AUTOMATIC FOREST DEGRADATION MONITORING BY REMOTE SENSING METHODS AND COPERNICUS DATA

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ABSTRACT:

Nowadays, forests are the most widely spread land cover and therefore play a significant role in ecology and create processes' dynamics. Forests are threatened by various harmful effects due to biotic (insects, fungi, viruses, weeds, animals) and abiotic (floods, fires, storms, droughts, polluted atmospheres etc.) damages. Also, human damage (anthropogenic impact) is numerous and varied. They are caused by direct human action on the forest and indirect activities and processes (damage due to grazing, consequent devastation and erosion of habitats etc.). Forest devastation and illegal logging are one of the immediate negative human activities that have a detrimental impact on the forest. The research refers to the state forests of two management units, Javornik and Ćorkovača-Karlice in the border area of the Republic of Croatia. Part of the forests (about 3,000 hectares) of these two management units are located in a mine suspected area along the state border with Bosnia and Herzegovina. This research aims to develop an automatic algorithm for forest degradation monitoring by remote sensing methods and Copernicus data. The developed algorithm was based on the Sentinel-2 (S2) optical satellite imagery and Google Earth Engine. The proposed automatic forest degradation monitoring algorithm was based on the ΔNDVI change detection approach. Accuracy assessment was done by independent data in higher, 3-m resolution based PlanetScope imagery. Preliminary results show very similar forest degradation values per all tested forest compartment/subcompartment for automatically generated S2 10-m imagery forest degradation map and 3-m forest maps obtained manually from PlanetScope imagery.

1. INTRODUCTION

Globally, the forests are the most widely spread land cover and therefore play a significant role in ecology and create processes' dynamics. To implement timely and effective adaptation actions against climate change, one of the main prerequisites is identifying changes, especially in the case of deforestation and forest degradation. In 2019, the Food and Agriculture Organization of the United Nations (FAO) adopted a program that aims at integrating forest and water management while ensuring the resilience of forests to climate change. European Union (EU) forests cover 182 million ha, i.e., 43% of its total area. The total forest area and forest lands in the Republic of Croatia are 2,759,039 ha, which is 49.3% country's land area, according to which it is in the group of forested European countries. Despite economic activities aimed at regulating and improving the structure and quality of stands, forest degradation occurs continuously over time with greater or lesser intensity. Therefore, monitoring forest degradation, especially the intensity and dynamics of tree damage, is necessary for forest management. As a source of information, satellite imagery and remote sensing have effective means to analyse forests. In the past, land use land cover (LULC) research has largely been researched based on the visual (Petit and Lambin 2001) or digital interpretation of the imagery (Wulder et al. 1998). In the last decade of the 20th century, with the launch of a new generation of high spatial resolution satellites (IKONOS), various remote sensing applications are used for environmental monitoring. The classification of satellite imagery is used to determine land cover (LC) maps to prepare data as input into geographical information systems (GIS) or spatial databases to monitor and detect forests and forest lands etc. The satellite imagery classification can be divided into supervised, unsupervised, or object-based methods (Jensen 1996). In some applications, the image classification result is the desired product, while in others, it is only a step on the way to obtaining the desired product (Dewan and Yamaguchi 2009; Gašparović and Klobučar, 2021; Deur et al., 2021).

This research aims to develop an automatic algorithm for forest degradation monitoring by remote sensing methods and Copernicus data. The developed algorithm was based on the Sentinel-2 (S2) optical satellite imagery and tested on a study site in Croatia.

