PRELIMINARY FINDINGS ON REMOTE SENSING OF FOREST COVER CHANGE, FOREST AND TREE HEALTH IN SOUTHEASTERN EUROPE

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ABSTRACT:

Forests are important to people, wildlife and climate. Yet, not all forests are healthy throughout time. Unhealthy forests are providing fewer services and productions to people, harbouring less biodiversity and regulating less climate. Here, the preliminary findings are presented in a literature review on remote sensing measuring the changes in forest cover and the health of forest and of trees in Southeastern Europe including Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia. The aim is to assess the publications that applied remote sensing data sources to investigate the changes in forest cover and forest health and tree health in the five Southeastern European countries by searching in Scopus and Google scholar. There is a higher number of studies applied to remote sensing data sources investigating forest cover change (92.4 percent) compared to forest health (6.7 percent) and tree health (0.8 percent) for five countries in Southeastern Europe. There was a disparity of remote sensing data source studies on forest cover change, forest health and tree health amongst five countries. Croatia and Slovenia lead by 68.9 percent and Albania, Bosnia and Herzegovina and Montenegro by 31.1 percent of publications, according to Scopus and Google scholar. There were found no remote sensing data source studies on forest cover, forest health and tree health including all five countries altogether. A way to move forward is to increase cooperation between researchers, academic organisations and policy-makers amongst the five countries.

1. INTRODUCTION

Forests are a crucial ecosystem on land. They harbour biodiversity and regulate climate. Yet, forests are threatened by deforestation and degradation (Wheeler et al. 2021, Assis et al. 2020) declining their health. Forests may be susceptible to diseases, fires, livestock, which negatively affect forest health, losing their (ecosystem) service capacity (Gao et al. 2020) to support wildlife, people and to regulate climate. Forests that are degraded cannot regulate climate as healthy forests. A recent study using remote sensing data analysis showed that forest degradation contributed three times more to the above ground biomass loss than deforestation indicating that forest degradation is the largest process determining carbon loss in Amazon forests in Brazil (Qin et al. 2021).

Remote sensing data sources are used to manage cropland (Pinter et al. 2003), to investigate urban forest health (Näsi et al. 2018), to measure spatial and temporal changes in natural forest cover, in order to investigate forest loss (deforestation) and forest gain (Borrelli et al. 2016; Hansen et al. 2013; Kuemmerle et al. 2009) and or natural tree health (Lévesque and King, 2003; Shendryk et al. 2016). Satellite image data were used to investigate agriculture-vegetated land (cropland) in Phalke et al. (2020).

Here, the preliminary findings in the literature on remote sensing measuring the changes in forest cover and the health of forest and of trees in Southeastern Europe including Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia were demonstrated. The work was to describe the presence of the remote sensing data sources and the scale of the study (country-level and regional level). Geographic and the remote sensing data sources applied were searched in Scopus and Google scholar. The aim is to assess the use of remote sensing data sources to investigate the changes in forest cover and the forest health and tree health in five countries of Southeastern Europe including Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia. Followed up steps of this work are shown.

2. METHOD

Literature search referred to the Preferred Items for Systematic Reviews and Meta-Analyses (PRISMA), which is a well-known framework used in various fields as medicine, ecology, remote sensing (Panic et al. 2013; Fedrowitz et al. 2014; Azizan et al. 2021). Differently from narrative literature review, PRISMA reduces the potential for literature selection bias (Frampton et al. 2017). A set of formulated questions help identify, select and analyse (Moher et al. 2010) research collected. The questions addressed were as follows: 1- Are there studies using remote sensing data sources to measure the changes in forest cover, forest health and tree health in the five Southeastern European countries (Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia)? 2- Are there differences in terms of publication quantity about study themes (the changes in forest cover, forest health, tree health)? A set of inclusion and exclusion criteria were introduced in order to reduce errors and bias (see Azizan et al. 2021) in the selection of literature. Studies were included if they met the inclusion criteria as follows: 1- they use and analyse remote sensing data and focus on the remote sensing applications on forest cover change, forest health and tree health, 2- they focus in at least one of the five countries Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia, 3- they were written in English language. Exclusion criteria were as follows: 1- studies did not discuss remote sensing data use and applications on forest cover change, forest health and tree health in one of the five Southeastern European countries, 2- they were reviews, presentations, master and doctoral theses.

