Satellite-based deforestation alerts with training and incentives for patrolling facilitate community monitoring in the Peruvian Amazon

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Despite substantial investments in high-frequency, remote-sensed forest monitoring in the Amazon, early deforestation alerts generated by these systems rarely reach the most directly affected populations in time to deter deforestation. We study a community monitoring program that facilitated transfer of early deforestation alerts from the Global Forest Watch network to indigenous communities in the Peruvian Amazon and trained and incentivized community members to patrol forests in response to those alerts. The program was randomly assigned to 39 of 76 communities. The results from our analysis suggest that the program reduced tree cover loss, but the estimated effects from the experiment are imprecise: We estimate a reduction of 8.4 ha per community in the first year (95% CI [−19.4, 2.6]) and 3.3 ha in the second year (95% CI: [−13.6, 7.0]) of monitoring. The estimated reductions were largest in communities facing the largest threats. Data from monitoring records and community surveys provide evidence about how the program may affect forest outcomes. Community members perceived that the program's monitors were new authorities with influence over forest management and that the monitors' incentivized patrols were substitutes for traditional, unincentivized citizen patrols that suffer from free riding and inhibit timely community detection of and responses to deforestation. Should our findings be replicated elsewhere, they imply that externally facilitated community-based monitoring protocols that combine remote-sensed early deforestation alerts with training and incentives for monitors could contribute to sustainable forest management.

deforestation | Amazon | community monitoring | common pool resources | collective action

Accelerating deforestation of the Amazon rainforest represents a grave threat to local ecosystems with global consequences for the climate crisis and preservation of biodiversity (1, 2). Over the past 40 y, governments and international nongovernmental organizations have invested in the use of satellite monitoring systems for the detection and measurement of deforestation (3). National governments in Brazil, Peru, and Colombia have adopted alert systems that generate remote-sensed deforestation data that measure tree cover loss (4). While remote sensing technologies now provide frequent, high-resolution deforestation alerts (5), there is not evidence that instituting these alerts reduces subsequent deforestation globally or in Latin America (6). One possible reason for the limited efficacy of early alerts is that local governments and communities often lack access to the resultant data to respond to and prevent further deforestation (7).

Several related challenges limit the efficacy of tropical forest protection policies in the Amazon. First, most national policies privilege centralized (state) prevention of deforestation or enforcement of antideforestation laws over community prevention efforts. However, state enforcement in remote regions of the Amazon is resource-intensive, and limited state capacity arguably curtails such enforcement. In turn, these failures of state enforcement leave populations living on the deforestation frontier—typically indigenous communities—responsible for confronting or deterring deforestation. Second, national investments in early deforestation alerts remain inaccessible to front-line communities (7). Thus, while community participation is central to the management of common pool resources (CPRs) (8–10), communities frequently lack information on where in vast communal forests deforestation has occurred until it is well under way and difficult to halt.

Responding to these challenges, we examine the effects of a community monitoring program that combined the sharing of satellite-detected early deforestation alerts with training and incentives for patrolling community forests. The monitoring program, based in the Peruvian Amazon, addresses these shortcomings in existing policies by: 1) making remote-sensed early deforestation alerts accessible to forest communities; and 2) strengthening communities' capacity for monitoring with training and incentives. Monitoring is well-documented as an institution that can facilitate sustainable governance of CPRs (11–13). The integration of remote-sensed alerts alongside training and incentives aims to increase the efficiency of monitoring by providing information on the location of tree cover loss in large communal territories.

The program trained three monitors selected by each participating community to conduct monitoring of community forests using a smartphone mapping application (*SI Appendix*, Fig. S6).

Significance

Remote-sensed deforestation alerts provide high-frequency information on tree cover loss in the Amazon. However, these alerts often do not reach immediately impacted populations. We conduct a randomized controlled trial to assess the effects of an externally facilitated community monitoring program in the Peruvian Amazon. The program selected, trained, and incentivized monitors to patrol communal forests while providing access to early deforestation alerts. This monitoring yielded imprecisely estimated reductions in average tree cover loss over 2 y of monitoring. Survey evidence suggests that community members perceived the new monitors as authorities with influence over forest management and that the monitors' incentivized patrols substitute for traditional citizen patrols that suffer from free riding and inhibit timely detection of and responses to deforestation.

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The monitors received monthly deforestation alerts from Peru's national Geobosques platform for monitoring deforestation, which relies on estimates of tree cover loss from Landsat-based Global Forest Watch (GFW) data. Monitors were remunerated for conducting monthly patrols to investigate deforestation in community forests. With the information collected by monitors, communities made autonomous decisions on how to respond to potential threats, either through direct intervention or by alerting state authorities.

We conduct a preregistered randomized controlled trial (RCT) in 76 communities in collaboration with local indigenous federations and Rainforest Foundation US, the nongovernmental organization (NGO) that designed and implemented the monitoring program. These communities depend on the natural resources afforded by the rivers and forests for their livelihoods and sustenance. Large-scale deforestation and degradation from timber extraction (14), slash-and-burn agriculture by invading settlers from the Peruvian highlands (15), and, increasingly, cultivation of low-altitude coca variants (16, 17) threaten the long-term survival of these communities.

