RETROFRAG · forest fragmentation and core forest - user guide

Author: Ladislav Šumichrast

RETROCHANGE / EOSC Federation · landscape use case Notebook: `forest_fragmentation.ipynb` · Interface: `forest_fragmentation_app.ipynb`

RETROFRAG quantifies forest fragmentation and core forest from prepared forest/non-forest maps. It supports a single-area baseline, comparison of the same area at two dates, and comparison of two areas under consistent rules. Users choose the analysis grain, minimum opening and patch sizes, and edge depth, then examine forest cover, patch structure, edges, core forest and forest area density. Outputs include maps, indicator tables, figures and provenance records, with sensitivity checks to support interpretation. Results depend on input-map quality and the chosen settings; the workflow does not classify imagery or establish habitat quality.

Contents

1 · What it is for . . . 3

2 · Quick start . . . 3

3 · The input map . . . 3

4 · Settings . . . 4

5 · What the interface shows . . . 6

6 · The indicators . . . 7

7 · The maps . . . 12

8 · Two dates: what changed . . . 12

9 · Comparing two areas . . . 13

10 · The checks . . . 13

11 · Reporting a number . . . 14

12 · What the numbers cannot say . . . 14

13 · Files of a run . . . 14

14 · References . . . 15

15 · About RETROFRAG . . . 16

Verification and input consistency (November 2026) . . . 16

1 · What it is for

> *How much of the forest is core forest, out of reach of edge effects? Is it one forest or many patches? And between two dates, or between two areas: did that core forest persist, grow, or get cut up?*

Forest *area* alone says little about habitat. Two landscapes with the same forest cover can differ completely in how much of that forest is core forest: shaded, wind-sheltered, with a forest microclimate, away from the light and drying of an edge.

The use case takes one or two **finished forest / non-forest maps** and returns a small set of reporting-ready indicators with their maps. It does not classify images, and it does not report land-cover change (how much forest was gained or lost, and where).

Three modes:

Mode	Question	Input
One map (`single`)	How fragmented is this forest, and how much of it is core forest? A baseline.	one map
Two dates, same area (`two_dates`)	How did its fragmentation change?	two maps of the same area on the same grid
Two areas (`two_areas`)	How do two forests differ in fragmentation?	two maps, any extents

2 · Quick start

With the interface, on your own computer. Open `forest_fragmentation_app.ipynb` in JupyterLab (or Positron / VS Code) and run it. The interface appears. Pick the mode and the map(s), adjust the settings if you wish, and press **Run the analysis**. At 2 m a 5 × 5 km map takes about half a minute. The optional **Open in web browser** button shows the same interface as a clean web page.

With the interface, on the EOSC EU Node (JupyterHub). Upload **both notebooks** (the interface notebook and the analysis notebook), this guide and your forest maps **into one folder**, open the interface notebook and run it.

- If a widget shows *"Error displaying widget: model not found"*, reload the page (F5) and choose **Kernel → Restart Kernel and Run All Cells**.
- The upload buttons take files up to about 2 MB. For a larger map, copy it into the folder and press **Look for new maps**.

Without the interface. Open `forest_fragmentation.ipynb`, edit the **Parameters** block (§3 of the notebook) and run all cells. Everything is written to `OUTPUT_DIR`.

Where things are found and written. The interface lists every GeoTIFF in `uploads/`, in `../data` and `../outputs` (the repository layout) and in its own folder and up to three levels below it. Results go to `../outputs/app/` if `../outputs` exists, otherwise to `outputs/app/` next to the interface notebook. No folder has to be created by hand.

3 · The input map

- A **single-band GeoTIFF** in a **projected coordinate system in metres**, with square pixels.
- One value for **forest** (default 1), any other value for **non-forest**.

- **No data** declared in the file, or equal to the no-data value in the settings (default 255). No-data is never counted as forest edge.
- For **two dates**, both maps must share the grid exactly (same CRS, extent, pixel size and origin). Only the area where *both* have data is analysed, so first-date values can differ slightly from a one-map run of the same map.
- For **two areas**, the maps can have any extent, but must have a pixel size that divides the chosen grain.

Every result inherits the quality of the map. Roofs and tree crowns can look alike on a single panchromatic band, and hedgerows, scrub and young regrowth count as forest. The use case takes the map as given; check it before you interpret the indicators.

4 · Settings

All distances and areas are in metres or hectares; the notebook converts them to cells itself. The interface's names are given first, the notebook's parameter in brackets.

