Impact of the COVID-19 Pandemic on Forest Area in Global Biodiversity Hotspots: Postprint

Authors: Zhou Shuai

Date: 2023-07-26T00:00:00+00:00

Abstract

Forests constitute a critical safeguard for maintaining biodiversity, and the loss of forest area frequently leads to regional biodiversity reduction or extinction. To investigate the impact of the COVID-19 pandemic on global biodiversity, this study examines forest loss area, biodiversity integrity data, annual COVID-19 infection data (for 2020 and 2021), and Gross Domestic Product (GDP) in global biodiversity hotspots, conducting correlation analysis, linear mixed-effects model construction, and regression prediction. The results demonstrate that although COVID-19 infections per million population exhibit a significant negative correlation with forest loss area—specifically, the pandemic significantly reduced forest loss caused by large-scale urban and agricultural expansion—the total forest loss in global biodiversity hotspots continued to increase during the two years of the pandemic outbreak (2020 and 2021). The primary reason is that the pandemic indirectly accelerated the harvesting of plantation forests and natural forests. Regression model predictions indicate that during the COVID-19 pandemic, forest loss area in global biodiversity hotspots increased by 5.83% and 21.78% in 2020 and 2021, respectively. Consequently, this study finds that while the COVID-19 pandemic exerted a certain inhibitory effect on forest loss in biodiversity hotspots, the area of forest loss continues to increase.

Full Text

Preamble

A Global Perspective on the Influence of the COVID-19 Pandemic on Forest Areas in Biodiversity Hotspots

ZHOU Shuai (1. Shanxi Academy of Forestry and Grassland Sciences, Taiyuan 030012, China; 2. Shanxi Agricultural University, Taigu 030800, Shanxi, China)

Abstract

Forests are critical for maintaining biodiversity, and forest loss often leads to regional biodiversity decline or extinction. To investigate the impact of COVID-19 on global biodiversity, this study analyzed forest loss area, biodiversity integrity data, annual COVID-19 infection data (for 2020 and 2021), and Gross Domestic Product (GDP) in global biodiversity hotspots through correlation analysis, linear mixed-effects modeling, and regression forecasting. The results revealed a significant negative correlation between COVID-19 infections per million population and forest loss area—specifically, the pandemic substantially reduced forest loss caused by large-scale urban and agricultural expansion. However, total forest loss in global biodiversity hotspots continued to increase during the two pandemic years (2020 and 2021), primarily due to the indirect acceleration of harvesting in both natural and plantation forests. Regression model predictions indicated that forest loss area in global biodiversity hotspots increased by 5.83% and 21.78% in 2020 and 2021, respectively, during the pandemic. Consequently, while COVID-19 exerted a restraining effect on forest loss in biodiversity hotspots, the overall forest loss area continued to rise.

Keywords: COVID-19, biodiversity, forest, remote sensing, predictive model

---

Biodiversity is closely linked to the survival environments of flora and fauna (Vais et al., 2020). In recent years, global biodiversity loss has intensified due to habitat reduction, threatening human living environments (Cardinale et al., 2012; Pereira et al., 2020). Research shows that forests harbor higher biodiversity than farmland, urban areas, and grasslands, making forest cover in biodiversity hotspots a key indicator for assessing biodiversity degradation (Gong et al., 2019; Marín et al., 2021).

As a crucial carrier of biodiversity, forest area is continuously declining. Reports from Global Forest Watch (www.globalforestwatch.org) show that global primary forest area decreased by 2.8% in 2019 (Chraibi et al., 2021). The causes include human activities such as logging, deforestation, and agricultural encroachment, as well as natural disasters like fires and pest infestations (Abd Latif et al., 2015; Rosa et al., 2021).

COVID-19 has significantly influenced human behavior and social norms, transforming workplaces, transportation, consumption patterns, and trade methods (Askitas et al., 2020; Baldwin & Tomiura, 2020). To slow virus transmission, governments worldwide implemented various activity restrictions, with "stay-at-home" policies being the most typical—effectively creating a global "human confinement experiment" (Bates et al., 2020). By comparing and analyzing data from this "experiment," we can understand human impacts on ecosystems and develop corresponding biodiversity conservation measures. Current studies have used data from citizen science platforms to assess pandemic impacts on regional biodiversity (Maria Sanchez-Clavijo et al., 2021) and freshwater fish diversity

(Cooke et al., 2021).

