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THE DESTRUCTION OF URBAN FORESTS IN UKRAINE: POTENTIAL SOCIAL IMPACTS, REMOTE SENSING-BASED MONITORING, AND CONSIDERATIONS FOR FUTURE RECONSTRUCTION

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The invasion of Ukraine by Russian forces in 2022 has resulted in the partial or complete destruction of cities and towns. In addition to damage to buildings and infrastructure in urban areas, the war has impacted the urban forests and greenspace areas. This synthesis seeks to summarize the social and psychological benefits of urban trees, report on the potential to use remote sensing and Earth Observation technology to assess the damage to urban forests due to the invasion, and review considerations for the reconstruction of Ukraine's urban forest.

Urban trees and parks produce numerous benefits including support of biodiversity and wildlife habitat, conservation of energy, reduction in air pollution, greater efficiency in stormwater management, as well as improvement of physical and mental health, and establishment of a sense of community. Positive effects of urban forests on human health and well-being have been documented for several decades and revealed a wide range of ways in which these benefits are expressed [1, 2]. In particular, earlier research three principal domains in which such benefits are manifested: (a) mitigation, or the reduction of harms (e.g., amelioration of microclimate or reduction in air pollution), (b) restoration, or re-building capacity for normal functioning due to reduced stress levels after contact with nature, and (c) instoration, or building new positive social interactions in green spaces [3, 4]. Various benefits have been reported among different socio-demographic groups, including positive effects on academic performance of school children when either the school grounds [5], or the local neighborhood contained trees [6]. In the context of recovering from war, rebuilding urban forests will thus likely provide for an improvement in social interactions among adults.

However, measuring the impacts of the ongoing armed conflict on these diverse urban forest benefits remains extremely difficult due to barriers to both field-based tree inventories and assessments of public perception under current war conditions. Remote sensing and Earth Observation technology can provide a preliminary insight into urban forest dynamics in response to the war effects based on instantaneous coverage or large regions, repeated data collection, and spectral contrasts between vegetation and built environment features [7]. To investigate this potential for

Ukraine's urban forests, we assessed changes in vegetation indicators derived from 10-m spatial resolution Sentinel-2 satellite image products within seven cities in Donetsk and Lugansk oblasts that have experienced a particularly high damage during the first year of the war: Mariupol, Severodonetsk, Bakhmut, Lyman, Popasna, Volnovakha, and Rubizhne. Given the lack of on-the-ground validation information, we applied a two-step hybrid change analysis approach where 1) May-September imagery of 2021 was first used to map pre-invasion built-up areas and woody and herbaceous vegetation using supervised random forest machine learning classification, and then 2) potential losses of vegetation were assessed from the changes in Normalized Difference Vegetation Index (NDVI), a popular indicator of vegetation greenness and cover, between July-August periods of 2021 and 2022.

Among the seven studied cities, major detected losses of greenness ranged between ~9 and 247 ha and constituted 1-10% of their 2021 vegetated areas, with the lowest in Lyman (~1%) and the highest - in Rubizhne (10.12%), Severodonetsk (8.95%), and Bakhmut (7.17%). For areas classified as woody in 2021, major NDVI losses constituted 21.11% of their 2021 extent in Rubizhne, 7.73% in Severodonetsk, and 0.98-3.75% in other cities. Herbaceous-dominated areas had pronounced NDVI losses within 0.80-9.62% of their 2021 extent with the largest effects in Bakhmut (9.49%) and Severodonetsk (9.62%). These results resonate with media reports and photographic records from these cities and nearby regions showing tree damage from direct military attacks, logging of urban and exurban green zones for the fuel, and the impacts of war-induced fires and pollution. Classification accuracy for 2021 urban green space mapping reached 88.7% in overall accuracy; 89.4%, 86.3% and 90.3% in user's accuracy for woody, herbaceous, and built-up, respectively; and 90.3%, 83.8%, and 92.1% for woody, herbaceous, and built-up, respectively. Misclassifications resulted mainly from 1) confusion between spectrally similar woody and herbaceous vegetation, and 2) heterogeneous urban landscapes where Sentinel-2 pixels were more likely to contain mixed spectral signals from multiple different classes.

These outcomes suggest important implications for urban forest monitoring under ongoing invasion and in the future. First, the impacts on urban vegetation are likely to be scattered in space and vary in magnitude and extent even within a single city. Second, some effects may induce partial tree damage or stress rather than complete removal of vegetation, and thus might be harder to detect, verify, or attribute to a specific timeline of events, especially with limited on-the-ground validation. Third, various landscape processes may convolute impact signatures in the available data, such as regeneration, and/or revegetation by faster-growing herbaceous species. Furthermore, some changes may be hard to detect in the 'mixed pixels' containing different landscape elements (buildings, trees). Strategies to navigate these caveats in the future assessments may include: 1) using multiple dates of available imagery in each year to emphasize seasonal contrasts among vegetation types and disentangling signals of damage from short-term spectral variation; 2) applying multiple change detection approaches together to reveal complementary aspects of urban vegetation change (such as combining classification of pre-war imagery with spectral index differencing to detect pronounced losses or gains in plant cover), and 3) combining traditionally popular visible, near- and shortwave-infrared reflectance products with other open-access satellite datasets such as thermal infrared indicating land surface temperature and synthetic aperture radar (SAR) sensitive to 3-D structure of urban environments.

When the war ends Ukraine must undertake the rebuilding of cities and towns. Such rebuilding must first focus on the reconstruction of housing and critical infrastructure, but at some point, reconstruction of urban forests and urban greenspaces will be considered. Studies of the reconstruction of urban forests following historical events such as World War II and the Bosnian war may help identify issues to be addressed in the reconstruction of urban forests in Ukraine [8]. Several issues are particularly important in the reconstruction of war damaged urban forests and greenspace: (1) people may have a strong preference for their original environment, including trees and greenspace, restored to pre-war conditions, (2) nursery stock may not be available immediately after the war, (3) impacts of bombing on soil at replanting sites, (4) importance of engaging local people in replanting trees, (5) implications of climate change in the selection of trees and plants for replanting, and (6) the psychological value of saving a few damaged trees as survivors of the war. The opportunity of local people to see trees that survived the war, in spite of the trees being damaged, can remind people that they too are survivors. Arborist should evaluate damage trees in various bombed cities in Ukraine to identify potential tree that should not be cut down and a system of signs should be developed to identify these trees in the future.

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