Setting	Default	What it does	When to change it
Grain (`TARGET_RES_M`)	2 m	Cell size for every measurement. A coarse cell is forest when at least half of it is forest (`COVER_MIN`).	2 m is about the effective resolution of KH-9. Use 10 m to sit next to Copernicus products. Compare only results at the same grain.
Fill openings and remove forest patches smaller than (`MIN_OPENING_HA`, `MIN_PATCH_HA`)	0.1 ha	Before anything is measured, openings smaller than this become forest and forest patches smaller than this become non-forest. Every indicator, in % as well as in hectares and counts, is measured on this cleaned map.	A hole a few crowns wide closes over with its own canopy and is not a forest boundary; tiny patches are mostly classification speckle. Core and perforation depend strongly on it: see the Opening size check.
Depth of edge influence (`EDGE_DEPTH_M`)	50 m	Forest farther than this from open land is core forest.	Next to clearcuts in old-growth Douglas-fir, edge influence on forest structure, growth and regeneration reached 16-137 m depending on the variable (Chen et al. 1992), and on microclimate 30 m to more than 240 m (Chen et al. 1995). The reach is thought to grow with the contrast between forest and open land (Harper et al. 2005). In European broadleaved forests next to farmland, the edge raised summer air temperature measurably up to 12.5-36.5 m into the stand, in line with earlier estimates of about 40-50 m (Meeussen et al. 2021); 50 m covers that with some margin.

Setting	Default	What it does	When to change it
Second, reporting edge depth (`REPORT_DEPTH_M`, advanced)	100 m	A second core depth, reported alongside.	The European Commission's Joint Research Centre (JRC) counted forest more than 100 m from the forest border as interior forest in its European fragmentation reporting (Estreguil et al. 2012). It is a reporting convention, not a measured edge depth; European edge-microclimate studies likewise take forest about 100 m from the edge as interior (Meeussen et al. 2021).
Window for forest area density (`FAD_WINDOW_M`)	675 m	Side of the square in which the forest share around each forest cell is measured (≈ 46 ha).	675 m is the middle of the five GuidosToolbox scales (27 pixels × 25 m). A larger window describes a larger neighbourhood but leaves a wider border band unassessed.
Cells joined into one patch (`CONNECTIVITY`, advanced)	8	8 = cells touching at a corner belong to the same patch (FRAGSTATS default); 4 = only cells sharing a side.	Keep 8 unless you need to match a study that used 4.
Value of forest cells / No-data value (advanced)	1 / 255	How the map is read.	Change to match your map.
A coarse cell is forest when at least this share is forest (`COVER_MIN`, advanced)	0.5	Rule for bringing a fine map to a coarser grain.	Rarely.
Grain check (`RUN_GRAIN_SWEEP`)	off in the interface	Repeats the analysis at 0.5, 2, 5, 10 and 20 m.	To see which results depend on the grain. Adds ~30 s.
Opening size check (`RUN_OPENING_SWEEP`)	off in the interface	Repeats the analysis with minimum openings of none, 0.1, 0.25, 0.5, 1 and 2 ha.	To see how much core and perforation depend on the minimum opening. Adds ~10 s.

Two conventions that are fixed, not settings:

- **The map border is never counted as forest edge.** Forest near it is treated as if the forest continued beyond the map. The share of core that rests on this assumption is reported (`core_near_border_pct`, and the dashed line of the core-depth curve).
- **Forest area density is assessed only where the whole window lies on the map.** Nearer the map border or a no-data gap the window would be cut off, catch fewer openings and read too high, so that forest is shown as *not assessed*. A map that reaches half a window beyond your area of interest loses nothing.

5 · What the interface shows

Tab	Content
At a glance	A sentence ready to quote; five headline tiles; the fragmentation profile (every indicator in %, grouped into *how much forest* and *how it is arranged*); forest depth and core blocks.
Maps	The morphology map (core, outer edge, perforation edge, islets) and the forest area density map. Two areas are drawn at one scale.
Core forest	Core forest against the assumed edge depth, 0-300 m.
Change *(two dates)*	Permanent core map and table; where the second date's core came from (flow diagram and table); forest area density classes on forest present at both dates; why the forest edge changed.
All indicators	Every indicator with its unit and a one-line explanation, grouped. For two dates a *change* column; for two areas a *difference* column (left blank for hectares and counts unless both areas are the same size).
Grain check / Opening size check *(if ticked)*	The same indicators at other grains / other minimum opening sizes.
Download	A zip with every figure, table and map of the run, a README and this guide.