There were Scopus-based search of international journals of Science of Remote Sensing, Remote Sensing of Environment, ISPRS Journal of Photogrammetry and Remote Sensing, ISPRS Open Journal of Photogrammetry and Remote Sensing, International Journal of Applied Earth Observation and Geoinformation and Google scholar, to select articles on forest cover change, forest health and tree health. All articles were searched in the English language. Searching was limited to studies in Southeastern countries including at least one of five countries of Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia until October 2021 excluding reviews, presentations, master and doctoral theses and any other regions. Croatia and Slovenia were expected to have more studies using remote sensing data sources to measure forest cover changes, forest health and tree health. Search terms were ‘remote sensing’, ‘forest cover change’, ‘forest health’, ‘tree health’, and ‘Southeastern Europe’ and five study countries in Table 1. The abstracts of studies were used for identifying geographical location and subjects (remote sensing, forest cover change, forest health and tree health). Open access studies were only read for remote sensing data source details. Articles including remote sensing, forest cover change and tree health in five countries in Southeastern Europe were manually selected and read.

3. PRELIMINARY FINDINGS

There were identified 84 studies using Scopus searching the PRISMA framework (Table 2). Yet, 78 percent of articles were excluded from Scopus searching, because they did not meet inclusion criteria. Studies using the term “remote sensing” and “forest cover change”, “forest health”, “tree health”, and either one of the study countries Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia in their title (and then in the abstract) or Southeastern Europe were manually considered as relevant literature at Google searching. Here, “forests”, “forest cover”, “vegetation classification”, “land use change”, “vegetated urban land” and “agriculture land” or “crop land” in at least one of the study countries were considered as an alternative of “forest cover change”. “Tree species classification”, “burned areas”, “forest diseases” were selected as alternatives of forest health and tree health at Google searching. The total of 101 studies were manually identified at Google search. The Google search results were grouped into sciencedirect publications and other publication sources. There were 119 studies identified by Google scholar and Scopus-based search for all five countries (Figure 1).

3.1 Remote sensing data source

The Scopus-based search engine produced six results for remote sensing data sources used for measuring forest cover change (including forests in general), for Croatia and Slovenia and none for Albania, Bosnia and Herzegovina and Montenegro and none for forest health and tree health in any of the study country of Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia. The Google scholar produced 48 studies of remote sensing data sources for measuring forest cover change, forest health and tree health in Croatia. There were, respectively, found 28 and 21 studies for measuring forest cover change and forest health in Slovenia and Albania, and 12 and 4 studies for measuring forest cover in Bosnia and Herzegovina and Montenegro. The highest number of sciencedirect publications (5) were written for Slovenia, (Figure 1).

The 100 percent of the most relevant studies used optical and near-infrared and infrared remote sensing data for analysing the changes in forest cover, forest health and tree health with a resolution varying from 1 m to 1 km (Table 3). All studies used multi-temporal scale satellite images to investigate the changes in forest cover. For this, the 100 percent of studies, respectively, used either MODIS or Landsat satellite images for analysing the changes in forest cover or Copernicus satellite images for investigating forest health. Optical remote sensing data were respectively used at local, country and European level for analysing the changes in forest cover in Bosnia and Herzegovina, Croatia, Albania and the five countries. Remote sensing data types and spatial data resolution are shown in Table 3.

There was a higher number of studies investigating forest cover change (including land use) compared to forest health and or tree health for five countries in Southeastern Europe. The studies of remote sensing data sources were respectively 6.7 percent and 0.8 percent used for forest health and tree health, and 92.4 percent for forest cover. Yet, there is a disparity of remote sensing data source studies on forest cover change, forest health and tree health amongst five countries of Montenegro (3.3 percent), Bosnia and Herzegovina (10 percent), Albania (17.6 percent), Slovenia (26.8 percent) and Croatia (42.0 percent) published in (sciencedirect.com and other publication sources).

3.2 Forest cover change

Natural vegetation and forests of the five countries were investigated using remote sensing sensors (MODIS and MERIS) and land cover maps at European level (Loozen et al. 2020; Pérez-Hoyos et al. 2012), laser remote sensing, digital aerial photography and space borne sensor data at global level (Tang et al. 2020; Barrett et al. 2016). Landsat-based maps were used to calculate the changes in forest cover between 1985 and 2012 in Eastern Europe including Bosnia and Herzegovina, Croatia, Montenegro and Slovenia (Potapov et al. 2015). The five countries were included at European and global level studies using satellite images of e.g., Sentinels (D’Andrimont et al. 2021) and maps of land cover e.g., CORINE land cover (Waser et al. 2006; Vilar et al 2019). Forest and non-forest land data were available at European level including the five countries by Pekkarinen et al. (2009).

