Adoption of community monitoring improves common pool resource management across contexts

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Pervasive overuse and degradation of common pool resources (CPRs) is a global concern. To sustainably manage CPRs, effective governance institutions are essential. A large literature has developed to describe the institutional design features employed by communities that successfully manage their CPRs. Yet, these designs remain far from universally adopted. We focus on one prominent institutional design feature, community monitoring, and ask whether nongovernmental organizations or governments can facilitate its adoption and whether adoption of monitoring affects CPR use. To answer these questions, we implemented randomized controlled trials in six countries. The harmonized trials randomly assigned the introduction of community monitoring to 400 communities, with data collection in an additional 347 control communities. Most of the 400 communities adopted regular monitoring practices over the course of a year. In a meta-analysis of the experimental results from the six sites, we find that the community monitoring reduced CPR use and increased user satisfaction and knowledge by modest amounts. Our findings demonstrate that community monitoring can improve CPR management in disparate contexts, even when monitoring is externally initiated rather than homegrown. These findings provide guidance for the design of future programs and policies intended to develop monitoring capabilities in communities. Furthermore, our harmonized, multisite trial provides sustainability science with a new way to study the complexity of socioecological systems and builds generalizable insights about how to improve CPR management.

community monitoring | common pool resources | multisite trial | institutional adoption | meta-analysis

The Intergovernmental Panel on Climate Change advocates an active role for local communities in achieving climate change mitigation goals (1). Locally, sustainable resource management of common pool resources (CPRs) can improve health, livelihoods, and crisis prevention (2–4); globally, these practices can combat climate

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change and preserve biodiversity (5–7). However, the promotion of sustainable CPR use poses challenges for community governance. A substantial literature documents that the design of resource governance institutions varies substantially between communities and across contexts (8). Such institutions are especially critical for sustainable resource use in developing contexts where state capacity to regulate or enforce resource use laws is limited (9, 10). Decades of observation of community CPR governance reveal substantial heterogeneity in both communities' adoption of CPR governance institutions and CPR status outcomes (8). Translating policy recommendations about "what works" from one context to another poses substantial challenges (11, 12). We highlight two research design challenges that compound this problem. First, most empirical observation of CPR management institutions comes from communities that have endogenously adopted these institutions. These communities may represent a minority of communities facing CPR governance challenges. This selection problem hampers our ability to assess whether other communities that face severe CPR governance challenges can be encouraged to adopt these institutional design features, and whether these institutions can improve CPR governance in these settings. Second, the multitude of design features hypothesized to affect CPR governance tends to emerge in consort. When this occurs, determining the effects of a single institution or design feature poses analytic challenges and constrains our ability to make policy recommendations for new contexts (13).

We respond to these challenges with a harmonized, multisite randomized controlled trial that examines the effects of a single institutional design feature—community monitoring—on CPR governance and outcomes. Across many resource systems, resource users face uncertainty about the status of the resource, others users' consumption of the resource, or the enforcement of rules for use. Laboratory and laboratory-in-the-field experiments suggest that many forms of uncertainty yield overextraction via coordination or cooperation failures (14–16). Two common remedies to uncertainty studied in the laboratory—self-monitoring of resource use and communication between users—can reduce overextraction by enabling coordinated decisions to limit resource use and facilitating regular enforcement (17–20). Community monitoring represents a "real world" analogue to these treatments. It generates information that groups need to coordinate behavioral and institutional responses to resource degradation (8, 21). In particular, monitoring helps groups of users craft appropriate rules for resource use and know whether their implementation of those rules is working to stem overextraction.

However, cost and technical barriers can limit the endogenous adoption of monitoring by communities, even when it may help to resolve information problems related to CPR management (22). Coordination around rule creation or enforcement can be difficult even with full information about resource status. Uncertainty about the prospects for collectively managing resources may cause users to further underinvest in monitoring. Moreover, in the context of large resource systems, high costs of regular monitoring can stymie enforcement (23).

Technological advances of the past two decades (e.g., remote sensing of forests, automated groundwater measurement) can generate accurate information about resources and their use at reasonable costs. Yet, these technologies have largely originated outside of frontline communities and often remain inaccessible (24). We ask whether outside actors (i.e., nongovernmental organizations [NGOs]) can introduce technology-facilitated monitoring from the outside in communities that have not adopted regular monitoring, even in the face of substantial CPR management challenges. We study when communities will adopt monitoring supported by external actors. We then assess the effects of monitoring on resource use and governance.

The six sites in our study allow us to examine the effects of monitoring across diverse settings. We study new monitoring programs of different resource systems with different (preexisting) CPR governance institutions. The sites span six countries and four continents. Collectively, the sites exhibit a variety of CPR management challenges including substantial uncertainty about CPR status that hinders coordination on rules for use, detection of rule violations, and enforcement of established rules. Our experimental sample consists of 747 communities, of which 400 were assigned to a harmonized intervention that sought to implement monitoring. We measure outcomes through objective on-the-ground or remote-sensed measurements of CPR status and through household surveys of over 16,800 respondents. Our research design thus contributes to a rich existing literature on community monitoring by 1) examining a much larger number of communities than existing studies, 2) documenting selection into monitoring, 3) providing a credible counterfactual to test the causal effects of monitoring, and 4) harmonizing outcome measurement across cases (see *SI Appendix*, section S1).

