Delineating HCV forest areas using density analysis: it's not clear-cut

Preprint at EarthArXiv

Manuscript submitted to Conservation Biology

Oskar Englund

Dept. of Natural Science, Design and Sustainable Development
Mid Sweden University
Campus Östersund

oskar.englund@miun.se

Abstract

High conservation value (HCV) areas include natural habitats with high ecological, biological, social or cultural values. The use of spatial analysis using Geographic Information Systems (GIS) to identify HCV areas is more cost-efficient and less time consuming that field surveys. GIS-based approaches can also be necessary for identifying HCV areas in heterogeneous landscapes where, e.g., HCV forests are scattered across a production landscape.

This study explores the use of density analysis to identify and delineate HCV forest areas in the county of Norrbotten, Sweden (99,000 km2). First, multiple official spatial datasets were used to identify the existence of HCV forest with a resolution of 10 m. Second, the share of HCV forest in relation to total forest area (i.e., HCV forest density) within a moving window of varying size around each 10 m cell in the county was calculated. Finally, HCV areas were delineated using different thresholds for HCV forest density. Stakeholders were involved in every step.

The results show that outcomes are highly dependent both on the size of the moving window and the density threshold. The use of a smaller search window results in greater precision and smaller HCV areas, while a larger search window identifies larger areas but fails to identify small or irregularly shaped HCV areas. Similarly, a low density threshold can be used to identify small and irregularly shaped HCV areas but results in inaccurate delineation of larger homogenous HCV areas. The opposite can be observed for a large density threshold.

The use of density analysis for the purpose of delineating HCV areas in mixed forest landscapes can be effective for rationalizing the inventory of HCV areas, but method selection is critical and manual evaluation and adjustments are necessary. The potential for further method development, considering other relevant aspects, e.g., ecological connectivity, is notable.

Introduction

High conservation value (HCV) areas include natural habitats of critical significance due to their high ecological, biological, social or cultural values (Areendran et al. 2020; Sahana et al. 2023). The main reason for identifying HCV areas was originally to maintain or enhance social and environmental values in production landscapes by identifying (and preserving) HCV forests within, but it has shifted to more broad landscape planning for nature restoration and biodiversity conservation (Areendran et al. 2020).

For some applications, there are concrete guidelines to help identify, assess and monitor HCV areas (Sánchez-Almendro et al. 2018), but given that HCV can refer to ecological, biological, social or cultural values and that there can be many reasons for conducting a HCV assessment, the methods and processes for identifying HVC areas are often determined on a case-by-case basis. The most common approach for identifying HCV areas is field surveys but also through stakeholder consultation (Areendran et al. 2020).

Field surveys are time consuming and expensive and thereby impractical for large-scale assessments (Applestein & Germino 2024). They can also be characterized by subjectivity, both concerning what to look for and where to look for it (Hughes et al. 2021). As more and more high-quality geospatial data is becoming accessible and new analytical tools are being developed, the use of remote sensing and spatial analysis using Geographic Information Systems (GIS) is becoming more common for identifying HCV areas (Larekeng et al. 2021; Abbasnezhad & Abrams 2022). Such approaches can enable the integration and analysis of multiple environmental datasets—also from field surveys—and can facilitate an objective delineation of high conservation value areas over extensive landscapes. However, it is crucial to approach GIS-based analyses with caution; unvalidated (and even validated) model outputs can be inaccurate. It is therefore essential to select appropriate methods, use high-quality data, and carefully evaluate the results (Englund et al. 2017), preferably in collaboration with relevant stakeholders.

GIS-based approaches can also be necessary for identifying areas for nature conservation in heterogeneous landscapes where, e.g., forests with high ecological values are scattered in a landscape that is otherwise characterized by degraded forest. In such cases, even if all such areas can be identified manually, GIS-based methods are needed to understand how these areas are connected, and to what extent surrounding land-use could be adapted or regulated to maintain or enhance the ecological values at the landscape scale. Identifying and protecting only patches with high ecological values creates a fragmented landscape with limited ecological connectivity (Benitez et al. 2024).

One approach to identify such "extended" HCV areas that has been used to inform decision-making in northern Sweden (Bovin et al. 2017), is to calculate the density of HCV forest within a certain distance from each cell in the landscape and then delineate extended HCV areas from cells that exceed a certain density threshold. The benefit of this approach is that it can identify areas with a large concentration of HCV forests, which in theory can be suitable to target for biodiversity conservation at the landscape scale.

The problem with this approach is that it is treacherously convenient; the method is understandable, the data are solid, and the maps that are generated are, as usual (Hauck et al. 2013), convincing.

However, methodological choices affect the results substantially and if such analyses should be used for decision making it is essential that these choices are informed and that the uncertainties are accounted for.

An additional aspect to consider in HCV assessment is the need for stakeholder consultation, which has become increasingly frequent (Areendran et al. 2020). This can ensure that appropriate ecological, biological, social or cultural values are accounted for, and that acceptable methods are used. But stakeholder consultations can serve yet another important purpose—to increase the quality of the research. Stakeholders can have important local knowledge and can therefore have valuable insights in which methods to use and what data that are available. When GIS-based methods are used, stakeholders can also contribute by evaluating preliminary model results, which can lead to refinements of the method.

