nature sustainability

ANALYSIS

https://doi.org/10.1038/s41893-021-00804-5

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Effectiveness of payment for ecosystem services after loss and uncertainty of compensation

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Payment for ecosystem services (PES) programmes seek to promote conservation via payments for desired resource-use behaviours. While PES has been found to produce some ecological and livelihood benefits, an understudied concern is what happens when payments stop. We assess how households' land-use behaviours changed in response to a temporary gap in payments and subsequent payment uncertainty in a programme in Ecuador, which paid communities to reduce their grazing on their communal lands. In 2015, after six years in operation, the programme lost funds and stopped payments. These resumed in 2017, but participants were only partially repaid retroactively, and future payments remained uncertain due to funding instability. Using a difference-in-difference modelling approach, we compare household grazing behaviour between communities in the programme and a set of control communities over ten years before PES payments, during PES payments and after the gap in payments in a period where participants were still owed at least one past payment and future payments were uncertain ($n = 871$ households). We find that grazing was significantly reduced by almost 20% over the ten-year period and that households continued to refrain from grazing even after experiencing payment loss. Our results demonstrate the importance of aligning programme objectives with community conservation and livelihood goals. Our discussion suggests how these conditions may interact with PES to prompt sustained behavioural change.

Major conservation organizations, governments and international donors increasingly use payment for ecosystem services (PES) and similar incentive-based policies to promote the sustainable development goals of conservation and poverty alleviation in impoverished communities[1,2]. The use of incentive-based policies such as PES, in which individuals or communities enter into conservation contracts and receive payment on the condition that they provide a specified ecosystem service or activity, is highly controversial[3–5]. Although PES has been found to provide small, but positive, ecological and livelihood benefits[6–8], we have scant evidence of the longer-term sustainability or permanence of land-use behaviours generated by PES[9–12].

Of particular concern is the ability of conservation-focused PES programmes (avoided deforestation, watershed protection) to attain new land-use behaviours that remain, even if payments stop[9]. Unlike short-term 'asset-building' PES programmes that pay farmers for a finite period to overcome start-up costs to adopt productive land-use changes and related ecosystem service provision, conservation-focused PES programmes are often 'use-restricting' and ask farmers to forgo productive uses in exchange for a payment. The assumption here is that participants will resume the unsustainable practice if payments cease, and thus, long-term payments are needed for continued conservation[9].

In a reality where market and donor funding fluctuate, and contracts ultimately end, many question how participants respond when payments become uncertain, or stop[13–15]. While some scholars fear that payments may even 'crowd out' previous intrinsic motivation to conserve and produce a 'no pay, no care' attitude[16,17], research suggests that the relationship between economic incentives, motivation and behaviour is multifaceted and may depend on a variety of factors, including, but not limited to, the targeted behaviour, perceived autonomy and self-efficacy, and payment type and size, in addition to the broader decision-making environment[12,15,18–21].

Within the array of incentive-based policy tools, the behaviours targeted by PES are especially complex. For one, payments are not one-time interactions but rather are linked to resource-use activities and contracts with extended time frames. PES contracts frequently ask poor, resource-dependent households to make changes that involve substantial economic costs and alter social and cultural relationships with the land[22,23]. Targeted behaviours, once changed, vary in the costs and ease in which they can be reversed.

Furthermore, distinct from many other incentive-based interventions[18], the desired ecosystem services benefits in PES commonly depend on collective compliance from all participants. Particularly in community-based programmes, communal land-use norms and governance arrangements often shape resource-use decisions, in addition to broader socioeconomic, policy and environmental transitions occurring in a region[15,24–28].

Finally, an incentive's impact on motivation may. in part, depend on participants' perceptions of the intervention. While programmes perceived to control behaviour may crowd out intrinsic motivation, potentially decreasing conservation activities and resulting in resumption of, or even greater, resource use post-PES, programmes perceived to be supportive of participant values, decision-making autonomy and social norms may 'crowd in' intrinsic motivation for conservation and potentially help sustain those behaviours absent payment[12,15,20,29–31].

So far, the empirical literature assessing the behavioural implications of payment and subsequent payment loss in PES programmes is largely limited to framed field experiments and hypothesized conditions of payment loss that are limited in their ability to capture decision processes in dynamic land-use contexts over

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extended periods[15,16,31,32]. Recent studies of land-use permanence in a short-term asset-building silvopastoral payment programme show the potential for PES to produce lasting land-use change[9,10,33]. The authors caution, however, that the findings apply specifically to asset-building programmes where payments support a switch to positive productive activities; they do not expect similar results in use-restricting PES programmes[9,33]. In this article, we contribute to the literature via a field-based assessment that traces the impact of the rise and unexpected decline of a use-restricting PES programme in Ecuador (Programa Socio Páramo) over a ten-year period.

Study context

In 2009, the Ecuadorian government created Socio Páramo, a PES programme to protect the *páramo*, a high-elevation ecosystem of grasslands and shrubs (at about 3,500 m) that provides valuable ecosystem services, including water regulation, biodiversity protection and carbon sequestration[34]. As in much of the northern Andes, the páramo is threatened by urbanization, subsistence land-use activities (grazing and farming) and climate change[35–37]. In Ecuador, highland communities have historically used their collectively owned páramo lands to graze sheep and cattle, and grazing is often considered a principal threat to the páramo and its water storage capacities[35,36,38,39].

This study focuses specifically on collective conservation contracts made by the Ecuadorian government with indigenous communities as part of the PES programme Socio Páramo in the central Ecuadorian highlands. Starting in 2009, highland communities voluntarily entered into 20-year conservation contracts in which they received collective payments twice yearly on the condition that they restricted resource use on their communal lands (reduced grazing and prohibited agriculture and hunting)[39]. Approximately six years into the programme, in 2015, the programme unexpectedly lost financial support and abruptly stopped payments. At that time, all field personnel were dismissed, and the programme was thought to be closing (T. Hayes, personal communication). For roughly 1.5 years, the PES programme was inactive, no payments were made for three payment cycles and there was little to no communication from the programme to the communities. Total payment loss to communities during this time ranged from US$17,068 to US$56,602. In April 2017, the programme slowly began to resume payments and restarted communications with communities (T. Hayes, personal communication). In 2018 (at the time of our study), the programme still owed at least one late payment to each of our study communities, and future payments remained uncertain due to programme instability.

