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Improving forest connectivity assessments using tree cover density maps

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A B S T R A C T

Forests are vital for sustaining biodiversity and regulating climate. However, the fragmentation of these critical ecosystems poses a serious threat to their ecological integrity and the myriad of organisms they support. In this paper we compare the degree of forest connectivity derived via the traditional approach of using a binary forest cover map with a new approach using a grayscale tree cover density map. Because connectivity is scale-dependent, the comparison is repeated for a series of analysis scales. We find that exploiting the additional information on tree cover density improves the precision of forest connectivity estimates. The degree of connectivity was on average 21% lower when using the tree cover density map compared to using the binary forest cover map. Additional benefits of using tree cover density maps are the detection and quantification of subtle temporal changes (gains and losses) and a more refined assessment of hotspots in forest connectivity that cannot be detected with binary maps. Improved assessment and monitoring capabilities can be instrumental to enhancing the design and assessing the efficacy of landscape management and restoration policies to improve forest connectivity. The generic conceptual approach is exemplified using the 2018 Copernicus Tree Cover Density dataset with all assessment tools available in open-source software packages.

1. Introduction

Forest ecosystems represent around 38 % of Europe's land area and are a critical component for biodiversity and climate change mitigation. However, pressures that lead to forest degradation and potentially undermine conservation and restoration efforts remain high (Maes et al., 2023). One of the aims of the European Green Deal,[1] a policy of the European Union (EU), is to increase the protection of healthy forests and restore degraded forests to a favorable condition. The adopted proposal for a Nature Restoration Law,[2] the flagship instrument of the European Green Deal, calls for binding targets to restore degraded ecosystems to enable the long-term and sustained recovery of biodiverse and resilient nature. Among its targets, the Nature Restoration Law calls to increase forest connectivity to satisfactory levels. The achievement of this target, however, requires robust information and spatially explicit indicators that accurately describe the status of forest connectivity across the EU.

There are many approaches to measuring connectivity, fragmentation, and other aspects of forest spatial patterns on a map (Gustafson, 1998; Li and Wu, 2004; Kupfer, 2012; Uuemaa et al., 2013, Lausch et al., 2015; Frazier and Kedron, 2017, Vallecillo et al., 2022). The choice of one approach over another depends, among other factors, on which aspects of pattern are deemed important in each study, and on the data available to conduct a meaningful analysis. In large-scale assessments, a desired level of detail or specificity must be balanced against data consistency and comparability over large areas. As a result, many national and international assessments have used forest maps derived from remotely sensed images which portray a few major land cover classes (e.g., forest, agriculture, urban, water, grassland) consistently at relatively high spatial resolution (e.g., 30 to 100 m). The fundamental information for calculating forest connectivity on such maps is the amount and distribution of forest. Furthermore, appropriate measures of forest area alone can be used to measure variation in connectivity and fragmentation over space, time, and measurement scale (Riitters and Wickham, 2012, Wickham and Riitters, 2019).

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[1] https://commission.europa.eu/strategy-and-policy/priorities-2019–2024/european-green-deal_en.
[2] https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en.

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On a binary forest/nonforest map, the degree of forest fragmentation can be evaluated by calculating the metric known as forest area density (FAD), defined as the percentage of area that is forest within a predefined analysis region. When mapped with a moving window analysis, a grid cell value represents the FAD within the surrounding window area. Larger values of FAD indicate higher connectivity because where there is more forest area, it is more likely that forest cells will be connected to other forest cells. Thus, connectivity is the complement of fragmentation. While connectivity is scale-dependent, or a function of the moving window size (Gonzáles-Ávila et al., 2023), its analysis is often conducted with a single moving window size that is representative for a specific ecological process or species of interest (Gustafson, 1998). To facilitate the visual interpretation, the full range of FAD values within [0, 100]% at the grid-cell level can be color-coded into a small number of categories showing the degree of connectivity (i.e., small, medium, high), and the resulting area for each category summarized for each reporting unit.

The FAD analysis has been adopted for reporting in FAO-UNEP SOFO 2020[3] (Vogt et al., 2019a), Forest Europe – State of Europe's Forests 2020[4] (Vogt et al., 2019b), Eurostat Regional Yearbook 2022[5] (Vogt & Caudullo, 2022a), EU Observatory on Deforestation and Forest Degradation[6] (Vogt & Caudullo, 2022b), MAES[7] (Maes et al., 2020, Maes et al., 2023), the US sustainability reporting under the international Montréal Process[8] (Riitters & Robertson, 2021) and the Resource Planning Act Assessment.[9] In the EU policy arena, the FAD approach has been embraced to measure the degree of forest connectivity in the 8th Environment Action Programme[10] (indicator 11) and the Nature Restoration Law[11] (Annex VI), which is integral to the European Green Deal,[12] the EU Biodiversity Strategy,[13] and the EU Forest Strategy.[14]

Previous FAD analyses used binary forest cover maps in which forest cover is either absent or present at a given location, i.e., a grid cell. Compared to the minimalistic information of binary forest cover maps, maps listing grid cell level tree cover density within the range [0, 100]% (e.g., Hansen et al., 2013; Kobayashi et al., 2016; Godinho et al., 2018; Eskandari et al., 2020; Hansen et al., 2022; Cilek et al., 2022) provide more precise information about forest cover at each location. Because tree cover density maps are being considered for inclusion in some of the assessment processes mentioned above, the objective of this paper is to compare the degree of forest connectivity derived via the traditional approach using a binary forest cover map versus a new approach using a grayscale (continuous) tree cover density (TCD) map. We expect that using the more detailed TCD information will lead to a more refined assessment that is more sensitive to small changes in forest canopy cover, and hence will better reflect changes in the degree of forest connectivity in comparison to the traditional binary approach.