2. MATERIALS AND METHODS

2.1 Study area and data

The research refers to the state forests of two management units, Javornik and Ćorkovača-Karlice, in the border area of the Republic of Croatia (Figure 1). Part of the forests (about 3,000 hectares) of these two management units is located in a mine suspected area along the state border with Bosnia and

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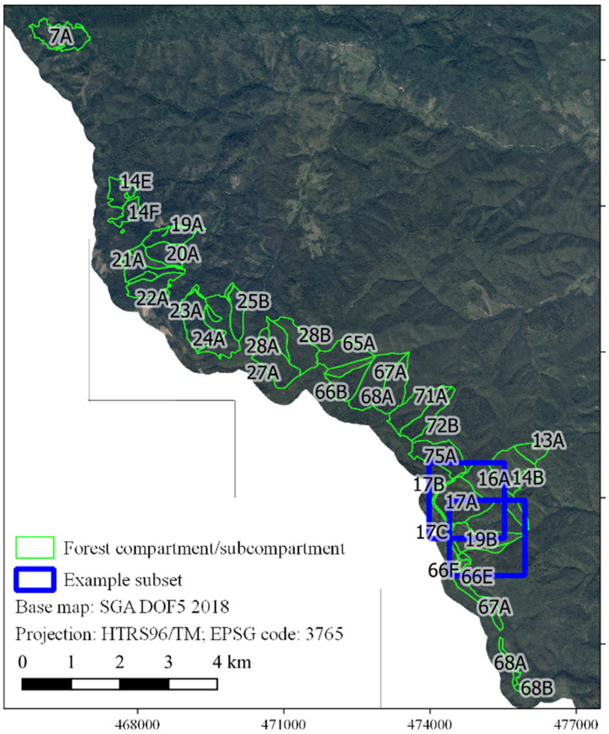
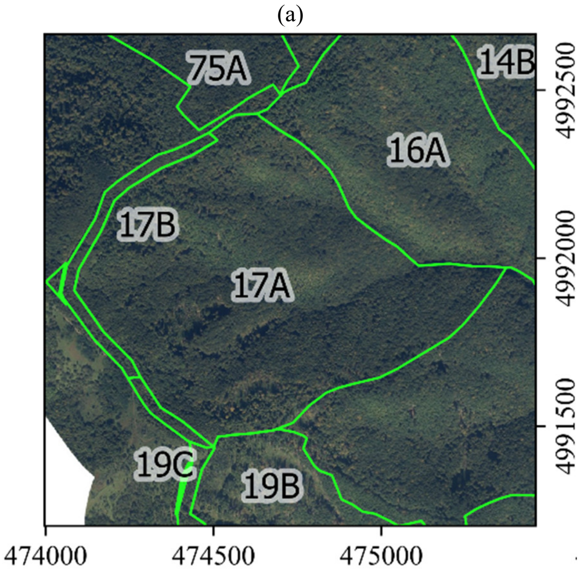
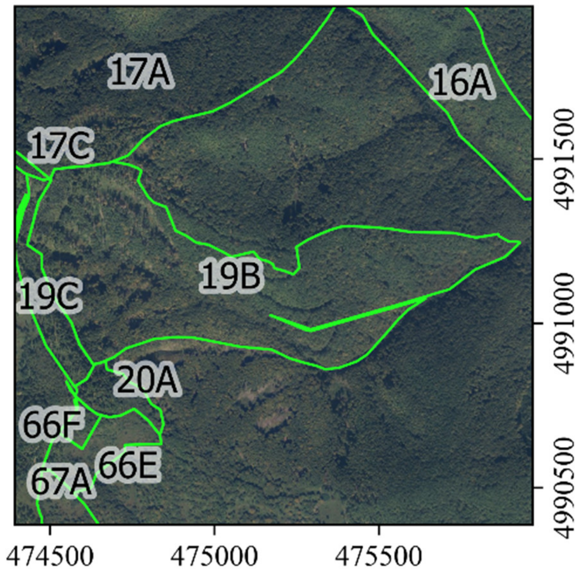
Herzegovina. As such, these forests have occasionally been the subject of illegal logging and devastation in the past to meet the needs of the local population for the firewood and timber trade. Therefore, the fundamental problem in determining the extent of damage (area, degree of damage, volume) is the inability to access such areas. Thus, physical access to areas of interest and field damage assessment is high risk, while on the other hand, remote sensing techniques are a fast and reliable way to assess forest damage (Mitchell et al. 2017, Pilaš et al. 2020). In this regard, drones, aerial and satellite imagery are available to users (Lechner et al. 2020). Satellite images equipped with optical and radar sensors and their fusion can be successfully applied to detect deforestation and illegal logging (Atzberger et al. 2020). In this research, optical satellite images Sentinel-2 were selected to determine the extent of the damage automatically. Forest compartments/subcompartments 17A and 19B (Figure 1) are used as two example sites to demonstrate the developed algorithm and results.



