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JRC TECHNICAL REPORT

An approach for pan-European monitoring of forest fragmentation

Algorithm Technical Basis Document (ATBD)

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Contents

Acknowledgements

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Abstract

This document describes the design process, definitions, and algorithmic implementation for the pan-European Assessment of Forest Fragmentation. This study is a preceding presentation of the indicator 4.7 in the State of Europe's Forests 2020 report, published by FOREST EUROPE. The spatial forest coverage is assessed from the Copernicus CORINE Land Cover dataset (CLC, version 20, downloaded in July 2019) for the years 1990, 2000, 2006, 2012, 2018. Spatially explicit maps and statistical summaries are derived at three reporting levels: CLC (entire CLC coverage), EU28 and at country level.

The *status product* consists of maps and summary statistics for each year and assessment level.

The *change product* highlights areas where non-forest and forest fragmentation classes changed over time. The change product is provided for the time frame 2000 to 2018, which is the longest time span with comparable data coverage.

1   Introduction

Forest area and its fragmentation is a key aspect in biodiversity, ecosystem services and the ever-increasing pressure from anthropogenic land use. Forest fragmentation may lead to the isolation and loss of species and gene pools, degraded habitat quality, and a reduction in the forest's ability to sustain the natural processes necessary to maintain ecosystem health.

The goal of the indicator is to provide quantifiable and intuitive classes to characterise the state and trend of forest fragmentation. To achieve this goal, FOREST EUROPE setup a dedicated expert group to discuss and evaluate appropriate methods for mapping and quantifying forest fragmentation following the CBD definition: *Forest fragmentation refers to any process that results in the conversion of formerly continuous forest into patches of forest separated by non-forested lands.*

The expert group concluded on the following key findings (**KF**):

KF1 - Data source: Corine Land Cover (CLC) data should be used as these are the only nationally produced, and hence acknowledged, land cover maps employing a harmonized method and legend throughout Europe for a series of time points: 1990, 2000, 2006, 2012, 2018.

KF2 - Definition of Forest: from the 44 CLC classes the following 4 classes represent forest land cover: 311 - Broadleaved forest, 312 - Coniferous Forest, 313 - Mixed Forest, 324 - Transitional Woodland-Shrub. The latter is included because it largely complies with national definitions of forest.

KF3 - Methodology: the method "Forest Area Density" (FAD) at Fixed Observation Scale (FAD-FOS) was selected to best match the fragmentation assessment requirements stipulated by FOREST EUROPE. In addition, the FAD methodology is complemented by the reporting scheme "Accounting", providing geographic maps and derived statistics in five forest patch size classes [100; 1,000; 10,000; 100,000; > 100,000] hectares.

KF4 - Measurement scale: an analysis scale of ~ 500 hectare was selected to be appropriate for the analysis of continuous forests and its diverse functions in the protection of biodiversity. This analysis scale translates into a moving window size of 23x23 pixels (=529 hectare) for the FAD methodology and using CLC data with a spatial resolution of 100 meters.

KF5 - Reporting style: reporting of forest fragmentation will be conducted for each forest patch with a single number by building the arithmetic average of all pixel-level FAD values of the given forest patch (APP: Average-Per-Patch reporting).

KF6 - Fragmentation classes: a FAD threshold value of 40% was defined to distinguish between continuous forest (FAD $\geq$ 40%) and patches of separated forest (FAD < 40%). The so-defined two classes Separated and Continuous are in compliance with the CBD definition.

KF7 - Indicator product: the final result of the analysis are spatially explicit maps and derived tabular statistics of forest fragmentation. Because the georeferenced maps are in equal area projection the derived statistics provide forest area and fragmentation statistics in percentage as well as actual area in hectares, allowing for a comparative analysis across Europe.

KF8 - Reporting scale: the indicator 4.7, with maps and statistics, is derived at three scales:

1) CLC (all countries covered by CLC: 45 = EEA-39 countries + Gibraltar, Guernsey, Jersey, Monaco, San Marino, Vatican City),

2) EU-28: EU Member States as of 7/2019, and

3) at national scale for each of the countries covered by CLC.

KF9 - Trends: maps and statistics on temporal trends of forest fragmentation are derived for each reporting scale and the longest possible time frame with a common data coverage (2000 to 2018).

The FOREST EUROPE expert group found that measuring the Forest Area Density (FAD) together with Accounting is well-suited to investigate the spatial arrangement and integrity of forest land cover. The fragmentation indicator addresses key fragmentation aspects, such as isolation of small fragments, extent of perforations, and large compact forest patches.

A conceptually similar FAD approach (originally by Riitters et al. 2002; Riitters and Wickham 2012; Wickham 2008) is used for official reporting on forest fragmentation by the US-Forest Service (2012, 2016), the US Montréal Process Report, (https://www.fs.fed.us/research/sustain/criteria-indicators/, Indicator 1.03 Fragmentation of forests), FAO (indicator 1.5), and the MAES project, enabling common usage of the same information scheme across disciplines and locations, and permitting rigorous evaluations of the trade-offs or synergies involved in land-cover pattern management strategies.

2   Implementation summary

This section provides an overview of data source used, necessary pre-processing steps, details on the algorithms applied, details on the output format and other documentary information on the status and change product of the indicator 4.7. For each assessment year (1990, 2000, 2006, 2012, 2018) all status & trend maps and related statistics are available on the JRC public data portal.

2.1   Input data source

The CORINE (CLC) land cover maps (https://land.copernicus.eu/pan-european/corine-land-cover) identify 44 land cover classes at a spatial resolution of 1 hectare per pixel (100 m x 100 m) for a series of assessment years over Europe. Further details can be found in the CLC Technical Guidelines (see references). The CLC (**KF1**) maps are assigned into the following input forest map:

- **Forest** (2-byte): the CLC classes 311, 312, 313, 324 are combined into a single forest layer, see (**KF2**).
- **Land** (1-byte): the CLC classes 111-512 but excluding the forest layer.
- **Inland waters** (3-byte): the CLC classes 411-512 (inland waters and wetlands) are treated as land but marked separately in the fragmentation for visual purposes.
- **No data** (0-byte): the CLC classes 521 and above (marine waters and missing data) are excluded from the land coverage or reporting unit.

2.2   Definition of country boundaries

CORINE data can exhibit a non-consistent pixel coverage across different years, which may be caused by different polygonization conducted by the member states at a given year. This effect is most apparent along coast lines (see Figure 1) but not present at inland country boundaries.

Figure 1. Example from Turkey showing land cover pixel differences for two CLC assessment years.
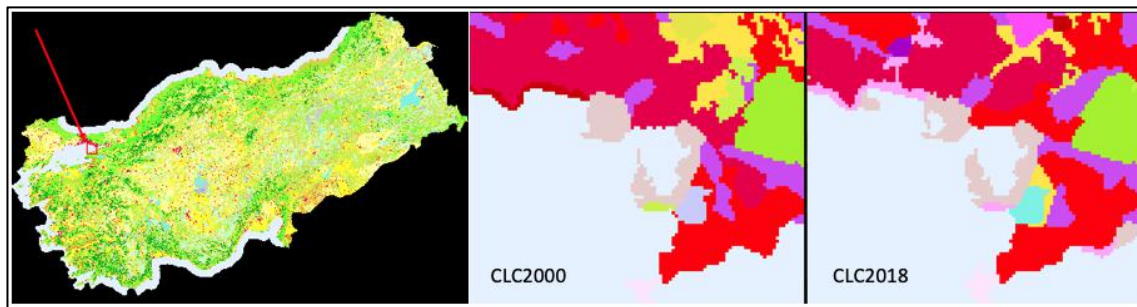
Source: JRC, 2019.