6 · The indicators

Each entry gives the indicator's name in the interface, its key in `*_indicators.csv`, its unit and direction, a one-line summary, and then what it measures, how to read it, its pitfalls, its source and whether it matches the R package landscapemetrics (Hesselbarth et al. 2019), which computes the FRAGSTATS metrics (McGarigal et al. 2012).

Four kinds of indicator. (1) *Identical to landscapemetrics*, checked with `scripts/check_frag_vs_landscapemetrics.R`: PLAND, LPI, MESH, ED, NP. (2) *Exact arithmetic from those*: coherence, largest patch as % of forest, edge per hectare of forest, patches per 100 ha of forest. (3) *Same idea as a FRAGSTATS metric but deliberately defined differently*: core forest and core blocks. (4) *From other published methods or our own*: forest area density (Riitters, GuidosToolbox), morphology (a simplified MSPA, Morphological Spatial Pattern Analysis), and the border, opening and two-date products.

How much forest

Area analysed

`area_ha` · ha

In one line: The area with data that was analysed; with two dates, the area where both maps have data.

- **Pitfalls:** hectare figures and counts from areas of different size cannot be compared directly.

Forest area

`forest_ha` · ha

In one line: Hectares of forest after the size rules (small openings filled, small patches dropped).

- **Pitfalls:** slightly larger than the raw map's forest, because openings under the minimum size are filled.

Forest cover (PLAND)

`pland_pct` · % of area · amount of forest, not its arrangement

In one line: How much of the analysed area is forest; read it first, every other indicator depends on it.

- **What it measures:** forest area ÷ area analysed × 100.
- **Read it:** habitat amount. It is *not* fragmentation in itself (Fahrig 2003): a landscape can lose forest without the remaining forest breaking up, and the other way round. That is why the profile keeps it apart from the arrangement indicators.
- **Pitfalls:** nearly independent of grain.
- **Source / landscapemetrics:** FRAGSTATS PLAND; identical to `lsm_c_pland`.

One forest or many patches

Largest patch of forest (LPI)

`lpi_pct` · % of area · higher = less fragmented

In one line: The largest single patch of forest as a share of the whole area (the FRAGSTATS form).

- **What it measures:** area of the largest connected patch ÷ area analysed × 100.
- **Pitfalls:** mixes the amount of forest with its arrangement; use the % of forest version to judge arrangement.
- **Source / landscapemetrics:** FRAGSTATS LPI; identical to `lsm_c_lpi`.

Largest patch of forest, % of forest

`lpi_forest_pct` · % of forest · higher = less fragmented

In one line: How much of the forest is one connected patch: near 100 % = one forest, low = many patches.

- **What it measures:** area of the largest connected patch ÷ forest area × 100 (= LPI ÷ PLAND).
- **Read it:** answers "one forest or many patches?" directly. At 94 % the forest is nearly one patch; at 10 % even the largest patch holds only a tenth of it.
- **Pitfalls:** with 8-connectivity, two blocks touching at one cell corner count as one patch, so a high value can hide narrow connections.
- **Source / landscapemetrics:** exact arithmetic from LPI and PLAND.

Effective mesh size (MESH)

`mesh_ha` · ha · higher = less fragmented

In one line: The forest area two random points in the landscape can both reach without leaving forest.

- **What it measures:** Σ (patch area)² ÷ area analysed (Jaeger 2000). Patches are cut at the map border.
- **Read it:** the measure used in European landscape-fragmentation reporting.
- **Pitfalls:** whether MESH or coherence stays stable when the area analysed changes size depends on the landscape (Jaeger 2000; Moser et al. 2007). Where the forest is broken into patches much smaller than the area, MESH stays about the same; where one forest runs beyond the map, as in the demos, MESH grows with the area. Prefer areas of similar size.
- **Source / landscapemetrics:** identical to `lsm_c_mesh`.

Coherence (MESH ÷ area)

`coherence_pct` · % · higher = less fragmented

In one line: The chance that two random points anywhere in the area lie in the same patch of forest.

- **What it measures:** MESH ÷ area analysed × 100 (Jaeger's coherence).
- **Read it:** includes the amount of forest. With 66 % forest cover it cannot exceed $0.66^2 \approx 44$ % even if all the forest is one patch, so a low value does not by itself mean a broken-up forest.
- **Pitfalls:** the same size question as MESH, the other way round.
- **Source / landscapemetrics:** exact arithmetic from MESH.