This paper presents a study made in close collaboration with the County Administrative Board (CAB) in Norrbotten County, Sweden, intended to provide a new and improved basis for land-use planning in boreal forest landscapes, based on density analysis of HCV forest. The goal of the project was to identify "extended" HCV forest areas throughout the 99,000 km2 county of Norrbotten, Sweden, using available geospatial data. The study revealed that there are important methodological choices that need careful consideration to generate useful results.

Material and Methods

This study explores the use of density analysis to identify and delineate HCV forest areas in the 99,000 km2 county of Norrbotten, Sweden (Fig. 1). All spatial operations were made using GRASS GIS (GRASS Development Team 2023a) with the coordinate reference system EPSG:3035. Cartography was done in QGIS (QGIS.org 2023). Python scripts used to produce the results are publicly available on GitHub (Englund 2024a).

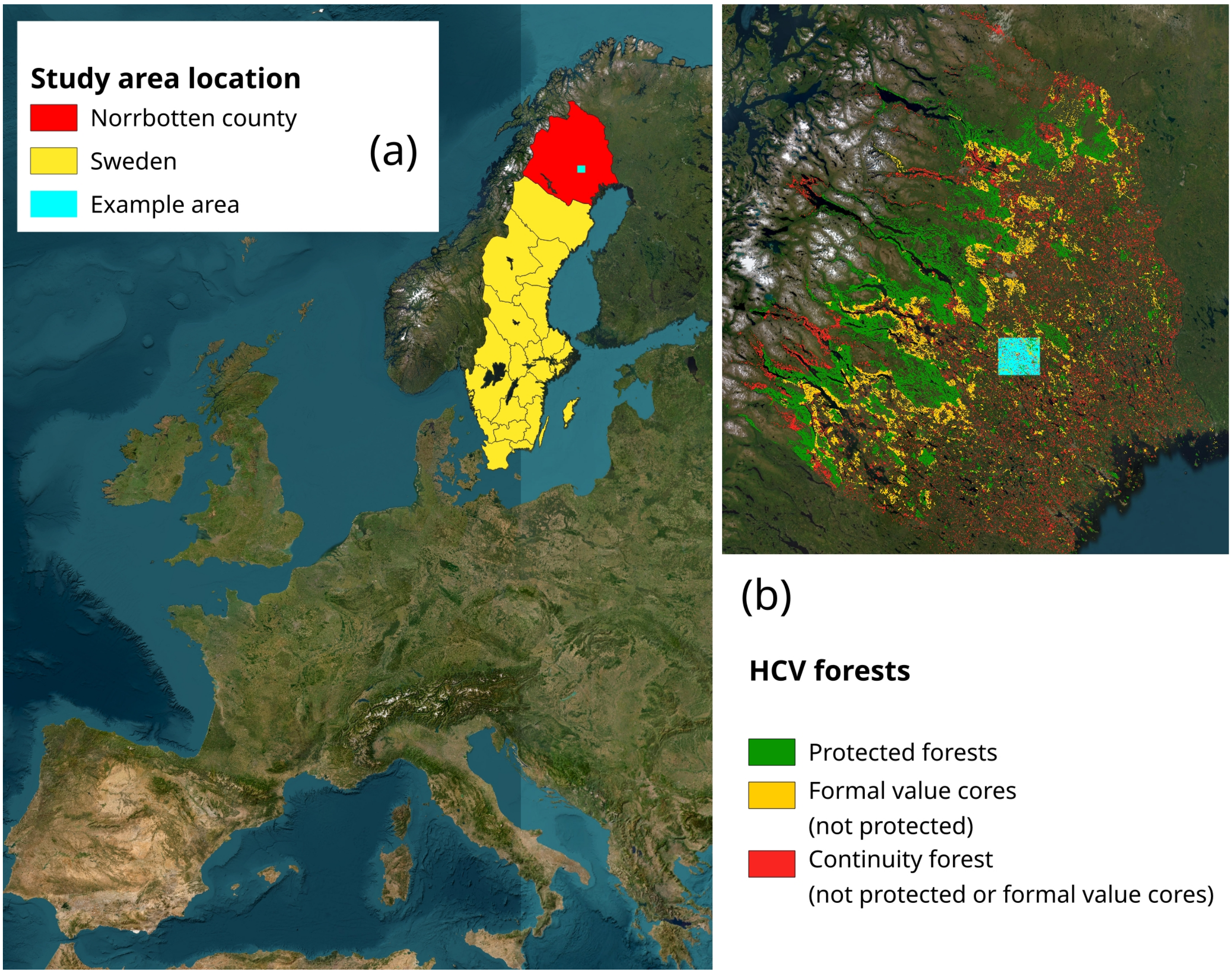

Figure 1: (a) Location of study area (Norrbotten county) in Europe and Sweden; (b) HCV forests

Input data and pre-processing

Official spatial datasets were used to identify the existence of HCV forest with a resolution of 10 m, as follows:

Protected land was identified, including national parks (Swedish Environmental Protection Agency 2023a), nature reserves (Swedish Environmental Protection Agency 2023a), Natura 2000 areas (birds directive and habitat directive) (Swedish Environmental Protection Agency 2023a), biotope protection areas (Swedish Forest Agency 2022a), and areas under nature conservation agreements (Swedish Forest Agency 2022b). Cells covered by any of these datasets were given the value 1.

Additional land that can be considered under restrictions but not under strict protection was identified, including land identified as HCV forest areas by the county administration board in Norrbotten, and key biotopes (Swedish Forest Agency 2022c, 2022d). Cells covered by these datasets were given the value 2.