We offer three main findings. First, we find high levels of uptake of monitoring across communities in five of the six sites. With sufficient support from facilitating NGOs, even communities that had not previously practiced monitoring were able to regularize monitoring for at least 1 year. Second, across sites, assignment to monitoring yields average reductions in CPR extraction/degradation, increases in citizen satisfaction with CPRs, and increases in citizen knowledge about their community's CPRs. Third, despite similarly sized and signed treatment effects, we provide suggestive evidence that the mechanisms through which monitoring changes resource use outcomes are conditioned on existing CPR governance practices.

We contribute to an emerging movement toward developing generalizable knowledge and policy recommendations through the first use of a multisite trial in sustainability science (25, 26). Our research design responds to criticisms of the external validity of experiments (19, 27). In so doing, we also engage with debates about merits of transplantation of CPR governance institutions from one context to another, often described in terms of skepticism of common policy interventions (panaceas) (11, 12). Specifically, we argue that more systematic analysis across contexts—like this project—is needed to evaluate the merits of general policy recommendations. In so doing, we join emerging bodies of work examining the emergence and function of institutional design features across multiple resource systems (28) and considering how existing community institutions (design features) condition the outcomes of conservation interventions (29). Our findings suggest that communities can be encouraged to monitor across a variety of contexts to affect modest improvements in CPR conservation. The magnitude of our effects suggests that additional policy "levers" (design features) may be necessary to achieve desired levels of sustainable use of CPRs. We conclude with a discussion of how such policy questions can inform future multisite trials.

Research Design

We design and analyze six harmonized randomized controlled trials on community monitoring of CPRs. In so doing, we adhere to the eight principles of the Evidence in Governance and Politics Metaketa Initiative for coordinated multisite trials: coordination

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across research teams, comparability of interventions, comparability of outcome measures, integrated case selection, preregistered implementation and analysis plans, third-party analysis, formal synthesis, and integrated publication. These principles are elaborated in *SI Appendix*, section S2.

The six interventions monitor groundwater in arid regions of Brazil and Costa Rica; surface water in urban China; and forests in rural Liberia, Peru, and Uganda. The sites comprise a convenience sample that was determined through competitive selection of research proposals (*SI Appendix*, section S13). As documented in Table 1, the CPRs face a variety of anthropogenic and natural threats, including overuse by community members, extraction (or pollution) by noncommunity members, and climactic conditions. In light of a large literature on the factors that may influence community governance of CPRs, the diversity of the sites allows for consideration of how the effects of monitoring vary in the presence of heterogeneous natural and institutional settings.

Each site implemented an experimental intervention with the aim of creating community monitoring practices in communities where such practices had not previously emerged. In the absence of the monitoring intervention, communities rely on patrols by government officials or appointees in Brazil, Costa Rica, China, and Uganda; patrols by landlords in Liberia; or patrols by the community writ large in Peru. (See *SI Appendix*, section S6 for more detail.) However, these forms of monitoring or oversight are believed to be stymied by resource constraints, bureaucratic shirking, or collective action problems. In practice, we show that existing forms of monitoring or patrols are, at best, infrequent across sites.

The monitoring programs were harmonized, to the extent possible, across the six sites. Table 1, components of harmonized

Table 1. Features of the research contexts and experimental designs

	Brazil	China	Costa Rica	Liberia	Peru	Uganda
Contextual features of CPR						
Resource	Groundwater	Surface water	Groundwater	Forest	Forest	Forest
Community	Rural villages	Urban microneighborhoods	Rural villages	Villages	Indigenous communities	Villages
Primary threat to resource	Drought, overuse	Individual, industrial pollution	Drought, overuse	Overcutting by residents	Extraction by outsiders	Overcutting by residents
Components of harmonized interventions						
Community workshops	✓	—	✓	✓	✓	✓
Monitor selection, training, incentives	✓	✓	✓	✓	✓	✓
Monitoring of the resource	✓	✓	✓	✓	✓	✓
Dissemination to citizens	✓	✓	✓	✓	✓	✓
Dissemination to management bodies	—	(Alternate arm)	✓	✓*	✓*	✓*
Experimental design						
Alternate treatment arm	Conservation plan making	Dissemination to government	—	Negotiation training	—	SMS reminders
Experimental design	Three-arm†	2x2 factorial	Two-arm	2x2 factorial	Two-arm	Three-arm†
No. of monitoring communities (N_M)	80	80	81	60	39	60
No. of nonmonitoring communities ($N_{\neg M}$)	40	80	80	60	37	50
Common outcome measurement						
Duration of implementation, mo	12	15	12	12	13	12
Primary compliance measure	SMS reports received	Dissemination posters	Reports submitted	Monitoring walks completed	Reports submitted	Reports submitted
Primary resource outcome	Well electricity usage	Pollutant concentration in water	Well electricity usage, water quality	Deforestation	Deforestation	Deforestation, forest quality
Endline citizen survey	✓	✓	✓	✓	✓	✓

N_M denotes the number of communities assigned to any treatment condition with community monitoring, and $N_{\neg M}$ denotes the number assigned to any treatment condition without community monitoring.

*In the forest studies, the community constitutes at least one of the possibly overlapping management bodies.

†In both three-arm designs, communities assigned to the alternative treatment arm received both monitoring and the alternative treatment.

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interventions, includes the five common characteristics of the monitoring programs. In all sites except China, the program was introduced through a community workshop(s) that included implementing partner organizations (generally NGOs) and most community members. Individual monitors were then selected and trained to conduct monitoring. While the monitor selection method varied across sites (*SI Appendix*, Table S8), common requirements of basic literacy and numeracy, physical mobility, and residence in the community yielded monitors that were drawn from the set of resource users with higher levels of formal education, on average, than fellow users (*SI Appendix*, Table S9).

