Pandemic impacts on protected rainforests and rural communities with variable health and livelihood support in West Kalimantan, Indonesia: a mixed-methods approach combining household surveys and remote sensing

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Summary

Background **Community support programmes can simultaneously improve human and ecosystem health. However, whether and how supported communities maintain these sustainable trajectories during major disruptions remains unclear. We used a mixed-methods approach to document how the COVID-19 pandemic impacted rural communities and protected rainforests in West Kalimantan.**

Methods **We surveyed 1016 households across six villages with non-governmental organisation (NGO)-affiliated health–livelihood support and four nearby unaffiliated villages to understand their pandemic experiences and logging activity. We also independently estimated weekly forest loss in protected rainforests in 28 NGO-affiliated and 698 unaffiliated villages using satellite imagery.**

Findings **The pandemic created an economic shock, whereby 50% of households lost income, struggled with increased costs of basic needs, or both. We expected this shock to increase the amount of logging; however, the average forest loss across West Kalimantan decreased by 39% after the pandemic declaration. This decrease was due to the combined effects of the global timber market crash in early 2020, pandemic travel restrictions, and heavy precipitation in 2020 and 2021. Before the pandemic, the average forest loss was 52% lower in NGO-affiliated villages than in unaffiliated villages, with this difference increasing to 68% during the pandemic. Correspondingly, NGO-affiliated households were more likely to report having alternative sustainable livelihoods, several sources of external support (eg, loans), and access to affordable health care and less likely to report increased spending on basic needs during the pandemic.**

Interpretation **Health and livelihood support can buffer communities during major disturbances, sustaining progress towards improved human wellbeing and forest conservation.**

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Introduction

The COVID-19 pandemic derailed progress towards conservation and Sustainable Development Goals worldwide.[1,2] Several countries experienced the highest rates of tropical rainforest loss in a decade; however, the hypothesised mechanisms linking deforestation to the pandemic were complex and spatially variable.[3–9] In poor rural communities, the socioeconomic shock was expected to increase reliance on forest resources due to declining incomes and insufficient support programmes.[10–14] Consequently, communities with access to support programmes that improve economic conditions or increase access to affordable health care might be less likely to engage in illegal logging or burning and thus more likely to have and maintain sustainable trajectories.[15,16] Here, we describe how rural communities living near protected rainforests with and without health–livelihood support responded to the COVID-19 shock in Indonesian Borneo.

West Kalimantan contains essential tropical forests and marine ecosystems that provide resources for local communities (five million people), harbour unique and diverse species, and sequester substantial amounts of carbon.[17,18] More than 50% of forest loss occurs in protected areas,[19] driven primarily by logging for cash income, land clearing for agriculture, and natural or anthropogenic wildfires.[20–22] To curb forest loss in protected areas, governmental and non-governmental organisations (NGOs) have combined community support, positive incentives, and deterrents (appendix pp 1–3).

The two NGOs considered in this study, Alam Sehat Lestari (ASRI) and Yayasan Planet Indonesia (YPI; figure 1), codesign support programmes with local and Indigenous

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Research in context

Evidence before this study

We searched Google Scholar and Web of Science for relevant literature published between March, 2020, and March, 2025, using the search terms (COVID-19 OR SARS-CoV-2 OR pandemic) AND (deforestation OR "forest loss" OR logging). Most peer-reviewed literature was about how deforestation or land use change can alter human–livestock–wildlife interactions, leading to zoonotic spillover of novel pathogens with pandemic potential. Studies about how the COVID-19 pandemic impacted forest loss or other aspects of conservation were mostly secondary literature (reviews, perspectives, etc). The primary literature contained less than ten remotely sensed forest loss analyses (usually Global Land Analysis and Discovery alerts) for the entire tropics or specific countries (ie, Brazil, Colombia, Peru, Ecuador, India, the Democratic Republic of the Congo, Bangladesh, and Indonesia), which estimated increased or unchanged forest loss trends in 2020 relative to those in recent years. Furthermore, a few small surveys (<70 participants) of conservation or forestry professionals or agroforestry farmers showed that during the pandemic, illegal logging rates or reliance on forest resources increased in Nepal, Madagascar, and West Java, Indonesia. We found no studies combining remotely sensed forest loss data and household surveys in the same location.

Added value of this study

We combined more than 1000 household surveys and weekly remotely sensed forest loss estimates in Kalimantan, Indonesia, to quantify how the COVID-19 pandemic impacted rural communities and their forest use. This fine-scaled analysis clarified how forest loss was impacted by increasing the need for cash incomes, reducing the ability to log because of lockdowns and high precipitation, and reducing cost:benefit ratios for logging because of market crashes. The balance of these considerations differed in non-governmental organisation (NGO)-affiliated and unaffiliated villages, primarily because households in NGO-affiliated villages were more likely to have alternative jobs with relatively low environmental impact and less likely to experience an increased need for cash incomes. Correspondingly, rates of forest loss were lower in NGO-affiliated villages before and during the pandemic.

Implications of all the available evidence

Reducing poverty and increasing social protection remain the most important pillars for achieving Sustainable Development Goals and advancing planetary health. In this study, we show how and why health and livelihood support programmes benefit rural poor communities and reduce tropical forest loss in Kalimantan. Similar mechanistic approaches might be used to codesign effective support programmes that address the underlying drivers of conservation and livelihood outcomes in other regions.