This sudden interruption of PES programme payments allows us to test how participants respond to loss of compensation and programmatic uncertainty in a use-restricting PES programme and explore the factors that may influence the degree of path dependency in PES-induced land-use changes. If use-restricting behaviour is dependent solely on PES payments, we expect that after experiencing payment loss and continued payment uncertainty, participants will have stopped engaging in PES-induced land-use restrictions and will have resumed use. If participants continue with land-use restrictions, however, the question is why?

In this Analysis, we use survey data combined with observed land-use assessments, focus-group discussions and leader interviews to (1) estimate the impact of PES programme intervention and subsequent loss on household land-use behaviour and (2) explore why household conservation behaviours endured in the context of payment loss and uncertainty. Our quasi-experimental design capitalizes on the gradual rollout of the PES programme to compare household land-use behaviour, specifically grazing, in a set of PES-participating communities with households in communities on an informal wait list to enrol ($n = 871$). We focus on grazing, whether a household grazes their animals (cows and sheep) in the collective páramo (dichotomous variable), as the PES contracts expressly ask communities to reduce grazing in their collective páramos and grazing was the most common use of the collective páramo in treatment and control communities before the start of the PES programme.

Results

To estimate the impact of the PES programme intervention and subsequent loss of intervention on household land-use behaviour, we apply the difference-in-difference (DID) framework to compare household grazing in 2008, approximately one year before the PES programme intervention, with grazing in 2013, five years into programme intervention, and with grazing in 2018, after communities experienced a period of payment stoppage and in a continued context of payment loss and programme uncertainty. We further verify our DID results with observed land-use data from field-based páramo assessments in 2013 and 2018 and analysis of aerial and satellite images of land use at the communal level.

To understand the reasons behind the observed land-use behaviours, our analysis explores how stated motivations, household and community characteristics, the nature of the targeted behaviour and broader socioeconomic transitions occurring in the region may be interacting with the PES programme and the resultant land-use decisions.

PES impact on household land-use behaviour. Figure 1 displays our raw data for the percentage of households using the collective páramo for grazing in PES participant communities compared with households in control communities from 2008 to 2018 (see Supplementary Fig. 2 for data disaggregated by community). The comparison of control and treatment communities (Fig. 1) shows that just over half of the households in both groups grazed animals in their communities' collective páramo lands before the start of the PES programme. Grazing in the treatment (PES) communities, however, declined at a greater rate over the ten-year period than it did in the control. Grazing reductions were also more uniform within treatment communities compared with control communities. In 2018, less than 5% of PES households grazed animals in the collective páramo, with minimal dispersion across communities (in 2018, households grazing within a PES community ranged from 0% to 6%). By contrast, in the control communities, while the number of households grazing animals declined, the decline was less consistent across communities (in 2018, households grazing within a control community ranged from 9% to 81%).

To analyse the significance of the differential grazing behaviour observed in Fig. 1, we perform a series of DID regressions to estimate the impact of programme participation and the resultant payment loss and continued payment uncertainty at the household level, controlling for a set of household and communal characteristics also predicted to impact grazing (Methods and Supplementary Table 3).

DID results indicate sustained grazing reduction even with payment loss and uncertainty. Table 1 shows the DID results that compare the number of households grazing animals on the collective páramo in PES communities with the number grazing in the control communities over three points in time. As shown in columns (2), (4) and (6), which include community fixed effect, the overall treatment effect between 2008 and 2018 is −0.198, an almost 20% reduction in the number of households grazing animals in the PES communities. The greatest impact on grazing, a 12% reduction, occurred during the initial PES programme years between 2008 and 2013 (see Hayes et al.[39]). Finally, the treatment effect in household grazing between 2013 and 2018 is a 6% reduction. Although this decrease is lower than in the first five years of the programme, these results counter our hypothesis that loss of payment would result in an increase in the number of households grazing.

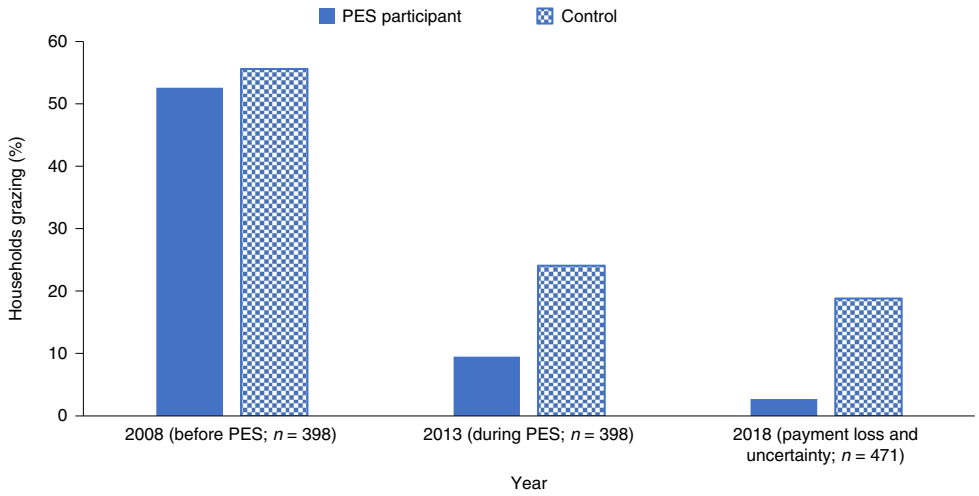

Fig. 1 | Household grazing in PES participant and control communities over time. Percentage of households grazing animals in the collective páramo in PES treatment communities compared with the control communities for 2008, 2013 and 2018.