(a)



(b)



(c)

Figure 1. Study area and example subsets (a) forest compartments/subcompartments 17A (b) and 19B (c). Base map is a digital orthophoto map (DOF) from State geodetic administration (SGA).

2.2 Automatic forest degradation monitoring by remote sensing methods and Copernicus data

Forests are threatened by various harmful effects (Tikvić and Ugarković 2021). Degradation of forests due to biotic (insects, fungi, viruses, weeds, animals) and abiotic (floods, fires, storms, droughts, polluted atmospheres etc.) damages are becoming more frequent and intense today (Wegmueller and Townsend 2021). Also, human damage (anthropogenic impact) is numerous and varied. They are caused by direct human action on the forest and indirect activities and processes (damage due to grazing, consequent devastation and erosion of habitats etc.). Forest devastation and illegal logging are one of the immediate negative human activities that have a detrimental impact on the forest (Hirschmugl et al. 2017). They are mainly a consequence of gaining forest benefits (Jovanović and Milanović 2017) and appear on individual trees, smaller or larger groups of trees and entire stands, forming irregular gaps in the forest canopy (Atzberger et al. 2020).

This research aims to develop an automatic algorithm for forest degradation monitoring by remote sensing methods and Copernicus data. The developed algorithm was based on the Sentinel-2 (S2) optical satellite imagery and tested on a study site in Croatia. All S2 imagery were collected in L2A preprocessing mode for the entire study site. Cloudy imageries were excluded, and areas covered by clouds and shadows were masked on all imagery. For each study year (2016-2021), S2 mosaic for the same phenological forest period were made. NDVI (Normalized Difference Vegetation Index; Carlson and Ripley, 1997) was calculated based on each yearly mosaic. Mosaic represents a large-scale composite image with a sequence of overlapped satellite scenes or tiles (Manandhar et al. 2021). Monitoring and detection of forest degradation was obtained by ΔNDVI calculated by the equation:

$$\Delta NDVI = NDVI_{y} - NDVI_{y+n}, \tag{1}$$

where: ΔNDVI = NDVI difference

y = starting year for monitoring
n = number of years for monitoring.

The entire previously described process is automatised using Google Earth Engine (GEE) and enables automatic forest degradation monitoring by remote sensing methods and Copernicus data without human supervision. Figure 2 shows true-colour composite and NDVI before and after forest degradation that is used for ΔNDVI calculation.

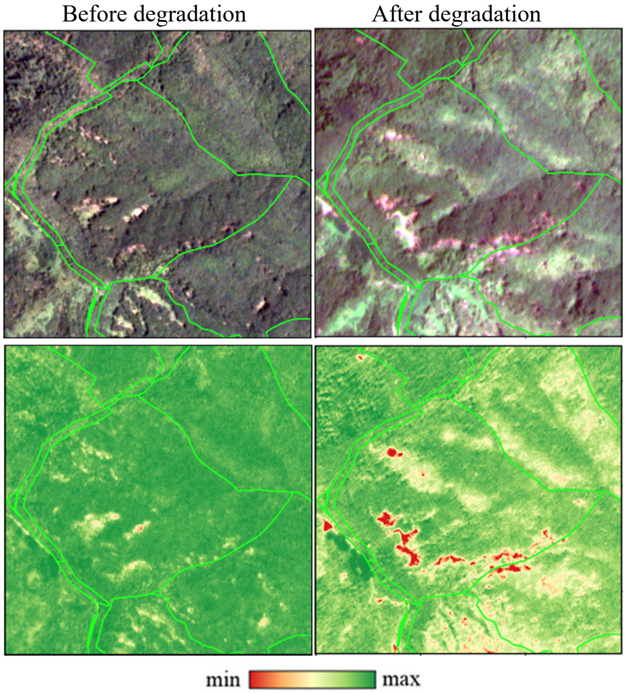


Figure 2. True-colour composite (above) and NDVI (below) before and after forest degradation for forest compartment/subcompartment 17A.