Probable and potential continuity forest, i.e., forests that have not been clear-cut during the last ca. 70 years (Ahlkrona et al. 2017), was identified (Swedish Environmental Protection Agency 2023b) and given the value 3.

Two input datasets were then created, one with protected land combined with additional land that can be considered restricted ("input_restricted"), and a second that also includes continuity forests ("input_restricted_contfor"), as described above. In the case of overlap between protected, restricted and continuity forest, the former was given priority. All cells not classified as forest in the national land use dataset (Swedish Environmental Protection Agency 2019) were removed from the two input datasets, including cells classified as temporary not forest (value 118 and 128). Finally, cells classified as forested in the land-use map but that has been subject to recent harvesting (i.e., harvested after the national land-use map was constructed, until October 2023) were removed from the two input datasets, based on a continuously updated database by the Swedish Forest Agency (Swedish Forest Agency 2023). A third input dataset containing all forest land ("input_forests") was also constructed in which all forest land was included, including temporary not forest and recently harvested forests.

Calculate density of HCV forests

The density of cells classified as *restricted* and *restricted_contfor* was identified by counting the respective number of cells in a moving window across the county. This was done using the r.neighbours tool in GRASS GIS (GRASS Development Team 2023b), executed using Python scripts (Englund 2024a). Three computations were performed, using the *input_restricted, input_restricted_confor, and input_forests* datasets (see above), respectively, with three sizes for the moving window radius: 250, 500, and 1000 m.

The density of *restricted* and *restricted_confor* cells in the 250, 500, and 1000 m radius neighbourhood of each cell across the landscape (i.e., the share of forest cells that are classified as HCV forest and HCV forest or continuity forest, respectively) was then calculated by dividing the number of *restricted* and *restricted_confor* cells in the neighbourhood with the number of *forest* cells in the same neighbourhood, using the output of r.neighbours, as described above. This was done using GRASS GIS through a Python script (Englund 2024a).

Delineating HCV forest areas

Different alternatives for HCV forest areas were delineated using different thresholds for the density of HCV forests and different sizes of the moving window. Vector data was created with thresholds of 25, 30, 35, 40, 45, and 50 %, for a 250, 500, and 1000 m search window, respectively, using GRASS GIS through a Python script (Englund 2024a).

Stakeholder involvement

Representatives from the CAB in Norrbotten County were involved in every step of the study: defining the scope, developing and evaluating methods, and evaluating the results. The collaborative process was iterative. We had regular meetings in which methods were presented and discussed and feedback was given. Each revision of the methods was jointly agreed upon. Similarly, preliminary results were sent to CAB for evaluation and feedback. This resulted in agreements on further adjustments of the methods.

Results

Effects of methodological choices

The HCV forest density varies considerably depending on the size of the search window (Fig. 2). A smaller search window provides much greater detail while a larger search window identifies only larger areas. This is an expected outcome and, at this point, the size of the search window can be considered a parameter to adjust according to the intended use case. That is, if the intention is to delineate smaller HCV areas, a smaller search window should be used, and vice versa if the intention is to identify larger, continuous, HCV areas.