Robustness tests of our DID estimates to an array of community and household specifications show qualitatively similar results, although the significance values of the estimates are at times lower in some of the alternative specifications (Supplementary Tables 5–7). As expected, households with more cattle are less likely to stop grazing. Conversely, households that considered the páramo to provide environmental benefits were less likely to graze in 2018. Irrespective of number of cows or attitudes towards the páramo, however, the PES treatment remains stable whether we include or exclude these variables from the set of regressors.

Observed data from the páramo transect assessments and analysis of aerial and satellite images further confirm the DID results. A páramo assessment gathered data from sample points along transect walks across the collective páramo in 2013 and 2018 (Methods). In 2013, the assessment found evidence of grazing in 3.9% of the sample points in PES treatment communities. In 2018, we found evidence of grazing in just 1.6% of the points. While evidence of grazing also declined in our control communities, grazing was still higher in control communities compared with the PES communities (Supplementary Fig. 3 and Supplementary Table 4). Analysis of land-cover images further suggests that the PES communities have continued to maintain the boundaries of their designated conservation lands, irrespective of payment loss. In 2018, there was no evidence that pasture and agricultural land uses had expanded into the designated PES conservation areas (Supplementary Fig. 4).

Explanations for continued compliance. Table 2 shows household perceptions towards payment loss aggregated at the community level for the six PES communities in our study. Communities often split the collective payment across a mix of communal projects and household investments in agricultural inputs or loans and, in some cases, direct cash to households. The perceived impacts of payment loss vary within and across communities and are largely aligned with payment size (Supplementary Note).

In household surveys, interviews with leaders and focus-group discussions, PES participants expressed frustration with the loss of past payments and continued programmatic uncertainty. Leaders and focus groups reported that in 2015, after informing their communities that the programme had stopped payments, leaders had to contend with community members calling for a return to the páramo.

The loss of income for some households, programmatic trust and, in some cases, motivation is concerning for the overall welfare of the households and their communities and their continued support for conservation measures. Contrary to our expectations, however, perceived economic loss, motivational loss and loss of trust did not result in a return to grazing during the study period. Communities A and B, for example, received some of the highest payments and reported relatively higher levels of economic impacts, motivational loss and loss of trust in the programme when payments stopped. Nonetheless, these communities had some of the largest overall decreases in grazing and continued compliance with the land-use restrictions (Supplementary Fig. 2).

Why do households continue to comply? While our research design does not enable us to test why households continue to comply, survey results, leader interviews and focus groups point to how programmatic alignment with household values, community conservation goals and the costs involved in changing grazing behaviour, and land-use transitions occurring in the region may, in part, explain why households sustained the behavioural changes initially attained in the PES programme.

The PES programme was perceived to support communal conservation goals. In interviews, community leaders frequently reported that they viewed participation in the payment programme as a means to promote nascent, and often controversial, conservation initiatives while providing tangible economic benefits to their constituents. In 2013, when asked whether and why they supported joining the PES programme, those that were in favour cited the conservation benefits in addition to the economic benefits for themselves or for their broader community[40]. In 2018, when discussing how households responded to payment loss, 17% of participants reported loss of motivation to conserve, yet many commented that although they were frustrated, it was their responsibility to care for their lands and they would continue to do so irrespective of payment. Residents also reported that when payments stopped, community leaders called on them to continue with their conservation commitments in deference to their own cultural and ecological values and out of respect for the conservation contracts they had collectively signed.

Land-use rules were embedded in communal decision-making processes. Leaders and residents emphasized that their community, not the PES programme, was at the forefront in deciding whether to participate and in creating the land-use rules. In community forums, leaders and residents collectively discussed and decided whether to join the PES programme[39,40]. Furthermore, while the PES

Table 1 | DID results comparing number of households grazing animals in páramo in PES and control communities, without and with community fixed effects

	Comparing 2008–2018		Comparing 2008–2013		Comparing 2013–2018	
	(1)	(2)	(3)	(4)	(5)	(6)
Time × PES (= treatment)	−0.200**	−0.198***	−0.116	−0.116***	−0.060	−0.065***
	(0.098)	(0.074)	(0.089)	(0.022)	(0.078)	(0.008)
PES	−0.027	0.073***	−0.033	0.057	−0.134*	−0.033
	(0.074)	(0.024)	(0.192)	(0.141)	(0.070)	(0.044)
$Time_t$	−0.325***	−0.339***	−0.314***	−0.315***	−0.027	−0.032*
	(0.037)	(0.020)	(0.047)	(0.024)	(0.057)	(0.019)
Population density	−0.387	-	−0.428	-	−0.213	-
	(0.334)	-	(3.523)	-	(0.304)	-
Number of cows	0.016*	0.011***	0.016**	0.015***	0.019**	0.015***
	(0.008)	(0.001)	(0.007)	(0.003)	(0.008)	(0.003)
Area pasture	−0.0121	−0.0076***	0.0002	−0.0056	−0.0107	−0.0079
	(0.0112)	(0.0013)	(0.0135)	(0.0055)	(0.0106)	(0.0062)
Wealth index	0.014	0.018	0.006	0.009	−0.021	−0.014***
	(0.013)	(0.013)	(0.016)	(0.007)	(0.015)	(0.003)
Distance to páramo	0.052	0.058**	0.119*	0.125***	−0.012	−0.008
	(0.048)	(0.023)	(0.064)	(0.025)	(0.045)	(0.033)
Age	0.0019	0.0019**	0.0012	0.0018***	−0.0010	−0.0014**
	(0.0013)	(0.0009)	(0.0014)	(0.0006)	(0.0010)	(0.0006)
Perception páramo	−0.100**	−0.079***	−0.112*	−0.102***	−0.086**	−0.069***
	(0.044)	(0.024)	(0.059)	(0.022)	(0.040)	(0.004)
Self-organization	0.016	0.047	0.001	0.039	−0.012	0.026*
	(0.042)	(0.050)	(1.684)	(0.299)	(0.033)	(0.014)
Perceived catch	0.064	0.057**	−0.003	−0.029**	−0.031	−0.007
	(0.049)	(0.028)	(0.056)	(0.014)	(0.039)	(0.030)
Constant	0.545***	0.393***	0.582	0.447	0.347***	0.215***
	(0.115)	(0.103)	(1.366)	(0.291)	(0.094)	(0.019)
Community fixed effects	No	Yes	No	Yes	No	Yes
Observations	845	845	780	780	845	845
R^2	0.297	0.326	0.224	0.236	0.135	0.193