Each site included the introduction of some technology used to aid in the monitoring or dissemination of findings. These ranged from a novel well water level sensor in Brazil to a smartphone app that transmitted monthly remote-sensed early deforestation alerts to monitors in Peru. These technologies facilitated direct measurement of status of the resource (namely, water levels, water quality, and forest loss). What monitors could directly infer about user behavior from observation of the resources varies across resource systems. As such, the harmonized treatment focuses on monitoring of the resource itself. Monitors were incentivized at locally appropriate rates to provide monthly or quarterly reports of their monitoring over the course of at least 1 year. The information from the reports was then disseminated to citizens through posted fliers (China) or in community meetings (other sites). Finally, this information was also disseminated to at least one relevant management body overseeing the CPR.*

We estimate the effects of the harmonized intervention—community monitoring—across sites. Four of the sites included an additional treatment arm in order to examine the effectiveness of an alternative intervention aimed to improve CPR use. In two sites, this second treatment arm was randomized in a 2×2 factorial design, and, in two other sites, the alternative treatment was a light-touch additive treatment provided in addition to monitoring in a subset of treatment communities. All specifications include indicators for assignment to the alternative treatment (where relevant), but our focus in this article is on the comparison between the communities assigned to monitoring and those communities not assigned to monitoring.

We first examine uptake of the monitoring intervention using implementation data over the course of the yearlong interventions. This allows us to check whether an exogenously introduced program can meaningfully change community practices. Our preregistered theory of change (*SI Appendix*, section S12) suggests that, for monitoring to change governance or resource outcomes, it must be practiced. We argue that the information generated from monitoring impacts resource use by changing citizens' expectations about enforcement and others' behavior, increasing monitors' efficiency in enforcing rules, and/or generating demand for adopting new rules (8).

We test four prespecified hypotheses about the effects of community monitoring. First, we hypothesize that community monitoring reduces resource use or extraction. Second, monitoring may also facilitate attitudinal and behavioral change in community members. We hypothesize that (perceived) changes in resource use facilitate higher satisfaction with the state of natural resources and their management. Third, the training workshops and information generated by monitoring may increase user knowledge of the CPR. Finally, we hypothesize that monitoring may increase the expression of resource stewardship attitudes and behaviors. We measure stewardship in terms of conservation norms and willingness to contribute to CPR monitoring as a public good.

To test our hypotheses, we rely on two sources of data. First, we measure the status of the CPR at baseline and endline. Collectively, the sites measure groundwater use by the electricity consumption of wells, water quality using independent water quality tests, deforestation using remote-sensed data, and forest biomass via on-the-ground surveys. Second, we measure social and political outcomes using harmonized household surveys. Our three primary attitudinal and behavioral hypotheses rely on harmonized survey questions that were asked in all sites at endline. Further, we measure several intermediate outcomes in our theory of change using the survey data. These original surveys represent a rare attempt to introduce harmonized measurement across cases to the study of CPR governance. Given the heterogeneity in both natural and social systems we study, these surveys also offer new descriptive insights about the state of and challenges for CPR governance.

The harmonization of interventions across sites facilitates a meta-analysis aimed at examining the effects of community monitoring across sites. This analysis allows us to answer two questions. First, what is the average effect of assignment to the monitoring programs across sites? Our primary estimand, the "meta" intent-to-treat (ITT) effect, quantifies the mean of the distribution of site-level ITTs of the community monitoring intervention. This quantity corresponds to our estimate of μ in a random effects meta-analysis. Second, do these effects differ across the six sites?

The meta-analysis of results from interventions on different CPRs introduces some challenges for comparability of outcomes across sites. For example, measures of groundwater usage do not naturally map onto measures of the area deforested. To harmonize measurement, we prespecified the components of each outcome measure (*SI Appendix*, Tables S6 and S7). We then create outcome indices by standardizing each component variable by its control group mean and standard deviation, creating a Z score (25, 30). To generate a single index for each outcome, we then average these Z scores of the index components and standardize again. This ensures that each outcome index in each site has a mean of zero and standard deviation of one for the (pure) control group.

The constituent studies we analyze resemble many community-level cluster-randomized experiments in social science in terms of the number of clusters. Thus, like much of this literature, the individual studies generally have limited statistical power to detect small treatment effects. The use of a meta-analysis affords precision gains by pooling the estimates from individual studies.

Results

Implementation and Uptake. We begin our analysis of the harmonized monitoring intervention asking the question, Did the intervention induce citizens to monitor CPRs in communities assigned to treatment? To better understand selection into monitoring, it is critical to understand whether a random sample of communities (those assigned to monitoring) in each experiment participated in community monitoring. Furthermore, in order to interpret findings on the effects of community monitoring, we seek to validate that monitoring occurred.

Fig. 1 examines the rates of monitoring, by site and quarter of the intervention. With the exception of the Brazilian intervention, we observe relatively high (>80%) rates of monitoring activity.

*In the Brazilian site, there exists no such management body, and the China project disaggregated the targets of dissemination to two targets, citizens and government officials in two treatment arms.