This effect may have an impact on the total country area reported in the statistical summary: while the country area for countries without coastlines (i.e. Austria or Switzerland) is identical in CLC2000 and CLC2018, the country area of Turkey is 2,368 hectares larger, or Finland is even 26,068 hectares smaller in 2018 compared to CLC2000. Due to this discrepancy across time it is not meaningful to apply a fixed country boundary mask on the CORINE dataset when deriving statistics for each country. Instead, and to account for the variability in land coverage along coastlines, an extended country boundary map was setup. This map has the same projection (EPSG: 3035) and spatial resolution (100 meters) as the CORINE maps and all country boundaries are taken from the official Eurostat GISCO (*Geographic Information System of the COmmission*) 2016[1] database. In addition, the coastlines of all countries are extended into the sea to include the exclusive economic zone[2] (up

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[1] https://ec.europa.eu/eurostat/web/gisco

[2] https://en.wikipedia.org/wiki/Exclusive_economic_zone

to 200 nautical miles from the actual coastline). Intersecting this so-extended territorial mask to the CLC dataset ensures to capture all land cover pixels of a given country in a given year regardless of spatial shifts along and in the vicinity of the costal boundaries.

Kosovo: within the context of this analysis, Kosovo (under United Nations Security Council Resolution 1244) is not listed separately but as a part of Serbia. Please note that CLC data for Kosovo is not available for the year 1990 leading to a partial map product and hence a biased statistical analysis for Serbia in the year 1990.

2.3   Forest fragmentation assessment scheme

The methodology (**KF3**) to measure forest fragmentation applies two conceptual models, *FAD* and *Accounting*:

FAD: Forest Area Density is defined as the proportion of all forest pixels within a fixed neighbourhood area. FOS measurements (FOS = FAD at Fixed Observation Scale) are conducted via a moving window algorithm to create a new map of forest area density: the given neighbourhood - a square window of size 23x23 pixels = 529 hectares (**KF4**) - is centred over a given forest pixel, the forest area density within that neighbourhood is measured and assigned in a new map at the location of the subject forest pixel. This process is repeated for all forest pixels resulting in a new map of the same dimensions but showing forest area density values for the analysed neighbourhood over each forest pixel; The area density map is then stratified by applying a threshold value of 40% (**KF6**) to derive the two fragmentation classes Separated (FAD < 40%) and Continuous (FAD ≥ 40%). In a second step, the pixel-level FAD-values are averaged for all forest pixels of a given forest patch (APP: Average-Per-Patch) resulting in a map showing the degree of forest fragmentation at the patch-level (**KF5**). Statistics of the forest fragmentation status maps are summarized with the following parameters (**KF7**):

1. Proportion [%] and area [ha] of fragmentation classes Separated and Continuous.
2. Total forest area [ha].
3. Total number of forest patches.
4. APS [ha]: average forest patch size = total forest area / total number of forest patches.
5. FAD_AV [%]: average FAD for all forest pixels in the original FAD image before conducting APP.

The above outlined fragmentation assessment scheme (FOS-APP 2-class) is implemented in the free software GuidosToolbox (Vogt & Riitters 2017) and further detailed in Vogt 2019a.

Accounting: Accounting is designed to provide a first overview and concise summary of the location and size class distribution of forest patches in a given forest map. The methodology provides a map product together with a statistical summary for a series of forest area classes (**KF3**). The forest area size classes can be used to describe the forest patch size class distribution at a given point in time, to directly compare the size distribution of different sites, as well as for temporal analysis which is of key importance in questions of landscape connectivity, restoration, risk assessment, habitat suitability and biodiversity studies.

The fragmentation assessment scheme Accounting is implemented in the free software GuidosToolbox (Vogt & Riitters 2017) and further detailed in Vogt 2019b.

2.4   Reporting levels

Maps & statistics for both FAD and Accounting are derived and reported at 3 levels (**KF8**):

1. **CLC** - all countries covered by CLC:
   1990: 33 countries: Austria, Belgium, Bulgaria, Czechia, Germany, Denmark, Estonia, Greece, Spain, France, Guernsey, Gibraltar, Croatia, Hungary, Ireland, Italy, Jersey, Lithuania, Luxembourg, Latvia, Monaco, Montenegro, Malta, Netherlands, Poland, Portugal, Romania, Serbia, Slovenia, Slovakia, San Marino, Turkey, Holy See.
   2000 and later: 44 countries: Albania, Austria, Bosnia and Herzegovina, Belgium, Bulgaria, Switzerland, Cyprus, Czechia, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Guernsey, Gibraltar, Croatia, Hungary, Ireland, Iceland, Italy, Jersey, Liechtenstein, Lithuania, Luxembourg, Latvia, Monaco, Montenegro, North Macedonia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Sweden, Slovenia, Slovakia, San Marino, Turkey, United Kingdom, Holy See = EEA-39 + Gibraltar, Guernsey, Jersey, Monaco, San Marino.

2. **EU-28:** Austria, Belgium, Bulgaria, Cyprus, Czechia, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Sweden, Slovenia, Slovakia, United Kingdom.

3. **National scale:** for each of the countries covered by CLC in the years 1990, 2000, 2006, 2012, 2018.

2.5   Change analysis

Tabular statistics can only provide a simple summary but they cannot capture geographical variability. Instead, the map product provides crucial information on any spatially explicit question, such as where is the forest, where are fragmentation hotspots, where did forest cover change occur and in which way. A quantitative and spatially explicit index is obligatory to evaluate progress in policy programs, for example landscape dynamics inside versus outside protected areas, or guidance in landscape planning and monitoring in risk assessment studies. As a consequence, an informative change analysis (**KF9**) should communicate key messages inherent in the statistical summary table as well as the geospatial variability coming from the map product only. Temporal trends of forest fragmentation are derived for the longest possible time frame with a common data coverage (2000-2018) and in the following two categories:

- **Statistical summary:** trends in each of the 2 forest fragmentation classes, total forest area, total number of patches, APS and FAD_AV.

- **Spatial maps:** an informative change analysis map should provide a clear message focusing on the two most important aspects: locate hotspots of changes and delineate areas where no changes occurred. In order to focus on those key messages, spatially explicit trend maps show forest cover and forest fragmentation changes follow a change-matrix scheme, showing changes between the three classes Background, Separated, Continuous. This change-matrix is complemented by the three additional classes Missing (outside reporting unit), Water (pixels where water was present at both times) and Water (pixels where water was present at one time only). With the focus on essential change areas we ensure to provide a clear message and facilitate interpretation. The final forest fragmentation change map provides a rich set of information extracted from the two time points of the individual state maps: where forest fragmentation is stable, has increased or decreased and where forest cover was present at one time only.

2.6 Implementation flowchart

Figure 2 provides an overview of the processing chain to derive Accounting and fragmentation status maps and the forest cover and fragmentation change map. The source code for pre- and post-processing steps (*fe47.pro* in the IDL language) and all output maps and statistics are provided in a single directory "FE47" together with this ATBD. The command-line version of GuidosToolbox (GTB), the GuidosToolbox Workbench (GWB), was used to conduct batch-processing tasks of Accounting and Fragmentation. The last section of the custom script *fe47.pro* generates the fragmentation change map. Further details on the individual processing steps can be found in the Annex or directly in the script *fe47.pro*.