See Online for appendix

communities. Considering community needs, programme details vary between villages and the two NGOs. Nevertheless, the programme types are generally similar: both NGOs improve access to affordable health care and health education (eg, permanent or mobile health clinics), provide sustainable livelihood training (eg, organic farming that minimises land rotation), reduce logging using incentives and education (eg, chainsaw buyback programme), and monitor forest loss in protected areas (appendix pp 1–3). Before the pandemic, NGO-affiliated villages were on sustainable trajectories, with the average rates of forest loss in protected areas being lower than those in unaffiliated villages. Similarly, before–after studies revealed forest loss declines in villages after collaborations with the NGOs began.[16,23–25]

We hypothesised that several pressures on communities could have increased the rate of forest loss in protected areas across West Kalimantan during the pandemic (figure 2). Most directly, we hypothesised that COVID-19 morbidity would have increased health care spending needs, which, in turn, might have increased logging in protected areas for cash income.[26] Less directly, if households lost other sources of income or support during the pandemic, increased reliance on land clearing for subsistence livelihoods or logging could have exacerbated forest loss.[11,26–28] Furthermore, government-mandated travel restrictions could have reduced patrols and other deterrents that prevent forest loss in protected areas.[11] These mechanisms are not mutually exclusive, where all mechanisms might have contributed to increased forest loss during the pandemic.

We also hypothesised that there could have been counterbalancing mechanisms that reduced forest loss during the pandemic (figure 2). The pandemic caused a global market crash, which could have reduced incentives for logging in protected areas.[5,17] Simultaneously, government-mandated COVID-19 travel restrictions likely reduced the ability to log or burn land, especially covertly.[7,11,28] Finally, new economic stimulus programmes or safety nets were put in place by governments and NGOs that could have reduced logging and land clearing pressures by providing people with alternative sources of income or other support. Again, these mechanisms are not mutually exclusive.

The proposed mechanisms for increasing and decreasing forest loss in protected areas could differ for NGO-affiliated villages. We hypothesise that it might have been difficult for NGO-affiliated villages to maintain low forest loss amid major disruptions, potentially eliminating the pre-pandemic difference in average forest loss between NGO-affiliated and unaffiliated villages. Alternatively, we hypothesise that NGO-affiliated villages with health–livelihood safety nets had a higher capacity to absorb the pandemic shock, with differences in forest loss rates between NGO-affiliated and unaffiliated villages remaining constant or even increasing during the pandemic. To disentangle these potential outcomes, we quantified forest loss in three types of protected areas across 726 villages in West Kalimantan. We also surveyed 1016 households across ten villages to quantify their pandemic experiences.

Methods

Household surveys

After an open-ended, qualitative pilot survey in January, 2021 (appendix p 3), we conducted a closed-ended, quantitative household survey in ten total villages in West Kalimantan from November, 2021 to December, 2021: six NGO-affiliated villages (three each for ASRI and YPI) and four nearby unaffiliated villages (two each for ASRI and YPI). We non-randomly selected NGO-affiliated villages that had the longest partnerships with ASRI (since 2008, >12 years) or YPI (since 2017–18, >2 years) to document the largest effects relative to the unaffiliated villages. We selected unaffiliated villages that were near NGO-affiliated villages (<60 km; figure 1) and had similar population sizes and proximity to forests (appendix pp 2–3, 28). The survey instrument, data collection protocol, and analyses were approved by the National Research and Innovation Agency of Indonesia (33/SIP/IV/FR/2022) and Stanford University Institutional Review Board (IRB: 58 069).

In each village, we sampled at least 100 household decision makers or income contributors who were at least 18 years old (N=1016 households; appendix p 29). Since village maps and demographic information were not available, we chose initial households through a convenience sample and then asked participants to suggest someone from a different household who would meet the inclusion criteria for the next interview (ie, snowball sampling). All participants were asked to recall their experiences from before the March, 2020 pandemic declaration and throughout the 20 months following the declaration. This before–after design allowed us to compare self-reported experiences across villages while accounting for potential baseline differences among households and villages that could have arisen owing to the small sample size or non-random selection.

Participants were asked to list every source of income and whether they earned less, the same, or more than before the pandemic. We aggregated jobs into ten subcategories organised within three impact categories: high-impact jobs (eg, commodity farming, mining, and logging), low-impact jobs (eg, small-scale farming and conservation jobs), and resource-neutral jobs (eg, public servant and labour; appendix pp 4, 12–13, 30, 33–34). For each impact category and each NGO, we determined whether households in NGO-affiliated villages were more likely to report generating income from that job category than households in nearby unaffiliated villages using logistic regression analyses. We also asked households whether they logged or burned and if and why households had stopped logging, which we analysed using both qualitative and logistic regression approaches (appendix pp 4–5, 14).

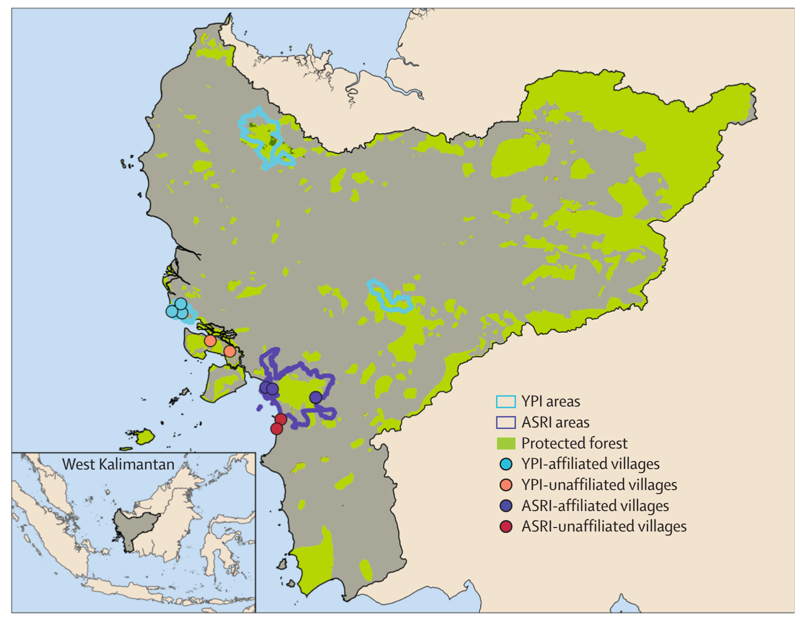


Figure 1: **A map of West Kalimantan in Indonesian Borneo**
The map shows the extent of protected forests (the three types are differentiated in appendix p 21), all villages that are affiliated with the two NGOs (outlined by polygons), and the ten NGO-affiliated and unaffiliated villages included in the household surveys (points). ASRI=Alam Sehat Lestari. YPI=Yayasan Planet Indonesia.