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There exist multiple plausible explanations for the lack of uptake of monitoring in Brazil. Qualitatively, the Brazilian intervention had less support on the ground from project personnel (i.e., NGO staff) than the other projects. Across communities in Brazil, monitoring uptake was most likely in communities facing lower coordination costs, higher resource benefits of monitoring, and fewer safety nets to mitigate any water shortages. Monitoring uptake was particularly unlikely in the 70% of communities where wells could not be opened, which limited the information that could be learned from monitoring (31). Because only 38% of treatment communities reported any monitoring, we estimate meta-analytic estimates with and without the Brazilian data.†

In the other sites, the vast majority of communities completed at least some monitoring. In China, Peru, and Uganda, all assigned communities completed at least some monitoring over the course of the intervention; in Costa Rica and Liberia, the rates of communities assigned to monitoring that monitored at least once were 84% and 95%, respectively. Analyses of the extensive margin of monitoring generate some grounds for concern about the sustainability of monitoring absent support from implementing organizations. In particular, the Liberian partner organization has no record of "official" reports of monitoring during the third quarter. However, this does not imply that some form of monitoring did not occur. As such, the point is omitted from Fig. 1.

Further examination of the intensity of monitoring relies upon intervention-specific operationalizations. Monitoring of forests garnered substantial attention from communities across three studies. In Liberia, the proportion of citizens that attended a meeting where forest issues were discussed increased from 10% in control to 76% in communities assigned to monitoring (32). In Peru, in communities assigned to monitoring, all sampled community leaders and 92% of citizens could name the individuals tasked with monitoring at endline (33). In Uganda, 74% of households in villages assigned to monitoring report monitoring of forests, nearly tripling the control group rate of 28% (34). As is clear from Fig. 1, across these five sites, monitoring was generally sustained over the course of the year. The intensity of report submission provides a less blunt measure of effort over time. In Peru, for example, the average rate of deforestation reports more than doubled over the course of the year even though incentives remained constant. In contrast, in Costa Rica, the frequency of reports submitted declined by a little over 20% over the course of the year (35). While posters were displayed regularly in China, there is little evidence that citizens read or absorbed the information presented (36).

In sum, we observe substantial uptake of community monitoring in five of the six sites. The consistent engagement between communities and NGO partners supporting monitoring seems to be important to motivating continued participation in monitoring, and represents a relevant policy-making consideration. Despite persuasive evidence of treatment uptake, the slippage (noncompliance) between assignment to monitoring and the occurrence of monitoring in all sites suggests that a focus on cases in which community monitoring actually occurs may lead to misleading inferences about the efficacy of such programs. By characterizing variation in uptake, we show that studying exogenously introduced monitoring provides a necessary complement to existing work on endogenously adopted monitoring.

†The meta-analyses without Brazil are not prespecified but follow from the prespecified theory of change in the preanalysis plan in *SI Appendix*, section 12.

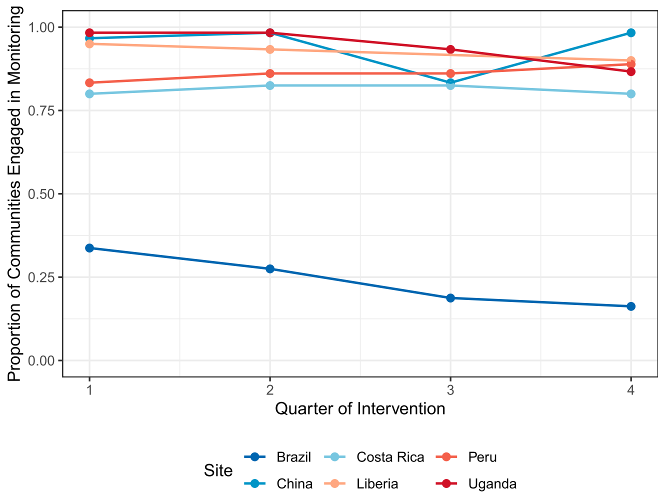

Fig. 1. Proportion of communities engaging in monitoring, by quarter (3mo) of the intervention. Note that monthly monitoring was incentivized in Brazil, Costa Rica, Peru, and Uganda. Records of monitoring in these sites are collapsed to quarters (3-mo periods) for comparability with the records from China and Liberia.

Effects of Monitoring. Fig. 2 visualizes the estimated ITT effects on our four principal outcome indices. Fig. 2, *Top Left* finds that assignment to community monitoring reduces resource use by 0.096 (SE 0.032) control group standard deviations, $p < 0.02$, in the prespecified one-tailed test. Substantively, this corresponds to reductions in deforestation in Liberia, Peru, and Uganda; reductions in pollutants in water in China and Costa Rica; and reductions in water use in Brazil and Costa Rica. While the estimates from each site are noisy, there are efficiency gains when pooling across the site-specific ITT estimates. For this reason, we are able to reject the null hypothesis in the meta-analysis estimate when we are unable to do so in the lower-powered constituent studies.

The overall estimated effect suggests that, on average, resource use decreases in communities assigned to monitoring. However, it is possible that receiving more information about the state or quantity of the CPR could lead communities to pursue opposite courses of action. In general, all communities in this study face a trade-off between short-term benefits from extraction and conservation. How communities respond to these competing pressures may account for heterogeneity—or even nonmonotonicity—in treatment effects. However, in Table 2, we do not detect evidence of heterogeneity across sites in a Q test ($p = 0.85$).

Instead, we probe heterogeneity in treatment effects within a site in two ways. First, we estimate quantile ITT effects, by site, in *SI Appendix*, Fig. S4. These estimates are quite noisy, but provide no evidence of nonmonotonicity, that is, distinguishable variation in the sign of treatment effects, within any site. Leveraging the harmonization across sites, we conduct a meta-analysis on these quantile ITTs. We recover no evidence that monitoring increases resource extraction/degradation at any decile. The meta-analysis shows that reductions in resource use are greatest in higher-decile levels of resource extraction.

