cover above 30%; an exception to this is tree cover where the objective is to map tree cover with a continuous range of 1-100% **Tree Cover Density (TCD)**, i.e. also below 30%, as far as detectable from 10-metre resolution satellite imagery. This definition is also in line with the Sparsely Vegetated class in the **CLC+ Backbone Raster**² and considers that detection / classification of vegetation below this threshold is typically more error-prone. The definition also aims at largely avoiding overlaps with the non-vegetated land cover characteristics such as **HRL Imperviousness**, which is focused on areas with less than 10% vegetation cover during any time of the year, for a reference period of 3 year.

Some overlaps between the three product groups are allowed by definition, for example areas with tree crops (i.e. olive, fruit and nut trees) which are included in both the Tree Cover & Forests and the Croplands products. Furthermore, specific vegetation types are not included in the HRL-

¹ https://land.copernicus.eu/en/eagle?tab=technical_implementation

² <https://land.copernicus.eu/en/technical-library/product-user-manual-clc-backbone-2021>

VLCC portfolio; this concerns areas dominated by natural shrubs (i.e. shrubs that are not under agricultural use) and associations of lichens and mosses.

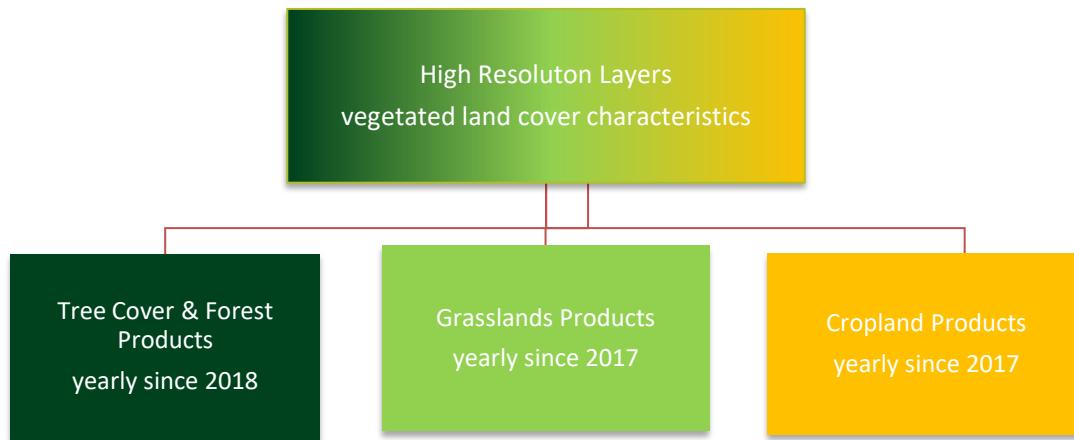


Figure 5-1: Products within the HRL vegetated land cover characteristics.

Given several interdependencies and potential overlaps among the **Grasslands**, **Croplands** and **Tree Cover & Forests** products, the overall workflow starts with the classification of **Base Vegetation Layer (BVL)**. A high-level description is provided for the overall workflow in Figure 5-2. The yearly BVL classification initially targets the separation of five basic land cover classes being:

1. *herbaceous vegetation*;
2. *cropland*;
3. *tree cover*;
4. *tree crops* (i.e. nomenclature overlap between broadleaved tree cover and permanent crops in the Croplands product);
5. *background class* (including bare and sparsely vegetated areas and non-agricultural shrubs);

In a subsequent post-processing step two further classes are derived to delineate the:

6. *potential overlap herbaceous – cropland* (i.e. pixels which are classified as cropland and herbaceous at least once in the time-series);
7. The second derived class is derived from the intersection of all areas classified as tree cover and a preliminary version of the Tree Cover Density to delineate areas with low Tree Cover Density and hence allowed *overlaps of herbaceous and tree cover*.

The derived yearly BVL is considered for the downstream productions of Grasslands, Croplands and Tree Cover & Forests products as follows:

- For the production of the Grasslands layers: all areas classified as *herbaceous*, *overlap herbaceous – tree cover*, or *overlap herbaceous – Cropland* are considered as the potential maximum extent for the **Herbaceous Cover (HER)** layer. In addition, the BVL classification probabilities for the *herbaceous* class are used as the main input for the derivation of the **HER** layer.
- For the Croplands layers: the areas delineated as *cropland*, *overlap herbaceous – cropland*, or *Tree Crops* are considered as the maximum extent for the **CTY** classification and further refinement.



- For the **Tree Cover & Forests** layers: the areas classified as *tree cover*, *overlap herbaceous – tree cover*, *tree crops* and the respective probabilities are used directly to derive the respective change layers and yearly **DLT** and **TCD** status layers.

Within the areas identified as *overlap herbaceous – cropland*, a further harmonization step is carried out downstream. To this end the **CTY** classification initially includes a class for *fodder crops* which are transferred to the **HER** layer if occurring in the designated overlap class.



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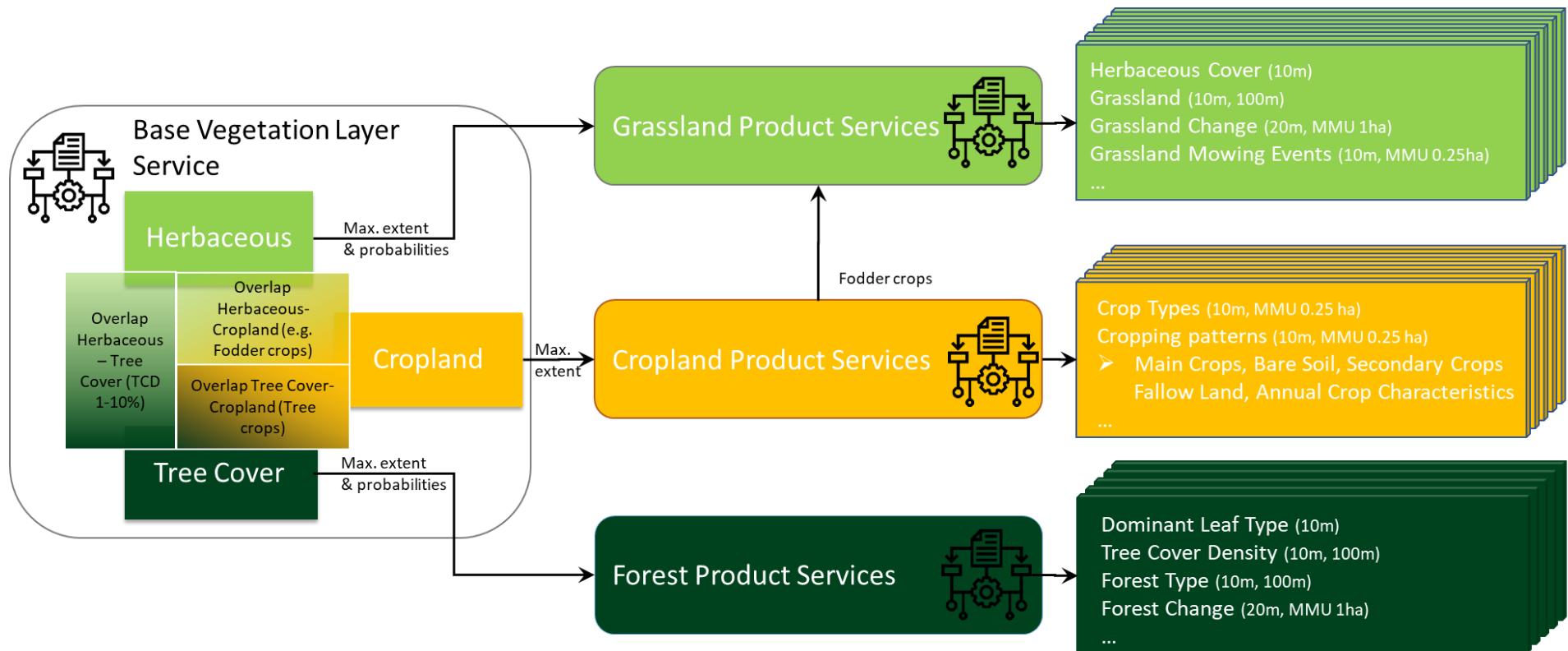


Figure 5-2: High-level overview of the relationship between the Base Vegetation Layer and the subsequent production of Grasslands, Croplands and Tree Cover & Forests products



6 Product application areas and examples of use cases

The **HRL Tree Cover & Forests, Grasslands** and **Croplands** set of products is designed for use by a broad user community as basis for environmental and regional analysis and for supporting political decision-making, such as the **Common Agricultural Policy (CAP)**, **LULUCF (Land Use, Land Use Change and Forestry)** regulation, the **Nature Restoration Regulation (NRR)**, or the proposed European **Forest Monitoring Law (FML)**. Notably, the NRR (Regulation (EU) 2024/1991) explicitly refers to the Tree Cover Density dataset as the basis for determining urban tree canopy cover, thereby establishing a direct legal reference to the HRL framework within EU legislation. With the new products the **EEA** will ensure continuity and further densification of the well-established HRL Tree Cover & Forests and Grasslands product time series. Those include a rich suite of raster products at a 3-yearly interval mapping the status of those land cover types with a spatial resolution of 10-metre and change layers at 20-metre spatial resolution.

As an example, the following sections provide short information on (potential) use cases at national level, for which the **Copernicus HRL Tree Cover & Forests** product represent a fundamental input.

6.1 Use Case: Monitoring of Tree Cover Change and Dominant Leaf Type

The **Tree Cover Presence Change (TCPC)** layer documents losses of tree cover between 2018 and 2021 which can serve as a reliable information source for forest authorities. The example shown in Figure 6-1 is also confirmed by the **Dominant Leaf Type (DLT)** layer pictured in Figure 6-2.