Patches of forest (NP)

`n_patches` · count · direction ambiguous

In one line: How many separate patches of forest there are; mostly small woods, hedgerows and strips.

- **What it measures:** connected patches of forest of at least the minimum patch size.
- **Read it:** the count rises both when a forest breaks apart and when trees colonise open land as new small patches. More patches does not by itself mean a more fragmented forest.
- **Pitfalls:** depends strongly on the minimum patch size and the grain.
- **Source / landscapemetrics:** FRAGSTATS NP; identical to `lsm_c_np`.

Patches of forest per 100 ha of forest

`patches_per_100ha_forest` · per 100 ha of forest · direction ambiguous

In one line: Patches of forest per 100 ha of forest: how subdivided the forest itself is, whatever the cover.

- **What it measures:** NP ÷ forest area × 100.
- **Pitfalls:** this is *not* FRAGSTATS patch density (PD), which divides by 100 ha of landscape; PD = NP ÷ area analysed × 100 can be computed from the table.
- **Source / landscapemetrics:** exact arithmetic from NP.

Edge

Forest edge per hectare of forest

`edge_per_forest_ha` · m per ha of forest · higher = more fragmented

In one line: Metres of forest-open boundary per hectare of forest.

- **What it measures:** total length of forest / non-forest cell boundaries (where both cells have data) ÷ forest area.
- **Read it:** the amount of edge the forest carries. Windthrow and drying concentrate at the edge. Where the forest meets meadows, the edge is also a habitat in its own right (the forest-meadow ecotone) and the line along which forest spreads into meadows that are no longer mown or grazed.
- **Pitfalls:** edges are traced along cell sides, so the length depends strongly on the grain (it shortens as cells get coarser; Wu 2004). Compare only at the same grain.
- **Source / landscapemetrics:** exact arithmetic from total edge (TE ÷ CA).

Edge density (ED)

`edge_density` · m per ha of area · higher = more fragmented

In one line: Metres of forest-open boundary per hectare of the whole area (the FRAGSTATS form).

- **Pitfalls:** differs from edge per forest hectare by exactly the forest share; mixing the two up is a common way to get a comparison wrong. Depends strongly on the grain.
- **Source / landscapemetrics:** FRAGSTATS ED; identical to `lsm_c_ed`.

Core forest

Core forest, % of forest

`core_pct` · % of forest · higher = less fragmented

In one line: Share of the forest farther than the edge depth from open land, beyond the reach of edge effects.

- **What it measures:** forest cells whose true (straight-line) distance to the nearest open land is greater than the edge depth. The map border and no-data are not open land.
- **Read it (management):** where forest-interior conditions can be expected; the zone where a new road, clearing or hard edge costs the most.
- **Read it (ecology):** forest beyond the reach of edge effects on light, wind and humidity, and on forest structure and composition (Chen et al. 1992, 1995; Harper et al. 2005).
- **Pitfalls:** how far edges reach differs between forests: less far into dense stands than into open, thinned ones (Meeussen et al. 2020, 2021). Core forest depends on the edge depth (see the core-depth curve) and strongly on the minimum opening size (see the Opening size check). Interior conditions are assumed from geometry, not measured.
- **Source / landscapemetrics:** same idea as FRAGSTATS core area (CPLAND), but *deliberately different*. landscapemetrics counts distance in cell steps up, down, left and right, which lets core reach closer to

diagonal edges, and by default treats the map border as edge. Ours equals an inward buffer of the forest in a GIS. The two can agree by chance or differ by several points; the check script prints both.

Core forest, hectares

`core_ha` · ha · higher = less fragmented

In one line: Hectares of core forest at the edge depth.

- **Pitfalls:** grows with the size of the area; compare between areas only as a share of forest.

Core forest at the second depth

`core_report_pct` · % of forest · higher = less fragmented

In one line: Share of the forest farther than the second, reporting depth (default 100 m) from open land.

- **Read it:** for comparison with European core-forest figures: the JRC counted forest more than 100 m from the forest border as interior forest (Estreguil et al. 2012), a reporting convention.

Core blocks

`n_core_blocks` · count · fewer, larger blocks = less fragmented

In one line: How many separate blocks the core forest forms, counting only blocks of at least the minimum patch size.