The dependent variable is the dichotomous variable 'grazing'. Bootstrapped standard errors are clustered at the community level with 400 repetitions for each bootstrap run. See Supplementary Tables 5–7 for robustness checks. *$P < 0.10$; **$P < 0.05$; ***$P < 0.01$.

programme required land-use restrictions, community members emphasized that the creation and approbation of any new land-use rules remained under the purview of community decision-making processes[41]. In leader and household interviews, we found no evidence that communities had relaxed their grazing rules since loss of payments. In 2018, 74% of households in participant communities continued to support the land-use rules in the páramo (compared with 79% in 2013).

PES contracts and payments prompted livelihood changes that were not easily undone and aligned with broader land-use changes in the region. The grazing restrictions promoted by the PES programme resulted in livelihood changes that, for many, would be costly to reverse. In 2018, 41% of households stated that due to participating in the PES programme, and subsequent land-use restrictions, they had sold their animals that had been grazing in the collective páramo; 42% had moved their animals to lower elevations ($n = 279$). For those households that had sold their animals, it would be costly to purchase new animals to resume grazing in the páramo, making the grazing restrictions particularly sticky.

Furthermore, similar to land-use transitions occurring in other highland regions[42–44], participant communities and their respective households often used at least part of the payments to shift to alternative livelihoods, spending funds on dairy farming (located on lower lands) and community tourism initiatives. Five of the six communities stated that they used part of the PES payment to invest in improved pasture lands and dairy cows kept at lower elevations, with two communities using the money to invest in infrastructure to support dairy farming. Four of the PES communities used payments to support nascent ecotourism initiatives.

In focus-group discussions in control and PES communities, elders discussed how their communities are changing as an unpredictable climate and poor soils make agriculture less profitable. Elders and community leaders noted the need to have livelihood options in their communities to keep young people at home and sustain their culture. As one focus-group participant noted, "we look for investments that are sustainable, thinking in the end of the [PES] project". However, while many see dairy farming and tourism as potential alternatives, more research is needed to assess the degree to which PES payments have served to support sustainable livelihood transitions.

Table 2 | PES payments and percentage of households in each PES community that perceived economic impacts, motivational loss and loss of trust in PES programme from PES payment loss

	PES community					
Household perceived impacts from payment loss	**A**	**B**	**C**	**D**	**E**	**F**
PES payment per household (US$ yr^{-1})	786	634	130	38	476	34
Loss of funds for household basic necessities (%)	62	85	4	6	38	0
Loss of funds for community projects (%)	4	85	28	42	25	10
Loss of motivation to conserve (%)	35	62	15	15	25	3
Loss of trust in PES programme (%)	65	69	37	37	56	4
Community size (number of households)	48	17	179	120	30	450
Households interviewed (2018)	26	13	68	67	16	69

Payment per household is for reference only; payment was made collectively to the community (not the household). See Supplementary Table 1 for information on total payment per community.

Discussion

In the field of sustainable development, and international development more broadly, there is long-standing concern over the ability of interventions to attain lasting benefits as funding fluctuates and projects cycle out[13,45,46]. Our findings from this case study in Ecuador indicate that use-restricting PES can produce new land-use behaviours that persist in a context of payment loss and uncertainty. Our analysis found that, on average, PES communities saw an additional 20% decrease in the number of households grazing compared with the control; we found no evidence that participants returned to previous levels of grazing when faced with payment loss.

Our results suggest several conditions that may explain why participants continue to conserve and point to specific ways in which PES and similar use-restricting incentive-based programmes may help crowd in communal conservation norms and increase the likelihood of sustained behavioural change. First, our study suggests how, particularly in the communal setting, programme support for community values and decision-making autonomy may have helped crowd in conservation norms and behaviours that, in turn, offset individual frustration with loss of compensation. While we cannot trace household motivations behind their respective land-use behaviours, our findings from our household survey, leader interviews and focus groups suggest that the PES programme's alignment with and respect for communal decision-making processes reinforced the legitimacy of land-use restrictions and supported community conservation norms[12,15,22,25,28].

Second, our findings suggest that the permanence of the behavioural change may depend, in part, on the ease in which participants can or desire to return to previous land-use practices. Our study focused on the impact of PES on grazing behaviour. Grazing, however, may be a particularly sticky land-use change compared with hunting or agriculture, which might be less costly to resume (Supplementary Discussion). In our study, when payments stopped, it was not simply a matter of returning cows to the páramo as many residents no longer owned those cows and communities were investing in other activities.

Furthermore, our study reaffirms the importance of the broader socioeconomic and environmental context[10,47]. Across the study region, we found households were moving away from grazing animals in the páramo. Our findings suggest that PES further nudged residents to emergent land-use alternatives in the region (namely, dairy farming and tourism) as communities used the programme and payments to further strengthen conservation plans for their páramos while also investing in livelihood alternatives.

Our assessment is limited to our case study's programmatic and regional conditions; we do not have comparison programmes or regions. We also recognize that the time period is relatively short to assess lasting behavioural change. It is possible that loss of motivation, lack of trust and frustration with intermittent payments may produce more grazing over time and potentially negatively impact other conservation behaviours. Moreover, we note the need to understand the socioeconomic impacts of payment loss as well as the potential implications of loss of trust for future conservation initiatives[48]. Finally, given the nature of the uncertainty in the PES programme, we cannot rule out that participants refrained from grazing, in part, due to hopes that the programme would resume payments in full so long as they continued with contract conditions. This does not invalidate the results but rather speaks to the volatility that many communities experience in working with a range of conservation and development programmes[13].