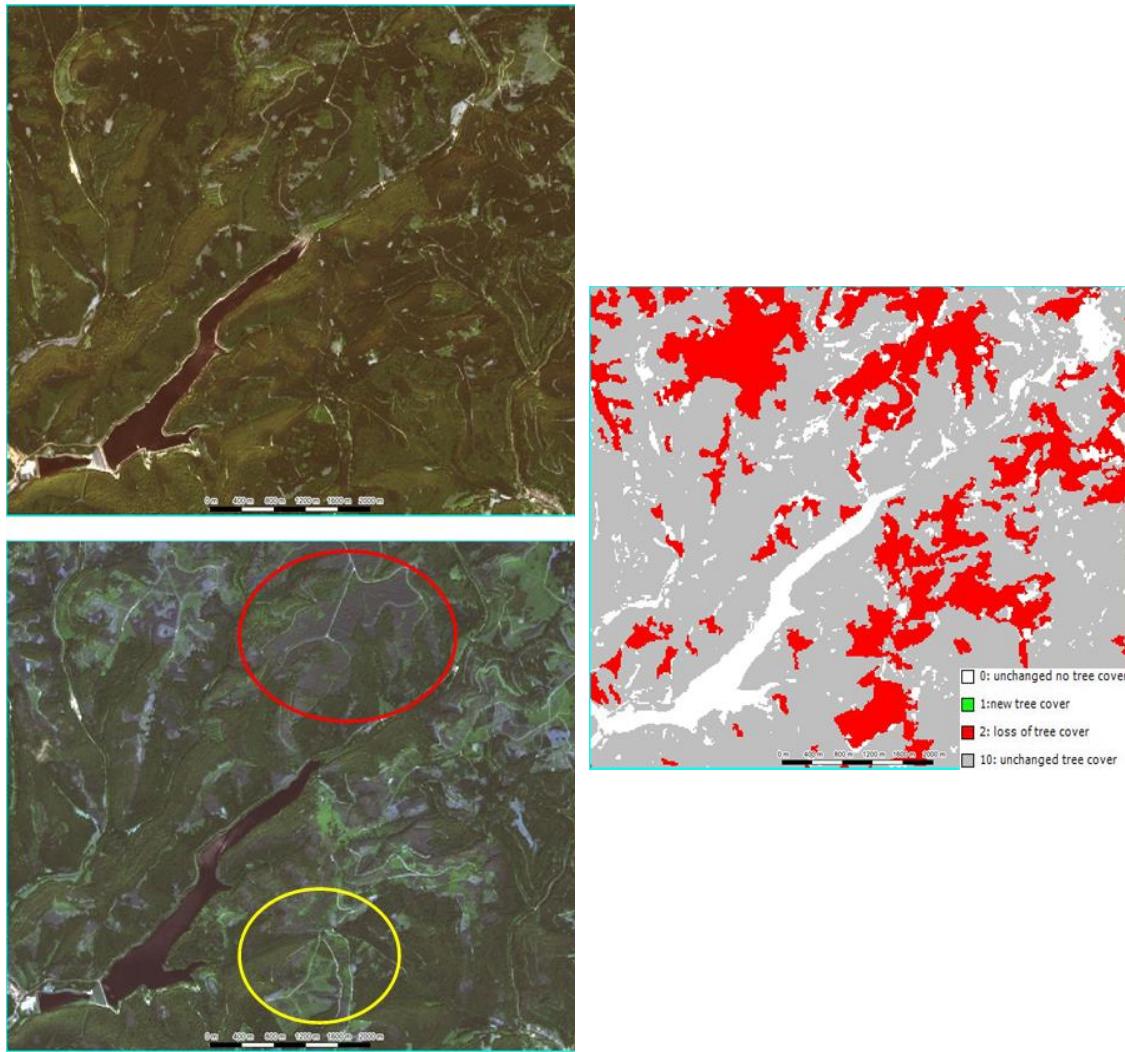


Figure 6-1: Right: Tree Cover Presence Change documenting tree cover loss areas between 2018-2021 in Harz mountains, Germany. Left side shows S2 scenes (top left: 2018, bottom left: 2021) with clearly visible clear cut sides (yellow circle) and dead trees (red circle), caused by drought and bark beetle infestation

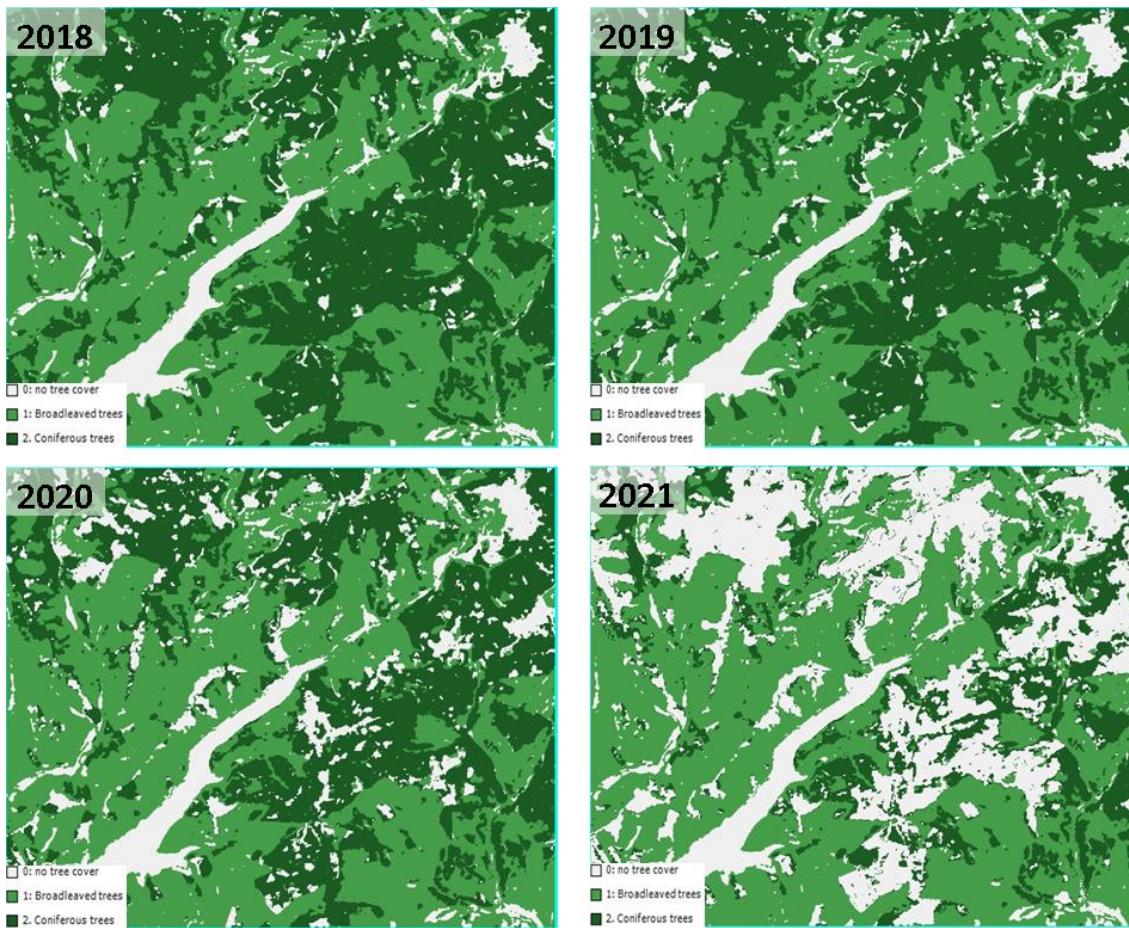


Figure 6-2: DLT time series showing the gradual decrease of coniferous tree cover from 2018 to 2021

6.2 Use case: Land cover specific monitoring

Detailed and dynamic information on the state of the land as provided by the **HRL Tree Cover & Forests** layers allows to analyse regional trends in the area occupied by these land covers, which could be relevant information for authorities and policy makers. Furthermore, applications which require information on the land cover status can benefit from the HRL Tree Cover & Forests. For example, in case of biomass mapping often land cover specific parametrization is applied. Using the Tree Cover & Forests, allows to do this in a much more detailed and dynamic way. In case of the Evoland³ project, it is intended to use these layers to apply specific parametrization over tree-covered locations.

6.3 Use Case: Feasibility study for tree species mapping

Umweltbundesamt (UBA), Germany: Explorative use of the **HRL Tree Cover & Forests** as base information and further analysis towards derivation of tree species from Sentinel-2 data in the frame of a feasibility study with German and Austrian partners. Results from 5 case study sites show that a number of 8-16 tree species could be detected using multi-temporal Sentinel-2 data. The study showed that a high number of available cloud-free satellite scenes and the availability

³ <https://www.evo-land.eu/method/biomass-mapping/>



of additional adequate local reference data for algorithm training are required for retrieval of the results⁴.

There is such demand for a tree species map in Germany at:

- **Umweltbundesamt (UBA -Environmental Protection Agency):** Assessment and risk analysis of forest ecosystems, assessment of material discharges (critical loads), monitoring of indicators in the framework of the German Strategy for Adaptation to Climate Change.
- **Bundesamt für Naturschutz (BfN – Federal Agency for Nature Conservation):** renewable energy planning, requiring tree species composition to identify valuable habitats; considering adaptation to climate change.
- **Thünen-Institut (TI – Federal Research Institute for Rural Areas, Forestry and Fisheries):** Tree species accounting for the German State-of-Forest report („Wald-Zustandsbericht“).

7 Product description

The **HRL Tree Cover & Forests** layers are generally provided in 100km LAEA tiles as shown in Figure 7-1. The five French Oversea Territories are provided in UTM with the layout of the respective territory. The layers are available as Cloud-Optimized GeoTIFFs (COG) per reference year and 100km LAEA tile aligned with the **EEA reference grid**. Each raster file is accompanied by a Persistent Auxiliary metadata (PAM) XML and an INSPIRE XML.

The **HRL Tree Cover & Forests** layers comprise two yearly primary status layers: **Dominant Leaf Type (DLT)** and **Tree Cover Density (TCD)**. The status layers at 10-metre spatial resolution share the same spatial extent and provide information on the leaf type (**DLT**) and the proportional tree cover at pixel level (**TCD**). These layers map trees wherever they occur, also outside of what is (technically) a forest.

In the **HRL Tree Cover & Forests** product there is an additional status layer that applies the **FAO** forest definition⁵, and can therefore be called a (sensu stricto) forest product: the **Forest Type (FTY)** layer (in 10 metres and 100 metres resolution). The fact that **TCD** and **DLT** do not have a forest definition and filtering applied, makes it possible for users to adapt the existing tree cover density / dominant leaf type layers to their own forest definition (if different from the FAO definition). Following the FAO definition, the FTY excludes tree cover with a density of less than 10%, trees located in urban areas or under agricultural use, and group of trees smaller than 0.5 ha. This information is sourced from **Corine Land Cover** and the **HRL Imperviousness** datasets and is made available in the auxiliary **Forest Additional Support Layer (FADSL)**. The Minimum Mapping Width (MMW) of 20 metres suggested by the FAO definition is not enforced and thinner tree cover elements mapped in the DLT are retained as long as they satisfy the MMU of 0.5ha.

⁴ https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-02-27_texte_16-2019_copernicus.pdf

⁵ <https://www.fao.org/4/ad665e/ad665e03.htm>

The yearly status layers classifications at a spatial resolution of 10 metres represent the input for two change layers which follow a 3-yearly update cycle. Those are a **Tree Cover Presence Change (TCPC)**⁶ and a **Dominant Leaf Type Change (DLTC)** layers in 20-metre spatial resolution and with a Minimum Mapping Unit of 1 ha. The **TCPC** layer includes four thematic classes out of which two indicate changes (*new tree cover/loss of tree cover*) between two time steps. The **DLTC** is derived by dedicated GIS operations from **TCPC** and the primary status layer (**DLT**) of 2018 and 2021. It includes 6 thematic classes, thereof 4 change classes.