- **What it measures:** connected groups of core cells; slivers smaller than the minimum patch size are not counted (they are left where edge zones almost meet).
- **Read it:** a few hundred hectares of core in one block is a working core-forest system; the same hectares in many small blocks is core habitat for almost nothing that needs space.
- **Source / landscapemetrics:** the idea of NDCA (number of disjunct core areas), on our core.

Largest core block

`largest_core_block_ha` · ha · higher = less fragmented

In one line: Area of the largest continuous block of core forest; compare it with a species' area requirement.

- **Pitfalls:** capped by the size of the area analysed.

Core held by the largest core block

`largest_core_block_pct` · % of core · higher = less fragmented

In one line: Share of all core forest that lies in the single largest core block.

Core within the edge depth of the map border

`core_near_border_pct` · % of core · lower = more reliable

In one line: Share of the core that lies close to the map border, where it rests on the assumption that the forest continues beyond the map.

- **Read it:** a quality flag, not a fragmentation indicator. A map that reaches beyond the area of interest makes it small.

Morphology

Every forest cell falls into one of four classes, which add up to 100 % of the forest: **core**, **outer edge**, **perforation edge** and **islet**.

These classes come from **MSPA, Morphological Spatial Pattern Analysis** (Soille & Vogt 2009), an image-analysis method in the JRC's GuidosToolbox (Vogt & Riitters 2017). MSPA sorts every forest pixel of a map by its shape and position: core, edge, perforation, islet, and three kinds of narrow linear forest (bridges that join two core areas, loops that return to the same core area, branches that end in open land). This use case keeps the first four and lets narrow linear forest fall into edge, perforation or islet. It also measures the edge width as true distance in metres, where MSPA counts pixels, so its classes are close to MSPA's but not identical.

Bridges, loops and branches are left out on purpose. At this resolution, narrow strips of forest (hedgerows, riparian galleries, lines of trees) are where a forest map is least reliable; with a 50 m edge width every strip narrower than about 100 m would become a linear class; and whether a strip works as a corridor depends on the species. For the full seven MSPA classes, run GuidosToolbox on the forest map this use case exports (`*_forest_<map>.tif`).

Edge zone along the outer margin

`outer_edge_pct` · % of forest · higher = more fragmented

In one line: Forest within the edge depth of the open landscape outside the forest: the forest-farmland boundary.

- **What it measures:** non-core forest in patches that have core, whose nearest open land is the open matrix (open land connected to the map border or a no-data gap).

Edge zone around openings (perforation)

`perforation_pct` · % of forest · higher = more fragmented

In one line: Forest within the edge depth of an opening enclosed by forest: the forest holed from inside.

- **What it measures:** non-core forest whose nearest open land is an opening enclosed by forest.
- **Read it:** holes are what management and succession change fastest.
- **Pitfalls:** size plays no part, as in MSPA: a large meadow fully enclosed by forest counts as perforation just like a small clearing, although its edge behaves more like an outer edge. Read a high value with the map. Over time, open land that becomes enclosed by regrowth turns outer edge into perforation without any new cutting.

Islets

`islet_pct` · % of forest · higher = more fragmented

In one line: Forest in patches so small or narrow that they have no core at all.

Openings enclosed by forest

`n_enclosed_openings` · count

In one line: How many openings of at least the minimum size lie inside the forest, not connected to the open landscape.

- **Pitfalls:** depends strongly on the minimum opening size (see the Opening size check). Openings touching the map border count as open landscape, because it cannot be seen whether they close beyond the map.

Forest area density (FAD)

FAD is the share of forest in a square window (`FAD_WINDOW_M`) around each forest cell (Riitters et al. 2002), classed as in the JRC GuidosToolbox: rare < 10 %, patchy 10-40 %, transitional 40-60 %, dominant 60-90 %, interior 90-< 100 %, intact 100 % (Vogt 2026). *Interior* here is only the name of a FAD class; it is not core forest.

Forest where FAD could be assessed

`fad_assessed_pct` · % of forest

In one line: Share of the forest far enough from the map border for its whole FAD window to lie on the map.

- **Read it:** every FAD figure refers to this part of the forest only.

Mean forest area density

`mean_fad_pct` · % · higher = less fragmented

In one line: Average forest share in the window around each assessed forest cell.

Forest in dense surroundings (FAD ≥ 90 %)

`fad_interior_intact_pct` · % of assessed forest · higher = less fragmented

In one line: Share of the assessed forest whose surrounding window is at least 90 % forest (classes interior and intact).