The changes in forest cover were identified at country level between 1991 and 2011 and grassland in Croatia (Cvitanović et al. 2016; Cvitanović et al. 2017), and the changes in forest cover between 1991 and 2001 in Albania (Jansen et al. 2006). There are different remote sensing systems like LiDAR, close-range remote sensing data to measure tree crown and height in forests (Mongus and Žalik, 2015; Jurjević et al. 2020) at country level. MODIS instrument data were used for vegetation analysis and orthophotos for identification of an invasive plant species in built-in and semi-natural areas in Slovenia (Zakšek and Schroedter-Homscheidt 2009; Dorigo et al, 2012), and forest canopy structure in old forests in Bosnia and Herzegovina (Garbarino et al, 2012).

There were approximately 35 publications including at least one of the five countries Albania, Bosnia and Herzegovina, Croatia, Montenegro and Slovenia at European or Global level, though there were no remote sensing data source studies on the changes in forest cover or in vegetation for five countries altogether until 20 October 2021 in Google scholar.

3.2.1 **Causes and effects of the changes in forest cover.** The changes in forest cover are forest gain and forest loss (deforestation), respectively, identified as the change from non-forest to forests and from forests to non-forest study unit (e.g., pixel). There were identified the changes in forest cover in Eastern Europe including Croatia, Montenegro, Slovenia and Bosnia and Herzegovina at European level (Potapov et al. 2015). Accordingly, forest cover increased from 1985 to 2012; forest loss was caused by timber harvesting, insect defoliation, forest conversion, large-scale wildfires and windstorms. Garbarino et al. (2012) identified that (old) forests in a natural reserve in Bosnia and Herzegovina were disturbed by humans causing 20 canopy gaps of an area above 250 square metres in forests. Witmer and O'Loughlin (2009) using remote sensing found that (vegetated) agricultural land was changed (affected) because of agricultural land abandonment caused by war in Bosnia and Herzegovina. Cvitanović et al. (2016) have identified forest increase in state-owned forests and forest loss from 1991 to 2011 influenced by slope and altitude and human factors (education structure, population age and density) in privately owned forests, though weakening because of the 'continuation of the de-agrarisation and de-ruralisation processes' in Northern Croatia. Forest loss detected between 1991 and 2001 were caused by policy failure and urbanisation in Albania (Jansen et al. 2006) showing the trend of the depletion of natural resources.

3.3 Forest health and tree health

Causes of forest health decline were forest loss, forest fires and invasive species (Senf et al. 2021; Stroppiana et al. 2012; Somodi et al. 2012) at European level.

There was at least one publication of remote sensing for measuring forest health in Croatia, Slovenia and Albania (Pernar et al. 2008; Decuyper et al. 2020; Hysa and Teqja, 2020), but none in Bosnia and Herzegovina and Montenegro. There was one publication on tree health in Croatia (Zagoranski et al. 2018).

Studies on forest health in Croatia, Slovenia and Albania, respectively, used Colour Infrared aerial photographs, WorldView-2 sensors, MODIS sensors and land maps to obtain data about forest and tree health in Croatia, about forest growth in Slovenia affected by climate and about tree cover density to be affected by wildfire in Albania (Table 3). Pernar et al. (2008) investigated factors affecting forest health interpreting Colour Infrared aerial photographs, because fir and beech forests were damaged in Velebit, Croatia. Decuyper et al. (2020) assessed the effect of extreme climate events on the beech tree growth (e.g., leaf burning) using crown data from (MODIS) in Slovenia. Hysa and Teqja, (2020) classified the forested lands by their wildfire spreading capacity using Corine Land Cover, Plant heat zones, Tree cover density, and Normalized difference vegetation index (NDVI). Zagoranski et al. (2018) used WorldView -2 sensors to estimate tree health conditions and damages in a forest park area in Zagreb, Croatia. Yet, there was no study using remote sensing data to detect and monitor tree leaf, bark and root disease (Table 3) in any of the five Southeastern European countries.

3.4 Publications

Substantial diverse publications were found using Google scholar for Croatian researchers writing to local and regional journals (hrcak.srce.hr) for a variety of remote sensing data source uses in forests including ecology and climate e.g., forest responses to extreme climate (Pilaš et al. 2014). Sciencedirect publications in Slovenia were exploring new methods using remote sensing data sources and vegetation (Horvat et al. 2016; Mongus and and Žalik, 2018), though publications were more concerned about remote sensing use in e.g., hydrology than forests. A reason could be forests have not changed for a long time in Slovenia (Čarni et al. 1998). Studies were on war effects in Bosnia and Herzegovina e.g. Witmer and O'Loughlin (2009). Forest disturbance was caused by forest cover decline (loss) (Senf et al. 2021) and by forest fires at regional level (Stroppiana et al. 2012). Forests disturbed by invasive species spread in Slovenia were studied by Somodi et al. (2012).