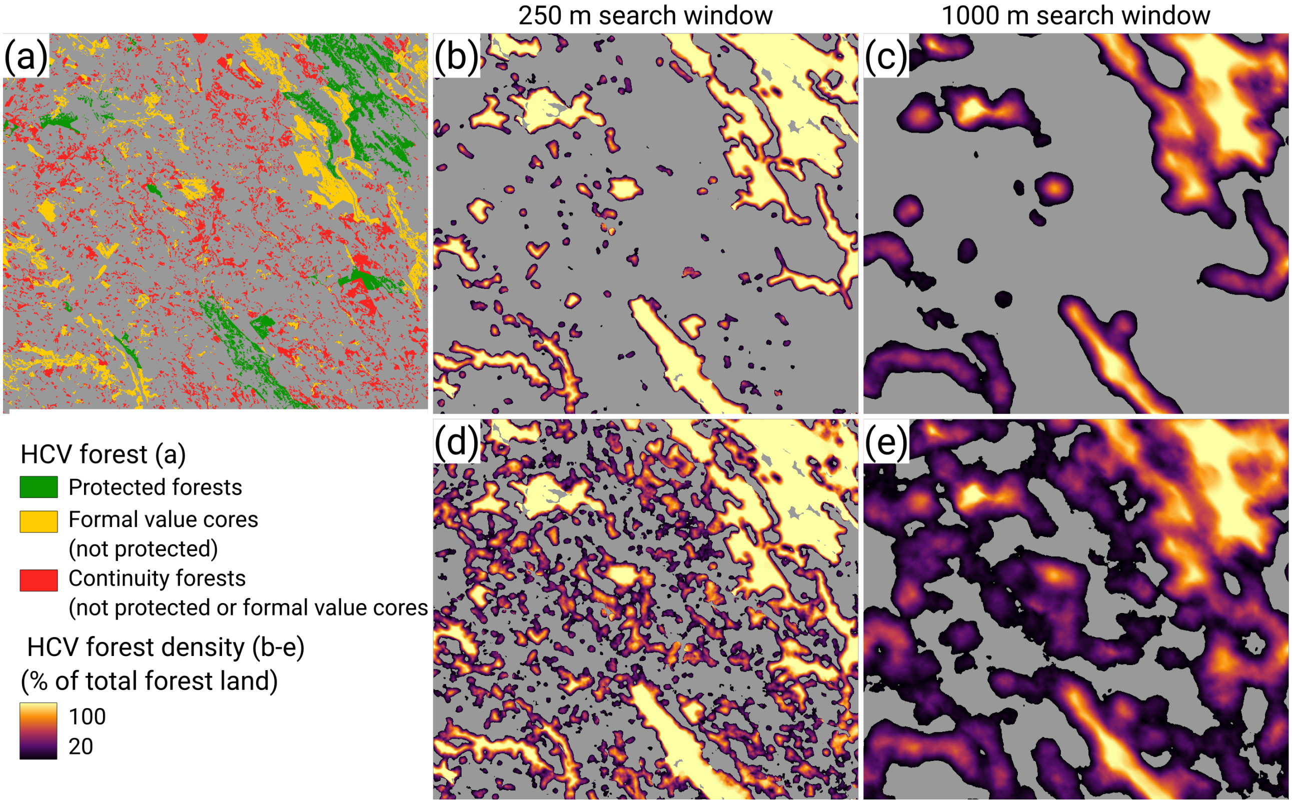

Figure 2: HCV forests in the example area (a) and the corresponding density as percentage of total forest area (b-e). Continuity forest is included in (d) and (e) and excluded in fig. (b) and (c). The search window is 250 m in fig. (b) and (d) and 1000 m in fig. (c) and (e). The location of the example area is shown in Fig. 1.

However, there are multiple implications with using a large search window. Most notably, a large search area generally fails to consider small, scattered areas of HCV forest (cf. Fig 3a and Fig 3c). This may, however, be acceptable and sometimes also desired—if the ambition is to delineate larger areas. Another concern is that a large search window combined with a density threshold of < 50% results in areas that extend unreasonably far outside of actual HCV forests (Fig. 3c). For example, if a clearcut is located in direct connection to a HCV forest, a large search window results in the inclusion of a greater part of the clearcut in the delineated HCV area than a small search window.

Finally, and most concerning, with a large search window, HCV areas can be erroneously identified as located in-between actual HCV areas (e.g., Fig. 3f). The reason for this is that, if the search window in one location includes two HCV areas separated in space, the centermost part of the search window (where there is no HCV forest) will have a larger density of HCV forest than the cells located in the actual HCV forest. This is a major issue.

Some of the above issues can be resolved by altering the density of HCV forest required for delineating HCV areas. Using 20% density instead of 50% density, for example, results in a greater inclusion of small and scattered HCV forests in HCV forest areas. This, however, at the expense of precision, since much non-HCV land is then also included (cf. Fig. 4c and Fig. 4f). But it should be noted that this lack of precision may not necessarily be undesired, as it indicates where it may be most effective to restore managed forest or manage forests with continuous cover forestry (Peura et al. 2018). The extension of HCV areas onto non-HCV land, such as the example above with a clearcut adjacent to a HCV forest, can to a large extent be resolved by increasing the required density from 20% to 50% (cf. Fig. 3c and Fig. 3f). Using a higher density threshold than 50% is not advisable since the resulting HCV areas would exclude HCV forest that is adjacent to non-HCV forest.