Accuracy assessment was done by independent data in higher, 3-m resolution based PlanetScope imagery. PlanetScope imagery was downloaded in the same time frame as S2 mosaic and the same phenology forest stage. Downloaded imagery was manually classified based on a supervised, machine learning image classification approach with a Random Forest classifier.

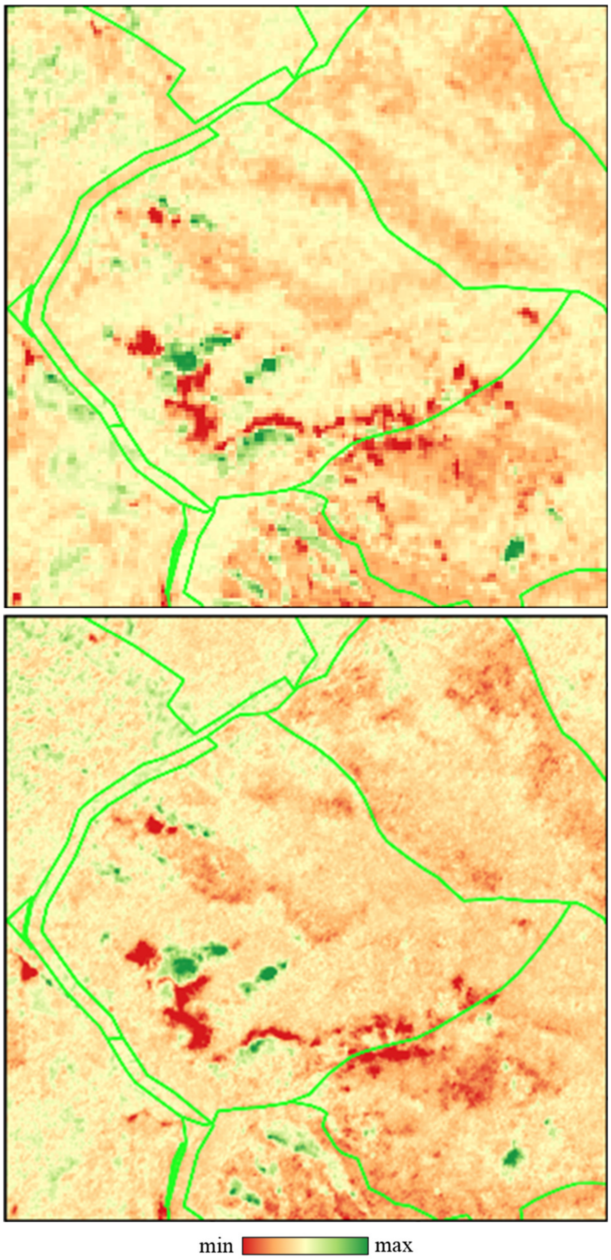


Figure 3. Automatically calculated ΔNDVI based composite for cloud- and shadow free 10-m S2 mosaic for 2016 and 2021 year (above) and corresponding PlanetScope ΔNDVI (below) in 3-m spatial resolution for forest compartment/subcompartment 17A.

3. RESULTS

The proposed automatic forest degradation monitoring algorithm developed on remote sensing methodology and Copernicus data enable the following results. An algorithm based ΔNDVI automatically creates a forest degradation map. Figures 3 and 4 show automatically calculated ΔNDVI for S2 imagery and correspond to PlanetScope ΔNDVI used for manual mapping forest degradation in 3-m spatial resolution for both example subsets, forest compartment/subcompartment 17A and 19B, respectively.