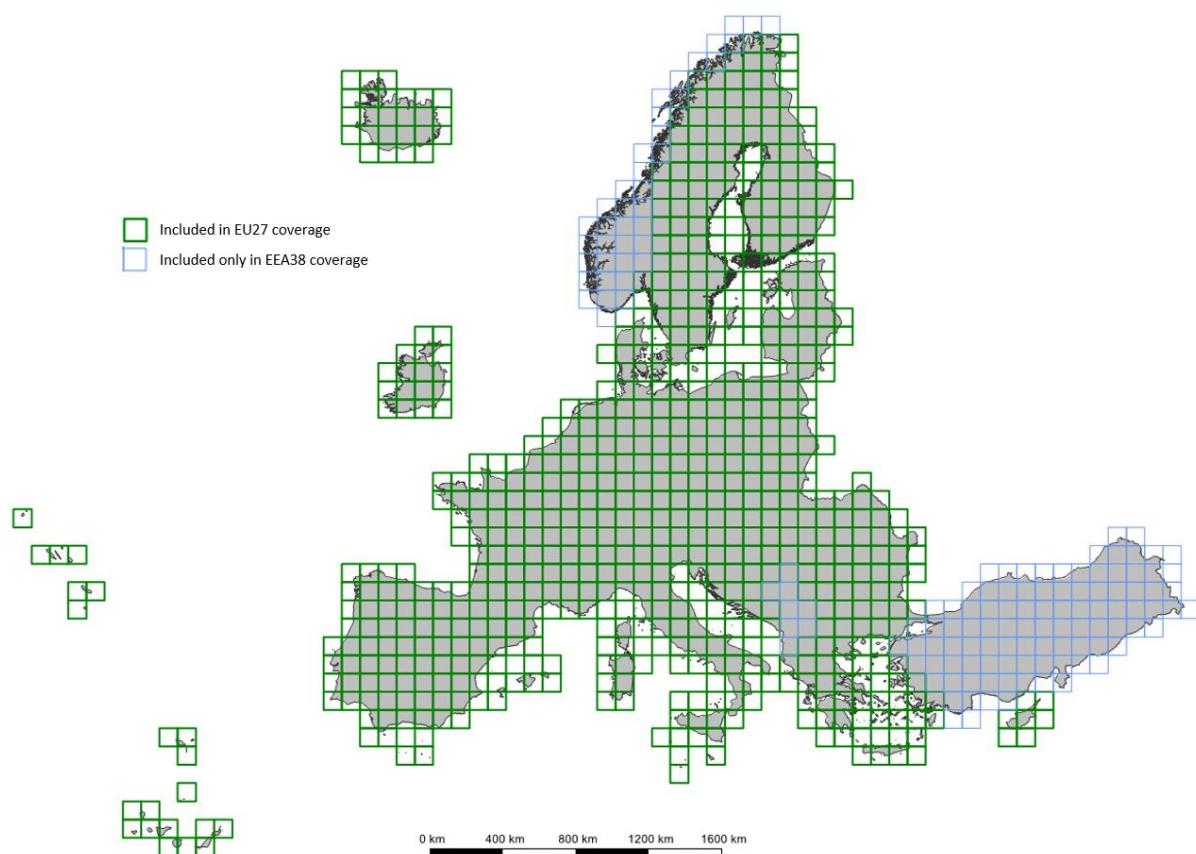


Figure 7-1: LAEA tile layout including distinction between tiles to cover EU27 and EEA38.

Further, aggregated layers of the status layers at 100-metre resolution are provided, as well as additional auxiliary layers and some reference datasets (Figure 7-2). The **TCD** at **100-metre** spatial resolution is derived through spatial aggregation from the 10-metre **TCD** status layer for the respective reference year. **Broadleaved Cover Density (BCD)** and **Coniferous Cover Density (CCD)** layers depict respectively the percentage of broadleaved and coniferous pixel at 100-metre spatial resolution. They are derived through aggregation of the 10-metre **DLT** for the respective reference year.

⁶ In previous productions the TCPC was still called Tree Cover Change Mask (TCCM)

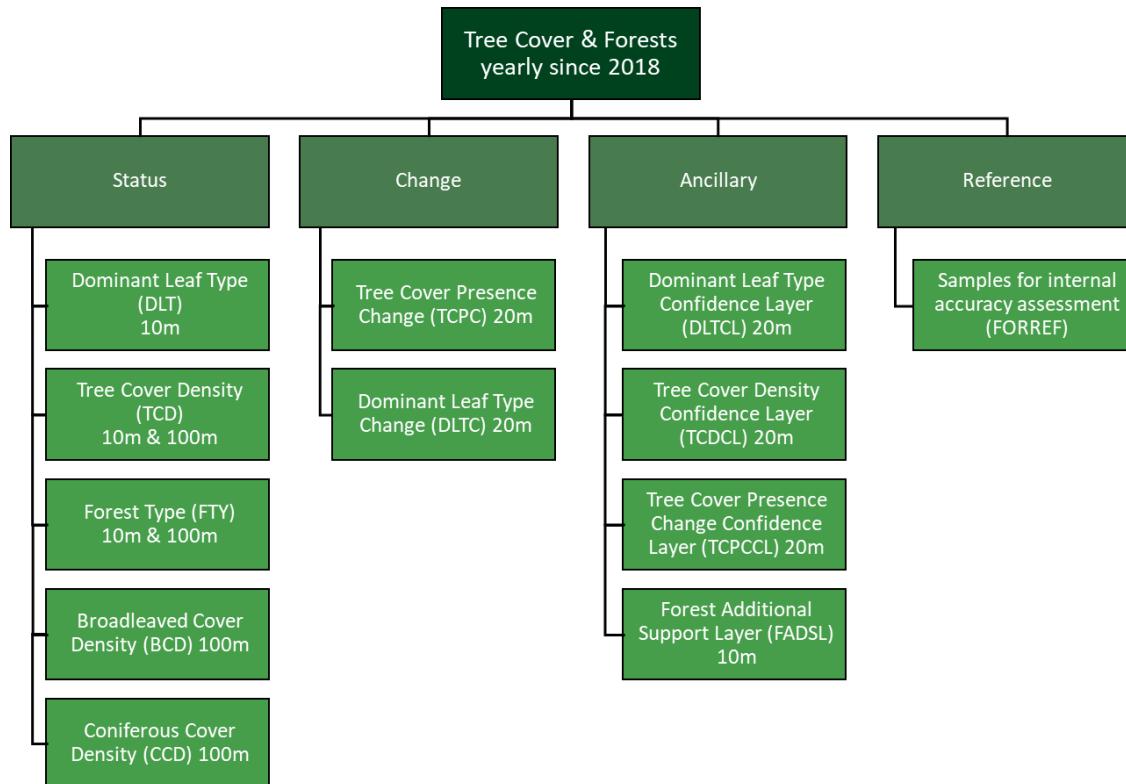


Figure 7-2 HRL Tree Cover & Forests product portfolio

7.1 Thematic characteristics of the Tree Cover & Forests Product

Table 7-1 provides an overview of the **Land Cover (LC)** and **Land Use (LU)** features that shall be included or excluded in the “tree cover” mapping, if detectable from the satellite imagery. In general, this definition has been kept consistent with previous productions since the initial reference year 2012.

The **Tree Cover Density (TCD)** is defined as the „*vertical projection of tree crowns to a horizontal earth’s surface*“ and provides information on the proportional crown coverage per pixel. Reference TCD values have originally been derived using **Very High Resolution (VHR)** satellite data and/or aerial ortho-imagery as reference data. Thereby TCD is assessed on different VHR sources by visual interpretation following a 10x10 point grid approach, resulting in proportional density information on a 100 x 100 metres grid level. This density information can be linked with the average spectral values from the input satellite data to train regression models which are subsequently used to estimate the TCD for areas where no reference data is available.

TCD shows a natural sensitivity towards phenology and radiometric influences (e.g. haze). Consequently, the magnitude of TCD values strongly relies on the availability and quality of adequate satellite input data and reference data and may vary regionally. Furthermore, extreme weather events and climate conditions (e.g. European drought 2018) show a negative influence on the magnitude of density values due to leaf colouring and leaf shedding.

Table 7-1: Elements to be included/excluded in tree cover



Elements included in the tree covered area <i>(if tree cover can be detected from the 10-metre imagery)</i>	Elements excluded from tree covered area <i>(if no tree cover can be detected from the 10-metre imagery)</i>
<ul style="list-style-type: none">• Evergreen/deciduous broadleaved, sclerophyllous and coniferous trees of any use• Forests (grown-up and under development)• Orchards, olive groves, fruit and other tree plantations, agro-forestry areas• Transitional woodland, forests in regeneration• Groups of trees within urban areas (alleys, wooded parks and gardens)• Forest management/use features inside forests (forest roads, firebreaks, thinnings, forest nurseries, etc.)• Forest damage features inside forests (partially burnt areas, storm damages, insect-infested damages, etc.)	<ul style="list-style-type: none">• Open areas within forests (roads, permanently open vegetated areas, clear cuts, fully burnt areas, other severe forest damage areas, etc.)• Dwarf shrub-covered areas, such as moors and heathland• Vineyards• Dwarf pine / green alder in alpine areas• Mediterranean shrublands (macchia, garrigue etc.)• Shrubland



7.2 Download content, file naming convention and file format(s)

Table 7-2: Download content, file naming convention and file format(s) for HRL Tree Cover & Forests layers

Name of layer	Acronym	Abbreviation	Data format	Metadata
Tree Cover Density (10 m)	TCD	TCD_S2018_R10m TCD_S2019_R10m ... TCD_S2023_R10m		
Tree Cover Density (100 m)	TCD	TCD_S2018_R100m TCD_S2019_R100m ... TCD_S2023_R100m		
Dominant Leaf Type (10 m)	DLT	DLT_S2018_R10m DLT_S2019_R10m ... DLT_S2023_R10m		
Tree Cover Presence Change (20 m)	TCPC	TCPC_C2018-2021_R20m		
Dominant Leaf Type Change (20 m)	DLTC	DLTC_C2018-2021_R20m		
Forest Type (10 m)	FTY	FTY_S2018_R10m FTY_S2021_R10m		
Forest Type (100 m)	FTY	FTY_S2018_R100m FTY_S2021_R100m		
Forest Additional Support Layer (10 m)	FADSL	FADSL_S2018_R10m FADSL_S2021_R10m		
Broadleaved Cover Density (100 m)	BCD	BCD_S2018_R100m BCD_S2019_R100m ... BCD_S2023_R100m		
Coniferous Cover Density (100 m)	CCD	CCD_S2018_R100m CCD_S2019_R100m ... CCD_S2023_R100m		
Tree Cover Density Confidence Layer	TCDCL	TCDCL_S2018_R10m TCDCL_S2019_R10m ... TCDCL_S2023_R10m		
Dominant Leaf Type Confidence Layer (10 m)	DLTCL	DLTCL_S2018_R10m DLTCL_S2019_R10m ... DLTCL_S2023_R10m		
Tree Cover Presence Change Confidence Layer (20 m)	TCPCL	TCPCL_C2018-2021_R20m		