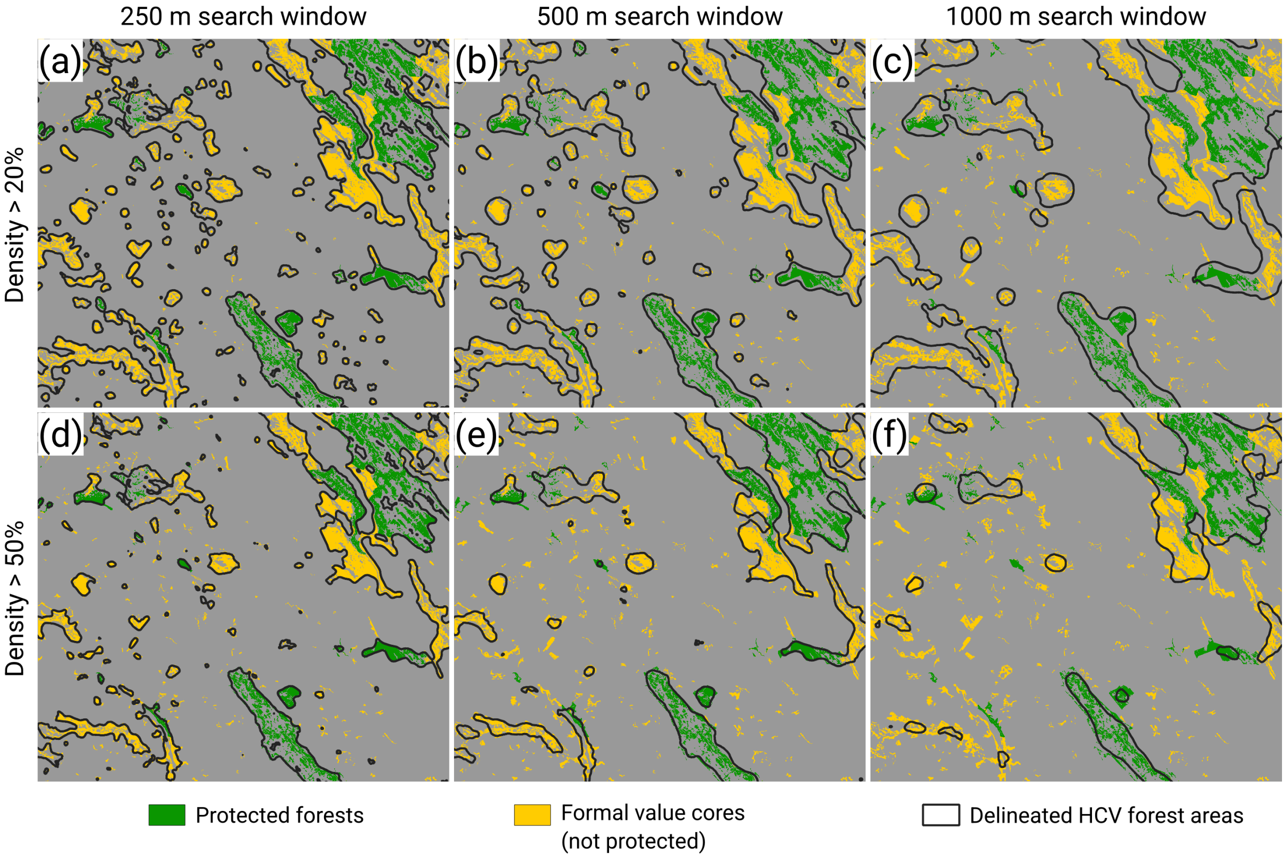

Figure 3: HCV forest areas (excluding continuity forests) delineated using a density threshold of 20% (a-c) and 50% (d-f), and a search window of 250 m (a,d), 500 m (b,e), and 1000 m (c,f), respectively. The location of the example area is shown in Fig. 1.

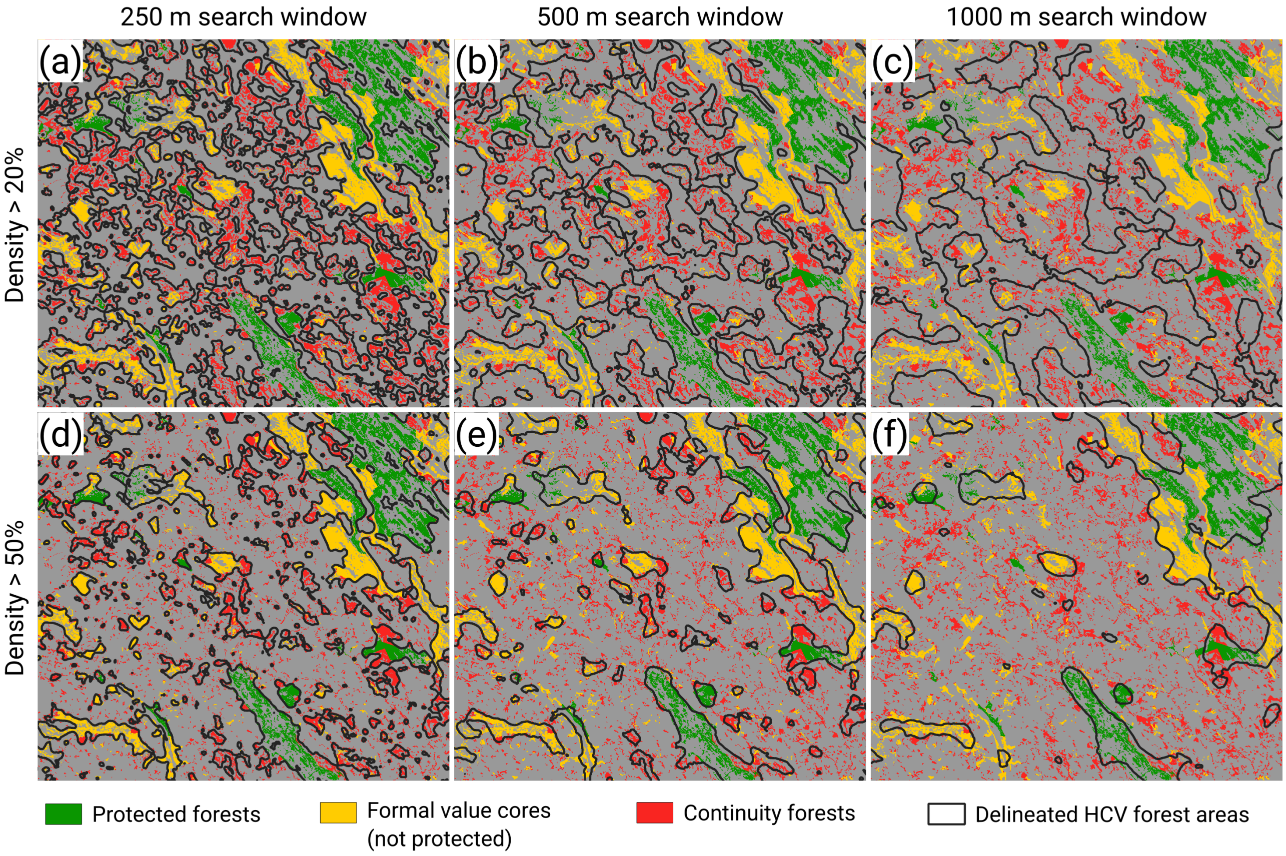

Figure 4: HCV forest areas (including continuity forests) delineated using a density threshold of 20% (a-c) and 50% (d-e), and a search window of 250 m (a,d), 500 m (b,e), and 1000 m (c,f), respectively. The location of the example area is shown in Fig. 1.