Figure 2. Overview of the processing chain to derive status and trends of indicator 4.7.
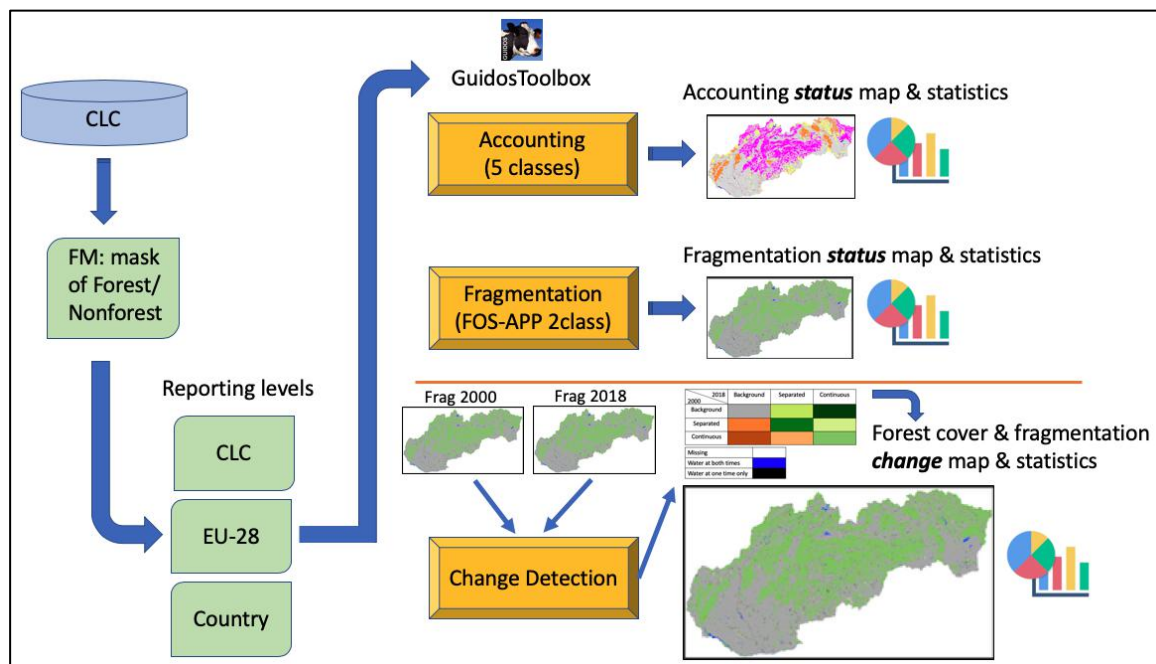
Source: JRC, 2019.

The IDL-script fe47.pro has the following sections for pre- and postprocessing:

a) Define country mask and cut CLC data for all reporting units and years.

b) Build forest mask from CLC data for all reporting units and years.

c) Setup all reporting units for GWB batch-processing.

d) Load GWB batch-processing results and generate a forest summary statistics form from all reporting units and years.

e) Generate trend maps and statistics for all reporting units.

f) Generate a forest trend summary statistics form from all reporting units.

Details on the file hierarchy and the input and output file data assignments are summarised in the Annex at the end of this document.

3   Implementation examples

This section provides examples of the individual processing steps as well as maps and details on the status and change products.

3.1   Status maps and statistics

Figure 3 shows the processing chain starting from the CORINE land cover data to the final map, providing spatial detail in two degrees of forest fragmentation (Separated and Continuous) and five patch size classes.

Figure 3. Processing steps to map forest fragmentation exemplified for Luxembourg, from left to right: CORINE 2012 land cover data, forest mask, forest fragmentation (FAD), and Accounting.
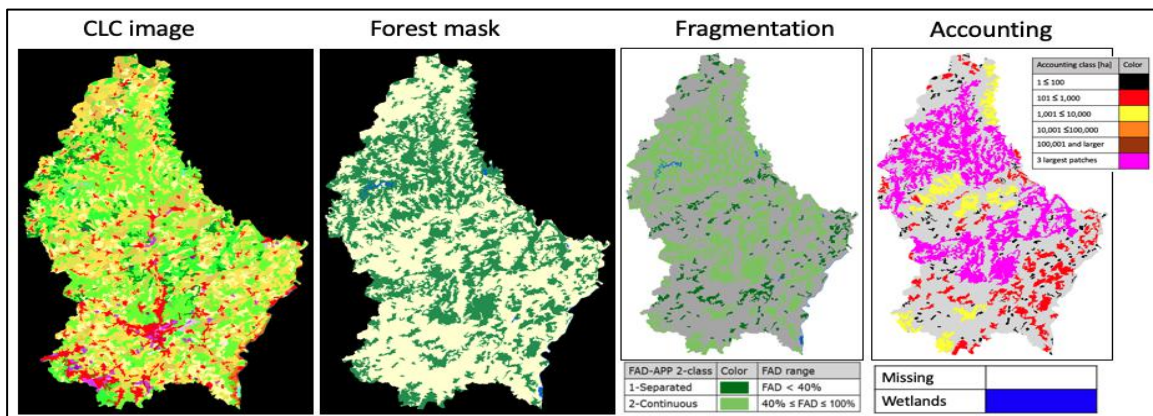
Source: JRC, 2019.

Figure 4. Zoom in on the fragmentation map of Portugal in 2018 showing the 2-class Average-Per-Patch (APP) fragmentation colour scheme (left) and the 5-class APP fragmentation colour scheme (right). Note: the map product shows actual APP values (see APP FAD value '7%' in the top panel and white arrows), the difference in the two images at the bottom is the colour scheme in use only.
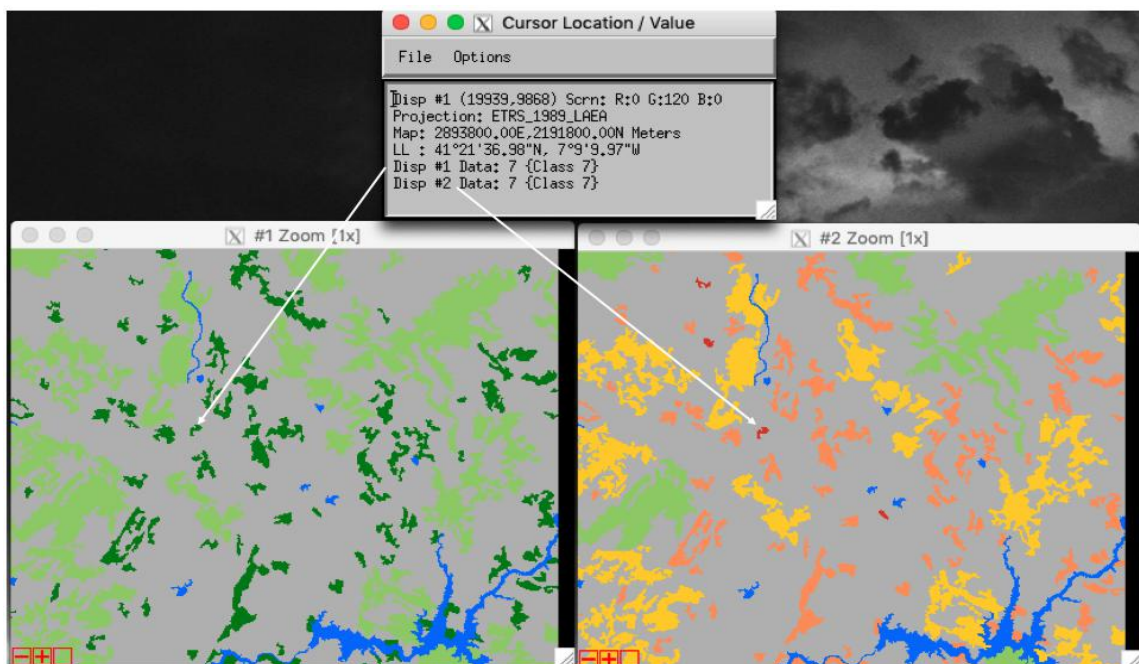
Source: JRC, 2019.

In addition to the two fragmentation classes Separated and Continuous, the fragmentation map can also provide an alternative classification scheme, segmenting the full range of FAD into the 5 sequential fragmentation classes Rare, Patchy, Transitional, Dominant and Interior (see also Figure 5). These 5 classes are a more refined version of the original 2-class scheme. It is important to note that the map product shows the actual APP FAD value (see top panel of Figure 4), which is only colour-coded into the 2-class range. Thus, the interested user can simply apply a different colour-table to reclassify the same image into any user-defined number of fragmentation classes without having to reprocess the data itself.