We asked households whether they received financial or resource support from sources outside the household (ie, money, food, or other material goods), and if so, who provided that external support (eg, government, NGOs, friends, or family). We determined whether the number of unique reported sources of support per household varied between NGO-affiliated and unaffiliated villages using Poisson generalised linear models (appendix pp 7, 16, 37).

We asked households about their health care needs, use, and spending before the pandemic declaration and during the pandemic (appendix pp 7–8, 17–20, 39–40). The questions included when and why participants sought health care, what was the cost of the care, and whether there was ever a time that they needed health care but could not access it and what caused that barrier. We aggregated these responses to those related to physical accessibility (ie, whether they were logistically unable to reach an open clinic) and affordability (ie, whether the cost of care was prohibitive). We compared the barriers to accessibility and affordability between NGO-affiliated and unaffiliated villages using logistic regressions.

Finally, we asked households what the biggest change was during the COVID-19 pandemic. We used a theme analysis to categorise these changes and logistic regression to compare the prevalence of these changes between NGO-affiliated and unaffiliated villages (appendix pp 5–7, 15, 38).

Satellite-based analysis of forest loss

We developed a satellite-based machine-learning method to estimate weekly forest loss. We used available LiDAR data

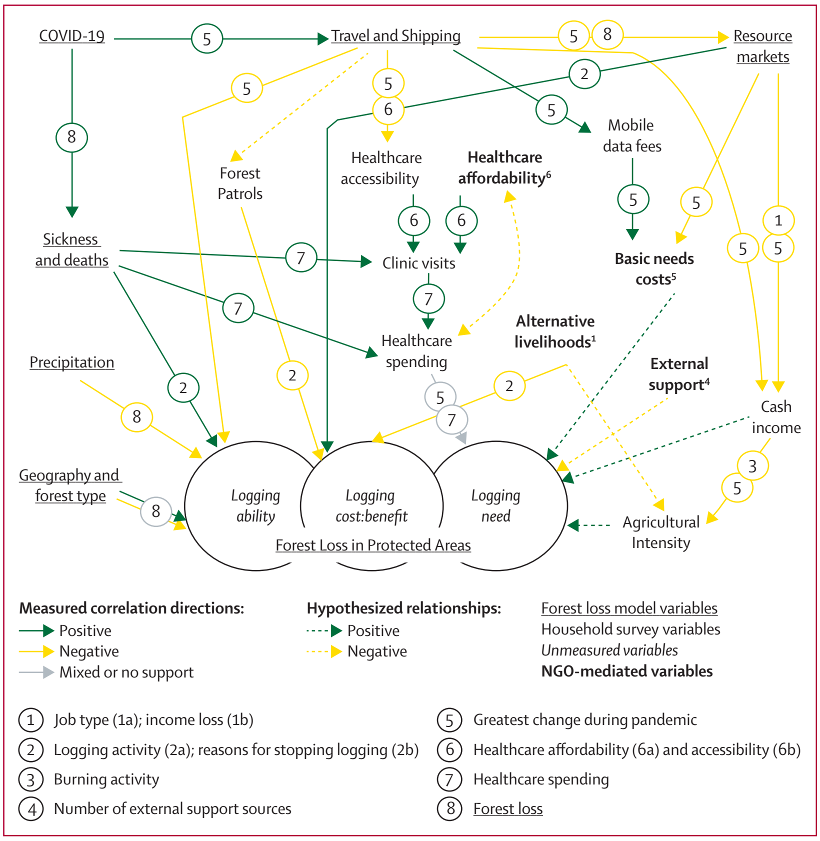


Figure 2: **Conceptual diagram of socioecological system**

The diagram shows the relationships measured and hypothesised between COVID-19, market crashes, support programmes, and the sociological and environmental variables quantified in this study by surveying households and quantifying forest loss. Each analysis is numbered; more details can be found in the appendix (pp 32–42).

from 2014 to classify whether 30-m^2 pixels in a 100 000-ha region of Kalimantan were forested (mean tree height >5 m)[29] or unforested (mean tree height <5 m). We used these known forest cover classifications to train a random forest machine-learning model that could predict whether a pixel was forested or not using more broadly available Landsat 8 satellite data obtained from Google Earth Engine (appendix pp 8–11, 22). Standardised training features were included as covariates, including land cover classifications (appendix p 31), vegetation indexes (appendix p 31), and topographic landscape features (eg, elevation, slope, and aspect). Based on 5-fold shuffle-based cross validation, this model had a mean imbalanced accuracy of 0·9782 (SE=0·0001) and a mean balanced accuracy of 0·9104 (SE=0·0007).

For more on **Google Earth Engine** see https://earthengine.google.com/

We used the trained model and Landsat 8 data to classify 30-m^2 pixels as forested or deforested each week across our time series (Jan 1, 2018 to Nov 22, 2021) for three types of protected forests (World Database of Protected Areas, including national parks and reserves; village forests; and protection forests) in Kalimantan. Landsat 8 data were available every 16 days; however, cloud cover often obscured pixels on a given image. Consequently, the specific date of pixel loss was interpolated using model probabilities (appendix p 9). We aggregated the pixel-level time series data to calculate how many pixels switched from forested to deforested each week in each forest type in each village.