4. CONCLUSION

4.1 Commons

Studies respectively identified the changes in forest cover using satellite images at European level, and at local and country level in Croatia, Bosnia and Herzegovina and Albania contributing in better understanding the causes and effects of these changes in forest cover. Multiple-temporal satellite images of MODIS, TM/ETM+ and MERIS sensors helped analyse the changes in forest cover in different periods of time and in long-term. Landsat and MODIS images were used at different spatial extent (local, country, continental), spectral and resolutions (15m, 250m) that were used for different research purposes e.g., the changes in forest cover and forest health, (Table 3).

Studies used satellite and aircraft platforms to obtain data about forest and tree health investigated at local level in Croatia, and at country level in Slovenia and Albania. All the studies tended to investigate forest and or tree health conditions/damages, but not tree diseases (e.g., leaf, bark, root diseases). High resolution remote sensing data were preferably incorporated with field works for investigating tree health and forest health (e.g. Zagoranski et al. 2018; Decuyper et al. 2020).

Optical remote sensing data is free and easily accessible. The tree health derived from optical remote sensing data were recommended for monitoring tree health and predicting future (tree health) conditions (Zagoranski et al. 2018), for indicating forests (e.g. beech) sensitive to climate changes and for planning (needed) mitigation interventions (Decuyper et al. 2020), for effectively identifying abandoned agricultural land and for evaluating conflict or war long-term impacts (Witmer and O'Loughlin (2009) on agriculture land.

Methods used for analysing the changes in forest cover, forest health and tree health were 1- visual aerial photography interpretation (e.g. Pernar et al. 2008), 2- pixel/object-based classification (Loozen et al. 2020), 3- phenology-based estimations/algorithms (e.g. Decuyper et al. 2020), Table 3.

4.2 Differences

There were found differences in the number of studies and themes amongst the five countries in Southeastern Europe. Remote sensing data sources for analysing forest cover (change) and structures (e.g., tree height, tree cover, forest canopy) have an increasing growing literature in Southeastern Europe, though there was a disparity amongst five countries (Figure 1). Croatia and Slovenia had a higher number of studies of remote sensing on forest cover compared to Albania, Bosnia and Herzegovina and Montenegro, Figure 1. Remote sensing data sources on forest health and tree health were critically lacking for the Southeastern European countries. There were no studies on forest cover, forest health and tree health in all five countries altogether, (Figure 1). This is also found by other researchers. For example, there were found differences in land use change studies and their impacts on biodiversity in Southeastern Europe countries of Slovenia, Croatia, Bosnia and Herzegovina, Montenegro and Albania (Figure 4a in Davison et al 2021). Accordingly, there were no such studies in Bosnia and Herzegovina.

4.3 Potential studies

The no full-text freely available publications did not provide sufficient information about their methods and data (e.g. n.a. in Table 3) limiting this work. This work did not aim either to explain the commons (similarities) and differences in remote sensing data analysis or causes and effects of the changes in forest cover in the five Southeastern European countries. Though, a future work might be needed on understanding the research gaps and needs in remote sensing data use and analyses in the five Southeastern European countries.

Remote sensing has been important for detecting broad-scale patterns of land-use change (including forest) (Davison et al. 2021), for providing details on the evolution of forests in Europe for a very long time (Zanon et al. 2018), for providing insights to support policy-making related to forest strategy (e.g. Borrelli et al. 2016) in Europe, for developing forest canopy mortality strategies (see Senf et al. 2021) in Europe, and for providing updated information to policy-makers about land degradation in Southern Europe (Prăvălie et al. 2017). This is already a real and valuable work done on forests using remote sensing data applications, and modelling in Europe. However, this preliminary work showed that the number of studies on the changes in forest cover, forest health and tree health at country level differed amongst the five southerneastern European countries. Forest health and tree health were far less studied (Tables 2 and 3). (New) studies could particularly investigate forest health and tree health and less studied areas of the five Southeastern European countries using (new) remote sensing data and applications. New studies could also aim at providing new and or updated information about forests to policy-makers (see e.g. Prăvălie et al. 2017), which can be valuable for the study country. There are publications amongst researchers in the five Southeastern European countries e.g. Kostić et al. (2021). Yet, the cooperation between researchers, academic organisations could be strengthened, increasing the quality and quantity of publications at local and country level in the future.

Next work steps are the description of detailed information of articles including remote sensing data source type, the measurements of the forest cover change, of forest health and of tree health at country, regional and transregional level.