All status maps are accompanied by summary statistics. Figure 5 provides a summary of Fragmentation and Figure 6 a summary of Accounting.

Figure 5. Example statistics for Fragmentation in Luxembourg, 2012 showing total forest area, number of forest patches and average patch size (APS) in hectare (second block) as well as forest proportions in the more refined 5-class scheme (third block top), the fragmentation classes Separated and Continuous (third block bottom), and the per-pixel and per-patch average FAD value (fourth block). For example, the fragmentation class Rare accounts for 0.3535 % of the entire forest area.

```
FOS-APP: Fixed Observation Scale summary analysis for image:
../input/clc2012_LU-fm.tif
===============================================================================
8-conn FG: area, # patches, aps [pixels]: 94761, 251, 377.53386
Fragmentation class at observation scale: 529.000 hectares/1307.19 acres
(Pixel resolution: 100[m], Window size: 23x23)
===============================================================================
FOS-APP 5-class:            FAD-APP 5-class  Color  FAD range
       Rare:     0.3535     1-Rare                  FAD < 10%
      Patchy:   13.4644     2-Patchy                10% ≤ FAD < 40%
 Transitional: 15.1687      3-Transitional          40% ≤ FAD < 60%
    Dominant:  71.0134      4-Dominant              60% ≤ FAD < 90%
    Interior:   0.0000      5-Interior              90% ≤ FAD ≤ 100%
FOS-APP 2-class:            FAD-APP 2-class  Color  FAD range
   Separated:  13.8179      1-Separated             FAD < 40%
   Continuous: 86.1821      2-Continuous            40% ≤ FAD ≤ 100%
===============================================================================
      FAD_av:    54.7414
    FADAPP_av:   54.5735
```

Source: JRC, 2019.

Figure 6. Example statistics for Accounting in Luxembourg, 2012 showing number, area and proportion of forest patches in 4 different size classes. The bottom part provides a summary and lists the 3 largest forest patches encountered.

```
Accounting size classes result using:
clc2012_LU-fm
Base settings: 8-connectivity, pixel resolution: 100 [m]
Conversion factor: pixel_to_hectare: 1.00000, pixel_to_acres: 2.47105
-------------------------------------------------------------------------------
Size class 1: [1, 100] pixels; color: black
        # Objects      Area[pixels]    % of all objects  % of total FGarea
          177              5574             70.5179            5.88217
-------------------------------------------------------------------------------
Size class 2: [101, 1000] pixels; color: red
        # Objects      Area[pixels]    % of all objects  % of total FGarea
           63             19197             25.0996           20.2583
-------------------------------------------------------------------------------
Size class 3: [1001, 10000] pixels; color: yellow
        # Objects      Area[pixels]    % of all objects  % of total FGarea
            9             23354              3.58566          24.6452
-------------------------------------------------------------------------------
Size class 4: [10001, 100000] pixels; color: orange
        # Objects      Area[pixels]    % of all objects  % of total FGarea
            2             46636              0.796813         49.2143
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
Sum of all classes:
        # Objects      Area[pixels]    % of all objects  % of total FGarea
          251             94761            100.000           100.000

Three largest object IDs and area[pixels]; color: pink
These 3 objects overlay objects listed above
1)           152             31303
2)            67             15333
3)            68              9063
```

Source: JRC, 2019.

Note that in Figure 6 the 5th class (larger than 100,000 ha) is omitted because no forest patch of this size was encountered in Luxembourg.

The forest statistics of all reporting units and for each year are further summarised in a customised spreadsheet table, which can be sorted for a variety of attributes. This table also contains a dedicated "Field Code Definition" sheet with definitions of each variable listed at the top of each column in Figure 7 allowing for further analysis in a GIS application. The summary table shows reporting unit and forest area, fragmentation classes, average patch size, number of patches and area in 5 different patch size classes, the area of the largest forest patch in area (hectares) as well as proportions by forest or country area.

Figure 7. Extract (first eight entries) of the summary spreadsheet 2018, providing statistics for all reporting units; the bottom panel shows an extract of the Field Code Definition sheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Names & Codes**			**Base Statistics**			**Fragmentation Statistics**							
2	Original sorting	COUNTRY	CNRTY_CODE	CNRTY_AREA 2018 (in ha)	FORES_AREA 2018 (in ha)	PERC_FOR 2018 (in %)	PERC_SEP (in %)	PERC_CONT (in %)	PERC_RARE (in %)	PERC_PATCH (in %)	PERC_TRANS (in %)	PERC_DOM (in %)	PERC_INT (in %)	FAD_AV (in %)
3	1	CLC	clc	584,572,992	200,918,750	34.37	7.79	92.21	0.42	7.37	8.99	83.00	0.22	71.90
4	2	EU28	eu28	439,019,328	159,505,733	36.33	8.26	91.74	0.47	7.79	9.14	82.36	0.24	72.01
5	3	Albania	AL	2,866,485	1,106,904	38.62	7.31	92.69	0.27	7.04	10.12	82.57	0.00	67.56
6	4	Austria	AT	8,394,356	3,715,822	44.27	6.06	93.94	0.19	5.87	9.81	84.12	0.00	69.05
7	5	Bosnia_Herzegovina	BA	5,121,534	2,656,470	51.87	5.21	94.79	0.14	5.07	3.94	90.84	0.00	74.54
8	6	Belgium	BE	3,064,066	628,981	20.53	19.90	80.10	1.28	18.63	15.50	64.59	0.00	60.89
9	7	Bulgaria	BG	11,098,772	4,237,649	38.18	7.59	92.41	0.45	7.14	8.15	84.26	0.00	73.21
10	8	Switzerland	CH	4,128,829	1,306,994	31.66	11.87	88.13	0.24	11.63	23.92	64.21	0.00	58.70

	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
1	**Forest Patch Statistics**										Five Forest Patch size classes from 100 ha to more than 100,000 ha			
2	NUM_PATCH 2018 (in #)	AV_P_SIZE 2018 (in ha)	NO_01 (in #)	HA_01 (in ha)	PERC_NO_01 (in %)	PERC_HA_01 (in %)	NO_02 (in #)	HA_02 (in ha)	PERC_NO_02 (in %)	PERC_HA_02 (in %)	NO_03 (in #)	HA_03 (in ha)	PERC_NO_03 (in %)	PERC_HA_03 (in %)
3	263,317	763.03	190,324	7,015,088	72.28	3.49	63,356	17,565,825	24.06	8.74	8,556	22,472,896	3.25	11.19
4	227,427	701.35	167,387	6,017,280	73.60	3.77	52,204	14,403,335	22.95	9.03	7,001	18,424,176	3.08	11.55
5	1,424	777.32	991	34,085	69.59	3.08	364	110,239	25.56	9.96	55	160,014	3.86	14.46
6	4,971	747.50	3,847	108,119	77.39	2.91	950	265,065	19.11	7.13	149	409,371	3.00	11.02
7	2,587	1,026.85	2,001	65,609	77.35	2.47	523	123,678	20.22	4.66	52	134,533	2.01	5.06
8	1,817	346.16	1,263	53,644	69.51	8.53	504	130,986	27.74	20.83	45	98,394	2.48	15.64
9	4,288	988.26	2,795	129,967	65.18	3.07	1,313	348,897	30.62	8.23	163	460,009	3.80	10.86
10	2,099	622.67	1,382	54,788	65.84	4.19	609	167,742	29.01	12.83	91	237,507	4.34	18.17