Regarding COVID-19's impact on biodiversity, some scholars are optimistic (Sills et al., 2020; Zambrano-Monserrate et al., 2020), while others remain cautious (Corlett et al., 2020). Some studies have found that the pandemic exacerbates biodiversity loss (Pinder et al., 2020; Rahman et al., 2021). From the perspective of COVID-19's impact on forests, Buongiorno (2021) used the GFPMX model to predict pandemic effects on forest products; Sannigrahi et al. (2022) analyzed the relationship between forest fires and COVID-19; and Lugo-Robles et al. (2021) assessed the relationship between forest area and the pandemic. However, no studies have examined global forest cover area. Given the close relationship between forest area and biodiversity, and the maturity of remote sensing monitoring techniques, this study focuses on analyzing forest loss area in global biodiversity hotspots during the pandemic period (2020 and 2021) to answer the following research questions: (1) Were there differences in forest loss area in global biodiversity hotspots before and after the COVID-19 outbreak? (2) If differences exist, is there an association between pandemic severity and forest loss area? (3) If an association exists, what is the magnitude of COVID-19's impact on forest loss area?

To address these questions, we selected countries where biodiversity hotspots cover more than 60% of national territory based on global biodiversity integrity data. Using remote sensing-derived forest loss area from 2001 to 2021, 2020-2021 COVID-19 infections per million population, and GDP data, we conducted correlation analysis and modeling to understand the relationship between pandemic severity and forest loss area in global biodiversity hotspots, providing data support for understanding the intrinsic link between forest cover and biodiversity and for developing conservation measures.

1.1 Data Acquisition

Based on Hill et al. (2019) and Global Forest Watch's "global biodiversity integrity" data, we used ImageJ software to select countries where biodiversity hotspots exceed 60% of national territory as study subjects (Figure 1 [Figure 1: see original paper]). From Global Forest Watch's "forest cover loss" layer and forest loss cause data, we extracted annual forest loss area (Hansen et al., 2013) and annual forest loss area from five causes (large-scale agricultural expansion, small- and medium-scale agriculture, plantation and natural forest harvesting, forest fire loss, and urban expansion) within national boundaries. COVID-19 data for study subjects were extracted from Our World In Data (www.ourworldindata.org), using cumulative cases per million population on December 31, 2020 and December 31, 2021 as the 2020 and 2021 infection data, respectively (Figure 1). GDP data for the two years before the pandemic (2018 and 2019) and during the pandemic were obtained from the United Nations website (www.un.org). Data from Global Forest Watch and Our World In Data have been used in multiple studies and are highly reliable (Curtis et al., 2018; Cook-Patton et al., 2020; Tegally et al., 2022).

The study basemap was obtained from the Resource and Environmental Science and Data Centre of the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences (https://www.resdc.cn/data.aspx?DATAID=205) and was used without modification.

1.2 Data Analysis Methods

When comparing annual forest loss area from 2001-2021 and 2019-2021, we normalized each country's annual forest loss area for both periods to exclude differences caused by original forest area. Spearman's test was used for correlation analysis between forest loss area and infections per million population. When constructing linear mixed-effects models, we selected data from the pre-pandemic period (2018-2019) and pandemic period (2020-2021) to create a balanced dataset. To assess the potential impact of economic strength on forest loss during the pandemic, we included annual GDP as a variable. The linear mixed-effects models used GDP and cumulative cases per million population as fixed effects, with country and sampling year as random effects, modeling forest loss area from five causes separately. Based on model fitting results, the relationship between pandemic severity and GDP (Pardhan & Drydakis, 2021), and the association between GDP and forest loss area (Wang et al., 2016), we initially constructed a linear mixed-effects structural equation model, which was then optimized using chi-square test significance to determine the final model of pandemic severity's impact on annual forest loss area. Annual forest loss area fitting used formula (1). Statistical analysis was performed using R 4.2.2 (R Core Team, 2023), with the "nlme" package for linear mixed models, "piecewiseSEM" package for structural equation modeling, and Origin 2019 and QGIS 3.28.3 for mapping.