7.3 Projection and spatial coverage

Table 7-3: Projection and spatial coverage for HRL Tree Cover & Forests layers

Name of layer	Acronym	Spatial coverage	Coordinate reference system (WKT)
Tree Cover Density	TCD	5.751.002 km ² (covering the full EEA-38)	PROJCS["ETRS89-extended / LAEA Europe", GEOGCS["ETRS89", DATUM["European_Terrestrial_Reference_System_1989", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], AUTHORITY["EPSG","6258"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], AUTHORITY["EPSG","8901"], UNIT["degree",0.0174532925199433, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4258"]], PROJECTION["Lambert_Azimuthal_Equal_Area"], PARAMETRE["latitude_of_center",52], PARAMETRE["longitude_of_center",10], PARAMETRE["false_easting",4321000], PARAMETRE["false_northing",3210000], UNIT["metre",1, AUTHORITY["EPSG","9001"]], AXIS["Northing",NORTH], AXIS["Easting",EAST], AUTHORITY["EPSG","3035"]]
Dominant Leaf Type	DLT		
Tree Cover Presence Change	TCPC		
Dominant Leaf Type Change	DLTC		
Forest Type	FTY		
Forest Additional Support Layer	FADSL		
Broadleaved Cover Density	BCD		
Coniferous Cover Density	CCD		
Tree Cover Density Confidence Layer Confidence Layer	TCDCL		
Dominant Leaf Type Confidence Layer	DLTCL		Except for French DOMs where the following CRS are used: YT: EPSG 32738 RE: EPSG 32740 MQ: EPSG 32620 GP: EPSG 32620 GF: EPSG 32620
Tree Cover Presence Change Confidence Layer	TCPCL		

7.4 Spatial resolution

The native spatial resolution of the Tree Cover & Forests products DLT, TCD and FTY is 10 metres and linked to the highest resolution of Sentinel-2 (red, blue, green and near-infrared bands) as the primary input data source. For products at 20 metres and 100 metres, aggregation rules are defined in the ATBD [7]. The spatial resolution should, however, not be confused with the size and location-precision of the elements that can be represented in the maps. The latter is limited by certain factors that are intrinsic to the available input data:

- Ground Resolved Distance (GRD) is a metric that better reflects the spatial resolution of a satellite sensor than the spatial resolution of the image. For Sentinel-2 recent estimates suggest a GRD around 12.5 metres [10]
- To fully leverage Sentinel-2, the analyses of the time-series are essential. Since the completion of the reprocessing of Sentinel-2 Collection-1 the multi-temporal co-registration is better than 4m in most cases⁷ whereas observations until August 2021 only had a co-registration accuracy of 12 metres before the reprocessing⁸.

⁷https://sentiwiki.copernicus.eu/_attachments/1673423/OMPC.CS.DQR.001.08-2025-Sentinel-2-MSI-L1C-DQR-September-2025-115.pdf?inst-v=21d709d1-2d56-4cc7-aec1-05e4dd76e738

⁸ S2-PDGS-MPC-DQR Issue: 66 Date: 02/08/2021



- Most other input data have a coarser spatial resolution (e.g. Sentinel-1 ~20 metre, Sentinel-2 short wave infrared at 20 metre).
- The detectability of land cover elements can be further limited by the intensity of their reflectance. This concerns for example vegetation on very bright soils or in urban areas where the reflectance of the brighter non-vegetated surfaces easily dominates the recorded reflectance within one pixel.

While it is difficult to quantify the cumulative effect and variability of these factors, limited detectability and spatial uncertainty of elements at a scale from 10-20 metres should probably be considered for the usage and validation of the maps.

Table 7-4: Spatial resolution for HRL Tree Cover & Forests layers

Name of layer	Acronym	Pixel size	MMU
Tree Cover Density	TCD	10 m / 100 m	N/A
Dominant Leaf Type	DLT	10 m	N/A
Tree Cover Presence Change	TCPC	20 m	MMU 1.0 ha per change classes (incl. hole filling of no-change patches inside change areas)
Dominant Leaf Type Change	DLTC	20 m	Inherited from TCPC no further MMU on leaf type classes applied
Forest Type	FTY	10 m / 100 m	0.5 ha
Forest Additional Support Layer	FADSL	10 m	N/A
Broadleaved Cover Density	BCD	100 m	N/A
Coniferous Cover Density	CCD	100 m	N/A
Tree Cover Density Confidence Layer	TCDCL	10 m	N/A
Dominant Leaf Type Confidence Layer	DLTCL	10 m	N/A
Tree Cover Presence Change Confidence Layer	TCPCL	20 m	1.0 ha inherited from TCPC



7.5 Temporal information

Table 7-5: Temporal information for HRL Tree Cover & Forests layers

Name of layer	Acronym	Reference year
Tree Cover Density	TCD	2018 2019 2020 2021 2022 2023
Dominant Leaf Type	DLT	
Broadleaved Cover Density	BCD	
Coniferous Cover Density	CCD	
Tree Cover Density Confidence Layer Confidence Layer	TCDCL	
Dominant Leaf Type Confidence Layer	DLTCL	
Forest Type	FTY	2018, 2021
Forest Additional Support Layer	FADSL	
Tree Cover Presence Change Confidence Layer	TCPCL	2018 vs. 2021
Tree Cover Presence Change	TCPC	
Dominant Leaf Type Change	DLTC	

7.6 Product characteristics and class codes

Table 7-6: Characteristics of HRL Tree Cover & Forests layers

Name of layer	Acronym	Classified feature	Class coding
Tree Cover Density	TCD	Tree cover; tree cover density from 1-100%. According to the vertical projection of tree crowns to a horizontal earth's surface as assessed by means of VHR satellite imagery with sub-metre resolution	0: all non-tree covered areas 1-100: tree cover density in % 255: outside area
Dominant Leaf Type	DLT	Dominant leaf type: broadleaved or coniferous.	0: all non-tree covered areas 1: broadleaved trees 2: coniferous trees 255: outside area
Tree Cover Presence Change	TCPC	Increase or decrease of tree cover extent.	0: unchanged areas with no tree cover 1: new tree cover 2: loss of tree cover 10: unchanged areas with tree cover 255: outside area
Dominant Leaf Type Change	DLTC	Various possible leaf type changes between two reference years.	0: unchanged areas with no tree cover 1: new broadleaved cover 2: new coniferous cover 3: loss of broadleaved cover 4: loss of coniferous cover 10: unchanged areas with tree cover 255: outside area
Forest Type	FTY	Forest Type: broadleaved or coniferous, largely following the FAO forest definition: $\geq TCD\ 10\%$; $>0.5\ ha\ MMU$; Urban trees and trees under predominantly agricultural use are excluded based on the FADSL.	0: all non-forest areas 1: broadleaved forest 2: coniferous forest 255: outside area



Forest Additional Support Layer	FADSL	Trees in urban context, trees predominantly used for agricultural practices.	0: all non-tree covered areas, and tree cover without urban context or agricultural use 3: trees predominantly used for agricultural practices – broadleaved (from CLC2018) 4: trees in urban context – broadleaved and coniferous (from IMD2018) 5: trees in urban context – broadleaved and coniferous (from CLC2018) 255: outside area
Broadleaved Cover Density	BCD	Aggregated density of broadleaved trees. Percentage of broadleaved pixels in the DLT for the respective reference year	0: all non-broadleaved covered areas 1-100: broadleaved cover density in % 255: outside area
Coniferous Cover Density	CCD	Aggregated density of coniferous trees. Percentage of coniferous pixels in the DLT for the respective reference year	0: all non-coniferous covered areas 1-100: coniferous cover density in % 255: outside area
Tree Cover Density Confidence Layer Confidence Layer	TCDCL	Standard deviation computed from the total variance as defined in [1]	0-100: standard deviation of TCD estimate 253: all non-tree covered areas 255: outside area
Dominant Leaf Type Confidence Layer	DLTCL	Probability margin (i.e. difference of probabilities for highest and second highest ranked leaf type class)	0-100: classification confidence 253: all non-tree covered areas 255: outside area
Tree Cover Presence Change Confidence Layer	TCPCL	Change in tree cover probability from 2018 to 2021. Higher absolute values signal higher confidence.	0-100: change confidence 253: all non-tree covered areas 255: outside area

8 Production quality assessment

The aim of this chapter is to inform about the procedures for internal validation and accuracy assessment for the status and change layer across the full **EEA38** area. While the different layers have their own quality requirements, all have in common an assessment of the thematic quality which relies on comparing mapped information within the layers with reference data at selected locations.

This procedure contains 3 steps that will be described in the following sections:

- Sampling design
- Response design
- Statistical Analysis

The internal validation of the **HRL Tree Cover & Forests** layers follows scientifically accepted and operationally proven validation design, applied in previous productions of various HRL's of reference years 2012, 2015 and 2018. According to the product specifications, results will be presented in the form of **Overall Accuracies (OA)**, **Producer's** and **User's Accuracies**.



8.1 Layers to be verified

While the full portfolio on **HRL Tree Cover & Forests** includes numerous layers and reference years, only a subset of them is concerned by the internal verification exercise. The focus of the assessment has been set on the primary layers being the **Dominant Leaf Type (DLT)**, **Tree Cover Density (TCD)** and change layers: **Tree Cover Presence Change (TCPC)** and **Dominant Leaf Type Change (DLTC)**. Furthermore, to keep the effort for the verification manageable the reference years 2018 and 2021 have been selected to align with the availability of important reference datasets such as the VHR IMAGE coverages of 2018 and 2021 imagery. Since the 2022 and 2023 have been produced in a new production cycle, the reference year 2022 has been considered in addition to check the consistency of the quality over time. An overview of the verified layers and their target accuracies is given in Table 8-1.

Table 8-1: Layers to be verified and target accuracies

Layer	Reference year or period	Target accuracy
DLT 10 m	2018, 2021, 2022	Min. 90% user's / producer's accuracy
TCD 10 m	2018, 2021, 2022	
TCPC 20 m	2018-2021	90% user's / producer's accuracy

8.2 Sampling Design

The sampling approach is dedicated to assess the accuracies of the **HRL Tree Cover & Forests** product at pan-European level and corresponds to a non-stratified, systematic and random sampling approach based on the 2 km by 2 km **LUCAS** grid. For the assessment of status layers, 10 000 samples are randomly selected over the extended LUCAS grid (Figure 8-1). It is likely that this initial drawing will not overlap many Tree Cover Changes between 2018 and 2021 due to the “rarity” of changes. The same is true for the **HRL Grasslands** changes which have been validated with the same point set. Therefore, 4 000 additional samples are randomly drawn specifically in the changes’ strata of **Tree Cover & Forests** and **Grasslands** products (2 000 in the tree cover change strata, 2 000 in the grasslands change strata), for a total of 14 000 points samples (Primary Sampling Units) across **EEA38**.