Our research design and data collection make two contributions. First, the experimental research design allows us to estimate the causal effects of the monitoring program on community resource governance and rates of tree cover loss. This study is part of a larger Evidence in Governance and Politics Metaketa initiative of six coordinated field experiments that test how external support for community monitoring affects the overuse or degradation of resources. The harmonized community monitoring treatments (*SI Appendix*, section SI1) facilitate a meta-analysis that is used to probe the external validity of our findings. The present paper contextualizes the findings from the experiment in Peru and elaborates study-specific policy implications. To date, there have been very few experimental studies of forest conservation (18), and the studies in this project represent early experimental studies of community monitoring on CPR governance.

Second, we compile high-frequency data on monitoring and tree cover loss, an original household survey, and semistructured interviews. Using these data, we examine how the introduction of monitoring interacts with existing community dynamics by bridging existing large-N studies that rely upon remote-sensed data (9) and smaller-N case studies of indigenous communities' forest-governance practices (19, 20).

We find imprecisely estimated reductions in tree cover loss in the treatment communities. Over the first year of the program, tree cover loss decreased by 8.4 ha (95% CI: [−19.4,2.6]). These reductions are concentrated in the communities most vulnerable to deforestation: We find no evidence of tree cover loss in the half of communities predicted to be at low risk for deforestation based on past trends. However, we identify a reduction of 22.0 ha (95% CI: [−46.3,2.3]) in tree cover loss in the higher-risk half of communities. In the second year, the effects of monitoring were substantially attenuated: Tree cover loss decreased only 3.3 ha (95% CI: [−13.6,7.0]). We further show that monitoring practices became routinized over time in treatment communities, and monitors' learning about where deforestation and degradation occurred led to more efficient detection of deforestation. Examining community governance, counter to our predictions, but consistent with recent findings elsewhere in Peru (21), we find that the treatment lowered community members' willingness to participate in or contribute to collective action on forest issues. Instead, the monitoring program effectively moved the task of patrolling the forests—a public good—to the domain of trained, remunerated monitors, who function as bureaucrats. Effective "bureaucratization" of forest-patrol tasks formerly subject to collective action failures is consistent with suggestive evidence of reduced tree cover loss.

Technology-Facilitated Monitoring

The combined challenges of monitoring a vast resource and limiting use by outsiders make protecting communal forests a CPR problem (22). The literature on CPRs has identified many factors that determine whether governance institutions can successfully manage resources for long-term sustainable use (10, 22). Key among these are the ability to monitor use and police or punish misuse (8, 23). Monitoring generates information on the current status and availability of resources (stocks and flows) and also the behavior of other users, all of which are necessary for enforcing compliance with norms or rules for resource use (11).

The monitoring program we document consists of three bundled attributes: monitor selection and appointment, training and incentivization of monitors to conduct patrols, and the provision of remote-sensed deforestation alerts. We study how monitors, community members, and deforesters respond to the exogenous creation of technology-facilitated monitoring. We elaborate our theory of change in *SI Appendix*, Fig. S21. In our theory of change, monitor teams respond to tree cover loss alerts by conducting patrols to collect on-the-ground information on these alerts and other deforestation in community territory. Relative to monitoring without the alerts, the alerts reduce the cost of locating disturbances, which increases the efficiency of monitoring vast territories. Monitor teams subsequently communicate this information to community members and authorities. Communities respond by deciding whether and how to take action to control users of forest resources.

In contrast to many forest CPR contexts, in the communities we study, deforestation is generally perpetrated by individuals outside the communities. However, interviews with community leaders reveal that these acts are often facilitated by side agreements with individual community members or families that are not disclosed to the rest of the community. As such, interventions against deforestation may consist of policing community collaboration, intervening against community invaders, or petitioning the Peruvian state for enforcement against deforestation. In the absence of state intervention, communities rely on collective action to police their members and/or outsiders to control deforestation. Thus, we conceptualize deforestation as an outcome produced by both community members and outsiders. Increased detection and policing by communities increases outside deforesters' costs of operating within communities and potential facilitators' costs of collaboration with these outsiders. These increased costs should reduce deforestation.

The monitoring program creates a set of monitoring positions in treatment communities, but does not occur in an institutional vacuum. All communities have local authorities, including traditional leaders (*apus*) and community assemblies for collective decision making. We study the effects of the monitoring program on communities' exercise of collective action against deforestation. We hypothesized that changes in collective action could occur via the provision and dissemination of information on forests or through changes in the organization of community governance institutions initiated by the monitoring program.

Research Design

We ask whether a monitoring program based on the transmission of remote-sensed tree cover loss alerts can reduce deforestation. To answer this question, we implement a preregistered RCT in 76 indigenous Native Communities in the Peruvian Amazon. The Peruvian constitution recognizes collective land rights for indigenous communities over the territory they have traditionally possessed. Collective lands are titled to the community and have strict protections that prevent transfer, seizure, or

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expropriation. Within the community, land use is established by community-specific traditional practices. Typically, family units have possession of small plots of land for houses and family gardens and can freely access community forests for hunting and extracting resources for family use.