We quantified how and why the number of pixels lost per village per week varied in West Kalimantan (or all of Kalimantan) using a negative binomial generalised linear mixed effects model, controlling for variable forest unit areas with a model offset (appendix pp 23–27, 41–42). By controlling for many possible time-variant and time-invariant explanatory variables and comparing the rates of forest loss in each village before and after the pandemic declaration, we evaluated whether the forest loss trajectories for the 28 non-randomly selected, NGO-affiliated villages were different from those of all the other unaffiliated villages in the region.

Role of the funding source

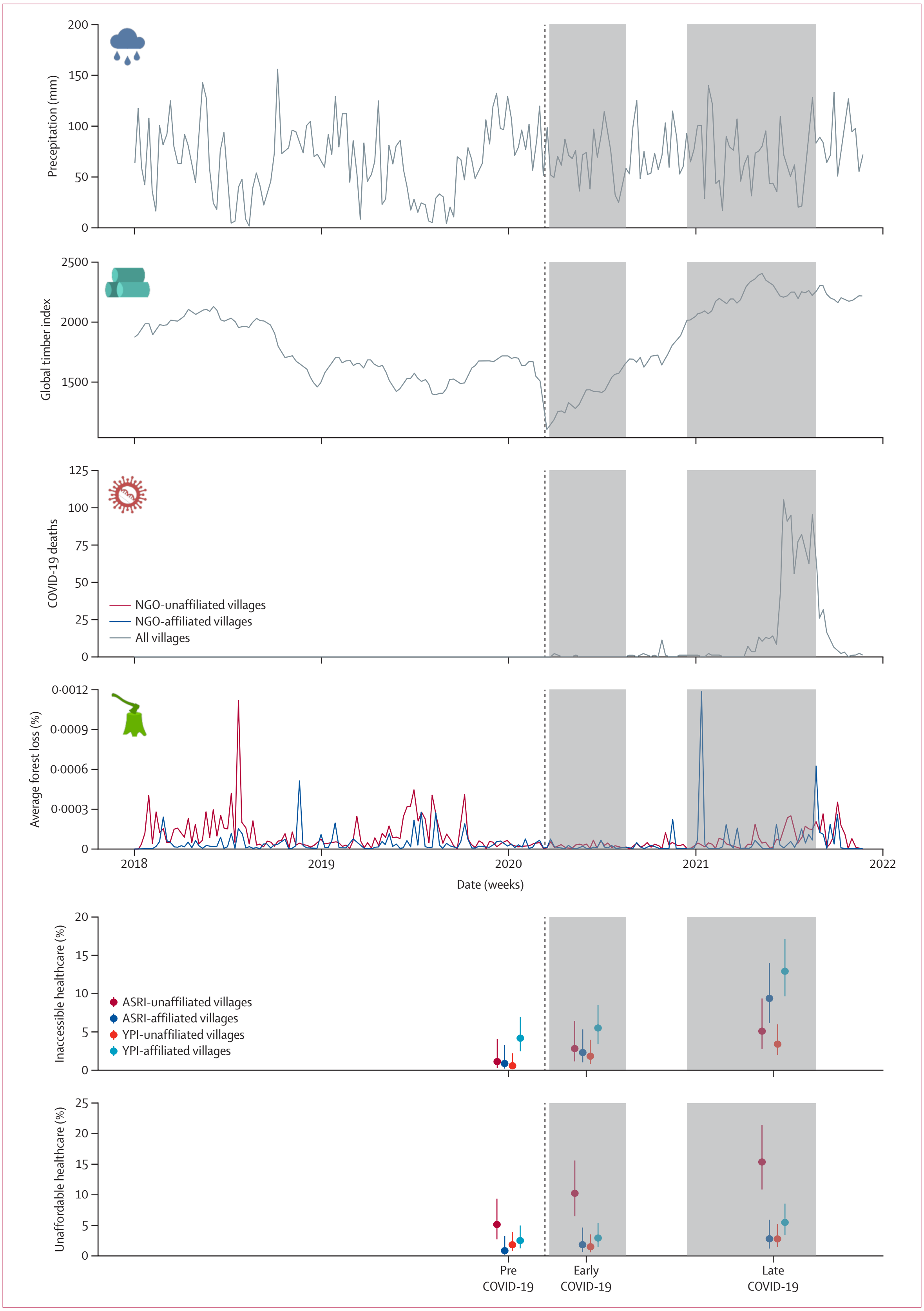
The funders had no role in study design, data collection, data analysis, data interpretation, or report writing.

Results

Household surveys

Households in the six NGO-affiliated and four unaffiliated villages had the same average number of income-generating jobs; however, their job types differed. Households in NGO-affiliated villages were more likely to do low-impact jobs (ASRI OR=2·02, 95% CI 1·39–2·95, p<0·001; YPI OR=2·21, 95% CI 1·55–3·17, p<0·0001) and were less likely to do high-impact jobs (ASRI OR=0·58, 95% CI 0·40–0·84, p=0·0041; YPI OR=0·58, 95% CI 0·41–0·83, p=0·0028; appendix p 12). Across all ten villages (1016 households), only 70 households self-reported that they engaged in logging (7%); however, there could be under-reporting owing to the sensitive nature of this topic (ie, one with legal sanctions). Households in YPI-affiliated villages (21 [7%] of 309) were significantly less likely to log than households in unaffiliated villages (31 [15%] of 213; OR=0·43; 95% CI 0·24–0·76, p=0·0044; appendix p 4). The amount of logging in Gunung Palung National Park was low (ASRI-affiliated villages: 15 [5%] of 319 households; unaffiliated villages: 3 [2%] of 175), with no significant differences between the groups (OR=2·83, 95% CI 0·91–12·34, p=0·104).