Figure 8-1: Spatial distribution of 14.000 Primary Sampling Units.

8.3 Response Design

The response design is the protocol used for retrieval of the validation/reference information for all sample units. Two types of datasets are used to perform the interpretation of samples units: guiding data and reference data.

Guiding data are those used for production of the **HRL Tree Cover & Forests** product and consist mainly of time-series of Sentinel data.

Reference data are complementary and independent data that can provide more spatial details and landscape context:

- **VHR_IMAGE_2018⁹** and **VHR_IMAGE_2021¹⁰**: very high resolution optical earth observation imagery, covering **EEA38** for the reference years 2018 and 2021 (+-1 year).
- Other external datasets:
 - o **Bing maps image/ cartography layer**
 - o **Open Street Map** data
 - o **Google Earth Image / cartography data**
 - o **Sentinel-2** imagery from January / March / May and July

The interpretation workflow consists of thematic plausibility analysis of a sample units. This means that the class assigned by the layer is known by the interpreter during the interpretation. Depending on the layer, the interpretation workflow can differ in ways described below.

⁹ [Copernicus Data Space Ecosystem – Copernicus Contributing Missions – VHR IMAGE 2018](#)

¹⁰ [Copernicus Data Space Ecosystem – Copernicus Contributing Missions – VHR IMAGE 2021](#)

Given the difficulty to assess the **Tree Cover Density (TCD)** or the **Dominant Leaf Type (DLT)** within a 10-metre pixel using the available guiding and reference data, it has been decided, for the status layers of 2018 and 2021, to opt for an approach already used for the validation of previous **HRL Tree Cover & Forests** layers. This approach consists of using **Secondary Samples Units (SSU)** distributed on a 5x5 grid around the initial sample unit (Figure 8-2). During the reference interpretation of each year, each SSU is assigned a code depicting if it overlaps a tree or not. If yes, the leaf type is to be identified. An SSU can then be labelled 0 (not tree), 1 (broadleaf tree) or 2 (coniferous tree).

SSU information is aggregated to derive **TCD** or the **DLT** around the initial sample unit, which will collect this aggregated information. Reference tree density information is the ratio between tree labelled SSUs (code 1 or 2) over the 25 SSUs. Reference Dominant Leaf Type information consists of the label majority (or relative majority) within the 25 SSUs: if 13 or more SSUs are labelled “no tree”, the initial sample unit gets the reference **DLT** label “no tree”. If less than 13 SSUs are labelled “no tree”, the initial sample unit gets the reference **DLT** label which corresponds to the majority of tree labelled SSUs (*coniferous* or *broadleaved*).

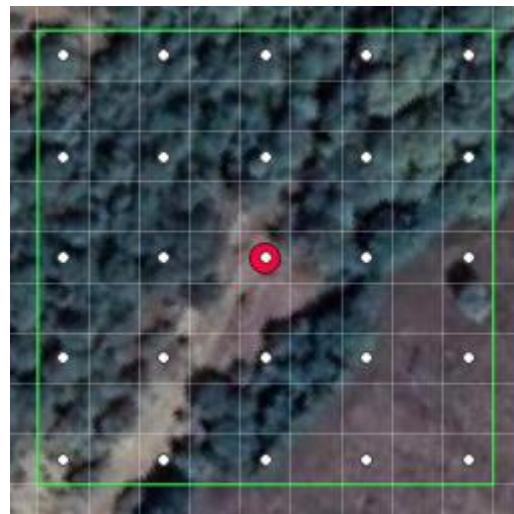


Figure 8-2: Secondary Sample Units used for 2018 and 2021 Tree Cover & Forests reference layers.
Red dot: initial sample; **white dot:** secondary sample unit; **green outline:** area around the initial sample that is used to derived product statistics.

To compare these reference information with the layers, an extraction is performed over the SSU extent (green outline in Figure 8-2): the average value of the **TCD** pixels is assigned to the initial sample; and the count of “*no tree*”, “*broadleaved tree cover*” and “*coniferous tree cover*” **DLT** pixels is used to assigned a **DLT** value to the initial sample. The initial sample can thus present **TCD** and **DLT** information as long as trees are present over the 5x5 SSU grid, even if the initial sample is not covering a tree-covered area. This explains why the percentage of samples labelled as tree cover can be systematically higher than the percentage of tree covered area.

For **change layers**, the initial sample is interpreted without using the SSU grid, as change layers specifications (existence of an **MMU** for example) are not compatible with the direct comparison of 2018 and 2021 SSU value to detect changes. The **MMU** is considered during the sample interpretation.

Regarding the **interpretation of the samples for 2022** there are some specificities that require further explanations. Since the **VHR_IMAGE_2021** contains mostly images from 2020 and 2021 the interpretation requires a stronger reliance on Sentinel-2 data from 2022. Given the coarser spatial resolution of Sentinel-2 compared to VHR, this leads to slightly higher uncertainties during visual interpretation compared to verification exercises for years 2018 and 2021.



The analysis for the year 2022 builds on results from the 2021 verification activity. As the amount of landcover changes between 2021 and 2022 is expected to be minimal, the reference dataset 2021 is expected to still be mostly valid in 2022. Thus, the response design focusses on a plausibility approach: reference dataset from 2021 is compared with 2022 products and:

- For samples where reference 2021 = product 2022 the sample is not revisited and the reference 2021 is considered still valid in 2022 (i.e. reference 2021 becomes reference 2022)
- For samples where reference 2021 ≠ product 2022, a new interpretation for the reference value is performed. This will allow to identify and update samples where land cover changes occurred, or correct errors within the reference database (= coding uncertainties in 2021 that can be clarified in 2022).

Such a plausibility approach was also used during 2021 verification activities. Following this plausibility analysis few samples might still contain different reference codes for 2021 and 2022 even if no actual changes have occurred on the ground. Such cases are typically caused by low quality EO data in both years which renders the interpretation difficult.

These limitations should be considered when comparing the accuracies of 2021 and 2022 since the higher uncertainty in the interpretation for 2022 might in some cases have biased the plausibility interpretation towards the values in the product.

8.4 Statistical Analysis

For the **HRL Tree Cover & Forests** the thematic accuracy level is requested to reach different targets defined by user's and producer's accuracies which need to be derived from confusion matrices. For the **Dominant Leaf Type (DLT)** layers the confusion matrices are constructed and User's and Producer's accuracies are derived for each class. For the **Tree Cover Density (TCD)** with continuous values between 0 and 100%, User's and Producer's accuracies for each percentage class would not provide meaningful information. Therefore 2 statistical analyses are produced:

- A scatterplot between **TCD** aggregated measures (product and reference) at sample location.
- User's and Producer's accuracies for 2 density classes: **TCD 0-<30%** and **TCD 30-100%**.

For the **Tree Cover Presence Change (TCPC)** layers, a confusion matrix can be constructed directly, and producer's and user's accuracies are derived for each class of land cover.

The row and column totals and the diagonal of the matrix are used to assess two further types of accuracy, the User's and Producer's accuracy:

- **Producer's Accuracy (PA)** for a given class = $\alpha\alpha/C\alpha$, representing an (inversely proportional) measure of Omission Error. For instance, an observation has been identified as tree-covered in the validation dataset but was actually classified as another class: it has been omitted from the target class.
- **User's Accuracy (UA)** for a given class = $\alpha\alpha/R\alpha$, representing an (inversely proportional) measure of the Commission Error (or contamination risk), i.e. errors due to the wrong allocation of an observation (i.e. mapped landcover) to a landcover class. For instance, an observation is classified as broadleaved tree cover, but identified as belonging to another class during the validation process: this observation has contaminated another class.

As mentioned in section 8.2, unequal sampling intensity resulting from the stratified systematic sampling approach for change layers will be accounted for by applying a weight factor (p) to



each Sample Unit, based on the ratio between the number of samples and the size of the stratum considered:

$$\hat{p}_{ij} = \left(\frac{1}{N}\right) \sum_{x \in (i,j)} \frac{1}{\pi_{uh}^*},$$

Where i and j are the columns and rows in the matrix, N is the total number of possible units (population) and π is the sampling intensity for a given stratum.

This is because the samples from the smaller strata (i.e. change layers) show a higher sampling intensity than those from the larger strata (i.e. status layers). Therefore, a correction for the sampling intensity will be applied to the error matrices produced following the procedure described by [3] and applied by [4], leading to a weighting factor inversely proportional to the inclusion probability of samples from a given stratum. Not applying this correction could result in underestimating or overestimating map accuracies. On the following sections, the confusion matrices generally contain the statistically correct weighted matrices. For the changes the unweighted matrices, are presented in addition to provide information on the actual number of samples per category and the impact of statistical weights.

8.5 Verification Results

8.5.1 Tree Cover Density

This section presents the results of **TCD** validation in the form of scatterplots (Figure 8-3, Figure 8-4) and confusion matrices (Table 8-2, Table 8-3). The **TCD** layers for 2018 and 2021 exceed the required Producer's and User's accuracies target (90%), both at EU27 (Table 8-2) and EEA38 level (Table 8-3). All validated **TCD** layers (2018, 2021 & 2022, both at **EU27** and **EEA38** level) show a strong correlation between layers and reference value (Figure 8-3, Figure 8-4), with a R^2 higher than 0.8. The figures are fairly consistent across all reference years, the accuracies and correlations seem slightly higher for the EU27 area when compared to full EEA38.