Our partners identified a population of 122 eligible communities in the Napo and Amazon River basins located in the Loreto department (*SI Appendix*, Fig. S1). These basins are among the largest in the Peruvian Amazon, and both experienced notable tree cover loss in the year prior to our intervention (*SI Appendix*, Fig. S2). Given a high level of community-led demand for the program, federation leaders, the implementing NGO, and a researcher convened a meeting in Iquitos to select communities for the experiment. In a deliberative forum, federation leaders assessed perceived interest, implementation logistics, and safety concerns to select 76 viable communities. The median experimental community lost the equivalent of 2.54% of its communal territory in tree cover between 2010 and 2016. This figure exceeds median tree cover loss of all titled communities in Loreto (*SI Appendix*, Fig. S3). Sixty of the 76 communities were titled at the time of selection. In our experimental sample, mean size of titled or claimed land in our study is 6,493 ha, and the mean community population was 486.*

To ensure equitable access to the treatment across federations and improve efficiency in estimation, we block-randomized, stratifying on federation, federation leaders' qualitative assessment of the severity of threats facing a community's forests, and geographic proximity. In the interest of transparent allocation of the treatment, the randomization was conducted by publicly drawing lots in the presence of all federation leaders. Ultimately, we assigned 39 communities to the monitoring treatment and 37 communities to control. We detail the intervention and its timing in *SI Appendix*, section S4. Thirty-six of the 39 communities assigned to the treatment participated in the monitoring program. Of the three communities in which implementation was stymied, just one—a community highly invested in timber extraction—was uninterested in participating. The other two communities were proximate to illegal activity such that program staff could not safely reach the communities (*SI Appendix*, Fig. S9). In light of this noncompliance (slippage) we estimate intent-to-treat (ITT) effects. We report treatment effects among compliers (complier average causal effects) in *SI Appendix*.

We measure aspects of each step of the causal chain. We rely on the monitoring outputs, both in the form of paper reports and digital records of monitoring patrols, to measure monitor effort and monitoring dynamics over time (12). These comparisons are nonexperimental, but allow us to estimate the efficiency gains in monitoring over time. We measure information dissemination and community responses to monitoring information using an original household survey of 742 households and interviews with community leaders conducted 1 y after the start of the program. Our principal behavioral outcome—rates of tree cover loss—come from monthly Landsat-based GFW data at a 30-m × 30-m resolution, which we aggregate to the community level. Given the near-absence of large-scale plantations with woody plants in the experimental region, detected instances of tree cover loss are almost certain to measure loss of native, biodiverse forest ecosystems (24). The tree cover measure, however, does not measure forest degradation (*SI Appendix*, section S8A). We prespecified a 1-y posttreatment period. However, our partners continued the program with the experimental treatment assignment for a second year. For this reason, we disaggregate tree cover loss outcomes into the first and second years. (See *SI Appendix*, Fig. S5 for a timeline.)

Results

We begin by estimating treatment effects on our ultimate outcome of interest: tree cover loss, before tracing the causal chain. Fig. 1 reports ITT effects of monitoring on cumulative tree cover loss in the posttreatment period. For each month, t, the dependent variable is the cumulative posttreatment tree cover loss (in hectares) through intervention month t in each community. We estimate the ITT for each month t using a cross-sectional regression of tree cover loss on a treatment-assignment indicator and covariates measuring recent (pretreatment) tree cover loss and the forested area of the community and block fixed effects, following Eq. **1**. The ITT estimates reveal substantial, if imprecisely estimated, reductions in tree cover loss over the course of the 2-y intervention. In the first year, we estimate that assignment to monitoring averted an average of −8.4 ha (95% CI [−19.4, 2.6]) of tree cover loss. In our prespecified one-tailed (lower) hypothesis test, this estimate corresponds to $p = 0.06$ (*SI Appendix*, Fig. S13). This effect is substantively large, if imprecisely estimated: The ITT represents a decrease of 52% from the average area of tree cover loss in communities assigned to control. In the second year of monitoring (between months 12 and 24), gains were more modest, at −3.3 ha (95% CI: [−13.6, 7.0], $p = 0.26$), highlighting the need for further research on how durable these effects are

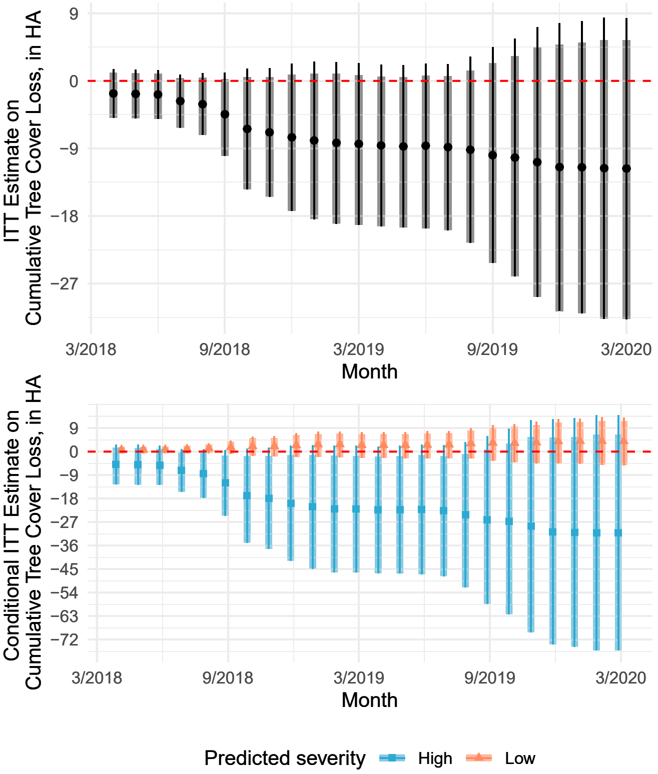

Fig. 1. *Upper* plots ITT estimates, and *Lower* plots conditional ITT estimates for communities with low and high predicted severity. All estimates are estimated by a cross-sectional specification with $n = 76$ communities, in which the dependent variable is cumulative posttreatment tree cover loss through the current month. The thin lines indicate 95% CIs calculated from heteroskedasticity-robust SEs. The upper bounds of the thick segments indicate the upper bounds of the rejection region in the prespecified one-tailed hypothesis test (with $\alpha = 0.05$). The outcome variable is right-skewed (*SI Appendix*, Fig. S15), which accounts for the wider CIs in the high-severity median of communities.