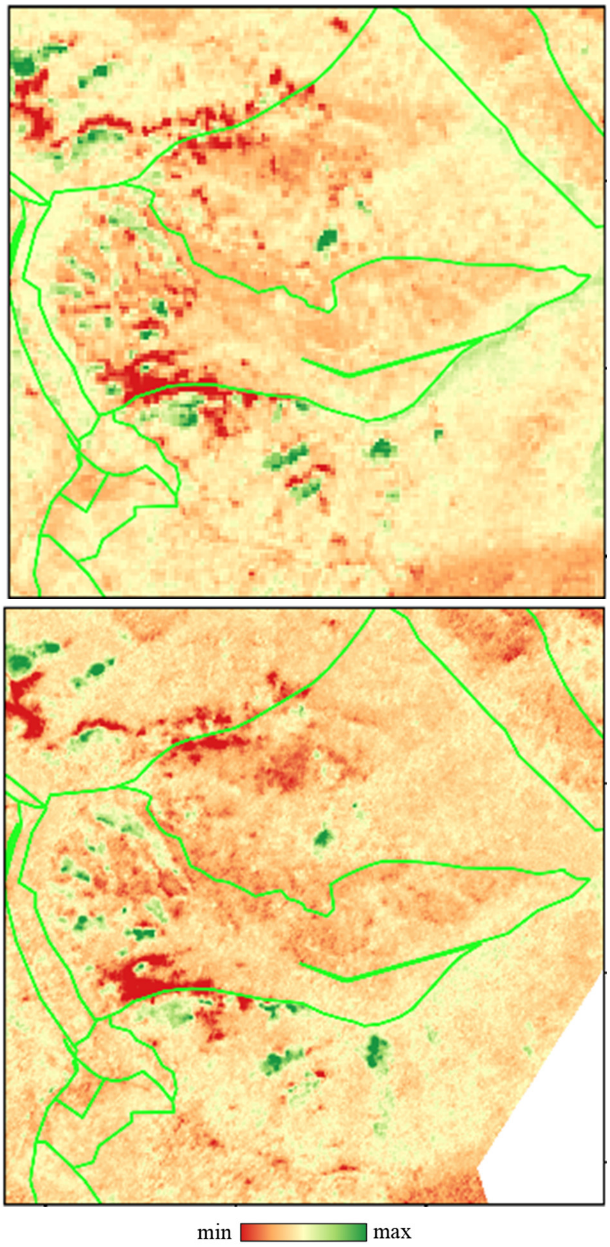


Figure 4. Automatically calculated ΔNDVI based composite for cloud- and shadow-free 10-m S2 mosaic for 2016 and 2021 years (above) and corresponding PlanetScope ΔNDVI (below) in 3-m spatial resolution for forest compartment/subcompartment 19B.

For accuracy assessment, 3-m resolution based PlanetScope imagery were used. The automatic forest degradation map made by the presented approach based on S2 10-m imagery and 3-m forest degradation map made by manual classification of the PlanetScope imagery are shown in Figures 5 and 6.