Articles on	Search terms
Remote sensing	"Remote sensing"
And Forest cover change or forest health or tree health	"forest cover change" or " forest cover" or "forest health" or "tree health"
And Southeastern Europe	"Albania" or "Bosnia and Herzegovina" or "Croatia" or "Montenegro" or "Slovenia" or "Southeastern Europe"

Table 1. Search terms of Scopus and Google scholar

Country	Results		
	Forest cover change	Forest health	Tree health
Albania	13	1	0
Bosnia and Herzegovina	8	1	1
Croatia	18	4	3
Montenegro	8	3	3
Slovenia	18	1	2
Total	65	10	9

Table 2. The number of publications found at Scopus searching for forest cover change, forest health and tree health per country.

Study themes	Platform /Sensor	Sensor resolution	Spatial extend	Time period	Reference
Forests/Forest cover change	Satellite/ MODIS, MERIS	250m, 1km	Europe	2002-2014; 2002-2011	Loozen et al. 2020
Forest cover change	Satellite/ TM, ETM+	30m	Eastern Europe	1985-2012	Potapov et al. 2014
Forests	Satellite/ Kompsat-2	1-m panchromatic; 4-m multispectral	Lom, Bosnia and Herzegovina	n.a.	Garbarino et al. 2012
Forest cover change	Satellite/ TM, ETM+	30m	Krapina-Zagorje, Croatia	1991–2011	Cvitanović et al. 2016
Forest cover change	Satellite/ TM, ETM+	15m	Albania	1991-2001	Jansen et al. 2006
Forest health	Aircraft/ Colour infrared films	1:25 000	Velebit, Croatia	2005	Pernar et al. 2008
Forest health	Satellite/ MODIS	250m	Slovenia	2001–2017	Decuyper et al. 2020
Forest health	Satellite/ Copernic	100m	Albania	2015	Hysa and

	us (portal)				Teqja, 2020
Tree health	Satellite/ WorldView-2	25m	Zagreb, Croatia	2014, 2016	Zagoranski et al. 2018

Table 3. Remote sensing data applied in the most relevant studies of forest cover change, forest health and tree health using Scopus. No relevant forest cover change studies were found for Slovenia and Montenegro.

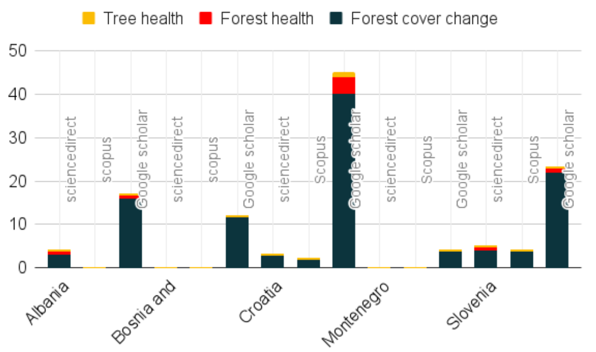

Figure 1. The number of publications meeting inclusion criteria at Scopus and Google scholar for forest cover change, forest health and tree health per country

REFERENCES

Assis, T., Aguiar, A.P., Von Randow, C., Gomes, D., Kury, J., Ometto, J., Nobre, C., 2020. CO2 emissions from forest degradation in Brazilian Amazonia. Environ. Res. Lett. 15. https://doi.org/10.1088/1748-9326/ab9cfc

Azizan, F.A., Kiloes, A.M., Astuti, I.S., Abdul Aziz, A., 2021. Application of Optical Remote Sensing in Rubber Plantations: A Systematic Review. Remote Sens. 13. https://doi.org/10.3390/rs13030429

Barrett, F., McRoberts, R.E., Tomppo, E., Cienciala, E., Waser, L.T., 2016. A questionnaire-based review of the operational use of remotely sensed data by national forest inventories. Remote Sens. Environ. 174, 279–289. https://doi.org/https://doi.org/10.1016/j.rse.2015.08.029

Borrelli, P., Panagos, P., Langhammer, J., Apostol, B., Schütt, B., 2016. Assessment of the cover changes and the soil loss potential in European forestland: First approach to derive indicators to capture the ecological impacts on soil-related forest ecosystems. Ecol. Indic. 60, 1208–1220. https://doi.org/https://doi.org/10.1016/j.ecolind.2015.08.053.

Čarni, A., Jarnjak, M., Oštir-Sedej, K., 1998. Past and present forest vegetation in NE Slovenia derived from old maps. Appl. Veg. Sci. 1, 253–258. https://doi.org/https://doi.org/10.2307/1478955

Cvitanović, M., Blackburn, G.A., Rudbeck Jepsen, M., 2016. Characteristics and drivers of forest cover change in the post-socialist era in Croatia: evidence from a mixed-methods approach. Reg. Environ. Chang. 16, 1751–1763. https://doi.org/10.1007/s10113-016-0928-0.