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*The 16 untitled communities were at varying points in the titling process, so we use the GPS coordinates of demarcated lands claimed by untitled communities as the territorial unit.

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over time. In sum, in the 2 y of the program, our ITT represents a 37% reduction in tree cover loss from the control group mean.

This overall ITT masks heterogeneity in the effect of monitoring across communities. We designate communities as "low" or "high" predicted severity of deforestation based on the pretreatment rates of tree cover loss. Low-severity communities are below the median of all experimental communities; high-severity communities are above the median. We estimate conditional ITT effects by interacting this severity indicator with the treatment indicator in our previous specification. Fig. 1, *Lower* plots the estimated conditional ITT effects. We show that gains are concentrated in communities with higher predicted severity. For example, in the first year of the program, assignment to monitoring averted tree cover loss of -22.0 ha (95% CI: $[-46.26, 2.32]$), $p = 0.04$ in a one-tailed test. The difference in conditional ITTs between the two subgroups is significant at the $\alpha = 0.05$ level at the 1-y mark and at the $\alpha = 0.1$ level for both years combined. We attribute the limited apparent efficacy of monitoring in communities at lower risk of tree cover loss to floor effects. This within-study evidence of floor effects is consistent with across-study evidence (18). These heterogeneous treatment effects combined with empirical cumulative distribution function plots in *SI Appendix*, Fig. S15 suggest reductions in the extent of tree cover loss emerge by deterring of large-scale tree cover loss events in the most affected decile of communities.

The estimates we present are relatively imprecise: In the full sample (Fig. 1, *Upper*), our ITT effects are not significant at the conventional $\alpha = 0.05$ level in any month, even with our prespecified one-sided hypothesis tests intended to increase statistical power. A frequent response to imprecise treatment effect estimates from (comparatively) small studies is to replicate the experiment. Given the harmonized trial design, this study of community monitoring has effectively been replicated in five other sites (25). Comparing our ITT estimates from Peru to the estimated mean of the distribution of ITT effects across sites, we observe reductions in resource use that are concentrated in the (ex ante) most severely impacted median of communities (*SI Appendix*, Fig. S36). Pooling the data across the sites yields gains to precision: Even though the estimated mean of ITT estimates is smaller than our ITT estimates in Peru, we are able to reject the null hypothesis of no effect in the full sample and the more severely impacted median of communities $(p < 0.005)$.

We report analogous causal effects among complier communities in *SI Appendix*, Fig. S14. More importantly, in *SI Appendix*, Table S5, we analyze monthly tree cover loss outcomes using panel specifications to estimate treatment effects. These specifications allow us to adjust for seasonal variation in deforestation to improve the precision of our estimates. While our estimates reveal that the largest tree cover loss reductions are concentrated in heavily impacted communities, as in Fig. 1, there are also reductions in the probability of experiencing any tree cover loss event that are concentrated in communities facing smaller-scale deforestation threats.

To what extent is tree cover loss simply displaced from treatment communities? This question is important for understanding both our treatment effects and the general equilibrium effects relevant for the study of conservation. To this end, we conduct an experimental analysis of spatial spillovers around experimental communities in *SI Appendix*, section S9. To do so, we compare levels of tree cover loss in concentric "buffer areas" around experimental communities (26). We do not find evidence of displacement effects: We cannot reject a null hypothesis of no differential displacement on tree cover loss outside treatment relative to control communities, nor do we detect variation in estimates of displacement as a function of distance from the experimental communities. Note, however, that estimates are relatively imprecise. While our point estimates on displacement are small relative to the point estimates in Fig. 1, both are estimated with considerable uncertainty.

Why might displacement from a targeted intervention be limited? In the region that we study, in the general absence of roads, most transportation occurs by boat. As a result, the areas most vulnerable to deforestation are located close to navigable rivers (*SI Appendix*, Fig. S10). Indigenous communities in Loreto are disproportionately river communities occupying a substantial proportion of territory along these rivers (*SI Appendix*, Figs. S11 and S12). By targeting protection to these vulnerable territories, our intervention increases arguably the cost of extraction.

Finally, we explore multiple explanations for the substantively, if not statistically, significant reduction in magnitude of the effect of monitoring in the second year in *SI Appendix*, section S10. Based on characterization of yearly posttreatment variation in tree cover loss within communities, we find suggestive evidence that a state enforcement campaign against coca cultivation in the Amazon basin (unrelated to the monitoring program) during the second year reduced tree cover loss in the most vulnerable control communities with the most intense tree cover loss in the first year of monitoring (*SI Appendix*, Figs. S19 and S20).