	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
1	a (1,000 km2)								**Largest Patch Statistics**	
2	NO_04 (in #)	HA_04 (in ha)	PERC_NO_04 (in %)	PERC_HA_04 (in %)	NO_05 (in #)	HA_05 (in ha)	PERC_NO_05 (in %)	PERC_HA_05 (in %)	MAX_HA (in ha)	MAX_PERC (in %)
3	957	24,888,374	0.36	12.39	124	128,976,567	0.05	64.19	57,962,566	28.85
4	735	19,047,115	0.32	11.94	100	101,613,827	0.04	63.71	50,168,490	31.45
5	12	331,326	0.84	29.93	2	471,240	0.14	42.57	351,872	31.79
6	22	738,457	0.44	19.87	3	2,194,810	0.06	59.07	1,215,009	32.70
7	10	285,014	0.39	10.73	1	2,047,636	0.04	77.08	2,047,636	77.08
8	4	69,496	0.22	11.05	1	276,461	0.06	43.95	276,461	43.95
9	14	303,409	0.33	7.16	3	2,995,367	0.07	70.68	2,686,637	63.40
10	14	436,353	0.67	33.39	3	410,604	0.14	31.42	174,636	13.36

	A	B	C	D
1	ARCMAP_FIELD_CODE	ALIAS	DEFINITION	UNIT
2	COUNTRY	International country name	See ATBD	String
3	CNTRY_CODE	2-digit international country code	See ATBD	String
4		**Base Statistics**		
5	CNTRY_AREA	Land area including inland waters but excluding ocean	See ATBD	Hectare
6	FORES_AREA	'Forest Area' inside or at the edge of each assessment Unit, based on the number of pixels classified as 'Forest' in the original source dataset.	See ATBD	Integer
7	PERC_FOR	Percentage of Forest inside each assessment Unit, depending on the area covered by pixels classified as forest.	See ATBD	Percent
8		**Fragmentation Statistics**		
9	PERC_SEP	Percentage of Forest fragmentation in class 'Separated' (FAD: [0,40[%)	See ATBD	Percent
10	PERC_CONT	Percentage of Forest fragmentation in class 'Continuous' (FAD: [40,100] %)	See ATBD	Percent
11	PERC_RARE	Percentage of Forest fragmentation in class 'Rare' (FAD:]0, 10] %)	See ATBD	Percent
12	PERC_PATCH	Percentage of Forest fragmentation in class 'Patchy' (FAD: [10, 40[%)	See ATBD	Percent
13	PERC_TRANS	Percentage of Forest fragmentation in class 'Transitional' (FAD: [40, 60[%)	See ATBD	Percent
14	PERC_DOM	Percentage of Forest fragmentation in class 'Dominant' (FAD: [60, 90[%)	See ATBD	Percent
15	PERC_INT	Percentage of Forest fragmentation in class 'Intact' (FAD: [90,100] %)	See ATBD	Percent
16	FAD_AV	FAD average of all forest pixels	See ATBD	Percent
17		**Forest Patch Statistics**		
18	NUM_PATCH	The 'Number of independent Forest patches'; a forest patch becomes independent if not a single '8-connection' to an adjacent forest pixel exists. All pixels that are connected by 'touching' at a corner point belong to the same patch (see graphic examples on the bottom-right).	See ATBD	Integer
		The 'Average Forest Patch Size', derived by dividing the total 'Forest Area' by		

foreststats2018   **Field_Code_Definition**   +

Source: JRC, 2019.

Figure 8. Forest fragmentation of CLC at 100 m² spatial resolution for the year 2018. Fragmentation is calculated for a local neighbourhood of 500 hectares and categorized into the 2 fragmentation classes *Separated* and *Continuous*.
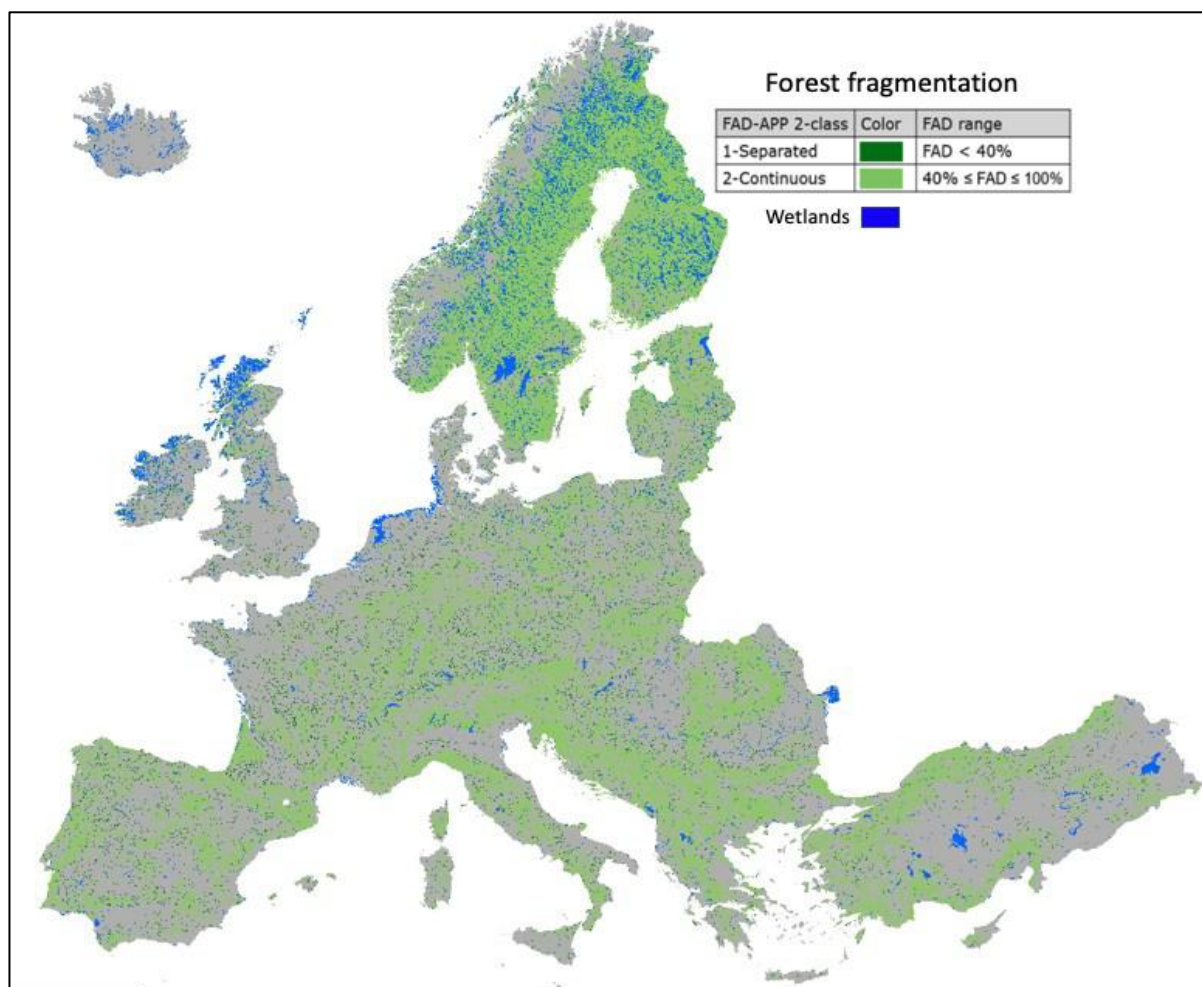
Figure 8 shows forest fragmentation at 100-meter spatial resolution for the year 2018 at CLC-scale (KF8). Unsurprisingly, the most intact forest areas can be found in areas with a high forest coverage, for example Scandinavia, the Alpine region, the Pyrenees and the northern Balkan countries. Areas of high fragmentation coincide with either a low amount of forest cover (Ireland, United Kingdom) or areas with high population density (the Netherlands), where agriculture and urban land cover is dominant and the forest area is highly fragmented into isolated small fragments. Maps for other assessment years (1990, 2000, 2006, 2012) are not shown here because they do not exhibit significant differences compared to Figure 8 when viewed at European scale.