Overall, 296 (29%) of 1016 households self-reported that they used to log at any point in the past but have stopped logging (appendix p 14). The most common self-reported reasons for stopping logging activities were related to the cost:benefit ratio for logging (200 [68%] of 296): logging was prohibited (148 [50%] of 296); patrols had increased (36 [13%] of 296); logging was too difficult or risky relative to other livelihoods (77 [26%] of 296); or the income from logging was not sufficient (8 [3%] of 296). Self-reported reasons also related to peoples' ability to log (125 [42%] 296): they were too old or sick (87 [29%] of 296); the forest no longer existed or had sufficient trees or was too far away (37 [13%] of 296); or the lumber company or sawmill no



200
150
100
50
0
Precepitation (mm)
2500
2000
1500
Global timber index
125
100
75
50
25
0
COVID-19 deaths
NGO-unaffiliated villages
NGO-affiliated villages
All villages
0·0012
0·0009
0·0006
0·0003
0
Average forest loss (%)
2018
2019
2020
2021
2022
Date (weeks)
20
15
10
5
0
Inaccessible healthcare (%)
ASRI-unaffiliated villages
ASRI-affiliated villages
YPI-unaffiliated villages
YPI-affiliated villages
25
20
15
10
5
0
Unaffordable healthcare (%)
Pre COVID-19
Early COVID-19
Late COVID-19

Figure 3: **Time series of three variables that influenced forest loss rates (weekly totals for all villages), satellite-based forest loss rates, and household-reported health care barriers in West Kalimantan**
The average weekly forest loss (%) was calculated from protected forests in 28 NGO-affiliated and 698 unaffiliated villages. The percentage of households that self-reported being unable to obtain health care owing to unaffordability or inaccessibility were calculated from six NGO-affiliated and four unaffiliated villages. The vertical dashed line indicates the March, 2020 pandemic declaration, and the vertical grey rectangles indicate the periods with travel restrictions.

longer existed (12 [4%] of 296). Households could report more than one reason.

Half of the households (484 [50%] of 968) reported losing income from at least one source during the pandemic. Similarly, 540 (53%) of 1016 households reported that the biggest change during the pandemic was economic hardship (appendix p 15) because of reduced income, increased cost of basic needs (eg, pesticides, fertiliser, fuel, and food), or both (appendix p 15). Households in NGO-affiliated and unaffiliated villages were equally likely to report losing income from all job types (appendix p 13). Households in YPI-affiliated households were half as likely to report increased household spending needs as one of the biggest changes during the pandemic (53 [17%] of 309 *vs* 61 [29%] of 213; logistic regression: OR=0·52; 95% CI 0·34–0·78, p=0·002); a similar, albeit non-significant, trend was observed for ASRI-affiliated households (87 [27%] of 319 *vs* 59 [34%] of 175; OR=0·74; 95% CI 0·50–1·10, p=0·134). For both NGOs, affiliated households reported approximately 60% more sources of external support for money, resources, or services (Poisson GLM: YPI coefficient=0·49, SE=0·09, p<0·0001; ASRI coefficient=0·47, SE=0·11, p<0·0001; appendix p 16).

On average, self-reported sickness, health care use, and monthly health care spending (without accounting for travel costs) increased during the pandemic (appendix pp 16–20), whereas self-reported health care affordability and access decreased (figure 3). However, sickness and health care challenges were only reported as one of the biggest changes during the pandemic by 18 (2%) of 1016 households. Households in ASRI-affiliated villages were less likely to report that affordability was a barrier than households in unaffiliated villages (logistic regression: OR=0·18, 95% CI 0·08–0·36, p<0·001; figure 3), whereas both groups reported similarly low accessibility barriers (OR=0·72, 95% CI 0·33–1·59, p=0·40; figure 3). In contrast, households in YPI-affiliated villages were slightly more likely to report that accessibility was a barrier (OR=1·81, 95% CI 1·06–3·16, p=0·032), whereas both groups reported similar affordability barriers (OR=1·58, 95% CI 0·60–4·62, p=0·181).

Satellite-based analysis of forest loss

Forest loss in West Kalimantan decreased by 39% across three types of protected areas after the March, 2020 pandemic declaration (Jan 1, 2018 to March 9, 2020, compared with March 16, 2020 to Nov 22, 2021; figure 3). The average weekly forest loss was lower during periods with government-restricted travel and higher during weeks with high COVID-19 cases or deaths (figure 3). Forest loss was also lower during weeks with high precipitation, with 2020 and 2021 being relatively wet years (figure 3, figure 4). The global timber market index was positively correlated with forest loss rates in unaffiliated villages (not with NGO-affiliated villages, see significant interaction in figure 4), such that the pandemic market crash was associated with reduced forest loss (figure 3).

Before the pandemic, the average forest loss was 52% lower in NGO-affiliated villages (0·051 pixels per week; SE=0·271; n=28 villages) than in unaffiliated villages (0·105 pixels per week; SE=0·176; n=698 villages); after the pandemic declaration, this gap increased to 68% (NGO-affiliated=0·031 pixels per week, SE=0·279; NGO-unaffiliated=0·098 pixels per week, SE=0·179; see significant interaction term; figure 4). In fact, the West Kalimantan model attributed most of the overall decline in forest loss to declines in NGO-affiliated villages. Comparing the 28 NGO-affiliated villages to all other villages across all of Kalimantan (n=1432) yielded similar results; however, the Kalimantan model estimated similar rates of decline in affiliated and unaffiliated villages (appendix pp 26–27, 41–42).