In this paper, we illustrate how exploiting the additional information contained in a TCD map could lead to a more realistic assessment of forest connectivity and provide new enhanced monitoring features that cannot be detected from binary forest cover maps. To inform potential uses of TCD maps, we address two key questions. First, how large is the difference and where is the difference in connectivity most pronounced? Second, how does the result change under different analysis scales? The answers to these questions can help guide the choices of forest maps that are used in future assessments.

2. Methods

The FAD metric was calculated for each forest grid cell of the binary forest cover map as the number of forest grid cells found within the moving window divided by the number of grid cells in the window. Maximum connectivity (100 %) occurs where all grid cells in the moving window, here 31x31 = 961 cells or ~ 10 km^2, are forested. The analogous metric on a grayscale map such as TCD is simply the mean tree cover percent within the moving window. Now suppose that a TCD map has been converted to a binary forest/nonforest map using a threshold TCD of 30 % to define forest. For this example, in a 3x3 window with 5 forest grid cells having 30 % tree cover, FAD = ((5*1) +(4*0))/9 = 5/9 = 0.555, or 55.5 %, while the mean tree cover density ($\overline{TCD}$) value is ((5*0.3) + (4*0))/9 = 1.5/9 = 0.166, or 16.6 %. We calculated and mapped both metrics using the software GraySpatCon (Riitters and Vogt, 2023).

The 2018 Copernicus TCD map[15] includes the territories of the EU, UK, Norway, Switzerland, and Türkiye, which are the focus of this study. The Copernicus High Resolution Layers Forest[16] defines TCD as the "vertical projection of tree crowns to a horizontal earth's surface" and provides information on the proportional crown coverage per grid cell. We used the same TCD map to define both tree cover percent and to derive a comparable binary forest/nonforest map. Using the same source dataset eliminates differences due to different definitions of forest, methods, and/or spatial and spectral properties of the sensor that were used for setting up potentially different source datasets.

The raw Copernicus TCD dataset has a spatial resolution of 100 m and grid cells are coded with rounded (ordinal) values of percent tree cover in the range [0 to 100]; the value of 255 is reserved for nodata. The binary forest cover map (tcd_bin) was defined by applying a threshold of 30 % to the TCD map, resulting in grid cells of either 0 (nonforest), 100 (forest), or 255 (nodata). While a TCD threshold value of 30 % may be debatable, this value was chosen by FAO to define forest grid cells from the layer Forest Fractional Cover[17] of the COPERNICUS Global Land Cover Map (Vogt et al., 2019a). The grayscale tree cover density map (tcd_gray) was masked using the binary forest map, therefore it has identical spatial coverage and number of forest grid cells as the binary forest cover map but with forest cells showing the actual TCD value within [30, 100] (Fig. 1).

Both FAD and $\overline{TCD}$ were calculated for the entire European map extent and then separated within biogeographical regions (Metzger et al., 2005). The scale-dependency of forest connectivity was analyzed by applying four moving window sizes with side lengths of 3, 9, 31, and 99 grid cells, corresponding to a local neighborhood analysis scale of 0.09, 0.81, 9.61, and 98.01 km^2, or rounded to the nearest square km, approximately 0.1, 1, 10, 100 km^2. These window sizes were selected to span a wide range of scales representing an approximately geometric progression of analysis scales.

[3] https://www.fao.org/documents/card/en/c/ca8642en.
[4] https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf.
[5] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Eurostat_regional_yearbook.
[6] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52021PC0706.
[7] https://www.eea.europa.eu/themes/biodiversity/mapping-europes-ecosystems.
[8] https://montreal-process.org.
[9] https://www.fs.usda.gov/research/inventory/rpaa/2020.
[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:357:FIN
[11] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0304.
[12] https://eur-lex.europa.eu/EN/legal-content/summary/european-green-deal.html.
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380.
[14] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0572.
[15] https://land.copernicus.eu/pan-european/high-resolution-layers/forests.
[16] https://land.copernicus.eu/user-corner/technical-library/forest-2018-user-manual.pdf.
[17] https://lcviewer.vito.be/2015.