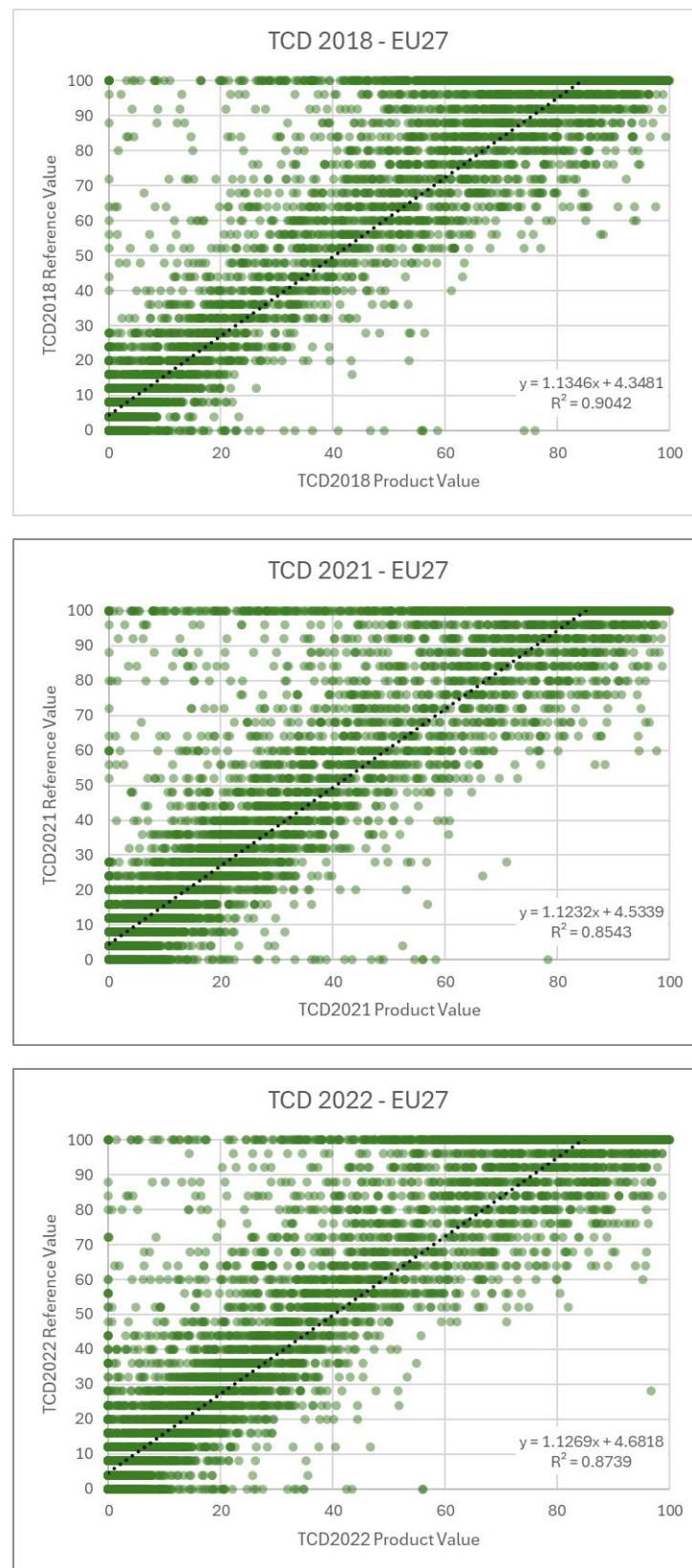


Figure 8-3: HRL TCD 2018, 2021 and 2022 scatterplots and correlations at EU27 level

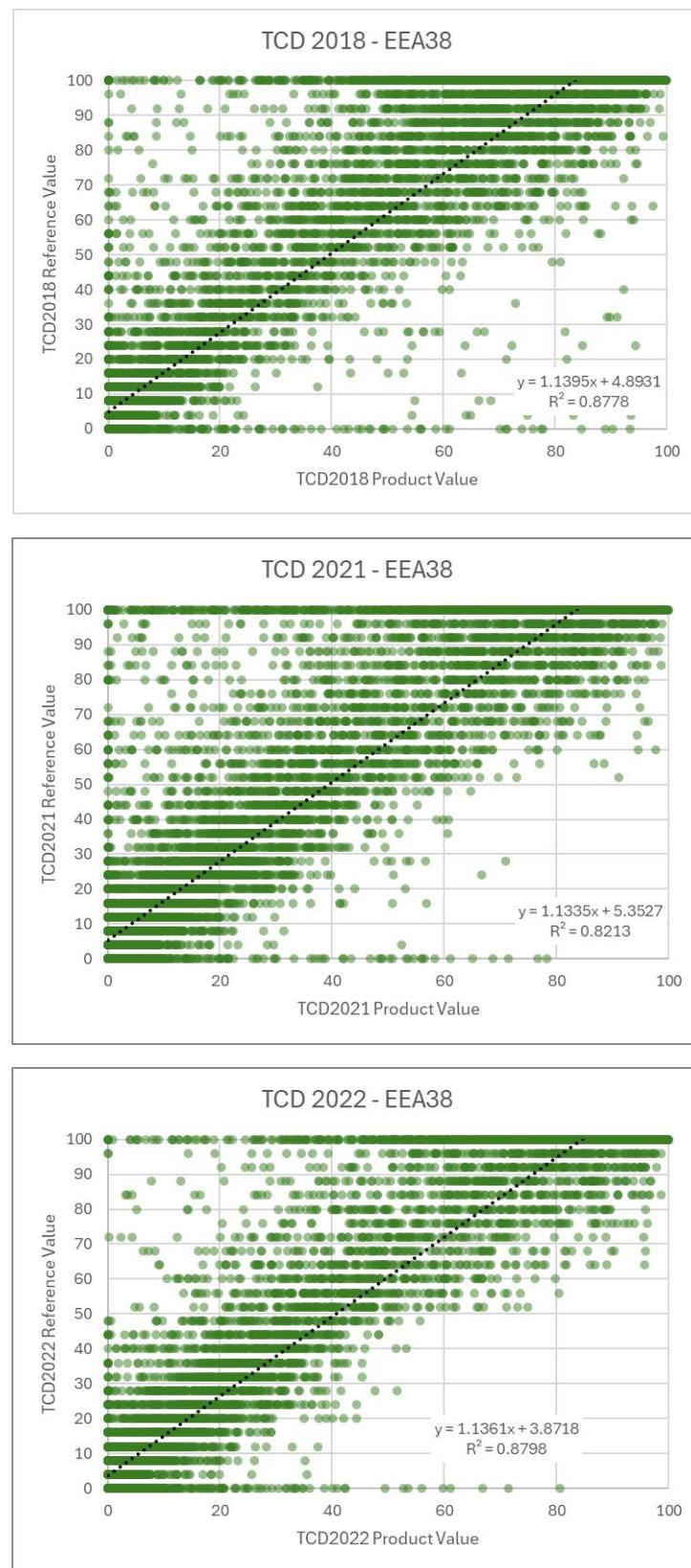


Figure 8-4: HRL TCD 2018, 2021 and 2022 scatterplots and correlations at EEA38 level

**Table 8-2: HRL TCD validation results at EU27 level**

TCD 2018 - EU27 Weighted		Reference		Total	User acc.	CI95%
		TCD <30%	TCD ≥30%			
Product	TCD <30%	3632.966	48.047	3681.012	98.69%	0.19%
	TCD ≥30%	122.137	2907.069	3029.206	95.97%	0.33%
	Total	3755.103	2955.116	6710.218		
	Prod. Acc.	96.75%	98.37%			
	CI 95%	0.30%	0.21%			

TCD 2021 - EU27 Weighted		Reference		Total	User acc.	CI95%
		TCD <30%	TCD ≥30%			
Product	TCD <30%	3648.468	60.333	3708.800	98.37%	0.21%
	TCD ≥30%	133.621	2867.798	3001.418	95.55%	0.34%
	Total	3782.088	2928.130	6710.218		
	Prod. Acc.	96.47%	97.94%			
	CI 95%	0.31%	0.24%			

TCD 2022 - EU27 Weighted		Reference		Total	User acc.	CI95%
		TCD <30%	TCD ≥30%			
Product	TCD <30%	4369.710	132.183	4501.893	97.06%	0.28%
	TCD ≥30%	154.245	2845.181	2999.427	94.86%	0.37%
	Total	4523.956	2977.364	7501.320		
	Prod. Acc.	96.59%	95.56%			
	CI 95%	0.30%	0.34%			

**Table 8-3: HRL TCD validation results at EEA38 Level**

TCD 2018 - EEA38 Weighted		Reference		Total	User acc.	CI95%
		TCD <30%	TCD ≥30%			
Product	TCD <30%	5879.209	180.076	6059.285	97.03%	0.28%
	TCD ≥30%	147.293	3563.293	3710.586	96.03%	0.33%
		Total	6026.502	3743.369	9769.870	
		Prod. Acc.	97.56%	95.19%		
		CI 95%	0.26%	0.36%		

TCD 2021 - EEA38 Weighted		Reference		Total	User acc.	CI95%
		TCD <30%	TCD ≥30%			
Product	TCD <30%	5897.438	194.569	6092.006	96.81%	0.29%
	TCD ≥30%	152.818	3525.046	3677.864	95.84%	0.33%
		Total	6050.256	3719.614	9769.870	
		Prod. Acc.	97.47%	94.77%		
		CI 95%	0.26%	0.37%		

TCD 2022 - EEA38 Weighted		Reference		Total	User acc.	CI95%
		TCD <30%	TCD ≥30%			
Product	TCD <30%	5989.833	225.207	6215.040	96.38%	0.31%
	TCD ≥30%	155.430	3640.400	3795.830	95.91%	0.33%
		Total	6145.263	3865.607	10010.870	
		Prod. Acc.	97.47%	94.17%		
		CI 95%	0.26%	0.39%		

8.5.2 Dominant Leaf Type

For the reference years 2018, 2021 and 2022, the **Dominant Leaf Type (DLT)** layers prove to accurately depict the tree coverage over the EU27 and EEA38 countries and their discrimination between *broadleaved trees* or *coniferous trees*. The thematic accuracies systematically reach the 90% target (considering the margin error depicted by the confidence interval) with the exception of the User's accuracy for broadleaved class at EEA38 level (still above 89%). Confusions matrices for the coverage of the EU27 and the EEA39 are presented in Table 8-4 and Table 8-5. The higher commission errors for the broadleaved class are dominated by two factors:

- At the borders of tree cover canopies to other vegetation types the DLT tends to overestimate the extent of the tree cover. This is closely related to the spatial uncertainties of the input data (see 7.4).
- The mixed spectral signal at such borders typically resembles broadleaved rather than coniferous trees.