- **Read it:** where the landscape around the forest is itself forested; the JRC calls 90 % "a reasonable threshold for core habitat" (their wording, not this guide's core forest).
- **Pitfalls:** depends on the window; quote it with the window size.

Forest in sparse surroundings (FAD < 40 %)

`fad_rare_patchy_pct` · % of assessed forest · higher = more fragmented

In one line: Share of the assessed forest whose surrounding window is less than 40 % forest (classes rare and patchy).

- **Read it (management):** where the forest thins out at the landscape scale: priority areas for keeping connectivity.

7 · The maps

Morphology map. Core (dark green), outer edge (light green), perforation edge (orange), islets (purple), non-forest (beige). The GeoTIFF codes are 1 core, 2 outer edge, 3 perforation edge, 4 islet, 0 non-forest, 255 no data.

Forest area density map. The six FAD classes on forest, with *rare* in orange so that isolated woods stand out; forest within half a window of the map border is lilac (*not assessed*). The GeoTIFF holds the FAD value itself: 1-100 % on forest (rounded down, so the value falls in its own class), 101 non-forest, 102 no data, 103 forest not assessed. Square shapes are expected: a single opening lowers FAD in every window that contains it.

Permanent core map *(two dates)*. Codes 1 permanent core, 2 new core on former forest edge, 3 new core on former open land, 4 core lost, 5 other forest, 0 non-forest, 255 no data.

Every GeoTIFF comes with a QGIS style (`.qml` of the same name), applied automatically when the map is opened in QGIS.

8 · Two dates: what changed

The two-date mode reports change in the **fragmentation indicators**, not land-cover change.

- **Change column.** Every indicator at both dates, with the change. Hectares and counts are comparable here, because both dates cover the same area.

- **Permanent core.** Core forest at both dates: forest that has kept forest-interior conditions for at least the time between the two maps. That continuity is what old-growth specialists depend on (epiphytic lichens and bryophytes, saproxylic beetles, wood fungi). The second date's core is split into *permanent*, *new on former forest edge* (edge that became core once nearby openings closed) and *new on former open land* (young forest on former fields, core by geometry only, with different soils and ground flora); the first date's core that disappeared is *lost*. The largest block of permanent core is given in hectares. "Permanent" means core at both dates, not necessarily in between, and it is not the same as old-growth.
- **Where the core came from.** A flow diagram and a table of morphology class at the first date against the second.
- **Forest area density on forest present at both dates.** How the surroundings of the persisting forest changed; the gain or loss of forest cells themselves is kept out, as in GuidosToolbox change analysis. The per-cell change is written to `*_fad_change.tif`.
- **Why the forest edge changed.** The change in boundary length split into *forest loss*, *infill* (enclosed openings closing over; their whole perimeter disappears) and *outward creep* (the outer edge advancing into open land; the boundary moves). A negative *forest loss* means the forest lost was mostly small patches whose whole perimeter disappeared. Metres per hectare compare the mechanisms fairly: infill usually removes far more edge per hectare than creep.

Less fragmented is not automatically better. Forest that grows over hay meadows and pastures replaces protected semi-natural grassland (EU habitat type 6520, mountain hay meadows). These indicators describe the forest; they do not weigh it against the open habitats it replaced.

9 · Comparing two areas

- Both maps are analysed at the same grain and with the same rules.
- Hectares and counts grow with the size of the area, so the interface gives no difference for them unless both areas are the same size (within 1 %). Compare shares and densities.
- A difference in forest cover drives most other differences. Read arrangement *given* the amount: core share of forest, edge per hectare of forest, largest patch as % of forest.
- The maps are drawn at one scale, so a smaller area also looks smaller.

10 · The checks

Grain check. The same analysis at 0.5, 2, 5, 10 and 20 m. In the Ruské demo, forest cover, coherence and the largest patch barely move, core forest is stable up to about 5 m, and edge length falls steadily as the grain coarsens. Quote edge figures only with their grain.

Opening size check. The same analysis with minimum openings of none, 0.1, 0.25, 0.5, 1 and 2 ha. Every opening, however small, gets a full edge zone, so a 0.1 ha opening about 35 m across turns roughly 1.4 ha of the surrounding forest into edge at 50 m. Core forest and perforation depend on this setting more than on any other. *None* shows the map with no size rule: every speck of classification noise then casts edge, and in the Ruské demo core forest nearly vanishes.