More field-based assessments are needed to test the mentioned conditions and the short- and long-term impacts of conservation payment programmes not only on resource-use behaviours but for a range of sociocultural, economic, equity and environmental outcomes. We encourage future studies to consider the socioeconomic and equity implications of participation and payment loss and for longitudinal studies to examine the link between stated motivation and behaviour. Finally, our study further reinforces calls for more comparative studies to better understand how programmatic design and contextual conditions shape PES[8,10]. By identifying how specific PES programme attributes interact with an array of participants in their respective settings, we will be better able to tailor our conservation policy tools to support sustainable ecosystem management practices that endure.

Methods

This study examines the influence of the Socio Páramo programme on land use in highland communities. Socio Páramo is a sector of the Ecuadorian government's umbrella PES programme, Programa Socio Bosque, which provides financial compensation to individuals and communities to conserve valuable ecosystems. We chose to study the effectiveness of the Socio Páramo programme in Quichua indigenous communities located in the central highlands in the provinces of Tungurahua and Chimborazo because the majority of the programme's work with highland communities (68%) has been in this region (Supplementary Fig. 1). The study, and specifically the methods described in this section, builds on our earlier published work that tested for the impact of the initial payment period (2009–2013) on land-use behaviour[39].

Quasi-experimental design. The PES programme began working in the highlands in 2009 and continued to recruit communities through 2013. It targeted páramo ecosystems that were threatened, provided valuable ecosystem services and were located in the poorest regions[49]. Participation was voluntary, and the number of communities wanting to enrol often exceeded programme capacity. In the central highlands, programme extension officers had an informal wait list of communities that wanted to enrol but had not yet been able to do so (Supplementary Methods).

Our research design takes advantage of the wait list and phased programme rollout to address potential self-selection bias in the decision to enrol and create a set of treatment and control communities[12,50,51]. As described by Hayes et al.[39], our treatment group consists of households living in six communities that, as of 2013, had been participating for the past two to five years in the PES programme. Our control group is households living in a set of five communities that had indicated interest in joining the programme and, in 2013, were on an informal wait list to enrol. Although these communities had planned to enrol, they were not able to before the programme lost funds and, thus, never enroled.

To control for possible observable sources of bias, communities were selected on the basis of the following criteria: identify as Quichua indigenous communities that collectively own páramo (hold formal or informal title), households depend

principally on farm-level activities for their livelihoods, communities had been using the páramo before 2008 when the PES programme entered the region, páramos are located at relatively similar altitudes and with similar topography and most residents can access the páramo in less than three hours by walking from their houses. All páramos are located in the same central region of the Andes and at roughly the same elevation (3,700 to 4,200 metres). Case study communities were also selected on the basis of community size and communal páramo size. Both participant and non-participant communities spanned a range of community sizes and organizational capacities typical of the highland communities in the region (Supplementary Methods and Supplementary Tables 1 and 2).

Data gathering. We use an adapted version of the Institutional Analysis and Development framework to structure our data gathering and consider how biophysical, household and communal factors may influence resource use in a collective setting such as those found in the Ecuadorian Andes[27,52]. While the PES programme targets grazing, agriculture and hunting, our analysis focuses specifically on household grazing as grazing was a principal land use identified before 2008 in our study region and a programmatic priority for protecting the ecosystem services of the páramo (T. Hayes, personal communication). Please see Supplementary Methods, Supplementary Discussion and Supplementary Table 3 for the questionnaire description of the variables in our analysis and discussion of the dependent variable.

Data on land-use behaviour, household and community attributes, and governance arrangements were gathered via a household questionnaire and focus-group discussion in each community. The 2018 data used the same methods as described in our earlier studies[39,41]. Key informant interviews with officials in governmental and non-governmental organizations were used to corroborate information on programme delivery and land-use changes in the communities. In addition, páramo assessments and an analysis of land-cover imagery further corroborate stated land-use behaviours. Consent was obtained from all participants. The study protocol was approved by the Seattle University Institutional Review Board.

The questionnaire gathered data on household land-use behaviour in participant and non-participant communities for three years: 2008, 2013 and 2018. The questionnaire administered in 2013 ($n=399$) asked the head of household about present land-use practices and included a series of recall questions about land use in 2008. A similar questionnaire was administered to households in the same communities in 2018 ($n=472$). Households were selected using a stratified random-sampling process based on geographic proximity to communal lands. The male or female head of household was asked to respond to the questionnaire about household activities (50% of the respondents were female). In the smaller communities ($n<50$), we administered the questionnaire to a minimum of 50% of the households; in the larger communities, we interviewed a minimum of 10% of the households (Supplementary Methods).

The questionnaire was orally administered by trained local interviewers with expertise in highland communities. Interviewers were instructed to clearly state that they had no alliances with governmental or non-governmental organizations working in the region and that all interviewee responses would be confidential. Interviews were conducted in Spanish, although a local guide was available if terms or questions needed to be interpreted to Quechua.

Páramo use was assessed by a set of questions that asked households whether the household grazed cattle or sheep in the páramo in 2013 and again in 2018. Grazing behaviour for 2008 was gathered via a set of recall questions in the 2013 questionnaire. Respondents were asked about previous grazing behaviours and changes to those grazing behaviours. Grazing behaviour in the páramo is not necessarily consistent throughout the year. The questionnaire specifically asked the respondent about their grazing behaviour over the entire year and explicitly asked where the respondent grazed livestock in the dry season and during times of drought. It also included closed- and open-ended questions about the activities of the household, including land-use practices and livelihoods, use of the páramo and participation in governance activities[39].