Annual forest loss area was fitted using formula (1):

$$= y_0 + A[\mu \frac{4}{-x_c} + (1-\mu) w_2 - x_c$$

where: y represents forest loss area; x represents year; y_0, A, μ, x_c, w are formula coefficients.

2 Results and Analysis

2.1 Forest Loss from 2001 to 2021

We identified 53 eligible countries. In the two years after the pandemic outbreak (2020-2021), total forest loss area in biodiversity hotspots continued to increase compared to 2019, rising by 3.66% in 2020 and 12.49% in 2021 (Figure 2 [Figure 2: see original paper]). After excluding the influence of original forest area among countries, the average forest loss area per country showed a declining trend, indicating substantial variation among countries (Figure 3 [Figure 3: see original paper]).

2.2 Forest Loss from 2019 to 2021

Figure 4 [Figure 4: see original paper] shows forest loss area for each country in 2019 (pre-pandemic), 2020 (first pandemic year), and 2021 (second pandemic year). The 53 countries exhibited four patterns of change: (1) **Descending type**: countries with sustained declines in forest loss in 2020 and 2021 compared to 2019 (Figure 4:a), totaling 28 countries; (2) **Ascending then descending type**: countries where forest loss increased in 2020 but decreased in 2021 (Figure 4:b), totaling 12 countries; (3) **Invariant type**: countries with no significant change trend (Figure 4:c), totaling 3 countries; and (4) **Ascending type**: countries with year-over-year increases in forest loss in 2020 and 2021 (Figure 4:d), totaling 10 countries.

Statistical analysis of the four patterns showed that during the two pandemic years, 75.47% of countries experienced decreased forest loss (sum of descending and ascending-then-descending types), while 18.87% showed increases (ascending type) (Figure 5 [Figure 5: see original paper]). Thus, in the two years following the COVID-19 outbreak, over three-quarters of countries in global biodiversity hotspots saw declining forest loss, while nearly one-fifth experienced increases.

Analysis of forest loss area across the four patterns revealed that ascending-type countries accounted for 53.82% of total forest loss area, while descending and ascending-then-descending types accounted for 26.82% and 6.14%, respectively, totaling 32.96% (Figure 6 [Figure 6: see original paper]). These changes indicate that ascending-type countries contributed the highest proportion of forest loss during the pandemic.

2.3 Association Between Pandemic Severity and Forest Loss Area

Spearman correlation analysis between forest loss area and infections per million population for biodiversity hotspot countries during the two pandemic years, first year, and second year showed a highly significant negative correlation over the two-year period (2020-2021). Similarly, in the first pandemic year (2020), pandemic severity showed a significant negative correlation with forest loss area. This trend became more pronounced in the second year (2021), with the correlation coefficient decreasing from -0.36 ($P < 0.01$) in 2020 to -0.43 ($P < 0.01$).

Linear mixed-effects models revealed that during the pandemic, infections per million population were significantly negatively correlated with forest loss from urban expansion, indicating that more severe pandemics reduced urban encroachment on forests (Tables 1-2). Tables 1 and 2 also show that both before and during the pandemic, forest loss from urban expansion and commercial harvesting was significantly affected by GDP. The structural equation model revealed four impact pathways of COVID-19 on forest loss (Figure 8 [Figure 8: see original paper]): (1) infections per million population → urban expansion → forest loss; (2) infections per million population → GDP → urban expansion → forest loss; (3) infections per million population → GDP → large-scale agricultural expansion → forest loss; and (4) infections per million population → GDP → plantation and natural forest harvesting → forest loss.

Across the four pathways, the standardized coefficients of COVID-19 infections per million population on forest loss were -1.4$×10^{-4}$ (= -0.07$×0.002), 0.5×10^{-4}$ (= 0.06$×0.41×0.002), −18.4×10^{-4}$ [= 0.06×(-0.18)$×$0.17], and 39.1$×10^{-4}$ (= 0.06$×0.21×0.31), *respectively, with an overall standardized coefficient* 4}$.