11 · Reporting a number

Quote every number with its settings: grain, minimum opening and patch size, edge depth and FAD window. `*_indicators.csv` repeats them on every row, the README of each run lists them, and the *Ready to quote* sentence ends with them. For FAD, also give the share of forest that was assessed. For core forest, say that it is measured as true distance with the map border not counted as edge, and compare only with results of the same method.

12 · What the numbers cannot say

- **The map is the ceiling.** Every indicator inherits the forest map's errors.
- **Two dates, two sensors.** Where two separately classified maps disagree along a shared boundary, the disagreement looks like a thin band of change. The size rule removes speckle, not a systematic shift of the boundary.
- **Conventions, not measurements.** Edge depth, minimum opening and patch size, grain and FAD window are choices. The core-depth curve and the two checks show how much each matters.
- **Geometry is not habitat quality.** Core by geometry is not old-growth forest, and forest edge is not a measured ecotone: edge effects depend on edge orientation, contrast and stand height, none of which is measured here.
- **The map border.** Core near it assumes the forest continues; FAD is not assessed within half a window of it. Both vanish if the map reaches beyond the area of interest.

13 · Files of a run

Every run writes files starting with `retrofrag_<name>_<mode>_<grain>m_`. The `*_README.txt` of the run lists each file with its meaning and the settings; the main ones are:

File	Content
`*_indicators.csv`	every indicator for every map, with unit, grain and rules
`*_provenance.csv`	inputs, all settings and package versions
`*_core_depth.csv`	core share at every edge depth 0-300 m, with and without core resting on the map border
`*_fad_classes.csv`	forest area in each FAD class
`*_forest_<map>.tif`, `*_morphology_<map>.tif`, `*_fad_<map>.tif`	the measured forest map, the morphology classes and FAD, each with a `.qml` style
`*_index_change.csv`, `*_morph_transitions.csv`, `*_fad_transitions.csv`, `*_edge_attribution.csv`, `*_permanent_core.csv/.tif`, `*_fad_change.tif`	two dates
`*_grain_sweep.csv`, `*_opening_sweep.csv`	the checks

File	Content
`*_00a…09_*.png`	the figures
`*_manual.md`	this guide

14 · References

- Chen, J., Franklin, J.F. & Spies, T.A. (1992). Vegetation responses to edge environments in old-growth Douglas-fir forests. *Ecological Applications* 2(4): 387-396. https://doi.org/10.2307/1941873

- Chen, J., Franklin, J.F. & Spies, T.A. (1995). Growing-season microclimatic gradients from clearcut edges into old-growth Douglas-fir forests. *Ecological Applications* 5(1): 74-86. https://doi.org/10.2307/1942053

- Estreguil, C., Caudullo, G., de Rigo, D., Whitmore, C. & San-Miguel-Ayanz, J. (2012). Reporting on European forest fragmentation: standardized indices and web map services. *IEEE Earthzine* 5(2). http://www.earthzine.org/?p=384031

- Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics* 34: 487-515. https://doi.org/10.1146/annurev.ecolsys.34.011802.132419

- Harper, K.A., Macdonald, S.E., Burton, P.J., Chen, J., Brosofske, K.D., Saunders, S.C., Euskirchen, E.S., Roberts, D., Jaiteh, M.S. & Esseen, P.-A. (2005). Edge influence on forest structure and composition in fragmented landscapes. *Conservation Biology* 19(3): 768-782. https://doi.org/10.1111/j.1523-1739.2005.00045.x

- Hesselbarth, M.H.K., Sciaini, M., With, K.A., Wiegand, K. & Nowosad, J. (2019). landscapemetrics: an open-source R tool to calculate landscape metrics. *Ecography* 42(10): 1648-1657. https://doi.org/10.1111/ecog.04617

- Jaeger, J.A.G. (2000). Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology* 15(2): 115-130. https://doi.org/10.1023/A:1008129329289

- McGarigal, K., Cushman, S.A. & Ene, E. (2012). FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program, University of Massachusetts, Amherst.