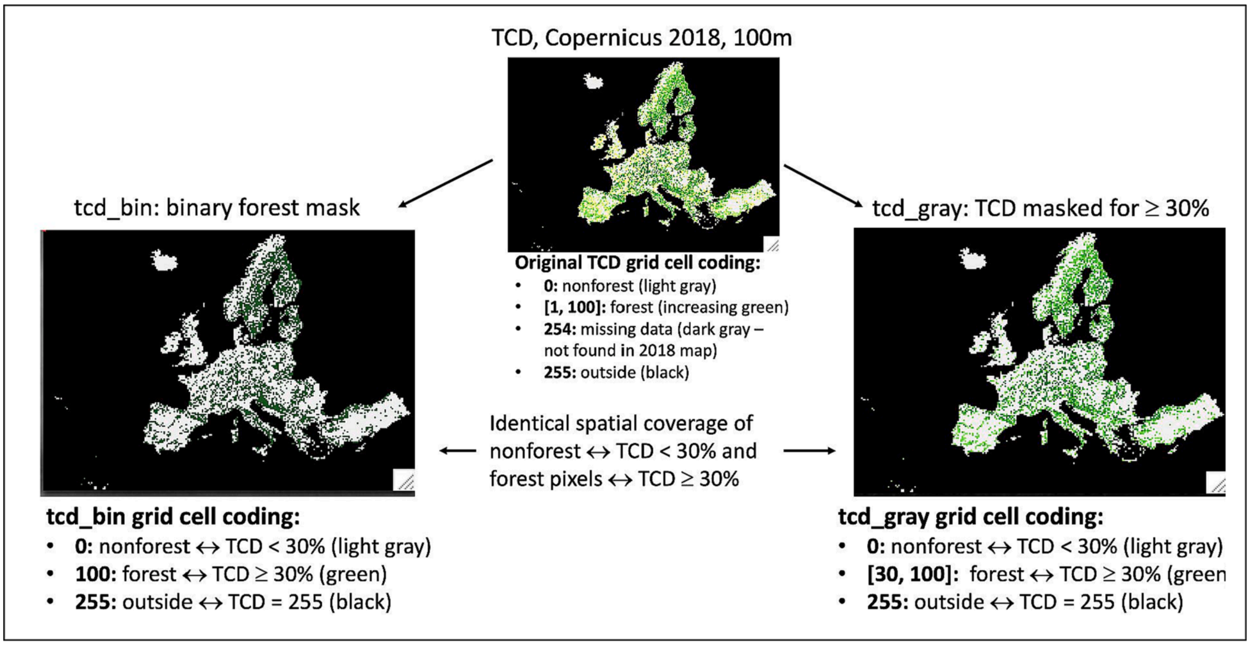

Fig. 1. Definition of tcd_bin, the binary forest cover map and tcd_gray, the grayscale tree cover density (TCD) masked map derived from the Copernicus TCD map.

3. Results

3.1. Difference in forest connectivity derived from the binary and the grayscale map

There were considerable differences in degree of forest connectivity derived from the binary map via FAD and the grayscale map via $\overline{TCD}$. Lower overall connectivity was found for the grayscale map (Fig. 2).

The summary differences in cell values for all forest cells (Fig. 3) shows that the degree of connectivity derived from the grayscale map is on average 21 % lower than that of the binary map, with average connectivity of 64 % and 43 %, respectively (Fig. 3).

In the EU-wide example map, 0.96 % of all forest cells on the binary map have the maximum connectivity of 100 % within their local neighborhood of ~ 10 km^2. The equivalent situation on a grayscale TCD map requires that all forest grid cells in the local neighborhood would need to have a TCD value of 100 %, which is never encountered. Maximum connectivity on the grayscale map is 98 %, which is found for only 0.0004 % of all forest cells.

3.2. Difference in forest connectivity across observation scales

The range of TCD values in [30, 100]% leads to a smooth distribution of the frequency curve for the grayscale connectivity (conGray). In contrast, the connectivity frequency curve of the binary map (conBin) shows a binned distribution, which is further examined for four observation scales with moving window side lengths of 3, 9, 31, 99 grid cells (Fig. 4).

The binned frequency distribution of the connectivity calculated using the binary map was most pronounced for the smallest observation scale of a 3x3 moving window (Fig. 4a). Here, the total number of grid cells is 9, and the potential number of forest cells within the moving window goes from 1 to 9 resulting in 9 potential FAD values of [11, 22, 33, …, 100]%. With increasing moving window size, the number of potential bins within the range [0, 100]% increases, leading to an increasingly smoother frequency distribution.

Increasing the moving window size reduces the average connectivity in both maps. However, this effect is less pronounced on the grayscale map where the average connectivity decreases from 56 % to 38 %, or 18 percent points, while connectivity on the binary map decreases from 85 % to 57 %, or 28 percent points. Across all observation scales, the average connectivity is 20 % lower on the grayscale map (Fig. 4e).

3.3. Forest connectivity across ecological regions

We investigated spatial differences in forest connectivity across ecological regions using the connectivity map created with the 10 km^2 moving window size. The two smaller scales of window size 3 and 9, equivalent to observation scales of 0.09 km^2 and 0.81 km^2, respectively, are probably too small to provide an ecologically meaningful assessment and statistically, even a size of 9 is only marginally sufficient to estimate a proportion based on binary observations. The 2018 EU map of Environmental Zones[18] (derived from Metzger et al., 2005) provides 15 ecozones (Fig. 5).