3.2 Change maps and statistics

Figure 9 shows an example of the forest fragmentation change map in full resolution to illustrate local details over a sample area south of Lisbon, Portugal. The trend map shows areas where forest cover changed, the degree of forest fragmentation is stable, or has increased or decreased. Blue pixels are assigned to inland water bodies present at both times of the change period; black pixels are water at one time only. Please note that coast lines and inland water bodies may slightly differ in CLC data sets of different years. The results of the change detection directly depend on the accuracy of the CLC land cover classification and may differ from official statistics on forest area.

Figure 9. Forest fragmentation status map south of Lisbon, Portugal in 2000 and 2018 (top panel) and fragmentation trend map (bottom left) with three examples (highlighted in circles).
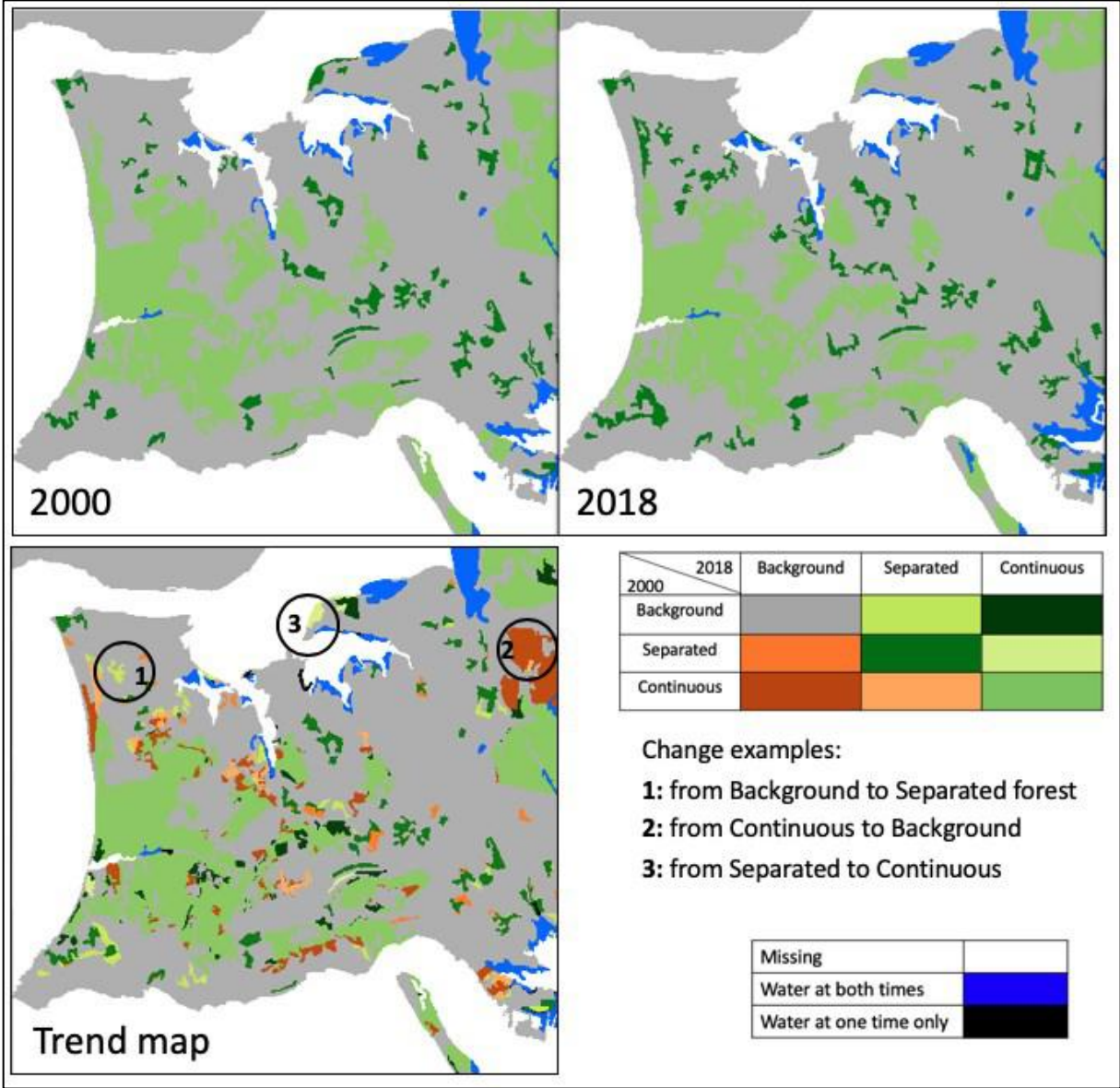
Source: JRC, 2019.

Each change map is accompanied by the respective summary statistics, see Figure 10.

Figure 10. Example summary statistic for the change map of Portugal, listing forest cover and fragmentation trends in hectare (upper half) and proportion (lower half) between the three classes and the years 2000 and 2018.

clc2000-2018_PT			
2000-2018	**Background**	**Separated**	**Continuous**
Background [ha]:	5188965	108516	292515
Separated [ha]:	88032	205019	66202
Continuous [ha]:	438777	83093	2588088
Background [%]:		2.80386	7.55805
Separated [%]:	2.27459	5.29732	1.71054
Continuous [%]:	11.33720	2.14697	66.87148

Source: JRC, 2019.

Percentage values listed in the lower half of Figure 10 are calculated with respect to the forest coverage present at either time of the change period; all eight percentage values add up to 100 %. All reporting units are further summarised into a single summary table, see Figure 11.

Figure 11. Extract (first eight entries) of the trend summary, providing all trend statistics for all reporting units in the time frame 2000 – 2018. The bottom panel shows the Field Code Definition sheet.

	A	B	C	D	E	F	G	H	I	J	K	L
1		**Names & Codes**						**Fragmentation Statistics (in ha)**				
2	Original sorting	COUNTRY	CNRTY_CODE	BG_BG (in ha)	BG_SEP (in ha)	BG_CON (in ha)	SEP_BG (in ha)	SEP_SEP (in ha)	SEP_CON (in ha)	CON_BG (in ha)	CON_SEP (in ha)	CON_CON (in ha)
3	1	CLC	clc	341,582,518	3,016,264	10,004,105	2,157,437	11,086,752	1,808,080	9,867,065	1,416,340	172,660,878
4	2	EU28	eu28	248,024,876	2,549,739	6,872,954	1,657,466	9,432,420	1,431,820	6,718,171	1,072,017	137,236,041
5	3	Albania	AL	1,505,900	26,120	139,433	18,219	35,768	18,878	163,983	18,558	866,897
6	4	Austria	AT	4,455,494	19,028	81,741	13,424	184,346	11,727	113,904	21,331	3,395,637
7	5	Bosnia_Herzegovina	BA	2,178,646	33,529	156,932	19,850	82,314	31,872	224,684	22,482	2,328,825
8	6	Belgium	BE	2,402,997	2,986	2,222	1,434	120,975	1,539	2,097	1,193	499,961
9	7	Bulgaria	BG	6,579,655	41,467	133,157	27,583	258,396	28,804	141,272	21,443	3,753,328
10	8	Switzerland	CH	2,629,773	7,407	81,473	6,243	130,962	16,435	36,269	16,522	1,053,845

	M	N	O	P	Q	R	S	T	U
1					**Fragmentation statistics (in %)**				
2	P_BG_SEP (in %)	P_BG_CON (in %)	P_SEP_BG (in %)	P_SEP_SEP (in %)	P_SEP_CON (in %)	P_CON_BG (in %)	P_CON_SEP (in %)	P_CON_CON (in %)	D_FAD_AV (in %)
3	1.42	4.72	1.02	5.23	0.85	4.65	0.67	81.44	0.07
4	1.53	4.12	0.99	5.65	0.86	4.02	0.64	82.19	0.28
5	2.03	10.83	1.41	2.78	1.47	12.73	1.44	67.31	1.35
6	0.50	2.13	0.35	4.80	0.31	2.97	0.56	88.40	0.94
7	1.16	5.41	0.68	2.84	1.10	7.75	0.78	80.29	-0.69
8	0.47	0.35	0.23	19.13	0.24	0.33	0.19	79.06	0.17
9	0.94	3.02	0.63	5.87	0.65	3.21	0.49	85.20	0.34
10	0.55	6.04	0.46	9.71	1.22	2.69	1.22	78.11	-1.17