Cvitanović, M., Lučev, I., Fürst-Bjeliš, B., Borčić, L.S., Horvat, S., Valožić, L., 2017. Analyzing post-socialist grassland conversion in a traditional agricultural landscape – Case study Croatia. J. Rural Stud. 51, 53–63. https://doi.org/https://doi.org/10.1016/j.jrurstud.2017.01.008

D'Andrimont, R., Verhegghen, A., Lemoine, G., Kempeneers, P., Meroni, M., van der Velde, M., 2021. From parcel to continental scale – A first European crop type map based on Sentinel-1 and LUCAS Copernicus in-situ observations. Remote Sens. Environ. 266, 112708. https://doi.org/https://doi.org/10.1016/j.rse.2021.112708

Davison, C.W., Rahbek, C., Morueta-Holme, N., 2021. Land-use change and biodiversity: Challenges for assembling evidence on the greatest threat to nature. Glob. Chang. Biol. 27, 5414–5429. https://doi.org/https://doi.org/10.1111/gcb.15846.

Decuyper, M., Chávez, R.O., Čufar, K., Estay, S.A., Clevers, J.G.P.W., Prislan, P., Gričar, J., Črepinšek, Z., Merela, M., de Luis, M., Notivoli, R.S., del Castillo, E.M., Rozendaal, D.M.A., Bongers, F., Herold, M., Sass-Klaassen, U., 2020. Spatio-temporal assessment of beech growth in relation to climate extremes in Slovenia – An integrated approach using remote sensing and tree-ring data. Agric. For. Meteorol. 287, 107925. https://doi.org/https://doi.org/10.1016/j.agrformet.2020.107925.

Dorigo, W., Lucieer, A., Podobnikar, T., Čarni, A., 2012. Mapping invasive Fallopia japonica by combined spectral, spatial, and temporal analysis of digital orthophotos. Int. J. Appl. Earth Obs. Geoinf. 19, 185–195. https://doi.org/https://doi.org/10.1016/j.jag.2012.05.004

Fedrowitz, K., Koricheva, J., Baker, S.C., Lindenmayer, D.B., Palik, B., Rosenvald, R., Beese, W., Franklin, J.F., Kouki, J., Macdonald, E., Messier, C., Sverdrup-Thygeson, A., Gustafsson, L., 2014. REVIEW: Can retention forestry help conserve biodiversity? A meta-analysis. J. Appl. Ecol. 51, 1669–1679. https://doi.org/https://doi.org/10.1111/1365-2664.12289

Frampton, G.K., Livoreil, B., Petrokofsky, G., 2017. Eligibility screening in evidence synthesis of environmental management topics. Environ. Evid. 6, 27. https://doi.org/10.1186/s13750-017-0102-2

Gao, Y., Skutsch, M.M., Paneque-Gálvez, J., Ghilardi, A., 2020. Remote sensing of forest degradation: a review. Environ. Res. Lett. 15. https://doi.org/10.1088/1748-9326/abaad7.

Garbarino, M., Borgogno Mondino, E., Lingua, E., Nagel, T.A., Dukić, V., Govedar, Z., Motta, R., 2012. Gap disturbances and regeneration patterns in a Bosnian old-growth forest: a multispectral remote sensing and ground-based approach. Ann. For. Sci. 69, 617–625. https://doi.org/10.1007/s13595-011-0177-9.

Hansen, M.C., Potapov, P. V, Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S. V, Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., Townshend, J.R.G., 2013. High-resolution global maps of 21st-century forest cover change. Science 342, 850–853. https://doi.org/10.1126/science.1244693.

Horvat, D., Žalik, B., Mongus, D., 2016. Context-dependent detection of non-linearly distributed points for vegetation classification in airborne LiDAR. ISPRS J. Photogramm. Remote Sens. 116, 1–14. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2016.02.011.
Hysa, A., Teqja, Z., 2020. Counting fuel properties as input in the wildfire spreading capacities of vegetated surfaces: case of Albania. Not. Bot. Horti Agrobot. Cluj-Napoca 48. https://doi.org/10.15835/nbha48311994.

Kostić, S., Wagner, W., Orlović, S., Levanič, T., Zlatanov, T., Goršić, E., Kesić, L., Matović, B., Tsvetanov, N., Stojanović, D.B., 2021. Different tree-ring width sensitivities to satellite-based soil moisture from dry, moderate and wet pedunculate oak (Quercus robur L.) stands across a southeastern distribution margin. Sci. Total Environ. 800, 149536. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.149536

Kuemmerle, T., Chaskovskyy, O., Knorn, J., Radeloff, V.C., Kruhlov, I., Keeton, W.S., Hostert, P., 2009. Forest cover change and illegal logging in the Ukrainian Carpathians in the transition period from 1988 to 2007. Remote Sens. Environ. RSE-07342.