The European environmental zones exhibit an overall similar skewed distribution with average difference values in connectivity of up to 26 % in Scandinavia and in the Mediterranean (Fig. 5 zone 1, 2, 13), versus a lower value of 12 % for the central Atlantic zone (Fig. 5 zone 7).

3.4. Hotspots of forest connectivity

In this section, we locate and then compare regions of very high connectivity on the binary and the grayscale connectivity map. For connectivity derived from the binary map we define very high connectivity for grid cells having a connectivity value of 90 % and higher. Since the average connectivity derived from the grayscale map is 21 % lower (Fig. 2), we define very high connectivity derived from the grayscale map for grid cells having a connectivity value of 69 % (i.e., 90 % – 21 %) and higher. To directly compare connectivity hotspots, we locate and mark grid cells with the 10-percent highest connectivity values (88 %-98 %) on the grayscale connectivity map in a different color (Fig. 6).

When accounting for the 21 % difference in average connectivity on the grayscale connectivity map (conGray ≥ 69 %), the overall distribution at EU-level resembles that of the very high connectivity derived from the binary map. However, the spatial coverage and distribution of

[18] https://sdi.eea.europa.eu/catalogue/idp/eng/catalog.search#/metadata/6ef007ab-1fcd-4c4f-bc96-14e8afbcb688.

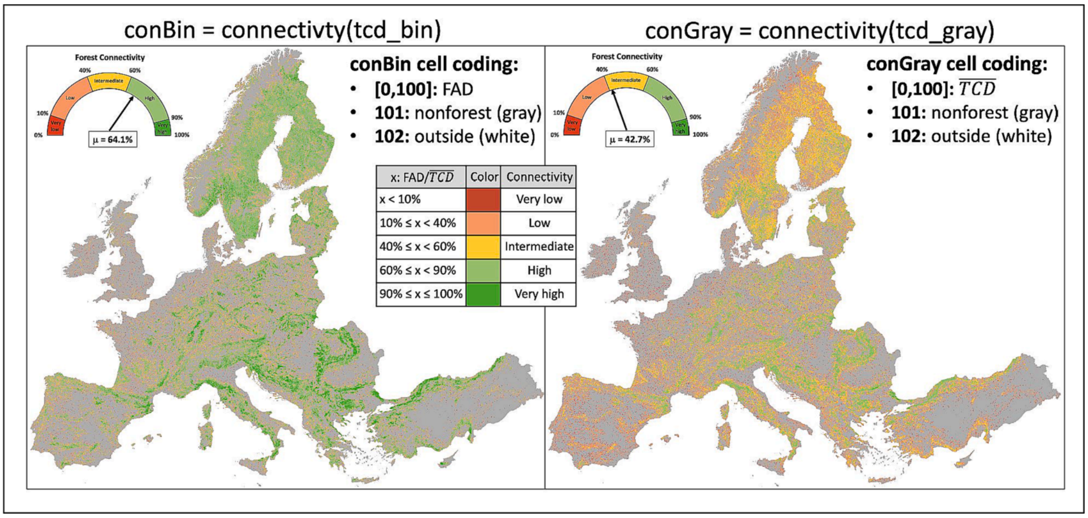

Fig. 2. Forest connectivity derived from the binary forest cover map (left) and the grayscale tree cover density map (right) calculated using a 10 km^2 moving window with the average connectivity value (μ) outlined in the gauge chart in the top left corner.