Implementation: The Regularization of Monitoring Practices. We now consider the process through which early alert-facilitated monitoring may have changed patterns of tree cover loss. We first consider uptake of monitoring by community monitors. Experimental findings from semistructured interviews with community leaders in treatment and control communities show that assignment to monitoring substantially increased the salience of monitoring in forest governance (*SI Appendix*, Fig. S34). Among the 36 treatment group communities that participated in community monitoring (the compliers), we examine reports submitted by monitors to our partner NGO. These reports represent instances of deforestation documented during monitoring trips. Note that the early alerts detect deforestation at a resolution of 30 m × 30 m; some instances of tree cover loss occur at a smaller scale. Fig. 2 shows an effectively monotonic increase in the rate at which community monitors reported instances of deforestation over the first year of the intervention. We estimate that, on average, reporting increases by an average of two reports per month (95% CI: $[0.97, 3.03]$). Over the course of the first year of treatment, the monthly count of reports submitted doubled.

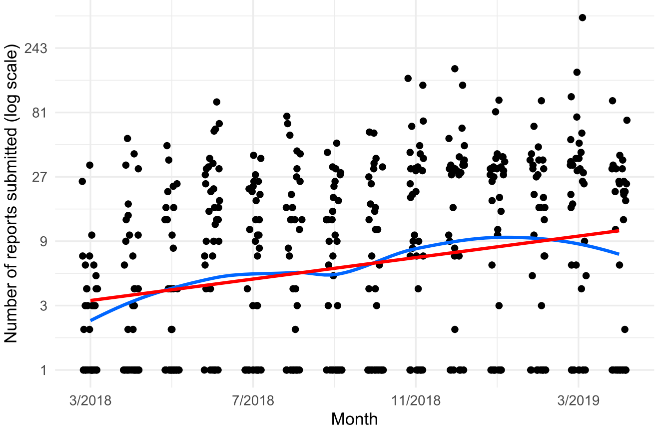

Fig. 2. Count of reports of deforestation instances per community per month in the $n = 36$ communities that were treated. Points are slightly displaced horizontally for legibility. The red line is estimated by a bivariate ordinary least squares regression, and the blue line is estimated by Loess.

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All communities submitted reports, though there exists variation in the number of reports submitted, ranging from 16 to 699, with a median of 195.

This pattern of increased detection is consistent with monitors learning about where deforestation is most likely to occur in their territory. There were no monetary incentives to submit more reports over the course of the intervention, simply a payment conditioned on monitoring once each month.[†] When we examine the distance traversed in monitoring or the number of patrols attempted in a month (measured over the first 10 mo of the intervention), there is no evidence of growth or decay over time (*SI Appendix*, Table S7). This behavior is consistent with the incentive scheme provided as part of the intervention. Thus, the increase in the number of reports generated is not simply a function of increased effort (time) devoted to monitoring. Instead, the efficiency of deforestation detection increases: An additional 0.83 (95% CI: [0.15, 1.51]) reports per kilometer patrolled were submitted in each month of the intervention (*SI Appendix*, Table S7). This pattern holds in between- and within-community comparisons. These findings are consistent with monitor learning about the location of deforestation events from the early alerts or on-the-ground monitoring experience over time. This learning facilitates more efficient detection of deforestation. These findings suggest that the information generated by monitoring grew over the first year of the intervention.

Changes in Community Governance. We hypothesized that the creation of community monitoring generates increased community awareness of deforestation threats and collective action in response to these threats. Dissemination of monitoring makes deforestation threats more salient and may reduce the costs of collective action. Further, the community workshops aim to improve communities' collective organizational capacity to mobilize politically and demand better enforcement by the state or to enforce community decisions against external actors (27).

In contrast to these hypotheses, however, in Table 1, we find no evidence that assignment to monitoring increases the salience of deforestation—whether respondents ranked forest issues among in the three most important community issues. Further, we find that monitoring led to lower levels of willingness to participate in forest-related collective action. Citizens in treatment communities offer less compensation for members of community patrols than those in control communities, and fewer citizens in treatment communities rely on collective means of information gathering (community assembly meetings or patrols) than those in control. We estimate sizable negative ITTs on these manifestations of collective action. Given modest intracluster correlation, our study is adequately powered to detect effects consistent with those documented in Table 1 (*SI Appendix*, Fig. S33), even with a relatively small number of communities (clusters).

These results are, on first glance, consistent theories of motivational crowding, in which the provision of extrinsic economic incentives for conservation reduces intrinsic motivations for conservation (28–30). Yet, inconsistent with standard accounts of crowding out, the monitoring intervention only introduces economic incentives for monitors, and not for all residents or the community as a whole. Extrinsic incentives for community-member participation in collective action are thus not altered by the intervention. We contend that this differentiation of roles and incentives within the community is central to the changes in community governance and tree cover loss outcomes that we observe.

Table 1. ITT effects and SEs on survey outcomes

Standardized outcome	Community sample	
	All surveyed	Full blocks
Salience of deforestation	−0.026 (0.104)	−0.114 (0.123)
Willingness to pay for patrols	−0.273 (0.125)	−0.222 (0.128)
Collective means of gathering info.	−0.329 (0.126)	−0.321 (0.137)

All outcomes are standardized *z*-scores. The larger sample includes $n = 63$ communities, and the smaller sample corresponds to the $n = 44$ communities in blocks with no community-level attrition. SEs clustered at the community level are in parentheses. See *SI Appendix*, section S13A for survey questions

To examine organizational changes in communities, we study the role of monitors in treatment communities. In treatment communities, awareness of the monitoring program was widespread by the time of the endline survey. Descriptively, all leaders were aware of the monitors, and 91% of citizens could identify at least one monitor by name (95% CI: [0.87, 0.95]). Monitors—a position that was nonexistent in control communities—appear to gain substantial attribution of responsibility for forest governance. We measure attribution of responsibility through responses to a question asking respondents whom they believe to be the authority responsible for forests in Fig. 3. Examining only the control group, there appears to be little consensus on where authority rests. The modal response of community government, most commonly the *apu*, is given by approximately half the sample. However, community government leaders themselves were 9 percentage points (17%) less likely than citizens to assume responsibility for forest management in this way. In sum, control communities do not seem to coordinate on a common authority for forest management.