- Meeussen, C., Govaert, S., Vanneste, T., Calders, K., Bollmann, K., Brunet, J., Cousins, S.A.O., Diekmann, M., Graae, B.J., Hedwall, P.-O., Krishna Moorthy, S.M., Iacopetti, G., Lenoir, J., Lindmo, S., Orczewska, A., Ponette, Q., Plue, J., Selvi, F., Spicher, F., Tolosano, M., Verbeeck, H., Verheyen, K., Vangansbeke, P. & De Frenne, P. (2020). Structural variation of forest edges across Europe. *Forest Ecology and Management* 462: 117929. https://doi.org/10.1016/j.foreco.2020.117929

- Meeussen, C., Govaert, S., Vanneste, T., Bollmann, K., Brunet, J., Calders, K., Cousins, S.A.O., De Pauw, K., Diekmann, M., Gasperini, C., Hedwall, P.-O., Hylander, K., Iacopetti, G., Lenoir, J., Lindmo, S., Orczewska, A., Ponette, Q., Plue, J., Sanczuk, P., Selvi, F., Spicher, F., Verbeeck, H., Zellweger, F., Verheyen, K., Vangansbeke, P. & De Frenne, P. (2021). Microclimatic edge-to-interior gradients of European deciduous forests. *Agricultural and Forest Meteorology* 311: 108699. https://doi.org/10.1016/j.agrformet.2021.108699

- Moser, B., Jaeger, J.A.G., Tappeiner, U., Tasser, E. & Eiselt, B. (2007). Modification of the effective mesh size for measuring landscape fragmentation to solve the boundary problem. *Landscape Ecology* 22(3): 447-459. https://doi.org/10.1007/s10980-006-9023-0

- 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(8): 815-822. https://doi.org/10.1007/s10021-002-0209-2

- Soille, P. & Vogt, P. (2009). Morphological segmentation of binary patterns. *Pattern Recognition Letters* 30(4): 456-459. https://doi.org/10.1016/j.patrec.2008.10.015

- Vogt, P. (2026). *Quantifying Forest Connectivity/Fragmentation*. GuidosToolbox product sheet, June 2026. European Commission, Joint Research Centre, Ispra. https://ies-ows.jrc.ec.europa.eu/gtb/GTB/psheets/GTB-Fragmentation-FADFOS.pdf

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

- Wu, J. (2004). Effects of changing scale on landscape pattern analysis: scaling relations. *Landscape Ecology* 19(2): 125-138. https://doi.org/10.1023/B:LAND.0000021711.40074.ae

15 · About RETROFRAG

RETROFRAG measures forest fragmentation, forest edges and core forest on any forest / non-forest map: one map, the same area at two dates, or two areas at one date. It was developed as a use case of the RETROCHANGE project (EOSC Federation), with forest maps derived from declassified 1975 KH-9 Hexagon satellite imagery as the worked examples.

- **Version:** 1.0, October 2026. The version is written into the README and the `*_provenance.csv` of every run, so each result can be traced to the version that made it.

- **Author and contact:** Ladislav Šumichrast, Technical University in Zvolen - xsumichrastl@tuzvo.sk

- **Files:** the analysis notebook `forest_fragmentation.ipynb`, the interface notebook `forest_fragmentation_app.ipynb`, this guide, and the environment file `env/environment-uc-fragmentation.yml`.

- **Requirements:** Python ≥ 3.9 with numpy, scipy, pandas, rasterio and matplotlib; the interface also needs ipywidgets ≥ 8 and nbclient. Missing libraries are installed on the first run. It runs in JupyterLab on the EOSC EU Node or on your own computer.

- **What it builds on:** FRAGSTATS indices (McGarigal et al. 2012), morphological spatial pattern analysis (Soille & Vogt 2009) and forest area density (Riitters et al. 2002; Vogt 2026). Forest cover, largest patch, effective mesh size, edge density and the number of patches match the R package landscapemetrics (Hesselbarth et al. 2019).

- **Example data:** Forest maps derived from KH-9 Hexagon imagery (1975); the modern Ruské map uses Ortofotomozaika 2017-2019 © GKÚ Bratislava, NLC. The map filename retains the label 2017. Producing the forest maps is not part of RETROFRAG.

- **Limits:** the indicators inherit any errors of the input map, and the settings (grain, size rule, edge depth) change the numbers, so quote the settings with every number (section 11). The tool is provided as is, without warranty.

Verification and input consistency (November 2026)

In `two_dates` mode, both the interface and the analysis notebook require equal coordinate reference systems as well as matching dimensions and grid transforms. Matching coordinate numbers alone do not establish a shared CRS. Reproject and align inputs before comparison; the comparison does not reproject them for you. The `two_areas` mode still allows different projected metric CRSs.

The map preview respects the file's validity mask and the selected extra **No-data value**, using the same exclusion rule as the analysis reader. Changing that setting refreshes both previews. The preview remains a sampled approximation for large rasters; the analysis reads their full coverage.

Run the focused regression checks from the application root in its analysis environment:

```
python -m unittest discover -s tests -v
```