Discussion

The COVID-19 pandemic created an economic shock for people living in rural West Kalimantan by reducing local wholesale prices for livelihood products, such as fish and timber;[5] increasing costs of basic necessities, such as food, fuel, and agricultural supplies; restricting travel and shipping; creating new financial and social hardships related to online learning;[30] and decreasing health care accessibility and affordability. We expected this economic shock to increase the rate of forest loss in protected areas due to an increased amount of logging for timber or burning to clear agricultural land (logging need; figure 2). Instead, the amount of forest loss decreased by 39%, which is corroborated by other studies that described declining rates of forest loss in Indonesia during the pandemic.[4,5] We show that regional forest loss declined because the cost:benefit ratio for logging and the ability to log decreased during the pandemic (figure 2), whereas differences in the need for cash incomes likely explained why the average rates of forest loss differed between NGO-affiliated and unaffiliated villages.

Our satellite-based analysis of forest loss and household surveys highlighted three important barriers to forest loss during the pandemic: the timber market crash and lower demand for timber reduced forest loss because logging was less lucrative (cost:benefit ratios for logging); government-implemented travel restrictions limited opportunities to log and transport timber (logging ability);[7,11,28] and relatively high weekly precipitation in 2020 and 2021 limited logging and burning activities (logging ability). Logging was reported to be a difficult and risky way to earn cash,

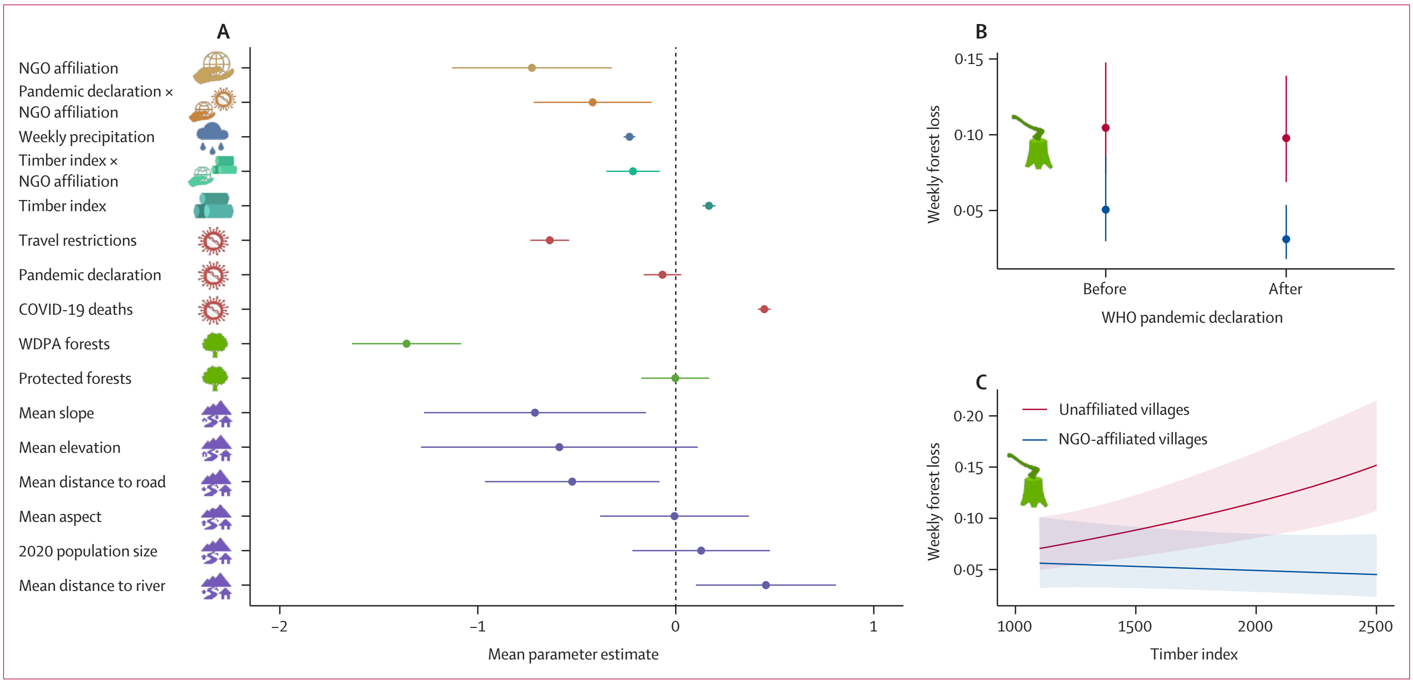


Figure 4: **Predictors of forest loss rates across space and time in West Kalimantan**

(A) Standardised effect sizes of the explanatory variables included in the negative binomial generalised linear mixed effects model. Interactions between variables are denoted with an X. Note that the forest type intercept was village forest (hutan desa). (B) After accounting for all other variables, average weekly forest loss (%) was lower in the NGO-affiliated villages (blue) than in the unaffiliated villages (red) before and after the pandemic declaration, and the rate of forest loss declined to a larger extent in NGO-affiliated villages during the pandemic (see significant interaction term, panel A). (C) There was also a significant interaction between the global timber index and NGO affiliation, where forest loss in NGO-affiliated villages did not respond to the timber market. NGO=non-governmental organisation. WDPA=World Database on Protected Areas.

especially in patrolled protected areas where logging is prohibited. Many households self-reported that they stopped logging because there were easier ways to earn income, with households in NGO-affiliated villages being more likely to have alternative, low-impact livelihoods.