Second, a prespecified analysis of heterogeneous treatment effects, by pretreatment severity of the resource problem, supports these findings. We observe that reductions in resource use are concentrated in the half of communities in which the CPR management problem was assessed to be most severe. Across sites, in the half of communities where resource extraction was predicted

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to be most severe, we estimate a conditional ITT effect of −0.111 (SE 0.049) including Brazil and −0.209 (SE 0.064) excluding Brazil. By contrast, in the other half of communities with lower severity, we estimate an ITT of −0.056 (SE 0.038) including Brazil and 0.048 (SE 0.033) excluding Brazil. The difference in conditional ITTs is not significant in the prespecified one-tailed test with Brazil ($p < 0.27$) but is highly significant excluding Brazil ($p < 0.005$). These differences in the efficacy of monitoring may be a byproduct of floor effects in the resource data (38). Alternatively, this finding is consistent with the observation that sufficient benefits (reductions in resource use) are necessary for communities to invest in maintaining monitoring institutions (39). This heterogeneity remains instructive for the design of future programs. Taken together, the results suggest that monitoring interventions may yield the highest improvements in sites where resource problems are particularly acute.

Turning to our other hypotheses, we find suggestive evidence that monitoring increases users' satisfaction with the CPR. Across all sites, this corresponds to a standardized effect of 0.051 (SE 0.035), implying $p < 0.08$ in a one-tailed test. In the five sites with high uptake of monitoring, we estimate a larger mean ITT effect of 0.085 (SE 0.026), $p < 0.005$ in a one-tailed test. As is evident from Table 2, there is no evidence of heterogeneity across these sites. Combined with the first result, the increase in user satisfaction indicates that, under monitoring, users sacrifice more short-term resource use but are nevertheless more satisfied. This result is encouraging, as it points to the possibility that these interventions may be sustainable over a longer time horizon.

SI Appendix, Fig. S6 decomposes the ITT effect across components of the satisfaction index. Across these sites, we find substantively and statistically significant increases in user satisfaction with resource quality and management but no detectable effects on satisfaction with other users' behavior. Interestingly, the median control group respondents in each site were "indifferent" (China) or "satisfied" (other sites) with CPR status and management (*SI Appendix*, Figs. S7 and S8). The increases we document thus represent increases on a relatively high baseline level of reported satisfaction.

We find compelling evidence that monitoring increases citizens' knowledge about their community's CPRs. We estimate the mean of the distribution of ITT effects is 0.081 (SE 0.018) control group standard deviations ($p < 0.005$). We detect no evidence of heterogeneity in the effects across sites. Further, examination of the index components suggests that these findings are not driven by any one component of the index or any site. *SI Appendix*, Fig. S10 finds small, positive mean ITT effects across index components measuring certainty, access to knowledge, salience of CPR issues, knowledge of (objective) resource status, and understanding of the causes of CPR degradation. These effects do not exhibit heterogeneity, despite higher levels of variation in these underlying (control group) measures across sites (*SI Appendix*, Figs. S11 and S12). Knowledge may be the most directly impacted outcome of our main outcomes, as both the community workshops and the monitoring output provided users with information. The workshops were successfully implemented in all sites where they were attempted, including Brazil, which may account for the consistency of predictive intervals on knowledge across both samples in Table 2.

In contrast to the first three hypotheses, our findings on stewardship are more ambiguous. In neither sample of sites do we find consistent evidence that monitoring increases expressed stewardship behaviors. We estimate that the mean ITT effect across sites is 0.003 (SE 0.068). Examining the site-specific estimates, we observe both positive and negative effects on stewardship. Indeed, we find evidence of heterogeneity in ITTs across sites in a Q test ($p < 0.005$). Recall that the index consists of measures of 1) norms against behaviors that degrade CPRs and 2) willingness to participate in (or contribute to) efforts to protect the CPR. Investigation of norms outcomes reveals that norms of conservation are extremely strong across contexts (*SI Appendix*, Fig. S14). Across variable scales, the proportion of users in control communities that expressed agreement with norms ranges from 82 to 99%. Substantively, this speaks to the strength of pro-conservation norms about resource use in six settings. Despite these norms, however, CPR management challenges persist. Empirically, widespread agreement with norms suggests ceiling effects may limit our ability to observe a strengthening of conservation norms, at least via the survey instruments we employed.

We observe heterogeneity in ITT effects with respect to the participation component of the stewardship index. In particular, the studies in Peru and Liberia find substantively and statistically significant ITT effects, albeit with opposite signs. We observe near-zero differences in the remainder of the sites. Among sites, the distributions of willingness to participate among respondents in (pure) control communities in Peru and Liberia are the most left-skewed. In other words, most respondents express willingness to participate to the maximum degree afforded by the survey questions in these sites. In Peru, assignment to monitoring appears to move forest patrol duties from the collective to a bureaucratic domain, as individual monitors become known as those responsible for monitoring activities. There are no similar reductions in participation in collective action in other domains, for example, community meeting participation (33). In contrast, in Liberia, given the relatively high levels of willingness to participate in control communities, community monitoring appears to mobilize some of the least predisposed citizens.

Intermediate Outcomes. In an effort to understand the process through which monitoring affects outcomes, we examine three prespecified intermediate outcomes. We hypothesized that assignment to monitoring would increase 1) user scrutiny on CPR management authorities, 2) citizen interest in CPR management, and 3) higher expectations of sanctioning for noncompliance with CPR rules.[‡] These outcomes are measured using the endline survey and indexed in the manner that all primary outcomes are indexed.