	A	B	C	D
1	ARCMAP_FIELD_CODE	ALIAS	DEFINITION	UNIT
2	COUNTRY	International country name	See ATBD	String
3	CNRTY_CODE	2-digit international country code	See ATBD	String
4		**Fragmentation Statistics (in ha)**		
5	BG_BG	Nonforest to nonforest (stable)	See ATBD	Hectare
6	BG_SEP	Nonforest to Separated	See ATBD	Hectare
7	BG_CON	Nonforest to Continuous	See ATBD	Hectare
8	SEP_BG	Separated to Background	See ATBD	Hectare
9	SEP_SEP	Separated to Separated (stable)	See ATBD	Hectare
10	SEP_CON	Separated to Continuous	See ATBD	Hectare
11	CON_BG	Continuous to Background	See ATBD	Hectare
12	CON_SEP	Continuous to Separated	See ATBD	Hectare
13	CON_CON	Continuous to Continuous (stable)	See ATBD	Hectare
14		**Fragmentation Statistics (in %)**		
15	P_BG_SEP	BG_SEP / forest area at either time	See ATBD	Percent
16	P_BG_CON	BG_CON / forest area at either time	See ATBD	Percent
17	P_SEP_BG	SEP_BG / forest area at either time	See ATBD	Percent
18	P_SEP_SEP	Separated stable / forest area at either time	See ATBD	Percent
19	P_SEP_CON	SEP_CON / forest area at either time	See ATBD	Percent
20	P_CON_BG	CON_BG / forest area at either time	See ATBD	Percent
21	P_CON_SEP	CON_SEP / forest area at either time	See ATBD	Percent
22	P_CON_CON	Continuous stable / forest area at either time	See ATBD	Percent
	D_FAD_AV	Difference: FAD_AV(2000) - FAD_AV(2018)		

trendstats2000-2018 | **Field_Code_Definition** | +

Source: JRC, 2019.

Figure 12. Forest cover and fragmentation change map of the area covered by CLC from 2000 to 2018.
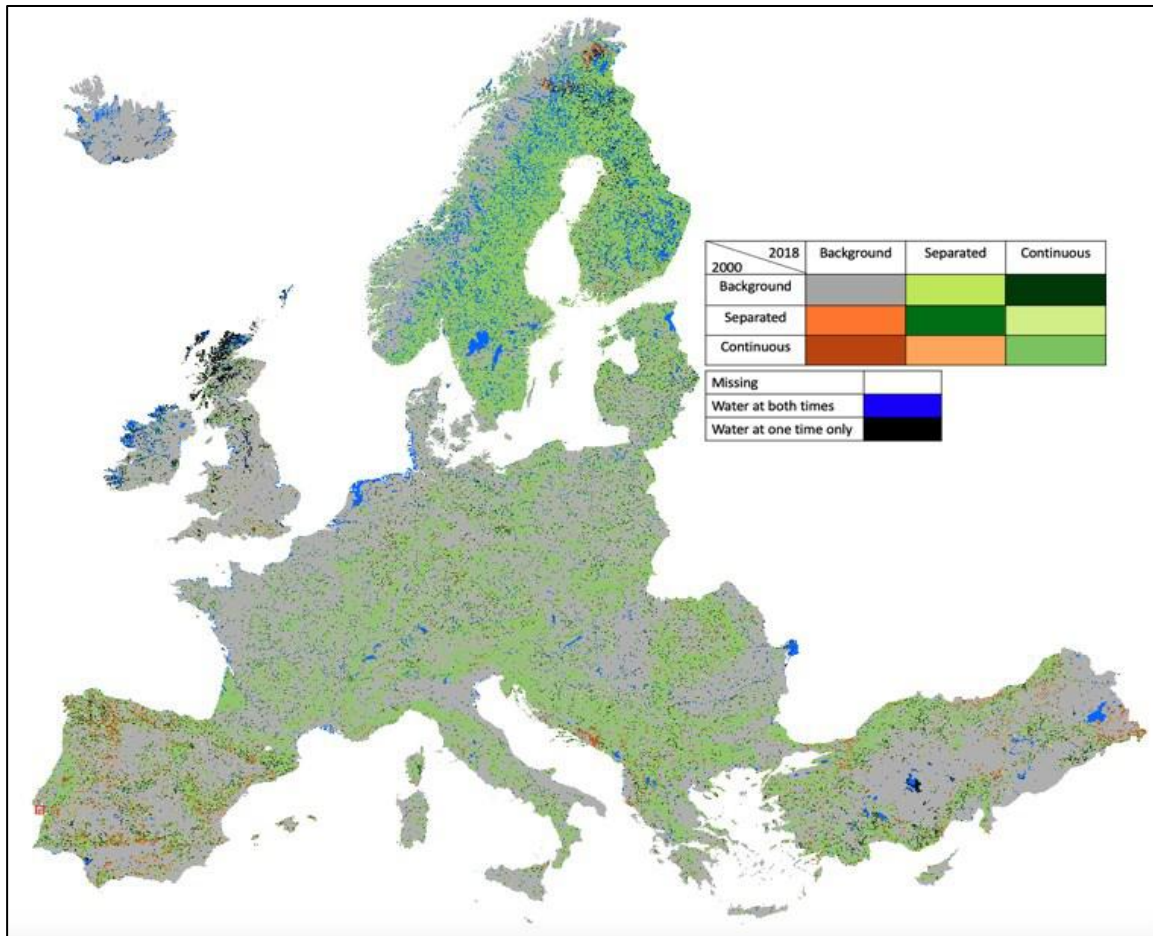
Figure 12 provides an overview of trends in forest cover and forest fragmentation at CLC-level in the time frame 2000 to 2018. Local details cannot be seen in this figure but will be available when zooming in to the full resolution of this image (see Figure 9). Major change areas can be found on the Iberian Peninsula, the Balkan, Turkey and the northern part of Scandinavia.

4 Conclusions

This document describes a methodology to map and quantify forest fragmentation as one of the pan-European indicators for sustainable forest management. The approach is based on processing of existing land cover classifications and measuring (a) the forest area density (FAD) at a fixed observation scale, and (b) a set of forest patch size classes (Accounting). The concept assures to simultaneously consider key aspects of fragmentation including, the amount of forest, the area of continuous forest, perforations inside forest patches, patch shape and linear features, and the distance between individual forest patches. The accuracy of the derived status and change data depends exclusively on the accuracy of the external input classification and may differ from official statistics on the forest area obtained by other means. In this context, the results of this study are indicative.

The purpose of the map product is to exploit the spatial information, which cannot be retrieved from summary indices and statistics: a geographic map of fragmentation classes is not only visually appealing but it permits localizing hotspots of fragmentation, which may support planning and risk assessment. The map product is useful to address spatially explicit assessment questions (*where*) such as:

- Where are forests located, mostly continuous or fragmented?
- Where in the reporting unit are the small (large) forest patches?
- Where are forest patches close or distant?
- Where are large forest patches close to each other?
- Where do changes occur?

The purpose of the summary statistics (foreststats<year>.xlsx) is to provide a concise and comparative overview allowing to answer essential quantitative assessment questions (*how much*) such as:

- How much of the individual patch size classes are present in the reporting units and what is the average forest density in forested areas (FAD_AV)?
- Which are the proportions of small/large forest patches?

The above, and other similar questions, can be easily addressed by using the filter function in the summary spreadsheet (foreststats<year>.xlsx).