To increase the reliability of the respondents' answers, questions positioned páramo use as a common livelihood strategy and gave respondents both closed- and open-ended opportunities to discuss whether and how they use the páramo and how their use had changed[53,54]. To address memory failure in the recall question for 2008, interviewers were instructed to establish a time frame of reference for each respondent[53,55]. In addition, for recall questions, rather than ask about the number of animals a household grazed in the collective páramo in the past, questions asked about grazing behaviour in terms of gradients of use (more today or less today) as gradients of use would be easier to recall and more accurate than specific number of animals. Later, these gradients of use were triangulated with other land-use responses (from closed- and open-ended questions) to create the binary variables of use[39]. We recognize that the binary condition of completely stopping grazing does not fully capture potential reductions in grazing; however, given variations in grazing throughout the year, we consider it to be a more accurate measure of grazing behaviour than asking households to provide the specific number of cows grazed in the páramo throughout the year.

Programme participants were also asked about their perceived need for land-use restrictions, their autonomy within the programme to decide land uses, the overall fairness of the payments, their distribution and the programme, the impact of payment loss on their well-being and the trustworthiness of the programme personnel. Questions regarding programme participation, however, were at the end of the interview so as not to contaminate participant response.

Focus groups were conducted with elders and previous leaders in each of the 11 communities in 2013 and 2018. In 2018, we divided focus-group discussions by gender to receive more input from women in the respective communities. During discussions, interviewers created a time line to establish key events and identify an event that occurred before the PES programme and at the time of the first loss of payments (2008 and 2015, respectively). These events were then used to help survey respondents recall earlier practices. Members also drew a map of the community and páramo lands, discussed the governance issues on the communities' lands, compared rules that existed according to the 2013 interviews with those that existed in 2018 and discussed livelihood and land-use changes occurring in their communities and the region.

Key informant interviews were conducted with the community leaders in each case study in 2013 and again in 2018. To select leaders, in each community, we asked to speak to the current president of the community and at least one other member of the community governing body (an elected body of at least five members) that had knowledge of general community characteristics and the decision to participate in the PES programme. In addition, in 2013 we interviewed the national PES programme director, all the regional programme coordinators working in the highlands and programme directors of all the local nonprofits working on land conservation in indigenous communities in the study region. The interviews asked about recruitment, community participation, use of PES payments, monitoring and enforcement. Follow-up interviews conducted in 2018 asked about the continuity of the PES programme and community land-use behaviours.

We triangulate stated behaviour with observed land-use data from páramo assessments and analysis of aerial and satellite images. The páramo assessment was a rapid field assessment conducted in each community in 2013 and 2018 to identify current land uses in the páramo and the state of degradation. An environmental scientist with expertise in páramo systems walked a set of transect lines that were purposefully selected to cover the various land uses and land covers in each páramo and prioritize more accessible areas[56]. The transect lines started at the top of a community's páramo and moved towards lower elevations, and evidence of cattle, sheep and fires was documented along the lines. Georeferenced samples were taken every 500 m, or less if the land cover or land use changed within the 500 m line[39].

The páramo assessment is further supplemented by a land-use/land-cover visual analysis of satellite images, including Pleiades 1A (February 2019) and SPOT 6 and 7 (December 2017). This analysis allowed us to identify páramo and agriculture/grazing zones, locate the agricultural frontier and identify agriculture/grazing activities in the areas under PES conservation contracts (Supplementary Fig. 4).

Estimating behavioural change. We use the (DID) framework to estimate the treatment effect of the PES programme on grazing[57]. We take advantage of the gradual rollout of the programme and the subsequent loss of the payments and distinguish between 'treated' households and 'control' households. We are interested in three sets of regressions.

The first estimates the primary DID treatment effect of the PES programme using the data from 2008 to 2013. These regressions are analogue to Hayes et al.[39], measuring the effect of the programme on grazing. Treated units are those that enroled in the programme ($\mathrm{PES}_i=1$), and the control units ($\mathrm{PES}_i=0$) did not enrol yet at the time of the survey in 2013. In addition, we separate between the treatment period ($\mathrm{Time}=1$) and the control period ($\mathrm{Time}=0$). The treated period is at the point of time of our survey in 2013 and the control time is 2008, hence five years before the survey when no one was enroled in PES. Our basic DID specification is given by equation (1), in which households are subscripted with i in community c and time is subscripted with t. Our parameters ($\alpha, \beta, \gamma, \delta, \eta, \varphi, \varepsilon$) are numerically estimated by ordinary least squares.

$$\mathrm{Grazing}_{cit} = \alpha + \beta\mathrm{PES}_i + \gamma\mathrm{Time}_t + \delta^c\,[\mathrm{Time}\times\mathrm{PES}]_{cit} + \eta C_c + \varphi H_i + \varepsilon_{cit}. \quad (1)$$

Our dependent variable is the dichotomous indicator $\mathrm{Grazing}_{cit}$, assigning whether the household i grazed their cows and sheep in the collective páramo c ($\mathrm{grazing}_{cit}=1$) at time $t=(2008, 2013)$. If household i did not have animals grazing inside of the páramo at time t, the dummy is set equal to zero. The treatment effect variable $[\mathrm{Time}\times\mathrm{PES}]_{it}$ is equal to the multiplication of PES_i and Time_t. Hence, our parameter of interest is δ, which shows the causal effect of the percentage change in grazing due to the PES programme. In additional specifications, we further estimate these models by sequentially including the set of regressors measured in 2013 from the simplest model to the most controlling. In robustness checks, we further control for a set of variables C that vary at the community level c and a set of variables H that vary at the household level i (Supplementary Table 5). To account for community-level peer effects as well as autocorrelation, we cluster our error term ε_{cit} at the community level, and due to the small number of clusters and the unbalanced nature of the cluster sizes, we bootstrap the standard errors with 400 repetitions in each regression.[58]

In our second set of regressions, we estimate the DID treatment effect over the entire time horizon of ten years, from 2008 to 2018, which includes the start of the PES programme in 2009 and then the unexpected halt of the programme in 2015. These regressions are analogue to the regression in equation (1), with 2018 data replacing the 2013 data and control variables measured in 2013 and 2018.