Selected results

Based on iterative evaluations of the results by the author and different functions in the CAB, a density threshold of 20% and a radius of 250 m were selected as the most appropriate for this particular context and use-case (Nilsson & Englund 2024).

In the case where continuity forests were included in the analysis, a total of 24 626 HCV areas were identified covering about 5.2 million hectares (Fig. 5a). The majority of this land is within one single connected area (3.6 million hectares) that stretches along the entire mountain chain, extending inland in a south-eastern direction, in one location nearly all the way to the Gulf of Bothnia (unofficially referred to as the Granlandet corridor). The median size of these HCV areas is 7 hectares.

Excluding continuity forests results in a total of 6259 areas covering a total of 3 million hectares (Fig. 5b). In this case, the large connected HCV area along the mountain range is separated into three HCV areas with a total area of about 2 million hectares. The median size of these HCV areas is 21 hectares.

The reason why the analysis that includes continuity forests results in substantially more numerous and generally smaller HCV areas is because the continuity forests are relatively scattered and fragmented outside of the mountain forest region (Svensson et al. 2020; Swedish Environmental Protection Agency 2023b).

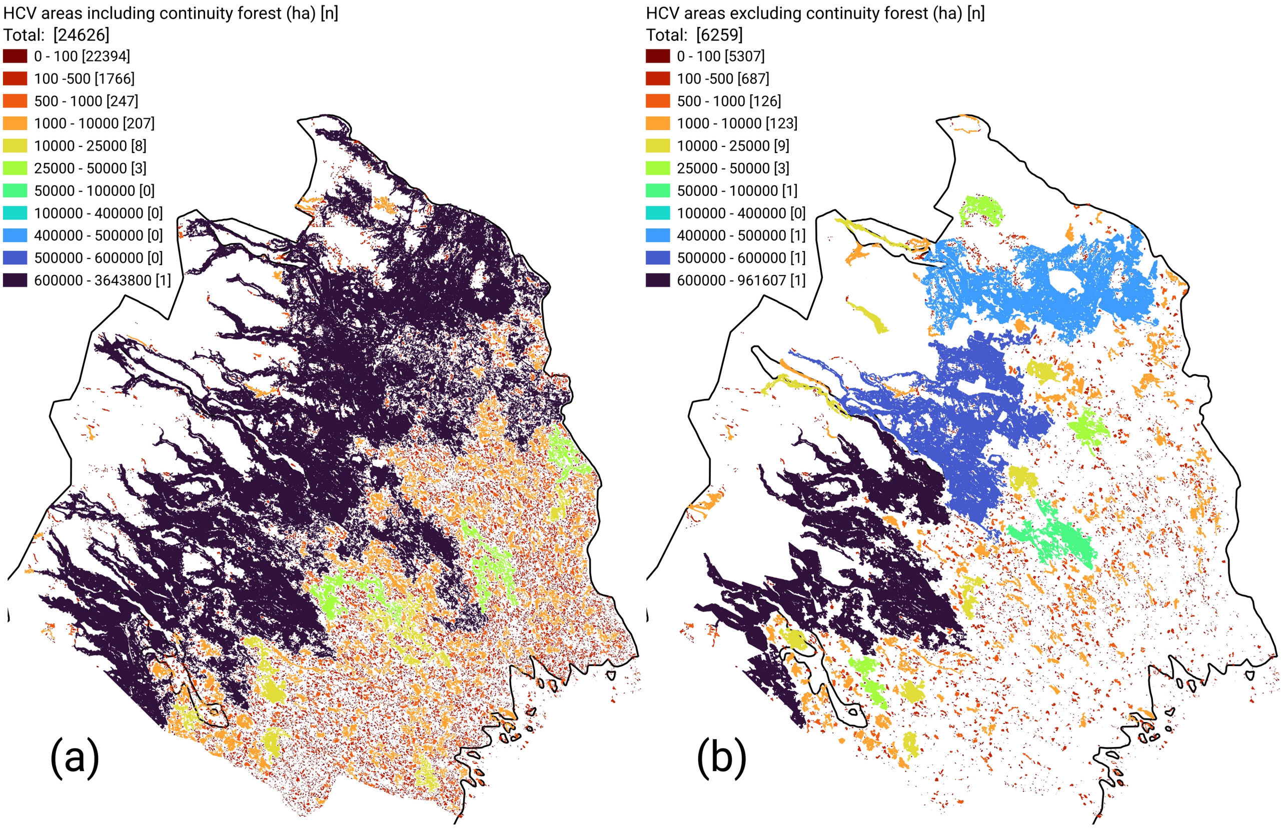

Figure 5: HCV areas in the County of Norrbotten, Sweden, resulted from a density analysis, including (a) and excluding (b) continuity forest

Discussion

As illustrated here, the use of density analysis to identify HCV forest areas is challenging. In this particular case, the county administration wanted to identify large areas for potential formal protection, but also smaller areas that are possibly important from an ecological perspective, by providing habitat for specific species and contributing to ecological connectivity across the landscape. They also wanted to identify HCV areas with high precision while avoiding manual adjustments of the results. As demonstrated here, identifying a manageable number of areas with high precision, while not excluding small areas, is impossible using this method. Compromises are therefore necessary: either identifying large, homogeneous HCV areas with low precision, many small areas with high precision, or somewhere in between. In this particular case, no combination of moving window and density threshold was considered by the CAB to delineate HCV areas sufficiently well, but that HCV areas produced using a 250 m radius and a 20% density threshold could be used as a basis for manually delineating HCV areas, using local expertise. As noted above, this option also indicates where it may be most effective to restore managed forest or manage forests with continuous cover forestry, or similar measures.