An illustration of the issue is provided in Figure 8-5. While some of the commission errors have been reduced for the production of the reference years 2022 and 2023 the significantly better user's accuracies for 2022 (Table 8-5) might be partially caused by the response design focusing on a plausibility analysis only (section 8.3)

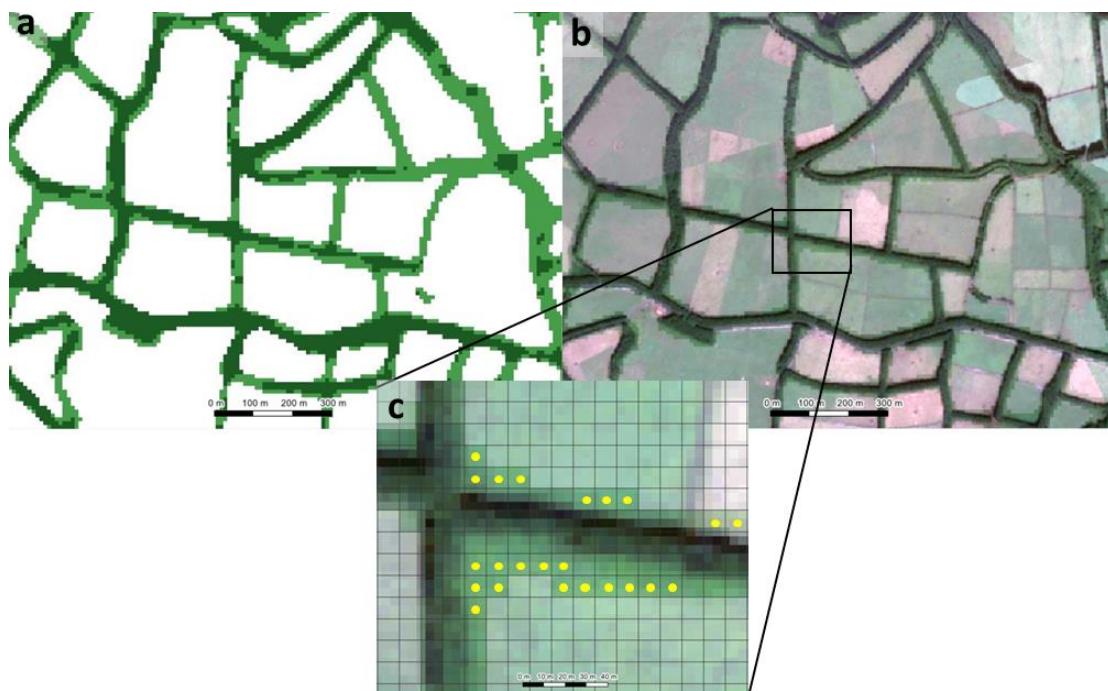


Figure 8-5: Illustration of typical broadleaved tree cover commissions errors in the DLT for an area Terceira island, Portugal. Shown are a) the DLT 2022 b) an overlay of the DLT 2022 on top of the VHR IMAGE 2021 and c) a zoom of the latter and the pixels with commission errors marked in yellow.

Table 8-4: DLT validation results at EU27 level



DLT 2018 - EU27 Weighted		Reference			Total	User acc.	CI95%
		No trees	Broadleaved	Coniferous			
Product	No trees	3985.259	39.052	10.000	4034.312	98.78%	0.18%
	Broadleaved	114.051	1188.796	17.029	1319.876	90.07%	0.50%
	Coniferous	39.046	6.007	1307.978	1353.031	96.67%	0.30%
	Total	4138.356	1233.856	1335.007	6707.218		
	Prod. Acc.	96.30%	96.35%	97.98%			
	CI 95%	0.32%	0.31%	0.24%			

DLT 2021 - EU27 Weighted		Reference			Total	User acc.	CI95%
		No trees	Broadleaved	Coniferous			
Product	No trees	4016.994	49.142	11.239	4077.376	98.52%	0.20%
	Broadleaved	110.046	1180.800	18.000	1308.846	90.22%	0.50%
	Coniferous	47.179	3.009	1270.809	1320.997	96.20%	0.32%
	Total	4174.219	1232.952	1300.048	6707.218		
	Prod. Acc.	96.23%	95.77%	97.75%			
	CI 95%	0.32%	0.34%	0.25%			

DLT 2022 - EU27 Weighted		Reference			Total	User acc.	CI95%
		No trees	Broadleaved	Coniferous			
Product	No trees	4039.374	38.070	16.022	4093.466	98.68%	0.19%
	Broadleaved	54.017	1215.836	37.007	1306.860	93.03%	0.43%
	Coniferous	18.017	10.002	1279.974	1307.994	97.86%	0.24%
	Total	4111.409	1263.908	1333.003	6708.320		
	Prod. Acc.	98.25%	96.20%	96.02%			
	CI 95%	0.22%	0.32%	0.33%			

**Table 8-5: DLT validation results at EEA38 Level**

DLT 2018 - EEA38 Weighted		Reference			Total	User acc.	CI95%
		No trees	Broadleaved	Coniferous			
Product	No trees	5364.541	76.064	35.020	5475.624	97.97%	0.24%
	Broadleaved	137.098	1458.973	48.085	1644.156	88.74%	0.53%
	Coniferous	53.178	13.025	1555.887	1622.090	95.92%	0.33%
	Total	5554.817	1548.061	1638.992	8741.870		
	Prod. Acc.	96.57%	94.25%	94.93%			
	CI 95%	0.30%	0.39%	0.37%			

DLT 2021 - EEA38 Weighted		Reference			Total	User acc.	CI95%
		No trees	Broadleaved	Coniferous			
Product	No trees	5398.229	90.204	37.395	5525.827	97.69%	0.25%
	Broadleaved	123.086	1463.861	45.015	1631.961	89.70%	0.51%
	Coniferous	50.232	10.012	1524.838	1585.082	96.20%	0.32%
	Total	5571.546	1564.077	1607.247	8742.870		
	Prod. Acc.	96.89%	93.59%	94.87%			
	CI 95%	0.29%	0.41%	0.37%			

DLT 2022 - EEA38 Weighted		Reference			Total	User acc.	CI95%
		No trees	Broadleaved	Coniferous			
Product	No trees	5475.738	66.075	28.017	5569.830	98.31%	0.22%
	Broadleaved	55.076	1688.878	11.007	1754.961	96.23%	0.32%
	Coniferous	17.050	4.000	1544.015	1565.064	98.66%	0.19%
	Total	5547.864	1758.953	1583.039	8889.856		
	Prod. Acc.	98.70%	96.02%	97.53%			
	CI 95%	0.19%	0.33%	0.26%			

8.5.3 Change layers

The validation of the **Tree Cover Presence Change (TCPC)** and **Dominant Leaf Type Change (DLTC)** suggest excellent **User's accuracies** and with nearly no false positives. The **Producer's accuracies for Tree Cover Losses** are somewhat lower but still between 83% and 87%. The Producer's accuracies of gains are evaluated somewhat lower with potential omissions of more than 50%. On the one hand, this appears plausible considering the generally subtler signals from gradual gains over time spans of three years. On the other hand, considering the general difficulty to sample for change omissions this result should be interpreted with caution:

Additional sampling (see section 8.2) was performed in the frame of change layers thematic assessment and the weighting factor linked to it have a significant impact on accuracy figures. While the additional sampling allows to get further samples within change area, the weighting factor mandatory to counterbalance the sampling effort between commission strata (i.e. change areas as labelled by the layer) and omission strata (i.e. stable areas as labelled by the layer). Due to the limited areas concerned by change, the weighting factor give an insignificant weight to additional samples within the change areas.



An error linked with a sample belonging to the omission strata (weight factor = 1) impacts the accuracy figures differently than an error linked with a sample belonging to the commission strata (weight factor around 0.002). Weighted and unweighted confusion matrices are presented in Table 8-6 and Table 8-7 to allow a better understanding of the results. While the weighted results present statistically corrected figures, it is currently not obvious whether they actually reflect the layer's quality. For example, at EEA38 level, the "*New coniferous*" class of the **DLTC** layer presents a producer accuracy of only 22%, whereas only 4 samples out of 51 indicate an omission of gains in coniferous tree cover. It is therefore important to also consider the unweighted matrices which provide a complementary overview of the quality.

**Table 8-6: HRL Tree Cover & Forests Change layers validation results at EU27 Level**

TCPC1821 - EU27 Weighted		Reference			Total	User acc.	CI95%
		Stable	Gain	Loss			
Product	Stable	6665.2	4.0	5.0	6674.2	99.9%	0.08%
	Gain	0.1	3.0		3.0	98.3%	0.80%
	Loss	1.0	0.0	31.9	32.9	96.9%	1.08%
	Total	6666.3	7.0	36.9	6710.2		
	Prod. Acc.	100.0%	42.5%	86.5%			
	CI95%	0.03%	3.06%	2.12%			

TCPC1821 - EU27 Unweighted		Reference			Total	User acc.	CI95%
		Stable	Gain	Loss			
Product	Stable	8143	5	5	8153	99.9%	0.07%
	Gain	7	150		157	95.5%	1.28%
	Loss	4	2	1388	1394	99.6%	0.41%
	Total	8154	157	1393	9704		
	Prod. Acc.	99.9%	95.5%	99.6%			
	CI95%	0.08%	1.28%	0.37%			

DLTC1821 - EU27 Weighted		Reference					Total	User acc.	CI95%
		Stable	New Broad.	New Conif.	Loss Broad.	Loss Conif.			
Product	Stable	6663.2	3.0	1.0	1.0	4.0	6672.2	99.9%	0.08%
	New Broad.	0.1	2.7	0.0			2.7	97.3%	1.00%
	New Conif.		0.0	0.3			0.3	96.1%	1.21%
	Loss Broad.	0.0	0.0		5.7	1.1	6.9	83.7%	2.29%
	Loss Conif.	1.0	0.0		0.1	25.0	26.1	95.8%	1.15%
	Total	6664.3	5.7	1.3	6.8	30.1	6708.2		
	Prod. Acc.	100.0%	46.7%	21.7%	84.0%	83.1%			
	CI95%	0.03%	3.09%	2.56%	2.27%	2.32%			

DLTC1821 - EU27 Unweighted		Reference					Total	User acc.	CI95%
		Stable	New Broad.	New Conif.	Loss Broad.	Loss Conif.			
Product	Stable	8141	4	1	1	4	8151	99.9%	0.07%
	New Broad.	7	100	3			110	90.9%	1.78%
	New Conif.		3	44			47	93.6%	1.52%
	Loss Broad.	3	1		244	13.0	261	93.5%	1.53%
	Loss Conif.	1	1		13	1118	1133	98.7%	0.71%
	Total	8152	109	48	258	1135	9702		
	Prod. Acc.	99.9%	91.7%	91.7%	94.6%	98.5%			
	CI95%	0.08%	1.71%	1.71%	1.40%	0.75%			

**Table 8-7: HRL Tree Cover & Forests Change layers validation results at EEA38 level**

TCPC1821 - EEA38 Weighted		Reference			Total	User acc.	CI95%
		Stable	Gain	Loss			
Product	Stable	9713.4	5.0	7.0	9725.4	99.9%	0.06%
	Gain	0.1	4.1		4.1	98.6%	0.20%
	Loss	1.0	0.0	39.3	40.3	97.4%	0.28%
	Total	9714.5	9.1	46.3	9769.9		
	Prod. Acc.	100.0%	44.8%	84.9%			
	CI95%	0.02%	0.86%	0.62%			

TCPC1821 - EEA38 Unweighted		Reference			Total	User acc.	CI95%
		Stable	Gain	Loss			
Product	Stable	11674.0	6.0	7.0	11687.0	99.9%	0.06%
	Gain	9.0	186.0		195.0	95.4%	0.36%
	Loss	9.0	2.0	1849.0	1860.0	99.4%	0.13%
	Total	11692.0	194.0	1856.0	13742.0		
	Prod. Acc.	99.8%	95.9%	99.6%			
	CI95%	0.07%	0.35%	0.11%			