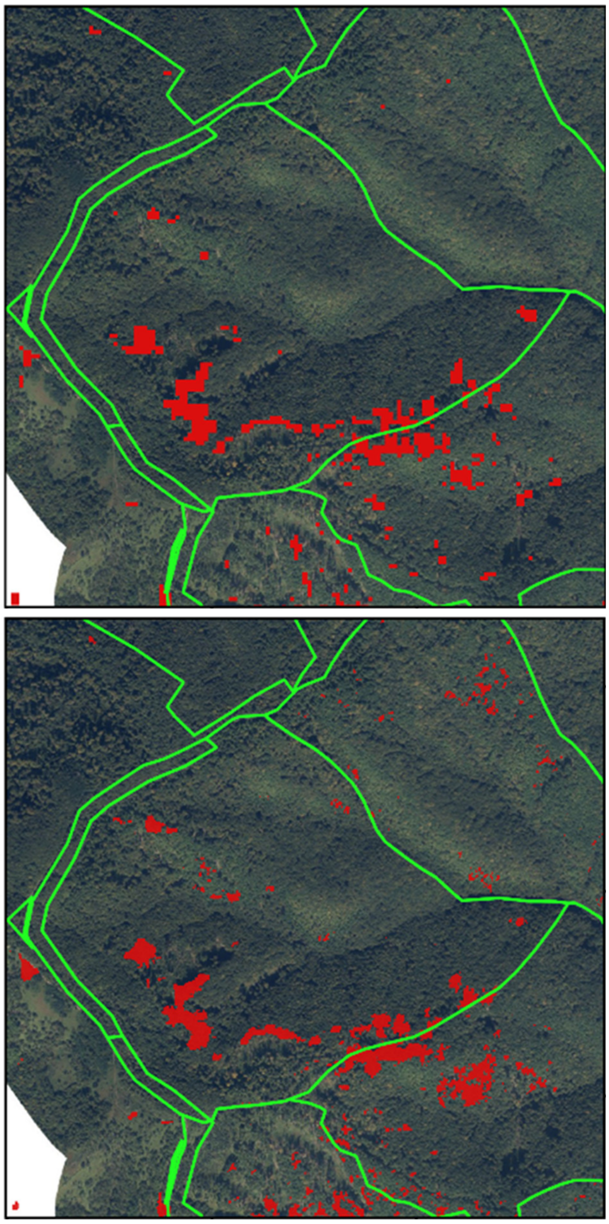


Figure 5. Automatically forest degradation map based on S2 10-m imagery (above) and 3-m forest degradation map (below) for forest compartment/subcompartment 17A (base map: digital orthophoto map).

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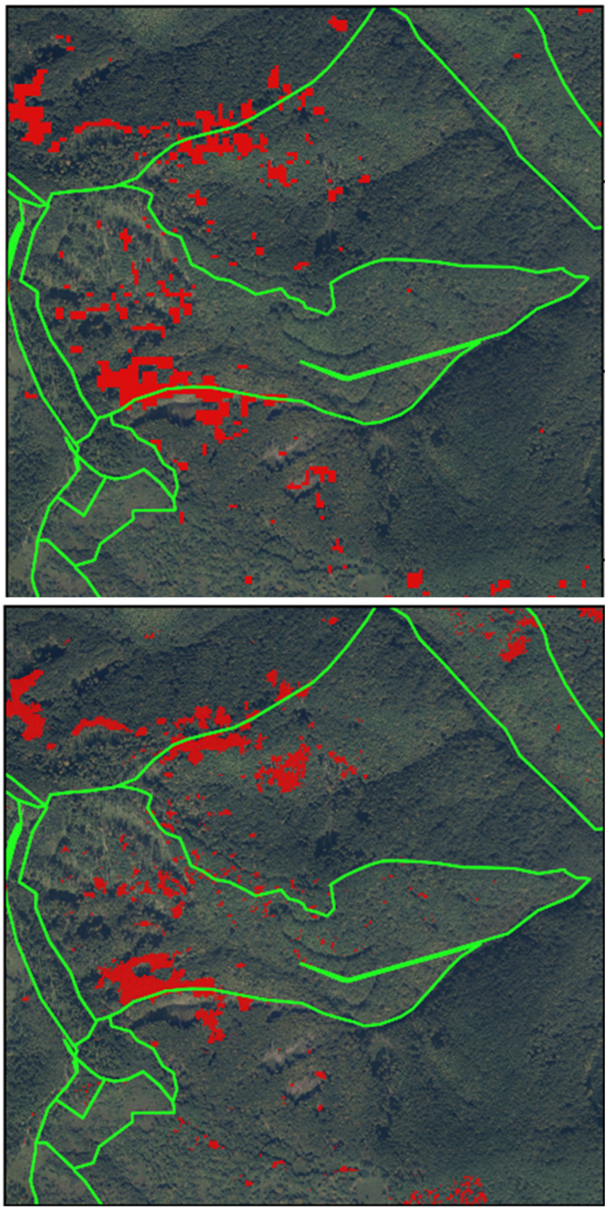

Figure 6. Automatically forest degradation map based on S2 10-m imagery (above) and 3-m forest degradation map (below) for forest compartment/subcompartment 19B (base map: digital orthophoto map).