To inform the use of the results outside of the CAB, we jointly concluded that "the density analysis can function as a basis for nature conservation planning and other kinds of land-use planning, provided that the user is informed about how the analysis was done". We also concluded that "the density of HCV forest in relation to other forest can be used as a basis for, e.g., delineating HCV forest areas or areas subject to nature restoration activities, if complemented with other information" (Nilsson & Englund 2024). What is referred to as "other information" here can simply be knowledge about the area, but also other data and analyses that cover different and complementary aspects, such as ecological connectivity (Mikusiński et al. 2021).

One problem with this method, ironically, is that the quality and resolution of the data is too high, resulting in scattered and irregular (discrete) input data. While it is certainly not advisable to use data of lesser quality to enable more manageable results, it may be possible to take additional aspects into consideration in the pre-processing, which could provide a more nuanced input. Recently, a new national model for Sweden was published that predicts the probability of HCV forest with a resolution of 100 m (Bubnicki et al. 2024). While 100m is much too coarse for this kind of density analysis, it could be used as additional input to compute the density of forest that exceeds a certain probability of being HCV, relative to other forest.

This is only one example of how new research opens up for new methods and research questions, and the scientific community needs to make continuous efforts to advance our collective toolbox, as the pool of high-quality geospatial data grows larger. But in order for our results to be put to good use, we also need to involve the decision-makers in the research. Had the CAB not been involved in this research, the results had not been considered for decision support, but it had also been of lesser quality. The iterative qualitative evaluation of the results, based on a long experience and good knowledge of the area within the CAB, resulted in several revisions of the method and improvements of the results. Involving decision-makers and/or other relevant stakeholders in HCV research is therefore key to conduct sound research that has potential to influence land-use planning and direct biodiversity conservation efforts to where they are most effective.

Data availability

Geospatial results have been published in an open data repository (Englund 2024b) and Python scripts for full reproduction of the study are publicly available on GitHub (Englund 2024a).

Acknowledgements

The author would like to extend his warmest gratitude to Tina Nilsson at the County Administration Board in Norrbotten for a close and successful collaboration.

References

Abbasnezhad B, Abrams JB. 2022. Testing the Applicability and Credibility of the High Conservation Value Forest (HCVF) Toolkit: A Systematic Global Review. Small-scale Forestry **21**:531–551.

Ahlkrona E, Giljam C, Wennberg S. 2017. Kartering av kontinuitetsskog i boreal region. Metria AB på uppdrag av Naturvårdsverket. Available from https://www.skogsstyrelsen.se/globalassets/aga-skog/skydda-skog/bilaga-3-kartering_av_kontinuitetsskog_boreal_region.pdf.

Applestein C, Germino MJ. 2024. Systematic Process for Determining Field-Sampling Effort Required to Know Vegetation Changes in Large, Disturbed Rangelands Where Management Treatments Have Been Applied. Rangeland Ecology & Management **92**:68–72.

Areendran G, Sahana M, Raj K, Kumar R, Sivadas A, Kumar A, Deb S, Gupta VD. 2020. A systematic review on high conservation value assessment (HCVs): Challenges and framework for future research on conservation strategy. Science of The Total Environment **709**:135425.

Benitez LM, Parr CL, Sankaran M, Ryan CM. 2024. Fragmentation in patchy ecosystems: a call for a functional approach. Trends in Ecology & EvolutionDOI: 10.1016/j.tree.2024.09.004. Available from https://www.sciencedirect.com/science/article/pii/S0169534724002258 (accessed December 18, 2024).

Bovin M, Näsström R, Ahlkrona E, Wennberg S, Naumov V. 2017. Landskapsanalys av skogliga värdekärnor i boreonemoral och nemoral region. Metria AB ordered by The Swedish Environment Protection Agency. Available from https://geodata.naturvardsverket.se/nedladdning/Rapport_Landskapsanalys_skogliga_v%C3%A4rdek%C3%A4rnor_boreonemoral_nemoral_region_2017.pdf (accessed October 8, 2024).

Bubnicki JW, Angelstam P, Mikusiński G, Svensson J, Jonsson BG. 2024. The conservation value of forests can be predicted at the scale of 1 hectare. Communications Earth & Environment **5**:1–17. Nature Publishing Group.

Englund O. 2024a. connectivity-NB: Python scripts for conducting a density analysis for HCV forest and preparing input to Omniscape (and post-processing the output) for simulation of structural connectivity in Norrbotten county, Sweden. GitHub. Available from https://github.com/oskeng/connectivity_NB.

Englund O. 2024b, September 27. HCV forest areas in Norrbotten County (Sweden) based on density analysis of HCV forests. Mid Sweden University via Swedish National Data Service. Available from https://doi.org/10.5878/6jnb- 7042 (accessed December 16, 2024).

Englund O, Berndes G, Cederberg C. 2017. How to analyse ecosystem services in landscapes—A systematic review. Ecological Indicators **73**:492–504.