Additionally, the need for cash income differed between NGO-affiliated and unaffiliated villages. In particular, NGO-affiliated households were equally likely to lose income during the pandemic, but they also had more sources of external support (eg, loans, resources, and services); could better afford health care (among ASRI-affiliated villages only); and were less likely to report increasing cost of basic needs as one of the biggest changes during the pandemic (among YPI-affiliated villages only). We hypothesise that NGO-affiliated households that received organic farming support from NGOs were less reliant on the chemical fertilisers and pesticides, which increased in cost during the pandemic. Overall, these differences in cash and resource access likely explained why (i) NGO-affiliated villages had lower average rates of forest loss; (ii) forest loss was only correlated with timber markets in unaffiliated villages; and (iii) fewer YPI-affiliated households self-reported logging. Taken together, self-reported behaviours and independently-assessed forest loss suggest that health–livelihood programmes provided opportunities that allowed NGO-affiliated villages to maintain their sustainable trajectories despite the economic shock.

We hypothesised that increased sickness and health care spending would drive forest loss during the pandemic; however, this hypothesis was not supported. Since the introduction of Universal Health Coverage (BPJS Kesehatan) in 2014, access to free health care across Indonesia has gradually increased. During this study, only ASRI-unaffiliated villages reported common challenges with health care affordability (up to 15% of households; figure 3). Health care spending increased during the pandemic as sickness and health care visits increased (appendix pp 17–20); however, the average cost of health care remained low, with only a few households reporting that health care spending was one of the biggest changes during the pandemic. Therefore, it seems unlikely that health care spending could have caused the positive correlation between COVID-19 cases and deaths and satellite-based estimates of forest loss that we observed (figure 4). Instead, COVID-19 cases appear to reflect compliance with lockdowns. Before lockdowns officially ended in 2021, people began to travel and gather at higher rates as vaccination rates increased and fear subsided. This trend corresponded to both increased COVID-19 cases and increased logging ability.

This dynamic and complex socioecological system provides an opportunity to describe resistance and resilience to a system shock. Household economies declined, indicating that they were not resistant to the pandemic-associated system shock. However, in NGO-affiliated villages, the amount of logging did not increase. Hence, the conservation effect of the support programmes could be described as resistant to the pandemic shock. Resilience is more difficult to define. One popular definition of resilience refers to a system's abilities to recover to a previous equilibrium.[31] However, such a recovery might not be measurable until after a shock has ended and a system has had time to potentially return to the previous state,[25] which did not occur during our study time period. An alternate definition of resilience is a positive adaptation during or following a challenge,[31,32] which could apply to some of the changes made by the government (eg, free vaccination), NGOs (eg, COVID stimulus programmes), and households (eg, changing jobs) that allowed communities to adapt to the pandemic crisis, preventing worse outcomes. In a world with many disturbances occurring rapidly and simultaneously, the most sustainable policies could create opportunities for positive adaptation, rather than maintain current conditions.

Surprisingly, forest loss decreased in West Kalimantan during the pandemic, which contrasts with trends in several other countries, such as Bangladesh and Brazil, where 2020 was associated with one of the highest rates of rainforest loss in a decade.[3,9] It is likely that cost:benefit ratios and logging and burning abilities were higher in other countries where forest loss increased during the pandemic; however, those socioeconomic, cultural, political, and legal comparisons are beyond the scope of the present study. This is a reminder that there is extensive variability across rainforest ecosystems, and aggregating data spatially and temporally might result in the loss of essential details. Our fine-scale and mechanistic approach was important for understanding why forest loss declined in West Kalimantan and investigating whether NGO-affiliated villages responded differently than nearby unaffiliated villages. Similar health–livelihood programmes might benefit rainforest conservation efforts elsewhere but only if they address the needs of those communities and consequently, the relevant mechanisms driving forest loss.[11]

Contributors

SRH, SHS, AH, AJM, AA, JA, AE, NF, NLF, QI, AM, IS, KW, IZS, IJ, and GADL designed the study, AH, IH, QI and IS collected and cleaned the survey data. SRH, AH, JDP, AJC, ZG, IH, AJM, NN, SB, YS, IJ, ZY-CL, and GADL analysed and visualised the data. All authors contributed to writing the paper and the decision to submit. SRH accessed and verified all the raw datasets and code.

Declaration of interests

AA, JA, AE, SB, NF, NLF, QI, AM, IS, and KW are currently or were recently employed by the non-profit organisations that collaborated with communities to design and implement the programmes. The remaining authors have nothing to declare.

Data sharing

All de-identified household survey data, village-level forest loss data, metadata, and code to reproduce all analyses are available on Dryad at https://doi.org/10.5061/dryad.02v6wwqfx.

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Editorial note: The *Lancet* Group takes a neutral position with respect to territorial claims in published text and institutional affiliations.

References

1 Yuan H, Wang X, Gao L, et al. Progress towards the Sustainable Development Goals has been slowed by indirect effects of the COVID-19 pandemic. *Commun Earth Environ* 2023; **4:** 184.

2 Lawler OK, Allan HL, Baxter PWJ, et al. The COVID-19 pandemic is intricately linked to biodiversity loss and ecosystem health. *Lancet Planet Health* 2021; **5:** e840–50.

3 Silva Junior CHL, Pessôa ACM, Carvalho NS, Reis JBC, Anderson LO, Aragão LEOC. The Brazilian Amazon deforestation rate in 2020 is the greatest of the decade. *Nat Ecol Evol* 2021; **5:** 144–45.

4 Céspedes J, Sylvester JM, Pérez-Marulanda L, et al. Has global deforestation accelerated due to the COVID-19 pandemic? *J For Res* 2022; **34:** 1153–65.

5 Wunder S, Kaimowitz D, Jensen S, Feder S. Coronavirus, macroeconomy, and forests: what likely impacts? *For Policy Econ* 2021; **131:** 102536.