Our third set of regressions focuses on the period of 2013 to 2018. This set of regressions has the advantage that both the 2013 and 2018 data are directly measured (and do not rely on the recall data of 2008). Here, we use 2018 as the treatment year, and 2013 is the control year. Hence, the results are to be interpreted as the effect of the unexpected loss of payments on the land-use behaviour.

Study limitations. We recognize several potential limitations in our study. First, in our research design and DID analysis, we have tried to account for differences between participant and non-participant communities that could bias the results. Our quasi-experimental design, however, is unable to measure characteristics of the participant and control communities over time in the period before the PES intervention, and thus the assumption that we would find parallel trends in the absence of intervention remains speculative. Likewise, the DID approach is unable to control for unobservable time-variant variables that may influence the outcome.[59]

Furthermore, as noted by Hayes et al.[39], unmeasured unobservable variables (these would be in ε_{cit}) could still be correlated with the treatment indicator, and this would bias our DID estimates. This assumption is hard to circumvent as we do not have any viable instrumental variables for programme enrolment. Following the intuition laid out by Altonji et al.[60], we examined the potential for omitted variable bias by testing the robustness of our DID estimates to an array of community and household specifications and consistently found similar treatment effects. In particular, we turn on and off the explanatory variables population density, number of cows, area pasture, wealth index, distance to páramo, age, perception páramo, self-organization and perceive catch and find that the inclusion or exclusion of all or a subset of these variables leads to qualitatively similar regression results of the overall treatment effect. While the stability of our estimates across these different DID specifications is reassuring, we acknowledge that our research design cannot conclusively rule out the possibility that unobserved factors are influencing our estimates. It would, however, be difficult to come up with a story of an unobserved driver that is correlated with the treatment variable but uncorrelated with the set of community and household controls.

Second, grazing behaviour is measured as a binary variable (grazing or not) based on stated behaviour at two points in time, 2013 and 2018. We have addressed the limitations of the recall data for 2008 by using memory recall aids[53,55]. We have also reduced the limitations of memory recall and the difficulty of farmers accounting for variations in grazing throughout the year by looking at presence or absence of grazing. We recognize that our binary measure of grazing can detect only whether a household stopped grazing, not whether the household reduced the number of animals. Likewise, there is the possibility that a household increased the number of animals they were grazing in the páramo. We have tried to account for possible changes in grazing by triangulating our stated behaviour with field observations from 2013 and 2018. While we recognize that grazing behaviour varies over time, thereby limiting point-in-time observations, if a household had greatly increased the number of cows they grazed in the páramo during this time period, we would expect to find significantly more animals and evidence of grazing in the páramo transects in 2018. We did not find this (see Supplementary Fig. 3 and Supplementary Table 4).

Third, we recognize that there may be other explanations for why households continue to refrain from grazing. Our interview and survey results suggest how programmatic alignment with community conservation goals, broader land-use trends in the region and the costs involved in resuming grazing at higher elevations may have made it less likely that households would resume grazing. It may also be possible that the period was too short and that households were concerned with complying with contract conditions and hoping for the PES programme to resume payments, even during the time that it appeared that the programme had stopped. Furthermore, grazing may be a particularly sticky land-use behaviour as it can be costly to replace cows once they have been removed. Three years of payment loss and continued programmatic and payment uncertainty may not capture longer-term behavioural changes, particularly for those that demand greater start-up costs to resume. We originally planned to study additional land uses, namely, agriculture. We found, however, that very few households in our treatment and control communities were using the páramo lands for agriculture in 2013 and before joining the PES programme (Supplementary Discussion and Supplementary Table 8). We encourage future studies to compare how PES payment and loss impacts land-use behaviours that range in the ease in which they can be stopped and then once again resumed.

Fourth, our analysis of community governance institutions is limited by the relatively small number of communities that met the quasi-experimental design selection criteria for the study. Thus, the findings provided an initial understanding of the potential ways in which communal institutions may interact with external payment programmes and support longer-term behavioural change and resource management institutions. Further research is needed to draw conclusions about the relationship between community governance institutions, incentive-based interventions and sustained behavioural change.

Finally, our study is not able to speak to the broader sustainability of the PES programme. To assess the overall sustainability of a PES programme would require a much wider set of indicators that includes, but is not limited to, an assessment of the economic impacts on participants, the ecological impacts of the resource-use restrictions, equity implications and the financial costs of the programme compared with the benefits.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Survey data are available at https://scholarworks.seattleu.edu/env-std-data/1/. Field páramo assessment data are available from the corresponding author on reasonable request as these field data are sensitive for the respective communities.

Code availability

Stata code for regression analysis is available at https://scholarworks.seattleu.edu/env-std-data/1/.

Received: 26 May 2021; Accepted: 6 October 2021;
Published online: 22 November 2021

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Acknowledgements

This study was supported by grants from the National Science Foundation: grants SES #1156271 (T.H., F.M. and H.W.) and SES #1734051 (T.H. and F.M.). We thank the Ecuadorian Environmental Ministry (MAE), which was crucial in facilitating fieldwork. We give special recognition to M. Bustamante, M. Peralvo, C. Felix, M. Garcia and L. Trujillo for their assistance in data gathering and analysis. Finally, we thank the residents of the study communities who welcomed us into their homes and facilitated our visits to their páramo.

Author contributions

T.H. and F.M. conceived the project and developed the analysis approach. T.H., H.W and F.M. analysed the survey and field assessment data. M.F.L.-S. and J.S. gathered and analysed the aerial and satellite images. J.S. conducted the páramo field assessment. T.H., F.M. and H.W. wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41893-021-00804-5.

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Peer review information *Nature Sustainability* thanks Krister Andersson, Julian Rode and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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Software and code

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Data collection	No software was used
Data analysis	SPSS v26; STATA v16; ArcGIS Pro v2.X.