GRASS Development Team. 2023a. Geographic Resources Analysis Support System (GRASS GIS) Software, Version 8.3. Open Source Geospatial Foundation. Available from http://grass.osgeo.org.

GRASS Development Team. 2023b. r.neighbors. Available from https://grass.osgeo.org/grass82/manuals/r.neighbors.html (accessed September 22, 2023).

Hauck J, Görg C, Varjopuro R, Ratamäki O, Maes J, Wittmer H, Jax K. 2013. "Maps have an air of authority": Potential benefits and challenges of ecosystem service maps at different levels of decision making. Ecosystem Services **4**:25–32.

Hughes AC, Orr MC, Ma K, Costello MJ, Waller J, Provoost P, Yang Q, Zhu C, Qiao H. 2021. Sampling biases shape our view of the natural world. Ecography **44**:1259–1269.

Larekeng SH, Nursaputra M, Nasri, Hamzah AS, Mustari AS, Arif AR, Ambodo AP, Lawang Y, Ardiansyah A. 2021. An assessment of high carbon stock and high conservation value approaches in mining area. IOP Conference Series: Earth and Environmental Science **807**:022034. IOP Publishing.

Mikusiński G, Orlikowska EH, Bubnicki JW, Jonsson BG, Svensson J. 2021. Strengthening the Network of High Conservation Value Forests in Boreal Landscapes. Frontiers in Ecology and Evolution **8**. Available from https://www.frontiersin.org/article/10.3389/fevo.2020.595730 (accessed March 28, 2022).

Nilsson T, Englund O. 2024. Ekologiska analyser av skogar och våtmarker i Norrbottens län: Nya metoder för täthetsanalyser och ekologisk konnektivitet (Ecological analyses of forests and wetlands in the County of Norrbotten, Sweden: New methods for density analysis and ecological connectivity). Länsstyrelsen i Norrbottens Län. Available from https://naturvardsverket.diva-portal.org/smash/record.jsf?pid=diva2:1904711.

Peura M, Burgas D, Eyvindson K, Repo A, Mönkkönen M. 2018. Continuous cover forestry is a cost-efficient tool to increase multifunctionality of boreal production forests in Fennoscandia. Biological Conservation **217**:104–112.

QGIS.org. 2023. QGIS Geographic Information System v. 3.32. Open Source Geospatial Foundation Project.

Sahana M, Areendran G, Sivadas A, Raj K, Sharma D, Sajid Sultan Md, Ghoshal A, Parameswaran S. 2023. Assessing high conservation value areas for rare, endemic and threatened (RET) species: A study in high altitude Changthang landscape of India. Journal for Nature Conservation **73**:126406.

Sánchez-Almendro AJ, Hidalgo PJ, Galán R, Carrasco JM, López-Tirado J. 2018. Assessment and Monitoring Protocols to Guarantee the Maintenance of Biodiversity in Certified Forests: A Case Study for FSC (Forest Stewardship Council) Forests in Southwestern Spain. Forests **9**:705. Multidisciplinary Digital Publishing Institute.

Svensson J, Bubnicki JW, Jonsson BG, Andersson J, Mikusiński G. 2020. Conservation significance of intact forest landscapes in the Scandinavian Mountains Green Belt. Landscape Ecology **35**:2113–2131.

Swedish Environmental Protection Agency. 2019. Nationella Marktäckedata (NMD). Swedish Environmental Protection Agency. Available from https://www.naturvardsverket.se/verktyg-och-tjanster/kartor-och-karttjanster/nationella-marktackedata/.

Swedish Environmental Protection Agency. 2023a. Naturvårdsregistret: beskrivning av öppna data. Available from https://geodata.naturvardsverket.se/nedladdning/naturvardsregistret/Naturvardsregistret_beskrivning_av_oppna_data.pdf (accessed September 21, 2023).

Swedish Environmental Protection Agency. 2023b. Probable and potential Continuity forest (Sannolikt och potentiell kontinuitetsskog). Geodatakatalogen. Available from https://geodatakatalogen.naturvardsverket.se/geonetwork/srv/swe/catalog.search#/metadata/2b9d4c76-3b0e-4a55-a16c-51513da84558.

Swedish Forest Agency. 2022a. Biotope protection areas (biotopskydd). Swedish Forest Agency download service. Available from https://geodpags.skogsstyrelsen.se/geodataport/feeds/Naturvardsavtal.xml.

Swedish Forest Agency. 2022b. Areas under nature preservation agreements (Naturvårdsavtal). Swedish Forest Agency download service. Available from https://geodpags.skogsstyrelsen.se/geodataport/feeds/Naturvardsavtal.xml.

Swedish Forest Agency. 2022c. Key biotopes (nyckelbiotoper). Swedish Forest Agency download service. Available from https://geodpags.skogsstyrelsen.se/geodataport/feeds/Nyckelbiotoper.xml.

Swedish Forest Agency. 2022d. Key biotopes from large forest companies (Storskogsbrukets nyckelbiotoper). Swedish Forest Agency download service. Available from https://geodpags.skogsstyrelsen.se/geodataport/feeds/StorskogsbrNyckelb.xml.

Swedish Forest Agency. 2023. Harvested forest areas (Utförda avverkningar). Swedish Forest Agency download service. Available from https://geodpags.skogsstyrelsen.se/geodataport/feeds/UtfordAvverk.xml.