Assignment to treatment changes these patterns substantially. Most centrally, we observe a 22.5 percentage point (95% CI: [14.4, 30.6]) increase in the proportion of citizens that attribute responsibility to the monitors. We observe statistically significant reductions in the proportion of respondents that are unsure as to the appropriate authority or who attribute authority to traditional leaders. While the creation or expansion of monitoring roles comprised a part of the treatment, community attribution of responsibility to these individuals was not fixed mechanically by the intervention. Indeed, we observe variation in the attribution of authority across communities. The large effect is also evident when comparing the blocks of communities with no attrition on the survey (*SI Appendix*, Fig. S25). The shift in attribution of responsibility toward monitors correlates positively with monitoring intensity (*SI Appendix*, Fig. S26). In communities with more active monitors, greater proportions of the community were apt to attribute forest-management authority to monitors. This finding provides suggestive evidence that the outputs of monitoring, beyond simply the designation of monitors, are visible and correspond to changes in the organization of forest governance.

We contend that the observed reductions in willingness to participate in/employ collective action is consistent with the attribution of authority to monitors. The designation of monitors moved some patrol activities from the collective domain to remunerated responsibilities of monitors. Bureaucratization represents one solution to problems of collective action that appears to be effective in the context we study. We do not observe reductions in collective action outside explicitly forest-related actions. Specifically, there is no evidence of a reduction in participation in community assembly meetings generally (*SI Appendix*, Fig. S30). Desire to participate in forest-related collective action could also be driven by changes in preferences with regard to forest management or conservation, distinct from

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[†] Further, unlike a payment for ecosystem services model, payments were not conditioned on forest-loss outcomes.

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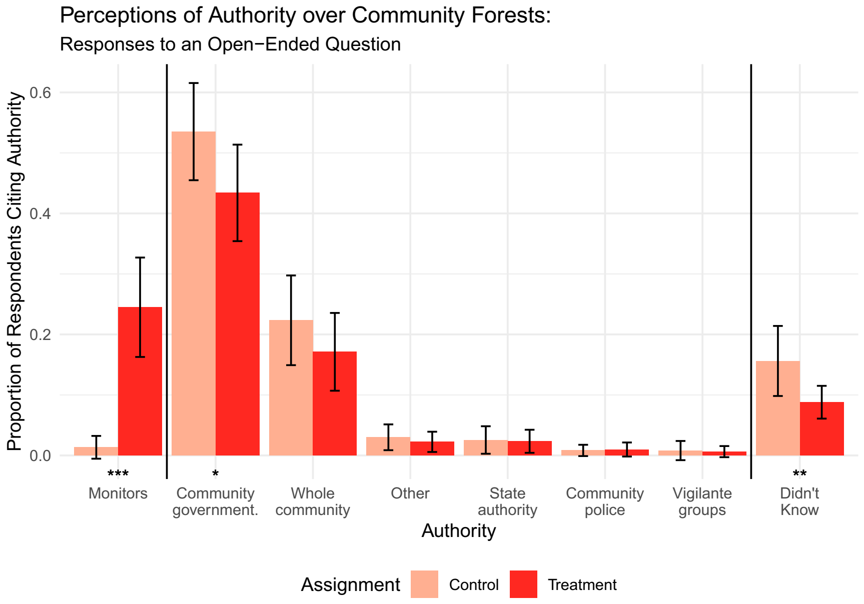

Fig. 3. The proportion of citizens citing each forest-management authority, by treatment arm, in the $n = 63$ surveyed communities (741 respondents). The 95% CIs are calculated from SEs clustered at the community level. *$P < 0.1$; **$P < 0.05$; ***$P < 0.01$.

the changes in the organization of forest governance. However, we find no evidence that the treatment detectably changed (average) preferences with regard to: the importance of forest issues, acceptable forest-use behavior (by community members), or time horizons (discounting) for forest use (*SI Appendix*, Fig. S31).

In sum, we find suggestive evidence that assignment to community monitoring introduced monitors as authorities over forest governance in the eyes of community members. With the available data, we cannot conclusively tie these changes in governance to the observed reductions in tree cover loss. However, patrolling became a remunerated task of monitors, who function as bureaucrats by delivering public goods. This bureaucratization represents one potential solution to the collective action problems thought to inhibit community responses to deforestation.

Policy Implications

This study documents a community monitoring program that actively involved indigenous communities in forest management and deforestation policy. We provide evidence of strong community uptake of the monitoring program, subsequent bureaucratization of community forest management, and suggestive evidence that community monitoring combined with remote-sensing technology may reduce tree cover loss. These findings produce three insights for the design of future policy.