Jansen, L., Carrai, G., Morandini, L., Cerutti, P., Spisni, A., 2006. Analysis of the spatio-temporal and semantic aspects of land-cover/use change dynamics 1991 - 2001 in Albania at national and district levels. Environ. Monit. Assess. 119, 107–136.

Jurjević, L., Liang, X., Gašparović, M., Balenović, I., 2020. Is field-measured tree height as reliable as believed – Part II, A comparison study of tree height estimates from conventional field measurement and low-cost close-range remote sensing in a deciduous forest. ISPRS J. Photogramm. Remote Sens. 169, 227–241.
https://doi.org/https://doi.org/10.1016/j.isprsjprs.2020.09.014.

Lévesque, J., King, D.J., 2003. Spatial analysis of radiometric fractions from high-resolution multispectral imagery for modelling individual tree crown and forest canopy structure and health. Remote Sens. Environ. 84, 589–602. https://doi.org/https://doi.org/10.1016/S0034-4257(02)00182-7.

Loozen, Y., Rebel, K.T., de Jong, S.M., Lu, M., Ollinger, S. V, Wassen, M.J., Karssenberg, D., 2020. Mapping canopy nitrogen in European forests using remote sensing and environmental variables with the random forests method. Remote Sens. Environ. 247, 111933. https://doi.org/https://doi.org/10.1016/j.rse.2020.111933

Näsi, R., Honkavaara, E., Blomqvist, M., Paivi, L.-S., Hakala, T., Viljanen, N., Tuula, K., Holopainen, M., 2018. Remote sensing of bark beetle damage in urban forests at individual tree level using a novel hyperspectral camera from UAV and aircraft. Urban For. Urban Green. 30. https://doi.org/10.1016/j.ufug.2018.01.010.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2010. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. Int. J. Surg. 8, 336–341.
https://doi.org/https://doi.org/10.1016/j.ijsu.2010.02.007

Mongus, D., Žalik, B., 2018. Segmentation schema for enhancing land cover identification: A case study using Sentinel 2 data. Int. J. Appl. Earth Obs. Geoinf. 66, 56–68. https://doi.org/https://doi.org/10.1016/j.jag.2017.11.004
Mongus, D., Žalik, B., 2015. An efficient approach to 3D single tree-crown delineation in LiDAR data. ISPRS J. Photogramm. Remote Sens. 108, 219–233. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2015.08.004

Panic, N., Leoncini, E., de Belvis, G., Ricciardi, W., Boccia, S., 2013. Evaluation of the Endorsement of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Statement on the Quality of Published Systematic Review and Meta-Analyses. PLoS One 8, 1–7. https://doi.org/10.1371/journal.pone.0083138

Pekkarinen, A., Reithmaier, L., Strobl, P., 2009. Pan-European forest/non-forest mapping with Landsat ETM+ and CORINE Land Cover 2000 data. ISPRS J. Photogramm. Remote Sens. 64, 171–183. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2008.09.004

Pérez-Hoyos, A., García-Haro, F.J., San-Miguel-Ayanz, J., 2012. Conventional and fuzzy comparisons of large scale land cover products: Application to CORINE, GLC2000, MODIS and GlobCover in Europe. ISPRS J. Photogramm. Remote Sens. 74, 185–201. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2012.09.006

Pernar, R., Seletković, A., Ančić, M., Vedriš, M. i Teslak, K., 2008. Assessing the health status of beech-fir forests using remote sensing methods. Period. Biol. 110, 157–161.

Phalke, A.R., Özdoğan, M., Thenkabail, P.S., Erickson, T., Gorelick, N., Yadav, K., Congalton, R.G., 2020. Mapping croplands of Europe, Middle East, Russia, and Central Asia using Landsat, Random Forest, and Google Earth Engine. ISPRS J. Photogramm. Remote Sens. 167, 104–122. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2020.06.022

Pilaš, I., Medved, I., Medak, J., Medak, D., 2014. Response strategies of the main forest types to climatic anomalies across Croatian biogeographic regions inferred from FAPAR remote sensing data. For. Ecol. Manage. 326, 58–78. https://doi.org/https://doi.org/10.1016/j.foreco.2014.04.012

Pinter, P., Hatfield, J., Schepers, J.., Barnes, E., Moran, M., Daughtry, C., Upchurch, D., 2003. Remote Sensing for Crop Management. Photogramm. Eng. Remote Sens. 69. https://doi.org/10.14358/PERS.69.6.647