Fig. 3 provides evidence that monitoring increases scrutiny on CPR management authorities. Indeed, we find a standardized effect of 0.12 (SE 0.043) control group standard deviations ($p < 0.005$ in a prespecified one-tailed test). The exclusion of Brazil increases the point estimate to 0.134 (SE 0.045) standard deviations. We do not detect evidence of heterogeneity in effects across sites in either sample (*SI Appendix*, Table S11). Given difficulties in assessing scrutiny in a survey, we rely on a rough proxy: whether citizens could identify the authority with oversight over the resource. This knowledge is necessary for bottom-up pressure on managers, although it does not guarantee that citizens exert this pressure. The Liberia site elicited managers' perceptions of pressure in a second survey. In that site, the two measures are positively, if weakly, correlated ($\rho = 0.13$), providing some reassurance for the common survey-based measure. We thus find that

[‡]In the experiment in China, the measure of scrutiny was not measured at the citizen level like in the other sites and is thus omitted.

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monitoring facilitates conditions under which citizens have the ability to scrutinize those in positions of authority.

Turning to the outcome measuring citizen interest in the CPR, we find no evidence that, on average, monitoring increases citizen interest in CPR governance. However, as is evident from visual inspection, we find very high levels of heterogeneity. The index consists of two measures. First, we examine self-reported attendance at community meetings in which CPR-related issues were discussed. Second, we ask whether citizens had discussed CPR issues with anyone in the past month. The attendance measure exhibits vast heterogeneity between sites in the control group responses, ranging from 11% in Liberia to 83% in Peru. The massive ITT effect in Liberia is driven by a 66 percentage point growth in reported attendance, which may be due to the creation of new meetings to discuss CPR issues. In other sites, monitors shared their findings in existing community fora. We observe no substantively or statistically significant differences in the other sites (*SI Appendix*, Fig. S15). ITTs on the discussion component are less extreme, although the standardized effect of 0.17 in Liberia is again sizable. We interpret these findings as evidence that the introduction of monitoring may have a greater ability to shift interest where CPR issues were initially less commonly discussed in community meetings. Note, however, that, despite this heterogeneity, the similarly sized effects across sites that we find on our ultimate outcomes do not seem to covary with effects on citizen interest.

Finally, we examine effects on users' perceptions of the likelihood of being sanctioned for misuse of CPRs. Misuse, of course, corresponds to different forms of extraction or degradation in different resource systems. We find no evidence of a higher perception of the likelihood in any site, or across sites, estimating a mean ITT of −0.009 (SE 0.034). The implications for enforcement are open to interpretation. On one hand, active monitoring increases the likelihood that misuse is detected or known. If, consistent with our estimates, sanctioning rates are held constant conditional on known misuse, enforcement could be increased by higher rates of detection alone. On the other hand, if rates of sanctioning (unconditional on detection) remain equal with or without monitoring, the evidence suggests monitoring does not (detectably) change enforcement. The ambiguity of this result motivates further discussion of the relationship between citizens and management authorities.

Discussion

The institutions developed to manage CPRs vary substantially across our six sites and also more generally. The ability of these institutions to successfully manage CPRs requires users or management authorities to solve several information problems. Specifically, information allows users to form expectations about the benefits of resource extraction and the potential costs of enforcement. Managers or authorities rely on information on use to target enforcement effort. Finally, information may generate pressures to redesign the rules governing resource use and facilitate coordination around new rules (8).

The introduction of externally facilitated community monitoring aims to generate and disseminate new information about the status and use of a relevant CPR. The sites were selected, in part, on the basis of researchers' and NGOs' 1) observations that information problems impede CPR management and 2) hypotheses that the information problems were plausibly solvable. Yet, the ways in which information provision translates into changes in resource depletion depends on the preexisting design of CPR institutions. We consider how this heterogeneity in these nonmanipulated (often nonmanipulable) design features permits or circumscribes the mechanisms through which such information problems can be solved through the creation of community monitoring.

The core finding of our meta-analysis holds that assignment of communities to externally facilitated monitoring reduced resource use/degradation across sites. Despite the heterogeneity in resource systems and CPR governance institutions in our sample, we cannot detect heterogeneity in ITT effects. We find other outcomes consistent with the idea that monitoring generated information. Across sites, citizens were more informed about the state of the resource and expressed greater scrutiny of resource management authorities. In light of the heterogeneity of our sites, the relative similarity in these effect sizes is striking.

Comparison of the sites suggests three mechanisms through which the introduction of monitoring alleviated informational problems in our six sites. We argue that monitoring could 1)