First, monitoring building upon existing community governance institutions and technology may promote community-level uptake and accessibility. Qualitatively, community demand for the monitoring program and, specifically, for maps of early alerts persisted throughout the intervention. We find descriptive evidence from treatment communities that monitor effort persisted throughout the first year of the intervention, and the efficiency of locating deforestation or forest degradation increased over time. In turn, monitors selected from and by the communities were quickly seen as authorities on forest management in treatment communities. With regard to design of the monitoring intervention, although early alerts were ostensibly free, monitor incentive payments and smartphones to access alerts were costly. Future research may seek to unbundle these aspects of the monitoring program to ascertain whether a lower-cost design can achieve similar outcomes.

Second, our finding that monitoring averted more tree cover loss in severely threatened communities suggests that monitoring may achieve greater effects on conservation when targeted to communities facing imminent deforestation threats. More broadly, we note that 79% of the communities we studied are fully titled, and all were demarcated with GPS coordinates. While conservation scholars and policymakers advance such collective titles as a policy intervention to reduce deforestation in the Amazon, evidence on the effects of titling remains mixed (9, 31–33). Descriptively, we show substantial scope to further reduce deforestation in these titled/demarcated communities. While our conclusions are scoped to this subset of communities, more work could explore whether community-targeted monitoring interventions can be effective in the absence of clearly defined collective forests.

Finally, we highlight the importance of studying the relationship between targeted community-level interventions and state-level enforcement policies. While protecting indigenous territories aids in sustaining communities and may increase the price of forest extraction, most of the Amazon is located outside these communities. As such, state intervention or enforcement is necessary to address deforestation in the region. A state enforcement campaign against coca production in the second year of the program in one river basin may have reduced the efficacy of community monitoring in combatting tree cover loss, suggesting possible substitution between state enforcement and community monitoring. At the same time, several communities in treatment sought assistance from the state in their efforts to combat deforestation that they detected. Further research on the complementarity or substitutability of state and community efforts can inform the appropriate targeting and scale of future community-targeted efforts to combat deforestation in the Amazon.

Materials and Methods

Data Sources and Outcomes. We outline our data collection with respect to the research design in *SI Appendix*, Fig. S8. This paper draws upon outcome data from four sources. First, we use records of monitoring implementation.

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These records come in two forms: monitoring reports ($n = 8,107$) and metadata collected from the smartphone app. Both records contain a monitor identifier in addition to the dates and coordinates of monitoring activities. Second, we draw upon an endline survey of individuals in 63 communities. The target in each community was 10 citizens, 1 community president, and 1 monitor (treatment) or would-be monitor (control). See *SI Appendix*, section S13 for a description of sampling, attrition, and balance in the survey sample. Third, we draw upon recorded open-ended interviews with all leaders and monitors/would-be monitors in the survey sample. Finally, we use remote-sensed deforestation alerts from Geobosques, the Peruvian government's system for early deforestation alerts—precisely the data conveyed to communities. The resolution of these data is 30 m × 30 m, or $900\mathrm{m}^2$. To account for seasonal patterns, temporally we aggregate by calendar-month. Cross-sectionally, we aggregate to the community level, consistent with the companion studies (25). We use posttreatment deforestation data from March 2018 through February 2020 to estimate treatment effects. Only the first year was prespecified, so we disaggregate the first 2 y for transparency.

Estimation. Consistent with our preanalysis plan, we use ITT effect estimators.

For cumulative tree cover loss outcomes in Fig. 1, we estimate:

$$Y_{jb} = \beta_0 + \beta_1 Z_j + \gamma_b + \boldsymbol{\kappa}_j \mathbf{X}_j + \epsilon_{jb}, \qquad [1]$$

cross-sectionally for each posttreatment month. In Eq. **1**, j indexes communities and b indexes blocks used for treatment assignment; Z_j is a treatment assignment indicator; γ_b are block fixed effects; and $\mathbf{X}_j$ is a matrix of pretreatment covariates. β_1 is the estimator of the ITT. For all survey outcome specifications, we estimate:

$$Y_{ijb} = \beta_0 + \beta_1 Z_j + \boldsymbol{\kappa}_{ij} \mathbf{X}_{ij} + \epsilon_{ijb}, \qquad [2]$$

where i indexes respondents. Given community-level attrition, we estimate a simpler specification using inverse probability weights without block fixed effects in *Results* and report subgroup estimates from the blocks with no community-level attrition. We report the results of other prespecified estimators in *SI Appendix*. All SEs are clustered at the level of treatment assignment, the community (j).

Institutional Review Board. This study was conducted with approval from the Institutional Review Boards of Columbia (protocols AAAR2625 and AAAS3824), Johns Hopkins University (protocol no. 8731), and Innovations for Poverty Action (protocol no. 14953). Informed consent was provided for all surveys and interviews.

Data Availability. Anonymized survey, implementation records, and processed remote-sensed deforestation data have been deposited in the Open Science Framework (https://osf.io/n5d46) (34).