Potapov, P. V, Turubanova, S.A., Tyukavina, A., Krylov, A.M., McCarty, J.L., Radeloff, V.C., Hansen, M.C., 2015. Eastern Europe's forest cover dynamics from 1985 to 2012 quantified from the full Landsat archive. Remote Sens. Environ. 159, 28–43. https://doi.org/https://doi.org/10.1016/j.rse.2014.11.027

Prăvălie, R., Patriche, C., Bandoc, G., 2017. Quantification of land degradation sensitivity areas in Southern and Central Southeastern Europe. New results based on improving DISMED methodology with new climate data. CATENA 158, 309–320. https://doi.org/https://doi.org/10.1016/j.catena.2017.07.006

Qin, Y., Xiao, X., Wigneron, J.-P., Ciais, P., Brandt, M., Fan, L., Li, X., Crowell, S., Wu, X., Doughty, R., Zhang, Y., Liu, F., Sitch, S., Moore, B., 2021. Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon. Nat. Clim. Chang. 11, 442–448. https://doi.org/10.1038/s41558-021-01026-5.

Tang, H., Armston, J., Hancock, S., Marselis, S., Goetz, S., Dubayah, R., 2019. Characterizing global forest canopy cover distribution using spaceborne lidar. Remote Sens. Environ. 231, 111262. https://doi.org/https://doi.org/10.1016/j.rse.2019.111262.

Senf, C., Sebald, J., Seidl, R., 2021. Increasing canopy mortality affects the future demographic structure of Europe's forests. One Earth 4, 749–755. https://doi.org/https://doi.org/10.1016/j.oneear.2021.04.008

Shendryk, I., Broich, M., Tulbure, M.G., McGrath, A., Keith, D., Alexandrov, S. V, 2016. Mapping individual tree health using full-waveform airborne laser scans and imaging spectroscopy: A case study for a floodplain eucalypt forest. Remote Sens. Environ. 187, 202–217. https://doi.org/https://doi.org/10.1016/j.rse.2016.10.014

Somodi, I., Čarni, A., Ribeiro, D., Podobnikar, T., 2012. Recognition of the invasive species Robinia pseudacacia from combined remote sensing and GIS sources. Biol. Conserv. 150, 59–67. https://doi.org/https://doi.org/10.1016/j.biocon.2012.02.014.

Stroppiana, D., Bordogna, G., Carrara, P., Boschetti, M., Boschetti, L., Brivio, P.A., 2012. A method for extracting burned areas from Landsat TM/ETM+ images by soft aggregation of multiple Spectral Indices and a region growing algorithm. ISPRS J. Photogramm. Remote Sens. 69, 88–102. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2012.03.001.

Vilar, L., Garrido, J., Echavarría, P., Martínez-Vega, J., Martín, M.P., 2019. Comparative analysis of CORINE and climate change initiative land cover maps in Europe: Implications for wildfire occurrence estimation at regional and local scales. Int. J. Appl. Earth Obs. Geoinf. 78, 102–117. https://doi.org/https://doi.org/10.1016/j.jag.2019.01.019.

Waser, L.T., Schwarz, M., 2006. Comparison of large-area land cover products with national forest inventories and CORINE land cover in the European Alps. Int. J. Appl. Earth Obs. Geoinf. 8, 196–207. https://doi.org/https://doi.org/10.1016/j.jag.2005.10.001.

Wheeler, C., Mitchard, E., Reyes, H., Herrera, G., Rubio, J., Carstairs, H., Williams, M., 2021. A New Field Protocol for Monitoring Forest Degradation. Front. For. Glob. Chang. 4. https://doi.org/10.3389/ffgc.2021.655280.

Witmer, F.D.W., O'Loughlin, J., 2009. Satellite Data Methods and Application in the Evaluation of War Outcomes: Abandoned Agricultural Land in Bosnia-Herzegovina After the 1992–1995 Conflict. Ann. Assoc. Am. Geogr. 99, 1033–1044. https://doi.org/10.1080/00045600903260697.

Zagoranski, F., Pernar, R., Seletković, A., Ančić, M. i Kolić, J., 2018. Monitoring the Health Status of Trees in Maksimir Forest Park Using Remote Sensing Methods. South-east Eur. For. 9, 81–87

Zakšek, K., Schroedter-Homscheidt, M., 2009. Parameterization of air temperature in high temporal and spatial resolution from a combination of the SEVIRI and MODIS instruments. ISPRS J. Photogramm. Remote Sens. 64, 414–421. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2009.02.006

Zanon, M., Davis, B.A.S., Marquer, L., Brewer, S., Kaplan, J.O., 2018. European Forest Cover During the Past 12,000 Years: A Palynological Reconstruction Based on Modern Analogs and Remote Sensing. Front. Plant Sci. 9, 253. https://doi.org/10.3389/fpls.2018.00253.