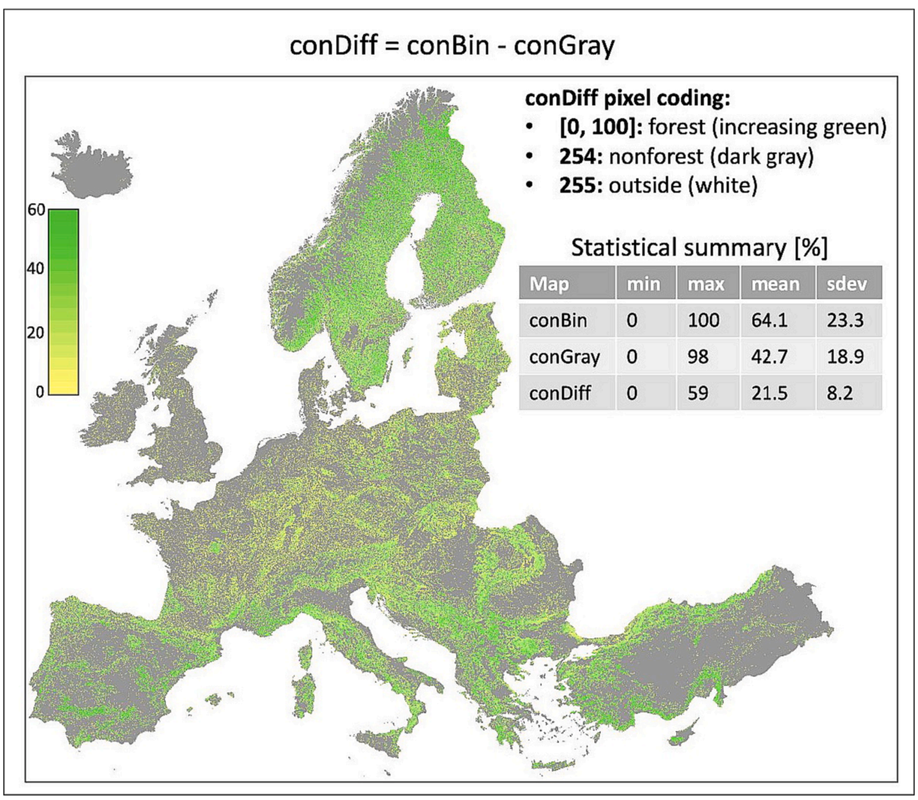

Fig. 3. Percent difference in forest connectivity derived from the binary forest cover map (conBin) and the grayscale tree cover map (conGray) created using a 10 km^2 moving window.

very high connectivity is not identical. For example, in the northeast of Finland and southern Spain, areas of very high connectivity are found on the connectivity map derived from the binary map (oval in Fig. 6, left panel) only. The reason is that grid cell connectivity values derived from the grayscale map (conGray) are not consistently smaller by 21 % but vary around this average value according to the TCD range within their local neighborhood (Fig. 4e). This is confirmed by connectivity values of only 50 % or less on the grayscale connectivity map in the indicated areas in northeastern Finland or southern Spain. Moreover, since the $\overline{TCD}$ at grid cell level is rarely higher than 90 % (Fig. 4c), the grid cells within the 10 % highest value in connectivity on the grayscale map, color-coded in green in Fig. 6, are only a small subset of the high connectivity coverage where $\overline{TCD} \geq 69$ %, see the example zoom-in over a densely covered forest cover region in the southeastern Carpathian Mountains in central Romania (Fig. 6).

4. Discussion

In this paper we outline a conceptual approach to measure forest connectivity on a grayscale tree cover density map. A direct comparison