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1. J. A. Foley *et al.*, Global consequences of land use. *Science* **309**, 570–574 (2005).
2. R. J. W. Brienen *et al.*, Long-term decline of the amazon carbon sink. *Nature* **519**, 344–348 (2015).
3. M. C. Hansen *et al.*, High-resolution global maps of 21st-century forest cover change. *Science* **342**, 850–853 (2013).
4. A. Voiland, Tracking amazon deforestation from above. NASA Earth Observatory (2019). https://earthobservatory.nasa.gov/images/145988/tracking-amazon-deforestation-from-above. Accessed 24 June 2021.
5. J. Lynch, M. Maslin, H. Baltzer, M. Sweeting, Choose satellites to monitor deforestation. *Nature* **496**, 293–294 (2013).
6. F. Moffette, J. Alix-Garcia, K. Shea, A. H. Pickens, The impact of near-real-time deforestation alerts across the tropics. *Nat. Clim. Change* **11**, 172–178 (2021).
7. M. Finer *et al.*, Combatting deforestation: From satellite to intervention. *Science* **360**, 1303–1305 (2018).
8. T. Dietz, E. Ostrom, P. C. Stern, The struggle to govern the commons. *Science* **302**, 1907–1912 (2003).
9. A. Blackman, L. Corral, E. S. Lima, G. P. Asner, Titling indigenous communities protects forests in the Peruvian Amazon. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 4123–4128 (2017).
10. A. Agrawal, A. Chhatre, R. Hardin, Changing governance of the world's forests. *Science* **320**, 1460–1462 (2008).
11. E. Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge University Press, New York, NY, 1990).
12. F. Danielsen, N. D. Burgess, A. Balm ford, Monitoring matters: Examining the potential of locally-based approaches. *Biodiverse. Conserve.* **14**, 2507–2542 (2005).
13. F. Van Lederhosen, Governing community forests and the challenge of solving two-level collective action dilemmas—A large-n perspective. *Global Environ. Change* **20**, 539–546 (2010).
14. M. Finer, C. N. Jenkins, M. A. B. Sky, J. Pine, Logging concessions enable illegal logging crisis in the Peruvian Amazon. *Sci. Rep.* **4**, 4719 (2014).
15. N. Shanee, S. Shanee, Land trafficking, migration, and conservation in the "no-man's land" of northeastern Peru. *Trop. Conserv. Sci.* **9**, 1940082916682957 (2016).
16. D. S. Salisbury, C. Fagan, Coca and conservation: Cultivation, eradication, and trafficking in the Amazon borderlands. *Geojournal* **78**, 41–60 (2013).
17. L. M. Dávallos, K. M. Sanchez, D. Armenteras, Deforestation and coca cultivation rooted in twentieth-century development projects. *Bioscience* **66**, 974–982 (2016).
18. J. Börner, D. Schulz, S. Wunder, A. Pfaff, The effective of forest conservation policies and programs. *Annu. Rev. Res. Econ.* **12**, 45–64 (2020).
19. K. Evans, L. Murphy, W. De Jong, Global versus local narratives of redd: A case study from Peru's Amazon. *Environ. Sci. Pol.* **35**, 98–108 (2014).
20. M. P. Gilmore, J. C. Young, The use of participatory mapping in ethnobiological research, biocultural conservation, and community empowerment: A case study from the Peruvian Amazon. *J. Ethnobiol.* **32**, 6–29 (2012).
21. R. Sexton. Information, participation, and elite disillusionment: Evidence from a field experiment in Peru. *Quart. J. Polit. Sci.*, in press.
22. A. Agrawal, Forests, governance, and sustainability: Common property theory and its contributions. *Int. J. Commons* **1**, 111–136 (2007).
23. L. Persha, A. Agrawal, A. Chhatre, Social and ecological synergy: Local rulemaking, forest livelihoods, and biodiversity conservation. *Science* **331**, 1606–1608 (2011).
24. R. Tropek *et al.*, Comment on "high-resolution global maps of 21st-century forest cover change". *Science* **344**, 981 (2014).
25. T. Slough *et al.*, Adoption of community monitoring improves common pool resource management across contexts. *Proc. Natl. Acad. Sci. U.S.A.* **118**, e2015367118 (2021).
26. P. M. Aronow, C. Samii, Y. Wang, Design-based inference for spatial experiments with interference. arXiv [Preprint] (2020). https://arxiv.org/abs/2010.13599. (Accessed 24 June 2021).
27. D. J. Yashar, *Contesting Citizenship in Latin America: The Rise of Indigenous Movements and the Postliberal Challenge* (Cambridge University Press, Cambridge, UK, 2005).
28. E. Ostrom, Crowding out citizenship. *Scand. Political Stud.* **23**, 3–16 (2000).
29. J. C. Cardenas, J. Stranlund, C. Willis, Local environmental control and institutional crowding-out. *World Dev.* **28**, 1719–1733 (2000).
30. J. Rode, E. Gómez-Baggetheun, T. Krause, Motivation crowding by economic incentives in conservation policy: A review of the empirical evidence. *Ecol. Econ.* **117**, 270–282 (2015).
31. M. T. Buntaine, S. E. Hamilton, M. Millones, Titling community land to prevent deforestation: An evaluation of a best-case program in Morona-Santiago, Ecuador. *Global Environ. Change* **33**, 32–43 (2015).
32. A. BenYishay, S. Heuser, D. Runfola, R. Trichler, Indigenous land rights and deforestation: Evidence from the Brazilian Amazon. *J. Environ. Econ. Manag.* **86**, 29–47 (2017).
33. K. Baragwanath, E. Bayi, Collective property rights reduce deforestation in the Brazilian Amazon. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 20495–20502 (2020).
34. J. Kopas, T. Slough, J. Urpelainen, Community monitoring and technology transfer to prevent deforestation: A field experiment in the Peruvian Amazon. Open Science Framework. https://osf.io/n5d46. Deposited 3 February 2020.

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