The proposed algorithm based on S2 imagery clearly shows very similar results as manually mapped forest degradation in 3-m resolution from PlanetScope imagery on both forest compartments/subcompartments.

3.1 Forest degradation monitoring and analysis

A proposed algorithm for automatic forest degradation monitoring by remote sensing methods and Copernicus data was used to get preliminary results for forest degradation for state forests of two management units, Javornik and Ćorkovača-Karlice in the border area of the Republic of Croatia. For all tested forest compartments/subcompartments, an automatic forest degradation map based on S2 10-m imagery and 3-m forest degradation map based PlanetScope for accuracy assessment. Forest degradation monitoring and analysis done for all tested forest compartments/subcompartments based on the proposed algorithm and 10-m resolution S2 imagery, and manually mapped forest degradation based on 3-m resolution PlanetScope imagery are shown in figure 7.

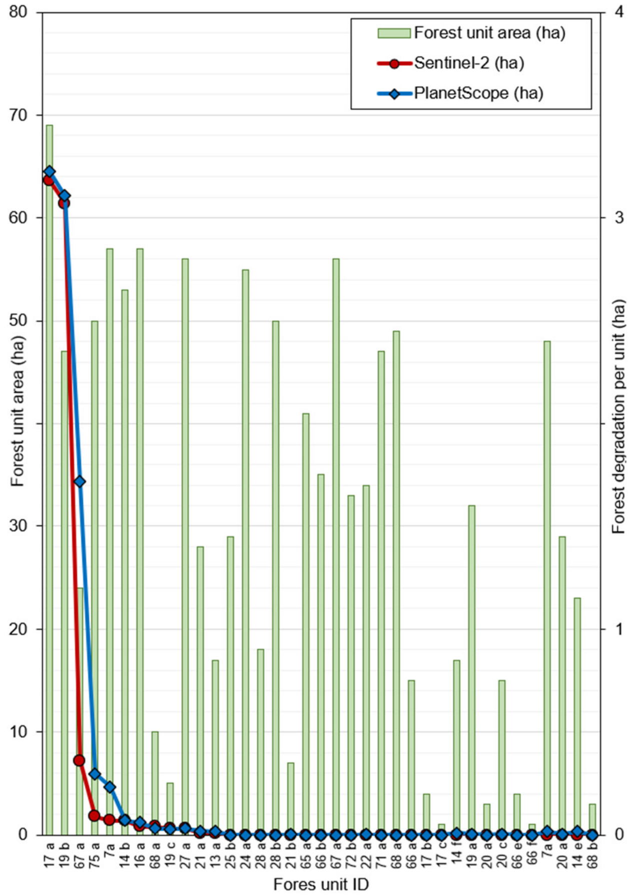

Figure 7. Forest degradation monitoring and analysis of two management units (Javornik and Ćorkovača-Karlice) by proposed automatically forest degradation mapping approach based on S2 10-m imagery and 3-m forest degradation maps obtained manually from PlanetScope imagery.

Figure 7 shows us similar forest degradation values per all tested forest compartments/subcompartments for automatically generated S2 10-m imagery forest degradation map and 3-m forest maps obtained manually from PlanetScope imagery. Results show that forest compartments/subcompartments 17A and 19B have the highest forest degradation.

4. CONCLUSIONS

The proposed algorithm for automatic forest degradation monitoring by remote sensing methods and Copernicus data shows similar results as independent higher resolution satellite imagery. As preliminary research, this study shows promising results for future studies of the application of S2 imagery and GEE for automatic forest degradation mapping. The developed methodology provides new knowledge valuable and applicable for various forest degradation problems. Also, this method allows rapid detection of forest disturbances, which have a significant impact on the environment and climate change. The proposed methodology presented in this research can be applied to various locations around the globe on other optical satellite imagery, e.g., Landsat, RapidEye and PlanetScope.

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