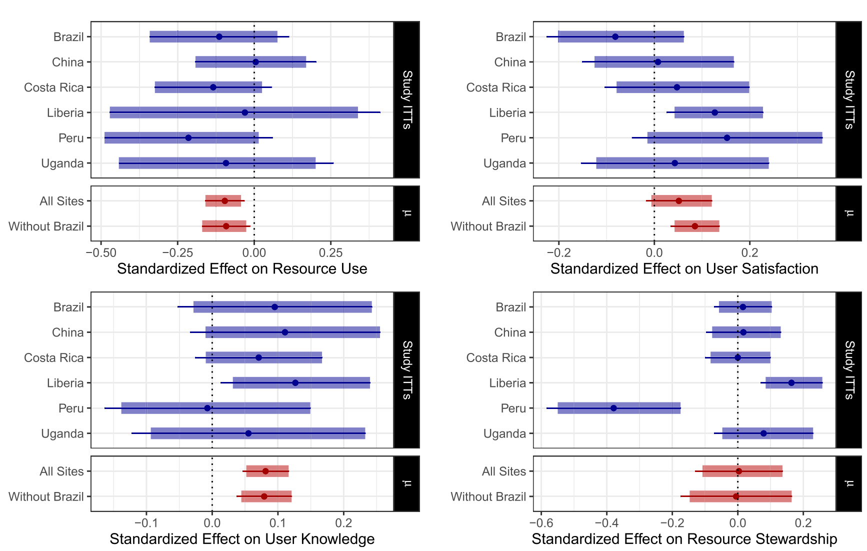

Fig. 2. Estimated site-level ITT effects (top six estimates) and mean ITT effects (bottom two estimates) (μ) across sites for each of our main hypotheses. The thin segments represent 95% CIs. The thick segments indicate the direction of the prespecified one-tailed hypotheses; where these segments do not bound zero, we reject null hypotheses at the $\alpha = 0.05$ level.

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Table 2. Quantifying heterogeneity across all sites ("All") or all sites except Brazil ("No Brazil")

Index	Sample	Q statistic	p value	Predictive interval
Resource use	All	1.99	0.85	[−0.186, −0.006]
	No Brazil	1.96	0.74	[−0.219, 0.036]
User satisfaction	All	6.71	0.24	[−0.107, 0.21]
	No Brazil	2.42	0.66	[0.002, 0.168]
User knowledge	All	2.16	0.83	[0.032, 0.131]
	No Brazil	2.12	0.71	[0.012, 0.147]
User stewardship	All	24.06	0.00	[−0.362, 0.369]
	No Brazil	23.85	0.00	[−0.524, 0.513]

Cochran's Q statistic and corresponding p values measure heterogeneity in individual study effects. The 95% predictive intervals for the ITT of a new study incorporates uncertainty in both the estimated mean and heterogeneity parameters. It is estimated using the Higgins–Thompson–Spiegelhalter estimator (37).

improve the efficiency of enforcement of existing laws/rules, 2) generate increased demand for enforcement of existing laws, or 3) facilitate the creation of new rules governing resource use. The operative mechanisms depend centrally on the organization of citizens, monitors, and management authorities. We emphasize the relationship between the community and management authority as an important determinant of the operative mechanism.

In the forest studies, communities maintain de jure authority over communal forests, even though they are generally not the only relevant management authority. In Peru, for example, environmental prosecutors are formally responsible for investigating and litigating deforestation cases in accordance with national law, even when such acts occur in titled, indigenous communities. However, per interviews with community leaders, the first-order deterrence of deforestation is led by communities. In Uganda, the National Forest Authority employs forest patrols in the forests that are studied. In Liberia, partially implemented land reforms mean that responsibility for monitoring will depend on the eventual legal status of communal forests. However, at the time of the study, the community oversees activities that take place in the forest. In contexts in which the community serves as a management authority, there is ostensibly greater scope for citizen pressure and new rule making. Indeed, the meta-analysis estimate of the ITT on scrutiny is driven by the estimates from two of these sites: Peru and Liberia. These two sites also document changes in the organization of responsibility for forest governance (Peru) and community decision-making (Liberia) (32, 33), consistent with the second and third mechanisms. In contrast, the Ugandan site emphasizes higher levels of enforcement.

In the context of ground and surface water, communities in our study are not management authorities. In Costa Rica, elected community-based water management organizations (CBWMOs) manage groundwater, and, in China, local governments are responsible for meeting water quality targets. In all cases, citizens have less scope to directly redefine the rules of resource use. In both settings, monitoring interventions were designed to inform management authorities—CBWMOs and local governments, respectively—in addition to communities. The emphasis on management authorities largely follows the first mechanism. To this end, the study from China is informative because it included dissemination of information to communities and local governments in the common and alternative treatment arms, respectively. The study finds a standardized effect of −0.21 (SE 0.10) on the government dissemination arm compared to a standardized effect of 0.005 (SE 0.10) on the community dissemination arm (36). When we pool the alternative (government dissemination) arm in the meta-analysis such that all studies were providing information to a management authority, our estimate of the mean ITT effect increases in magnitude from −0.09 (SE 0.04) to −0.14 (SE 0.03) standardized units (*SI Appendix*, Fig. S17).

In sum, while there is evidence in favor of all three mechanisms translating the information generated by monitoring into behavioral changes, the evidence suggests different mechanisms operate across sites. Nevertheless, the estimates in Fig. 2 and *SI Appendix*, Fig. S17 suggest that these mechanisms yield similarly sized effects. This finding speaks to the robustness of externally facilitated monitoring as a policy tool to incrementally reduce resource use or degradation across diverse contexts. Our multisite trial allows us to evaluate the robustness of monitoring in a new way. Further research is needed to evaluate other possible interventions in this manner.