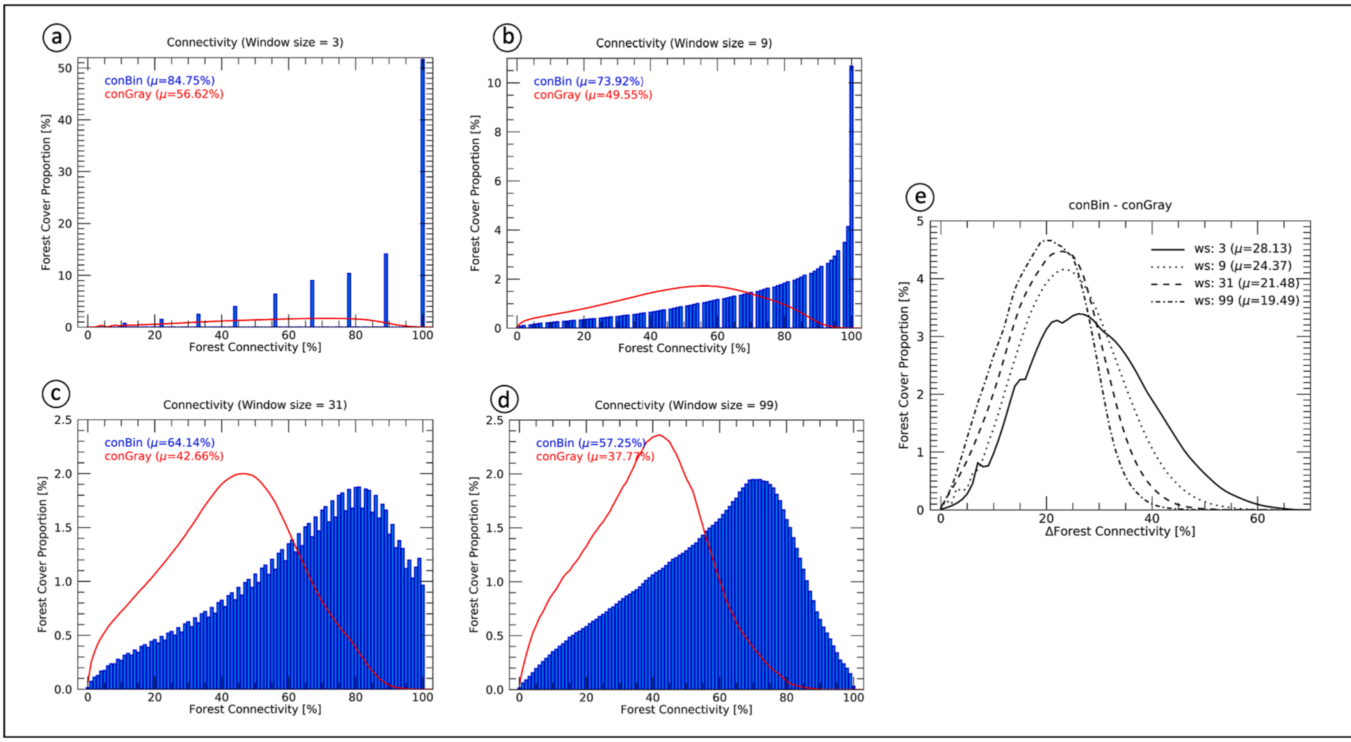

Fig. 4. Scale-dependency of the connectivity histogram for four moving window sizes (side length of 3, 9, 31, 99 grid cells) and the average connectivity difference value μ, derived from the binary and grayscale map (a – d); and summary of difference in connectivity for the four selected observation scales (e). Note the different scales in the vertical axis of the panels. The frequency distributions were normalized to show the proportion in forest cover. This choice was taken to better illustrate the strong impact of the moving window size on the resulting connectivity.

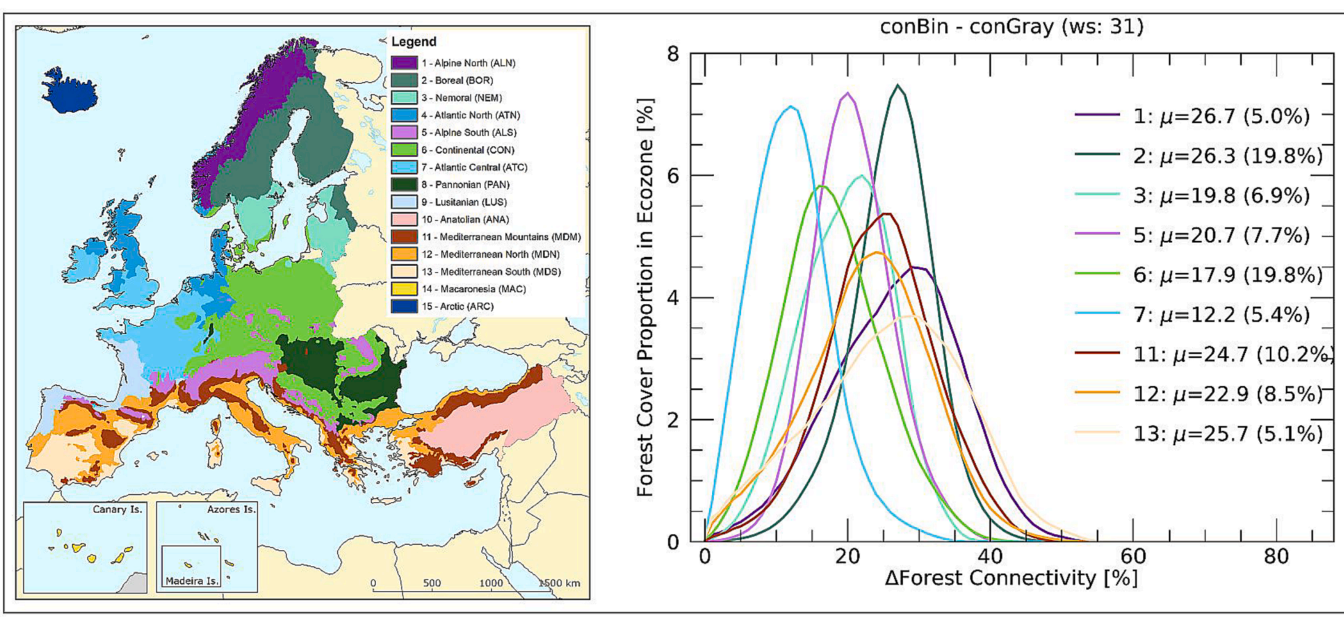

Fig. 5. European environmental zones (left). Difference between forest connectivity maps derived from a binary map and a grayscale map (right) per environmental zones with at least 5% of European forest cover, listing the average connectivity difference value (μ) and the proportion of EU forest cover in parenthesis.

to using a binary forest cover map shows that the latter leads to around 20 % higher degree in connectivity for most forest cells and across various observation scales.

The key difference between measuring connectivity on a binary map (via FAD) and on a grayscale map (via $\overline{TCD}$) is caused by the additional information of tree cover density at the grid cell level. When comparing the connectivity map derived from the binary and the grayscale map, we did not find a direct relation between FAD and $\overline{TCD}$. The explanation is that a given neighborhood can have the same number of forest grid cells but with a varying degree in TCD within these forest grid cells as result of e.g., non-stand replacing disturbances, or climatic and environmental constraints. Similarly, the degree of connectivity increases with increasing TCD of the forest cells within the local neighborhood, while the same situation does not trigger any change in connectivity on a bi-