2.4 Estimated Impact of the Pandemic on Forest Loss Area

To quantitatively assess COVID-19's impact on forest loss in biodiversity hotspots, we fitted total forest loss area from 2001-2019 using the PsdVoigt1 formula and predicted the 2020 and 2021 forest loss area assuming no pandemic. The fitted model achieved an R^2 of 0.78 ($P < 0.001$) (Figure 9 [Figure 9: see original paper]). The model revealed that in the first year after the outbreak, forest loss area increased by 1,069,039.2 ha (5.83%) above the predicted value, and in the second year, it increased by 3,767,853.9 ha (21.78%).

Discussion

Previous studies have observed close links between human economic activity and forest loss (Wang et al., 2016), with commercial development responsible for destroying 27% of global forest land (Curtis et al., 2018). Our study found similar patterns: before the pandemic, economic activity was significantly associated with forest loss from urban expansion and large-scale agricultural development (Tables 1-2). After the outbreak, GDP remained significantly associated with urban expansion, large-scale agricultural expansion, and plantation/natural forest harvesting (Table 2). Thus, human economic activity consistently influenced forest loss before and during the pandemic.

Existing research presents mixed findings on the pandemic-forest relationship. Regarding forest cover, Lugo-Robles et al. (2021) found forest area significantly positively correlated with WHO-reported public health events and similar associations between COVID-19 infection rates and forest area, while Li et al. (2022) found negative correlations between forest cover and COVID-19 fatality rates in low-income countries. For forest loss, some studies found positive correlations with the pandemic (Brancalion et al., 2020; Rahman et al., 2021), while others observed negative relationships (Yang et al., 2020). Inconsistent spatiotemporal scales may explain these divergent conclusions. For instance, Lugo-Robles et al. (2021) and Li et al. (2022) examined average forest cover over periods, while Brancalion et al. (2020), Yang et al. (2020), and Rahman et al. (2021) focused on partial countries or regions.

Our study identified two manifestations of COVID-19's impact on forest loss. First, the pandemic increased deforestation: studies found deforestation doubled within one month of lockdown implementation in tropical regions (Brancalion et al., 2020), with similar phenomena observed in Bangladesh (Rahman et al., 2021). Second, the pandemic inhibited urban expansion, a finding also reported by Yang et al. (2020). The first phenomenon may relate to COVID-19's impact on human health and healthcare systems and various isolation policies implemented to reduce infection rates (Askitas et al., 2020; Baldwin & Tomiura, 2020). For example, pandemic protection and isolation policies increased demand for forest products, leading to extensive harvesting of plantations and natural forests. The second phenomenon may stem from stay-at-home policies that suppressed economic development, thereby limiting urban expansion and large-scale agricultural development, while reduced wildlife trade protected forests and their associated biodiversity (Gibbons et al., 2022).

During the pandemic, only 10 countries experienced sustained increases in forest loss, yet their contribution reached 53.82% of total forest loss, explaining the contradictory trends in Figures 5 and 6. This may relate to large variations in original forest cover among countries, different pandemic policies, and random events. For instance, Indonesia's slowed deforestation during the pandemic resulted from reduced oil palm expansion and falling oil prices (Gaveau et al., 2022).

Remote sensing technology for large-scale forest loss monitoring is now mature (Hill et al., 2019), with Global Forest Watch calculating global forest loss area (Bovolo & Donoghue, 2017). However, studies have found that different remote sensing product resolutions and ground disturbance types affect forest cover calculations, potentially causing estimation biases in spatial extent and timing of forest loss (Milodowski et al., 2017). Future research should incorporate multi-source observation data to improve accuracy. Additionally, factors such as national pandemic policies, human behavior changes, and sudden forest disasters could be integrated into impact models to improve estimation precision. Our modeling approach to assess COVID-19's impact may confound other factors, potentially inflating the pandemic's effect. However, given our data's high reliability and analytical accuracy, results support the conclusion that measures similar to "human confinement experiments" can suppress human activity to reduce forest loss, though complex network relationships may induce larger-scale forest loss, ultimately reducing regional biodiversity.