DLTC1821 - EEA38 Weighted		Reference					Total	User acc.	CI95 %
		Stable	New Broad.	New Conif.	Loss Broad.	Loss Conif.			
Product	Stable	8695.4	3.0	1.0	1.0	4.0	8704.4	99.9%	0.06%
	New Broad.	0.1	3.7	0.0			3.8	98.0%	0.24%
	New Conif.	0.0	0.0	0.3			0.3	95.3%	0.37%
	Loss Broad.	0.0	0.0		8.0	1.1	9.1	87.4%	0.58%
	Loss Conif.	1.0	0.0		0.1	30.1	31.2	96.5%	0.32%
	Total	8696.5	6.8	1.3	9.1	35.2	8748.9		
	Prod. Acc.	100%	55.3%	22.3%	87.9%	85.5%			
	CI95%	0.02%	0.86%	0.72%	0.57%	0.61%			

DLTC1821 - EEA38 Unweighted		Reference					Total	User acc.	CI95 %
		Stable	New Broad.	New Conif.	Loss Broad.	Loss Conif.			
Product	Stable	10656	4	1	1	4	10666	99.9%	0.05%
	New Broad.	8	133	3			144	92.4%	0.46%
	New Conif.	1	3	47			51	92.2%	0.47%
	Loss Broad.	8	1		328	21	358	91.6%	0.48%
	Loss Conif.	1	1		13	1487	1502	99.0%	0.17%
	Total	10674	142	51	342	1512	12721		
	Prod. Acc.	99.8%	93.7%	92.2%	95.9%	98.3%			



CI95%	0.07%	0.42%	0.47%	0.34%	0.22%
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9 Terms of use and product technical support

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List of Abbreviations & Acronyms

Abbreviation	Name
ATBD	Algorithm Theoretical Basis Document
BCD	Broadleaved Cover Density
BfN	Bundesamt für Naturschutz (Federal Agency for Nature Conservation)
BVL	Base Vegetation Layer
CAP	Common Agricultural Policy
CCD	Coniferous Cover Density
CL	Confidence Layer
CLC	CORINE Land Cover
CLMS	Copernicus Land Monitoring Service
COG	Cloud-Optimized GeoTIFFs
CORINE	Coordination of information on the environment
DLT	Dominant Leaf Type
DLTC	Dominant Leaf Type Change
DLTCL	Dominant Leaf Type Change
EAGLE	EIONET Action Group on Land monitoring in Europe
ECoLaSS	Evolution of Copernicus Land Services based on Sentinel Data
EEA	European Environment Agency
EEA38	The 32 member and 6 cooperating countries of the EEA
EIONET	European Environment Information and Observation Network
EO	Earth Observation
EU	European Union
EU27	The 27 member states of the EU
FADSL	Forest Additional Support Layer
FAO	Food and Agriculture Organization of the United Nations
FML	Forest Monitoring Law
FTY	Forest Type
GIS	Geographic Information System
GSAA	GeoSpatial Aid Application
H2020	Horizon2020
HR	High Resolution
HRL / HRLs	High Resolution Layer / High Resolution Layers
HRL VLCC	High Resolution Layer – Vegetated Land Cover Characteristics
ID	Identification Number
JRC	Joint Research Centre
LAEA	Lambert Azimuthal Equal Area projection
LC	Land Cover
LU	Land Use
LUCAS	Land Use / Cover Area frame Survey
LULUCF	Land Use, Land Use Change and Forestry
MMU	Minimum Mapping Unit



MMW	Minimum Mapping Width
NRR	Nature Restoration Regulation
OA	Overall Accuracy
PA	Producer Accuracy
PAM	Permanent Auxiliary Metadata
SSU	Secondary Samples Units
TCCM	Tree Cover Change Mask
TCPCCL	Tree Cover Presence Change Confidence Layer
TCD	Tree Cover Density
TCDCL	Tree Cover Density Confidence Layer
TCPC	Tree Cover Presence Change
TI	Thünen-Institut (Federal Research Institute for Rural Areas, Forestry and Fisheries)
UA	User's Accuracy
UBA	Umweltbundesamt (Environmental Protection Agency)
VHR	Very High Resolution
XML	Extensible Markup Language



References

- [1] T. Duan et al., NGBoost: Natural Gradient Boosting for Probabilistic Prediction (2020), ICML 2020
- [2] Eurostat. (2018). LUCAS Survey 2018. [Data set]. <https://ec.europa.eu/eurostat/web/lucas/database/primary-data>.
- [3] Selkowitz, D. J., & Stehman, S. V. (2011). Thematic accuracy of the National Land Cover Database (NLCD) 2001 land cover for Alaska. *Remote Sensing of Environment*, 115(6), 1401-1407.
- [4] Olofsson, P., Foody, G. M., Stehman, S. V., & Woodcock, C. E. (2013). Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment*, 129, 122-131.
- [5] ECoLaSS (2019). Deliverable D3.2 - Service Evolution Requirements Report Vol. 2 https://www.ecolass.eu/_files/ugd/c90769_5a431f06039141a6b4db4d6b4596d272.pdf (accessed 28 October 2024)
- [6] Nextspace (2018). Work performed by the Nextspace consortium – Observation Requirements (February 2018); <https://www.copernicus.eu/en/documentation/technical-documents/technical-documents> (accessed 28 October 2024)
- [7] CLMS HRL VLCC (2025). HRL VLCC Algorithm Theoretical Basis Document; <https://land.copernicus.eu/en/technical-library/algorithm-theoretical-basis-document-pan-european-land-cover-characteristics>
- [8] CLMS HRL Forests 2018 (2021). HRL Tree-cover/forest and change 2015-2018 User Manual, <https://land.copernicus.eu/en/technical-library/hrl-forest-2018>
- [9] CLMS HRL Grassland 2018 (2021). Grassland 2018 and Grassland change 2015-2018 User Manual, <https://land.copernicus.eu/en/technical-library/hrl-grassland-2018-product-user-manual>
- [10] Dadras Javan, F., Samadzadegan, F., Toosi, A., Schneider, M., & Persello, C. (2025). Ground Resolved Distance Estimation of Sentinel-2 Imagery Using Edge-based Scene-Driven Approach. PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science, 93(2), 131–152. <https://doi.org/10.1007/s41064-024-00330-x>



Annex I – Colour tables for HRL Tree Cover & Forests

Table 0-1: Colour palette and attributes of TCD 2018-2021

Class Code	Class Name	Red	Green	Blue	
0	all non-tree covered areas	240	240	240	
1	1% tree cover density	253	255	115	
2-49	2% to 49% tree cover density	colour shades in between			
50	50% tree cover density	76	230	0	
51-99	51% to 99% tree cover density	colour shades in between			
100	100% tree cover density	28	92	36	
255	outside area	0	0	0	

Table 0-2: Colour palette and attributes of DLT layer

Class Code	Class Name	Red	Green	Blue	
0	all non-tree covered areas	240	240	240	
1	broadleaved trees	70	158	74	
2	coniferous trees	28	92	36	
255	outside area	0	0	0	

Table 0-3: Colour palette and attributes of FTY layer

Class Code	Class Name	Red	Green	Blue	
0	all non-forest areas	240	240	240	
1	broadleaved forest	70	158	74	
2	coniferous forest	28	92	36	
3	mixed zones (only for aggregated 100m layer)	76	133	67	
255	outside area	0	0	0	

**Table 0-4: Colour palette and attributes of FADSL**

Class Code	Class Name	Red	Green	Blue	
0	all non-tree covered areas, and tree cover without urban context or agricultural use	240	240	240	
3	trees predominantly used for agricultural practices – broadleaved (from CLC2018)	204	173	71	
4	trees in urban context – broadleaved and coniferous (from IMD 2018)	255	85	0	
5	trees in urban context – broadleaved and coniferous (from CLC 2018)	168	56	0	
255	outside area	0	0	0	

Table 0-5: Colour palette and attributes of DLTC layer

Class Code	Class Name	Red	Green	Blue	
0	unchanged areas with no tree cover	255	255	255	
1	new broadleaved cover	20	255	20	
2	new coniferous cover	0	150	0	
3	loss of broadleaved cover	255	0	0	
4	loss of coniferous cover	255	128	0	
10	unchanged areas with tree cover	191	191	191	
255	outside area	0	0	0	

**Table 0-6: Colour palette and attributes of TCPC layer**

Class Code	Class Name	Red	Green	Blue	
0	unchanged areas with no tree cover	255	255	255	
1	new tree cover	20	255	20	
2	loss of tree cover	255	0	0	
10	unchanged areas with tree cover	191	191	191	
255	outside area	0	0	0	

Table 0-7: Colour palette and attributes of BCD layer

Class Code	Class Name	Red	Green	Blue	
0	all non-broadleaved covered areas	240	240	240	
1	1% broadleaved cover density	253	255	115	
2-49	2-49% broadleaved cover density	colour shades in between			
50	50% broadleaved cover density	76	230	0	
51-99	51-99% broadleaved cover density	colour shades in between			
100	100% broadleaved cover density	28	92	36	
255	outside area	0	0	0	

Table 0-8: Colour palette and attributes of CCD layer

Class Code	Class Name	Red	Green	Blue	
0	all non-coniferous covered areas	240	240	240	
1	1% coniferous cover density	253	255	115	
2-49	2-49% coniferous cover density	colour shades in between			
50	50% coniferous cover density	76	230	0	
51-99	51-99% coniferous cover density	colour shades in between			
100	100% coniferous cover density	28	92	36	
255	outside area	0	0	0	

Table 0-9: Colour palette and attributes of TCDCL

Class Code	Class Name	Red	Green	Blue	
0	0% prediction interval	8	99	0	
1-49	1-49% prediction interval	colour shades in between			
50	50% prediction interval	255	255	0	
51-99	51-99% prediction interval	colour shades in between			
100	100% prediction interval	255	0	0	
253	all non-tree covered areas	240	240	240	
255	outside area	0	0	0	

**Table 0-10: Colour palette and attributes of DLTCL**

Class Code	Class Name	Red	Green	Blue	
0	0% classification confidence	255	0	0	
1-49	1-49% classification confidence	colour shades in between			
50	50% classification confidence	255	255	0	
51-99	51-99% classification confidence	colour shades in between			
100	100% classification confidence	8	99	0	
253	all non-tree covered areas	240	240	240	
255	outside area	0	0	0	

Table 0-11: Colour palette and attributes of TCPCCl

Class Code	Class Name	Red	Green	Blue	
0	0% change confidence	255	0	0	
1-49	1-49% change confidence	colour shades in between			
50	50% change confidence	255	255	0	
51-99	51-99% change confidence	colour shades in between			
100	100% change confidence	8	99	0	
253	all non-changed areas	240	240	240	
255	outside area	0	0	0	