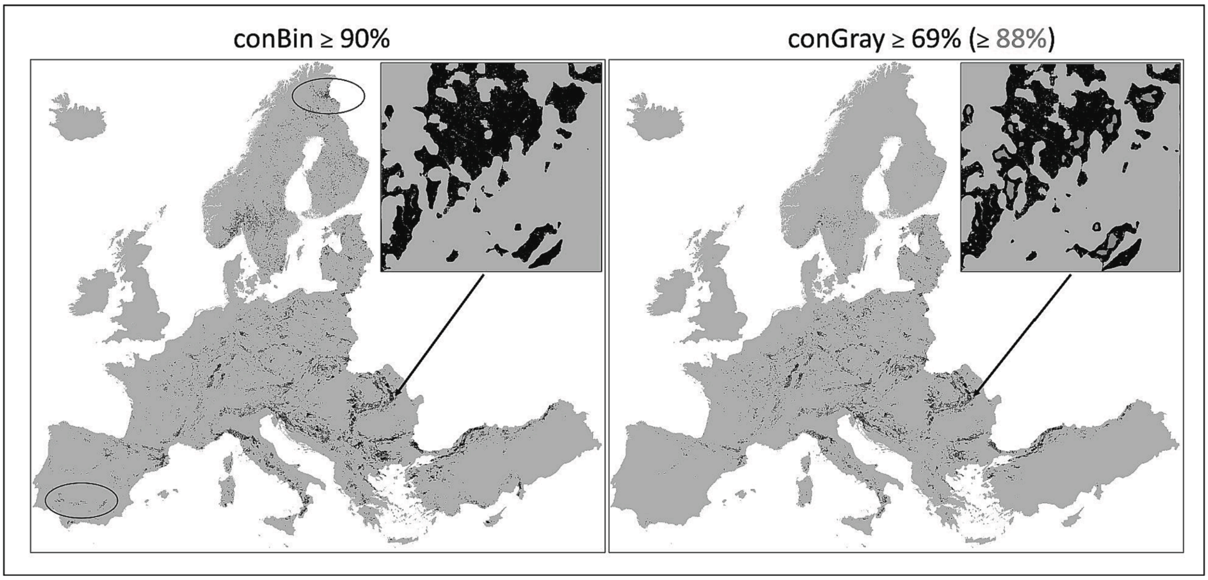

Fig. 6. Locations of highest forest connectivity derived from the binary forest cover map (left) and the grayscale tree cover density map (right) with a zoom on a location in the south-eastern Carpathian Mountains. Oval shapes on the binary map highlight example areas which were not assigned with very high connectivity on the grayscale map.

nary map. This suggests that using TCD may be more sensitive to subtle effects of forest restoration. For instance, the presence of young trees after reforestation could be represented by moderate to low values in TCD but those cells might be considered non-forest in a binary forest map.

Previous analysis of forest loss on TCD maps typically defined forest loss as a stand-replacing disturbance at the level of individual grid cells (e.g., Hansen et al., 2013). In our approach, forest loss or gain of any degree in neighboring grid cells affects $\overline{TCD}$ of a given grid cell location, thus offering enhanced interpretation of fragmentation as a spatial attribute. For example, a single grid cell with a high TCD value may persist over time but is likely affected by fragmentation or edge effects if all other tree cover in the neighborhood is lost. The statement "the higher the average tree cover density ($\overline{TCD}$), the more connected is the local forest neighborhood", which is equivalent to saying, "more trees in the same area make a forest more dense and connected", is not only very intuitive but it is also more realistic because the implicit assumption of a TCD of 100 % on a binary map will be an overestimation for most forest grid cells. One conclusion is that mapping of forest connectivity is improved when including the TCD information from grayscale maps. This finding was confirmed across various analysis scales (moving window sizes) in this study. It follows that change analyses are also improved when using TCD information.

Most ecological zones showed quite similar reductions in average connectivity in the temperate regions (Fig. 5). However, significant differences are evident in the Boreal and Mediterranean regions with connectivity values of only 50 % or less on the grayscale connectivity map (Fig. 6), which is explained by the typically lower tree density in these regions (Piper et al., 2016) or the frequent presence of water bodies in Scandinavia. While the average difference in connectivity between binary and grayscale connectivity maps is 21 %, this number is not evenly distributed across ecoregions (Fig. 5). This means that the comparison using the 69 % threshold could be problematic in those areas because even natural forests in good condition will have low tree density and therefore will deliver a lower, but more realistic connectivity value when using the TCD map. While a full interpretation of differences among ecoregions is beyond the scope of this paper, we can speculate that ecoregion-specific thresholds could be used to define forest cover; or in the case of Scandinavia, the specific effect of water could be eliminated simply by treating those grid cells as "missing" in our approach.[19]

When looking at temporal change in connectivity on binary maps, a change requires that a grid cell changes its status from forest to non-forest, or vice versa. In contrast, on grayscale maps, even subtle changes in TCD above the forest cover threshold level will trigger a temporal change in connectivity. This implies that analyzing TCD grayscale maps over time allows for capturing temporal changes in connectivity that cannot be detected on binary forest maps. From a spatial perspective, the results of this study demonstrated that the connectivity analysis derived from the grayscale map enhances the information delivered from the binary map. As a result, using grayscale TCD-maps contributes to a more realistic connectivity assessment. These benefits strongly suggest that analyzing a grayscale map not only better matches the actual situation in the field but is also more sensitive to detecting and quantifying temporal changes in connectivity, which is of particular importance when monitoring forest ecosystems at regular high temporal frequency such as every 1 to 3 years.