Conclusion

This study covered 53 countries. Compared with pre-pandemic levels, average forest loss per country decreased during the two pandemic years (2020-2021), while total loss area increased, primarily because the 10 countries with sustained forest loss increases contributed 53.82% of total loss. COVID-19 infections per million population showed highly significant negative correlations with forest loss area, with significant negative effects on forest loss from urban expansion. The pandemic influenced forest loss through four pathways, with total impact comparable to the magnitude of urban expansion-related forest loss reduction. A regression model based on 2001-2019 forest loss data showed that total forest loss in 2020 and 2021 increased by 5.83% and 21.78% above predicted values, respectively. Results demonstrate that COVID-19 impacted forest loss in global biodiversity hotspots, suppressing some human-driven forest destruction while still increasing forest loss through complex network relationships.

References

ABD LATIF Z, ZAQWAN HM, SAUFI M, et al., 2015. Deforestation and carbon loss estimation at tropical forest using multispectral remote sensing: case study of Besul Tambahan permanent forest reserve [C]. 4th International Conference on Space Science and Communication (IconSpace). Langkawi, MALAYSIA, 2015: 348-351.

ASKITAS N, TATSIRAMOS K, VERHEYDEN B, 2020. Lockdown strategies, mobility patterns and covid-19 [J]. Covid Econ, 23: 263-302.

BALDWIN R, TOMIURA E, 2020. Thinking ahead about the trade impact of COVID-19 [J]. Econ Time COVID-19, 59: 59-71.

BATES AE, PRIMACK RB, MORAGA P, et al., 2020. COVID-19 pandemic and associated lockdown as a "Global Human Confinement Experiment" to investigate biodiversity conservation [J]. Biol Conserv, 248: 108665.

BOVOLO CI, DONOGHUE D NM, 2017. Has regional forest loss been underestimated? [J]. Environ Res Lett. 12(11): 111003.

BRANCALION PHS, BROADBENT EN, DE-MIGUEL S, et al., 2020. Emerging threats linking tropical deforestation and the COVID-19 pandemic [J]. Perspect Ecol Conserv, 18(4): 243-246.

BUONGIORNO J, 2021. GFPMX: A cobweb model of the global forest sector, with an application to the impact of the COVID-19 pandemic [J]. Sustain, 13(10): 5507.

CARDINALE BJ, DUFFY JE, GONZALEZ A, et al., 2012. Biodiversity loss and its impact on humanity [J]. Nature, 486(7401): 59-67.

CHRAIBI E, ARNOLD H, LUQUE S, et al., 2021. A remote sensing approach to understanding patterns of secondary succession in tropical forest [J]. Rem Sen, 13(11): 2148.

COOK-PATTON SC, LEAVITT SM, GIBBS D, et al., 2020. Mapping carbon accumulation potential from global natural forest regrowth [J]. Nature, 585(7826): 545-550.

COOKE SJ, TWARDEK WM, LYNCH AJ, et al., 2021. A global perspective on the influence of the COVID-19 pandemic on freshwater fish biodiversity [J]. Biol Conserv, 253(2021): 108932.

CORLETT RT, PRIMACK RB, DEVICTOR V, et al., 2020. Impacts of the coronavirus pandemic on biodiversity conservation [J]. Biol Conserv, 246(2020): 108571.

CURTIS PG, SLAY CM, HARRIS NL, et al., 2018. Classifying drivers of global forest loss [J]. Science, 361(6407): 1108-1111.

GAVEAU D LA, LOCATELLI B, SALIM MA, et al., 2022. Slowing deforestation in Indonesia follows declining oil palm expansion and lower oil prices [J]. Plos One, 17(3): e0266178.

GIBBONS DW, SANDBROOK C, SUTHERLAND WJ, et al., 2022. The relative importance of COVID-19 pandemic impacts on biodiversity conservation globally [J]. Biol Conserv, 36(1): e13781.

GONG J, XIE Y, CAO E, et al., 2019. Integration of inVEST-habitat quality model with landscape pattern indexes to assess mountain plant biodiversity change: a case study of Bailongjiang watershed in Gansu Province [J]. J Geogr Sci, 29(2019): 1193-1210.

HANSEN MC, POTAPOV PV, MOORE R, et al., 2013. High-resolution global maps of 21st-century forest cover change [J]. Science, 342(6160): 850-853.

HILL SL, ARNELL A, MANEY C, et al., 2019. Measuring forest biodiversity status and changes globally [J]. Front For Glob Chang, 2: 70.