Conclusion and Policy Implications

Our multisite randomized controlled trial on community monitoring introduces a new approach to studying the effects of CPR governance institutions in light of the complexity inherent in socio-ecological systems. Within Ostrom's framework (40), the interventions we document aim to manipulate a single aspect of the

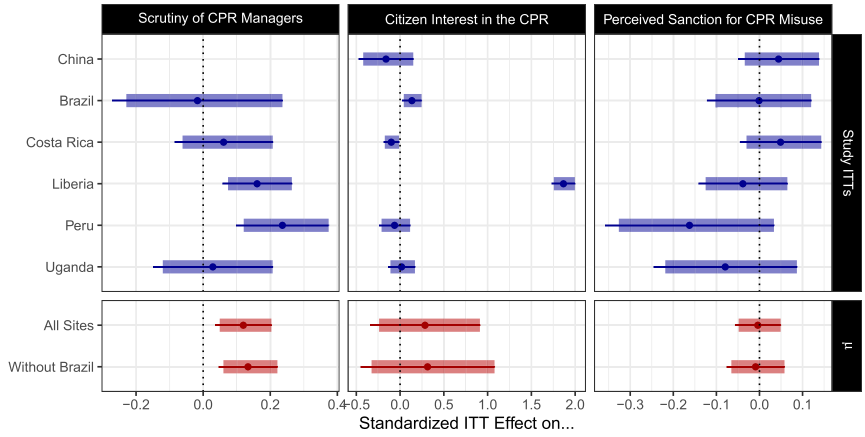

Fig. 3. Estimated mean ITT effects (μ) across sites for each of our hypotheses on intermediate outcomes. The thin segments represent 95% CIs. The thick segments indicate the direction of the prespecified one-tailed hypotheses; where these segments do not bound zero, we reject null hypotheses at the $\alpha = 0.05$ level.

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governance system by introducing community monitoring practices. We then measure how monitoring changes the knowledge, attitudes, and behaviors of users as well as effects on CPR status (resource units). Importantly, the use of parallel experiments in multiple sites—indeed, within different resource systems—leverages the heterogeneity (complexity) in contexts to draw more general inferences about the effects of resource governance.

We find that creation of community monitoring leads to modest, but robust, reductions in resource use. In all of the sites that we study, researchers and partner NGOs explicitly or implicitly hypothesized that information problems represented one barrier to CPR management when designing the monitoring interventions. Our selection of sites for monitoring and adoption of monitoring technologies reflected these convictions. The effects that we estimate thus pertain to contexts in which information problems of different forms are believed to hinder sustainable CPR management. The diversity of resource systems, regions, and existing CPR design features within these papers suggests that uncertainty is likely quite widespread in CPR management. By studying six heterogenous contexts, the limited heterogeneity that we detect in the effects of monitoring across sites favors broad applicability of our findings.

From a policy perspective, we therefore argue that community monitoring can be productively deployed in diverse settings and resource systems where information problems represent a barrier to CPR management. Yet, the magnitude of the reductions that we identify suggests that monitoring alone is likely insufficient to solve all problems of CPR management, at least within a 1-year time frame. As such, while we do not suggest that monitoring is a panacea for CPR management, it does represent one component of effective CPR management that can be deployed across contexts to reduce extraction.

Our research design manipulates a single institutional design feature, among many proposals in the CPR literature. This design choice provides some advantages and some opportunities for further research. If the goal is to find a comprehensive (if elusive) "fix" for CPR management problems, one could imagine a similar multisite design that bundles more levers into a single treatment (e.g., ref. 25). This represents a powerful approach to understanding the reductions in resource overuse that could be achieved through available policies. However, it provides fewer opportunities to isolate which levers work or to understand whether similar effects could be achieved with a less comprehensive treatment. Our focus on community monitoring represents a measured approach to generating generalizable evidence about the effects of specific policy interventions. By reducing the complexity of socioecological systems on one dimension—our treatment—we present one path forward to develop policy-actionable knowledge in a complex world.

Materials and Methods

Sampling and Assignment. The selection of sites occurred via a competitive process per the request for proposals reproduced in *SI Appendix*, section 13. Details on the sampling and assignment of communities in each site are reported in *SI Appendix*, Tables S2 and S3. We report balance statistics at the community and respondent levels in *SI Appendix*, Table S4 and Fig. S2.

Implementation. We report the timeline for implementation across sites in *SI Appendix*, section 5.

Estimation. We employ random effects meta-analysis to estimate the distribution from which ITT effects are drawn. We first estimate the ITTs on standardized *z*-score indices on each outcome family. The site-specific ITT estimators reported in this paper are of the form

$$Y_{ijb} = \beta_0 + \beta_1 Z_j^M + \beta_2 Z_j^A + \boldsymbol{\gamma}_b + \boldsymbol{\kappa}\mathbf{X}_{ij} + \epsilon_{ijb},$$

where Y_{ijb} is the outcome measure for individual (or resource measurement) i in community j in block b. Z_j^M indicates that a community was assigned to the community monitoring treatment. As such, β_1 is the estimator of the ITT of assignment to monitoring on outcome Y_{ijb}. Z_j^A is an indicator for assignment to an alternative treatment arm, where one was implemented. $\mathbf{X}_{ij}$ is a matrix of prespecified individual or community-level covariates, and $\boldsymbol{\gamma}_b$ is a vector of block fixed effects. For all outcomes below the community level, we cluster standard errors at the community level. We conduct a random-effects meta-analysis on the estimated β_1 from each site, using the DerSimonian and Laird (41) estimator of the between-site variance (τ). We test for heterogeneity in estimated ITTs across sites using Cochran's Q -test. For discussion of the statistical power of this test in the context of our study, see *SI Appendix*, Fig. S18.

Institutional Review Board. The metastudy was conducted with Institutional Review Board (IRB) approval from Columbia University (Protocol AAAS3537). Each of the constituent studies was conducted with IRB approval from each of the principal investigators' institutions. All survey data were collected with informed consent of all participants.

Data Availability. All anonymized data and replication code have been deposited in Open Science Framework (https://osf.io/5pvud) (42).

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