In the European Union, there are distinct differences in the national definition of forest, either for historical reasons, climatic or ecological conditions, or driven by national land use policies. For example, as outlined in Tomppo et al. (2010), the forest definition in Greece [or Germany] consider: Crown cover: $\geq$ 10 % [50 %]; Area: $\geq$ 0.5 ha [0.1 ha]; Width: $\geq$ 30 m [10 m]; Minimum tree height: 5 m at maturity *in situ* [not defined]. Most European countries provide a national forest inventory (NFI) and various attempts have tried to harmonize the different national definitions and reporting schemes at EU-level (Tomppo et al., 2010; Vidal et al., 2016a; Vidal et al., 2016b; Avitabile et al., 2023). Here, using a TCD map could facilitate the harmonization process by analyzing the full range of TCD values, which is a first step towards consolidating different national forest definitions. For example, a basic level of harmonization is provided by common use of a TCD map, while each country could reify connectivity estimates for national purposes by incorporating comparable maps of tree height (e.g., from LiDAR data) and information about forest patch size and width (from additional spatial analyses of thresholded TCD data). From an ecological

[19] While this analysis included water as a nonforest class, in practice it is possible to incorporate comparable land cover data to exclude water or any other land cover that is not considered a "fragmenting agent.".

perspective, the TCD map can be used to setup ecoregion specific TCD thresholds of good ecosystem condition (Maes et al., 2023), accounting for the natural maximum tree density expected within a biogeographical region. In this case, multi-national consolidation is better achieved to the extent that ecoregions span multiple countries. Our analyses illustrate how analyzing a TCD map could allow for a more comprehensive comparison between different biogeographical zones in large area assessments.

In general, it is critical to understand whether and where policy changes or land management actions have affected forest conditions. Because the public typically demands accountability for policies and land management, it is most helpful if that information can be available in near real-time. We showed that only the TCD map allows for capturing small temporal changes in forest connectivity, which is a crucial feature to assess the impact and potential success in forest restoration plans. We outlined why using a binary forest map may lead to an overestimation of approximately 20 % for the indicator forest connectivity, as compared to an otherwise comparable grayscale forest density map. Since this information has a direct impact on the degree of forest connectivity, it may be beneficial in the design and implementation phase of forest policy programs. Policy instruments that require close monitoring of forest connectivity, such as the proposals for the EU's Nature Restoration Law and Forest Monitoring Law,[20] would benefit from harmonized, wall-to-wall pan-European connectivity metrics that can be delivered at regular temporal intervals of three years or shorter. Monitoring forest restoration measures at local and landscape levels would require metrics sensitive to subtle changes in the short term, such as those resulting from tree planting, for instance. The $\overline{TCD}$ is well suited for this purpose. Realizing the full potential of using grayscale maps in forest connectivity assessments for landscape management and restoration warrants further research and collaboration with policymakers, scientists, data providers, and nature conservation authorities.

The results of this study are generic but indicative. As with other studies investigating forest pattern attributes, the results are driven by the choice of the dataset and the definition of forest and tree cover density. We used a TCD cutoff threshold of 30 % but expect conceptually similar results when using a different TCD threshold, or a different TCD dataset with different spatial resolution or map coverage. We could also have assigned an arbitrary lower value to the 100 % fixed value for forest cells in the binary map, which would have reduced the difference in connectivity between binary and grayscale maps, however the essential conclusion holds true. Analyzing a grayscale tree cover density map provides more comprehensive information than analyzing a binary forest cover map because it exploits the additional information on TCD, which is strongly associated to connectivity at grid cell level and hence offers more insights compared to FAD. The stronger link to connectivity may be especially important with respect to species or ecological processes that are sensitive to degree of forest cover. While this research focused on the assessment of forest connectivity, it is worth noting that a similar design could be applied to other thematic topics by analyzing other grayscale maps, showing for example the degree in habitat quality, imperviousness, or green infrastructure restoration potential. The transition from analyzing a binary thematic layer to analyzing a gradual thematic layer should always open new avenues due to exploiting the additional information content contained in the grayscale map.

The original data that support the findings of this study were obtained from publicly available datasets, and the websites providing access to these datasets are included in the article. The final processed data are openly available at https://doi.org/10.6084/m9.figshare.25117070.

[20] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023PC0728.

CRediT authorship contribution statement

Peter Vogt: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Kurt Riitters:** Writing – review & editing, Software, Methodology, Investigation, Formal analysis, Conceptualization. **José I. Barredo: . Jennifer Costanza:** Writing – review & editing. **Bernd Eckhardt:** Writing – review & editing. **Karen Schleeweis:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The section "Data availability" provides the information on the shared data

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