The purpose of the trend statistics (trendstats2000-2018.xlsx) is to provide a concise and comparative overview allowing to answer essential quantitative change assessment questions (*how much*) such as:

- What is the extent of forest area change from Continuous to Separated (i.e., in Figure 11 sort column K to find the largest CON_SEP in hectare)?
- What is the percentage of stable Continuous forest cover from 2000 to 2018 (i.e., in Figure 11 sort column T to find the highest P_CON_CON in %)?

The above, and other similar questions, can be easily addressed by using the filter function in the summary spreadsheet (trendstats2000-2018.xlsx). The accompanying map product provides additional information on the location of change hotspots.

References

CLC Technical Guidelines, online document available at:
https://land.copernicus.eu/user-corner/technical-library/clc2018technicalguidelines_final.pdf

Forest Service U.S. Department of Agriculture. 2012. Future of America's Forest and Rangelands: Forest Service 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-87. Washington, DC. 198 p., doi:10.2737/WO-GTR-87

Forest Service U.S. Department of Agriculture. 2016. Future of America's Forest and Rangelands: Update to the 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-GTR-94. Washington, DC. 250 p. https://www.fs.usda.gov/treesearch/pubs/53212

Montréal Process Working Group:
https://www.montrealprocess.org/documents/publications/techreports/MontrealProcessSeptember2015.pdf

Riitters, K.H., Wickham, J.D., O'Neill, R.V., Jones, K.B., Smith, E.R., Coulston, J.W., Wade, T.G. & Smith, J.H. 2002. Fragmentation of continental United States forests. Ecosystems 5, pp. 815-822.

Riitters, K.H., Wickham, J.D. 2012. Decline of forest interior conditions in the conterminous United States. Scientific Reports 2, Article number: 653, doi:10.1038/srep00653

Vogt P., Riitters, K. 2017. GuidosToolbox: universal digital image object analysis. European Journal of Remote Sensing 50:1, pp. 352-361, doi:10.1080/22797254.2017.1330650

Vogt, P. 2019. GuidosToolbox Workbench (GWB): Linux server command-line version of GuidosToolbox available at: https://forest.jrc.ec.europa.eu/en/activities/lpa/gwb/

Vogt, P. 2019a. Product sheet: Measuring Forest Area Density to quantify Forest Fragmentation. http://ies-ows.jrc.ec.europa.eu/gtb/GTB/psheets/GTB-Fragmentation-FADFOS.pdf

Vogt, P. 2019b. Product sheet: Image Object Accounting. http://ies-ows.jrc.ec.europa.eu/gtb/GTB/psheets/GTB-Objects-Accounting.pdf

Wickham, J.D., Riitters, K.H., Wade, T.G., Homer, C. 2008. Temporal change in fragmentation of continental US forests. Landscape Ecology 23, pp. 891-898, doi:10.1007/s10980-008-9258-z

List of acronyms

APS	Average Patch Size
APP	Average-Per-Patch
ATBD	Algorithm Technical Basis Document
CLC	CORINE Land Cover, data coverage (1990, 2000, 2006, 2012, 2018)
EU28	CLC data coverage of EU28 member states (2000, 2006, 2012, 2018)
FAD	Forest Area Density
FAD_AV	Average FAD value of all forest pixels
FAD	FAD at Fixed Observation Scale
FOREST EUROPE	Ministerial Conference on the Protection of Forests in Europe
GIS	Geographic Information System
GTB	GuidosToolbox (https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/)
GWB	GuidosToolbox Workbench (https://forest.jrc.ec.europa.eu/en/activities/lpa/gwb/)

List of figures

Annex

This section describes the file hierarchy and input and output formats in the various sub-directories of the base-directory **FE4.7**. Files are shown in *italics* and directories in **bold**.
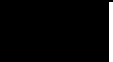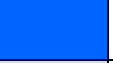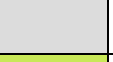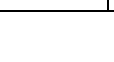
- **clc<year>:** directory with input/output data for fragmentation analysis:
  - **batch_ACC:** Accounting maps and statistics of all reporting units.
  - **batch_FOS:** FAD maps and statistics of all reporting units.
  - *clc<year>v20.tif*: CLC land cover map, version 20 for <year>.
  - *foreststats<year>.xlsx*: enhanced, searchable statistics with field code definitions.

- **trend:** directory with trend analysis data, sorted into:
  - maps of fragmentation trends for all reporting units.
  - *trendstats2000-2018.xlsx*: enhanced, searchable statistics with field code definitions.

- **docs:** directory with general documentation and processing source code:
  - *TechnicalReport_FE4.7.pdf*: current document
  - *fe47.pro*: IDL program (source code) for pre- and post-processing, providing step-by-step instructions on the individual processing methodologies.
  - *fmapcolors.sav*: colour table used by *fe47.pro*.

Note: to keep the file size of the base-directory **FE4.7** to the minimum, intermediate data sets and derived forest masks at EU and country level are not included in the results. The spatial coverage of the forest mask is identical to the coverage in the Accounting or FAD maps.

All map products are provided in geotiff format and in the data type byte. Details of the geo-header information can be retrieved with the gdalinfo command or by any GIS application. Details on the input and output pixel values are summarized in the following figures:

Accounting: clc<year>/batch_ACC/clc<year>_<reporting-unit>-fm_acc/

File name: clc<year>_<reporting-unit>-fm_acc.tif

Value	Class	RGB – Colour Code		Description (see section 2.3)
0	Background	220/220/220		Non-forest land cover
1	Size class 4	255/140/0		Forest patches: $10,001 \leq 100,000$ hectares
9	Size class 5	160/60/0		Forest patches: $\geq 100,001$ hectares
33	Size class 2	255/0/0		Forest patches: $101 \leq 1,000$ hectares
65	Size class 3	255/255/0		Forest patches: $1,001 \leq 10,000$ hectares
80	Largest patch	255/0/255		3 largest forest patches
103	Size class 1	0/0/0		Forest patches: $1 \leq 100$ hectares
105	Water	0/0/255		Inland waters
129	Missing	255/255/255		No data or outside reporting unit

Fragmentation: clc<year>/batch_FOS/clc<year>_<reporting-unit>-fm_fos-app2_23/

File name: clc<year>_<reporting-unit>- fm_fos-app2_23.tif

Value	Class	RGB – Colour Code		Description (see section 2.3)
0 - 39	Separated	0/120/0		Forest patches in class: Separated
40 - 100	Continuous	140/200/100		Forest Patches in class: Continuous
101	Background	175/175/175		Non-forest land cover
102	Missing	255/255/255		No data or outside of reporting unit
105	Water	0/100/255		Inland waters
Alternative 5-class scheme (listed in the statistics)				
0 - 9	Rare			Forest patches in class: Rare
10 - 39	Patchy			Forest patches in class: Patchy
40 - 59	Transitional			Forest patches in class: Transitional
60 - 89	Dominant			Forest patches in class: Dominant
90 - 100	Interior			Forest patches in class: Interior

Trend: trend/

File name: clc2000-2018_<reporting-unit>.tif

Value	Class	RGB – Colour Code		Description (see section 2.5)
0	Water	0/0/0		Inland water at one time only
3	Water	0/100/255		Inland water at both times
11	BG_BG	175/175/175		Non-forest land at both times (stable)
12	BG_SEP	200/232/88		Background to Separated
13	BG_CON	7/64/0		Background to Continuous
21	SEP_BG	252/127/40		Separated to Background
22	SEP_SEP	20/120/0		Separated at both times (stable)
23	SEP_CON	217/239/139		Separated to Continuous
31	CON_BG	191/76/0		Continuous to Background
32	CON_SEP	253/174/97		Continuous to Separated
33	CON_CON	140/200/100		Continuous at both times (stable)
255	Missing	255/255/255		No data or outside reporting unit

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