6 Useni Sikuzani Y, Mpanda Mukenza M, Mwenya IK, et al. Quantifying forest cover loss during the COVID-19 pandemic in the Lubumbashi Charcoal Production Basin (DR Congo) through remote sensing and landscape analysis. *Resources* 2024; **13:** 95.

7 Amador-Jiménez M, Millner N, Palmer C, Pennington RT, Sileci L. The unintended impact of Colombia's Covid-19 lockdown on forest fires. *Environ Resour Econ (Dordr)* 2020; **76:** 1081–105.

8 Tleimat JM, Fritts SR, Brunner RM, Rodriguez D, Lynch RL, McCracken SF. Economic pressures of Covid-19 lockdowns result in increased timber extraction within a critically endangered region: a case study from the Pacific Forest of Ecuador. *Ecol Evol* 2022; **12:** e9550.

9 Rahman MS, Alam MA, Salekin S, Belal MAH, Rahman MS. The COVID-19 pandemic: A threat to forest and wildlife conservation in Bangladesh? *Trees People* 2021; **5:** 100119.

10 Sayer JA, Endamana D, Ruiz-Perez M, et al. Global financial crisis impacts forest conservation in Cameroon. *Int For Rev* 2012; **14:** 90–98.

11 Saxena A, Dutta A, Fischer HW, Keleman Saxena A, Jantz P. Forest livelihoods and a 'green recovery' from the COVID-19 pandemic: insights and emerging research priorities from India. *For Policy Econ* 2021; **131:** 102550.

12 Laudari HK, Pariyar S, Maraseni T. COVID-19 lockdown and the forestry sector: insight from Gandaki Province of Nepal. *For Policy Econ* 2021; **131:** 102556.

13 van Versendaal L, Schickhoff U. The evolution of threats to protected areas during crises: insights from the COVID-19 pandemic in Madagascar. *Hum Ecol* 2025; **52:** 1157–72.

14 Pieter LAG, Utomo MMB, Suhartono S, et al. The nexus of COVID-19 pandemic and rural agroforestry farmers' livelihoods in Tasikmalaya Regency, East Priangan, Indonesia. *For Soc* 2022; **6:** 335–54.

15 Ngonghala CN, De Leo GA, Pascual MM, Keenan DC, Dobson AP, Bonds MH. General ecological models for human subsistence, health and poverty. *Nat Ecol Evol* 2017; **1:** 1153–59.

16 Jones IJ, MacDonald AJ, Hopkins SR, et al. Improving rural health care reduces illegal logging and conserves carbon in a tropical forest. *Proc Natl Acad Sci U S A* 2020; **117:** 28515–24.

17 Busch J, Ferretti-Gallon K, Engelmann J, et al. Reductions in emissions from deforestation from Indonesia's moratorium on new oil palm, timber, and logging concessions. *Proc Natl Acad Sci U S A* 2015; **112:** 1328–33.

18 Lutz JA, Furniss TJ, Johnson DJ, et al. Global importance of large-diameter trees. *Glob Ecol Biogeogr* 2018; **27:** 849–64.

19 Lawson S, MacFaul L. Illegal logging and related trade: indicators of the global response. Chatham House, 2010.

20 Curran LM, Trigg SN, McDonald AK, et al. Lowland forest loss in protected areas of Indonesian Borneo. *Science* 2004; **303:** 1000–03.
21 Austin KG, Schwantes A, Gu Y, Kasibhatla PS. What causes deforestation in Indonesia? *Environ Res Lett* 2019; **14:** 024007.
22 Wijaya A, Sugardiman Budiharto RA, Tosiani A, Murdiyarso D, Verchot LV. Assessment of large scale land cover change classifications and drivers of deforestation in Indonesia. *Int Arch Photogramm Remote Sens Spatial Inf Sci* 2015; **XL-7/W3:** 557–62.
23 Webb K, Jennings J, Minovi D. A community-based approach integrating conservation, livelihoods, and health care in Indonesian Borneo. *Lancet Planet Health* 2018; **2:** S26.
24 Miller AE, Davenport A, Chen S, et al. Using a participatory impact assessment framework to evaluate a community-led mangrove and fisheries conservation approach in west Kalimantan, Indonesia. *People Nat* 2020; **2:** 1061–74.
25 Novick B, Crouch J, Ahmad A, et al. Understanding the interactions between human well-being and environmental outcomes through a community-led integrated landscape initiative in Indonesia. *Environ Dev* 2023; **45:** 100791.
26 Diffenbaugh NS, Field CB, Appel EA, et al. The COVID-19 lockdowns: a window into the Earth System. *Nat Rev Earth Environ* 2020; **1:** 470–81.
27 Malahayati M, Masui T, Anggraeni L. An assessment of the short-term impact of COVID-19 on economics and the environment: A case study of Indonesia. *EconomiA* 2021; **22:** 291–313.
28 Saavedra S. Was global deforestation under lockdown? *Environ Dev Econ* 2024; **29:** 83–106.
29 Parker D, Tosiani A, Yazid M, et al. Land in limbo: nearly one third of Indonesia's cleared old-growth forests left idle. *Proc Natl Acad Sci U S A* 2024; **121:** e2318029121.
30 Putri RS, Purwanto A, Pramono R, Asbari M, Wijayanti LM, Hyun CC. Impact of the COVID-19 pandemic on online home learning: an explorative study of primary schools in Indonesia. *Int J Adv Sci Technol* 2020; **29:** 4809–18.
31 Folke C. Resilience: the emergence of a perspective for social–ecological systems analyses. *Glob Environ Change* 2006; **16:** 253–67.
32 Olsson L, Jerneck A, Thoren H, Persson J, O'Byrne D. Why resilience is unappealing to social science: theoretical and empirical investigations of the scientific use of resilience. *Sci Adv* 2015; **1:** e1400217.