LI H, ZHANG G, CAO Y., 2022. Forest area, CO2 Emission, and COVID-19 case-fatality rate: a worldwide ecological study using spatial regression analysis [J]. Forests, 13(5): 736.

LUGO-ROBLES R, GARGES EC, OLSEN CH, et al., 2021. Identifying nontraditional epidemic disease risk factors associated with major health events from world health organization and world bank open data [J]. Amer J Trop Med Hyg, 105(4): 896-902.

MARIA SANCHEZ-CLAVIJO L, JINETH MARTINEZ-CALLEJAS S, ACEVEDO-CHARRY O, et al., 2021. Differential reporting of biodiversity in two citizen science platforms during COVID-19 lockdown in Colombia [J]. Biol Conserv, 256: 109077.

MARÍN AI, ABDUL MD, BASTRUP-BIRK A, et al., 2021. Mapping forest condition in Europe: methodological developments in support to forest biodiversity assessments [J]. Ecol Indic, 128: 107829.

MILODOWSKI D, MITCHARD E, WILLIAMS M, 2017. Forest loss maps from regional satellite monitoring systematically underestimate deforestation in two rapidly changing parts of the Amazon [J]. Environ Res Lett, 12(9): 094003.

PARDHAN S, DRYDAKIS N, 2021. Associating the change in new COVID-19 cases to GDP per capita in 38 european countries in the first wave of the pandemic [J]. Front Public Health, 8 (2021): 599532.

PEREIRA HM, ROSA IM, MARTINS IS, et al., 2020. Global trends in biodiversity and ecosystem services from 1900 to 2050 [J]. bioRxiv, 2020: 2020.04.14.031716.

PINDER AC, RAGHAVAN R, BRITTON JR, et al., 2020. COVID-19 and biodiversity: the paradox of cleaner rivers and elevated extinction risk to iconic fish species [J]. Aquac Conserv, 30(6): 1061-1062.

RAHMAN MS, ALAM MA, SALEKIN S, et al., 2021. The COVID-19 pandemic: a threat to forest and wildlife conservation in Bangladesh? [J]. Trees, Forests and People, 5: 100119.

RITCHIE H, MATHIEU E, RODÉS-GUIRAO L, et al., 2020. Coronavirus pandemic (COVID-19) [DB/OL]. Our world in data.

ROSA MR, BRANCALION PH, CROUZEILLES R, et al., 2021. Hidden destruction of older forests threatens Brazil's Atlantic Forest and challenges restoration programs [J]. Sci Adv, 7(4): eabc4547.

SANNIGRAHI S, PILLA F, MAITI A, et al., 2022. Examining the status of forest fire emission in 2020 and its connection to COVID-19 incidents in West Coast regions of the United States [J]. Environ Res, 210: 112818.

SILLS J, PEARSON RM, SIEVERS M, et al., 2020. COVID-19 recovery can benefit biodiversity [J]. Science, 368(6493): 838-839.

TEAM RC 2023. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

TEGALLY H, SAN JE, COTTEN M, et al., 2022. The evolving SARS-CoV-2 epidemic in Africa: Insights from rapidly expanding genomic surveillance [J]. Science, 378(6615): eabq5358.

VAIS AA, VARAKSIN GS, NEZAMOV VI, et al., 2020. Assessment of key habitats of suburban forests in Krasnoyarsk[C]. 3rd International Conference on Agribusiness, Environmental Engineering and Biotechnologies (AGRITECH). Krasnoyarsk, RUSSIA, 202010.1088/1755-1315/548/7/072008.

WANG JY, XIN LJ, TAN MH, et al., 2016. Spatial heterogeneity in Chinese forest area change in the Early 21st Century [J]. Forests, 7(10): 232.

YANG W, WANG X, ZHANG K, et al., 2020. COVID-19, urbanization pattern and economic recovery: an analysis of Hubei, China [J]. Int J Environ Res Public Health, 17(24): 9577.

ZAMBRANO-MONSERRATE MA, RUANO MA, SANCHEZ-ALCALDE L, 2020. Indirect effects of COVID-19 on the environment [J]. Sci Tot Env, 728(2020): 138813.

Note: Figure translations are in progress. See original paper for figures.