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Behavioural & social sciences study design

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Study description	This is a mixed method study using a quasi-experimental design
Research sample	This study examines the influence of the PES program, Programa Socio Bosque (PSB) in Quichua indigenous communities located in the central highlands in the provinces of Tungurahua and Chimborazo (see figure 1). We chose to study the central highlands because the majority of the program's work with highland communities (68%) has been in this region. Our research design exploits the waitlist and phased program rollout to address potential self-selection bias in the decision to enroll and create a set of treatment and control communities. Our treatment group consists of households living in six communities that, as of 2013, had been participating for the past two-five years in the PES program. Our control group is households living in a set of five communities that had indicated interest in joining the program and, in 2013, were on an informal waitlist to enroll. Although these communities had planned to enroll, they were not able to before the program lost funds and thus, never enrolled. To control for possible observable sources of bias, communities were selected based on the following criteria: identify as Quichua indigenous communities that collectively own páramo (hold formal or informal title); households depend principally on farm-level activities for their livelihoods; communities had been using the páramo prior to 2008 when the PES program entered the region; páramo is located at relatively similar altitudes and with similar topography; and, most residents can access the páramo by walking from their houses in less than 3 hours. All páramo is located in the same central region of the Andes and at roughly the same elevation (3,700 to 4,200 meters). Case study communities were also matched based on community size and communal páramo size. Both participant and non-participant communities spanned a range of community sizes which is typical of the highland communities in the region. For the specific community and household level characteristics we refer the reader to our tables A and B in our supplementary section 6 Descriptive statistics.
Sampling strategy	The questionnaire gather data on household land-use behavior in participant and non-participant communities for three time periods: 2008; 2013; and 2018. The questionnaire administered in 2013 (n = 399) asked the head of household about present land-use practices and included a series of recall questions about land-use in 2008. A similar questionnaire was administered to households in the same communities in 2018 (n=472). Households were selected using a stratified random sampling process based on geographic proximity to communal lands. The male or female head of household was asked to respond to the questionnaire about household activities (50% of the respondents were female). In the smaller communities (n<50), we administered the questionnaire to a minimum of 50 percent of the households, in the larger communities, we interviewed a minimum of 10 percent of the households. There is a 4% margin of error for the total population of the 11 communities at a 95% confidence level.
Data collection	Our primary data collection tool was a questionnaire. The questionnaire was orally administered by trained local interviewers with expertise in highland communities. Interviewers were instructed to clearly state that they had no alliances with governmental or non-governmental organizations working in the region and that all interviewee responses would be confidential. All respondents received information about the study prior to the interview and gave their informed consent prior to conducting the interview. Interviews were conducted in Spanish, although a local guide was available if terms or questions needed to be interpreted to Quechua. All responses were written into the questionnaire form that was later recorded in a Excel spreadsheet. The researchers conducted pilot surveys to finalize the questionnaire and trained the data collectors, but they were not present during the household interviews. All data was checked by the researchers as it was inputed into Excel. In addition, focus groups were conducted with elders and previous leaders in each of the 11 communities in 2013 and 2018. In 2018, we divided focus group discussions by gender to receive more input from women in the respective communities. During discussions, interviewers created a timeline to establish key events and identify an event that occurred prior to the PES program and at the time of the first loss of payments (2008, and 2015 respectively). These events were then used to help survey respondents recall earlier practices. Members also drew a map of the community and páramo lands, discussed the governance issues on the communities' lands, compared rules that existed according to the 2013 interviews to those that existed in 2018, and discussed livelihood and land-use changes occurring in their communities and the region. In 2013 and 2018, key informant interviews were conducted by the researchers with the leaders in each case study community and with the national PES program director, regional program coordinators working in the highlands, and with program directors of local nonprofits working in the region. These interviews were conducted orally based on a semi-structured interview guide with the researcher writing down records of the responses. We triangulate stated behavior with observed land-use data from páramo assessments and analysis of aerial and satellite images. The páramo assessment was a rapid field assessment conducted in each community in 2013 and 2018 to identify current land-uses in the páramo and the state of degradation. An environmental scientist with expertise in páramo systems walked a set of transect lines that were purposefully selected to cover the various land-uses and land-covers in each páramo and prioritize more accessible areas (Peralvo, 2013). The transect lines started at the top of a community's páramo and moved toward lower elevations and the trained environmental scientist documented evidence of cattle, sheep and fires along the transects in a spreadsheet and georeferenced samples were taken every 500 meters, or less if the land-cover or land-use changed within the 500-meter line.

	The páramo assessment is further supplemented by a land use/land cover visual analysis of satellite images including Pleiades 1A (February 2019) and SPOT 6 and 7 (December 2017). This analysis allowed us to identify páramo and agriculture/grazing zones, to locate the agricultural frontier and identify agriculture/grazing activities in the areas under Socio Bosque conservation contracts.
Timing	The first set of data was collected from September 2013-February 2014. The second set of data was gathered January-July 2018.
Data exclusions	The study originally sought to compare 12 communities, however, one community was excluded from the analysis. The community was initially intended to serve as a control community, however, by the time the researchers started data collection, this community was in the process of joining the Socio Bosque program and therefore, could no longer be treated as a control.
Non-participation	In our recruitment process, there was one community (an intended control community) that did not wish to participate in the study.
Randomization	Please see above description of the research sample that describes how our treatment and control communities were chosen from a waitlist.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☐	☒ Human research participants
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Human research participants

Policy information about studies involving human research participants

Population characteristics	All participants were Quichua heads of households (male or female). The age ranged from 16 to 84 with an average age of 46. The respondents had, on average, 5 years of education with 87% depending primarily on on-farm sources of income (agriculture and animals).
Recruitment	See above for recruitment. In our research design and analysis, we have tried to account for differences between participant and non-participant communities, nonetheless, unmeasured unobservable variables (these would be in εcit.) could still be correlated with the treatment indicator and this would bias our DID estimates. This assumption is hard to circumvent as we do not have any viable instrumental variables for program enrollment. We examined the potential for omitted variable bias by testing the robustness of our DID estimates to an array of community and household specifications and consistently found similar treatment effects.
Ethics oversight	The study protocol was approved by the Seattle University's Institutional Review Board for both 2013 and 2018.

Note that full information on the approval of the study protocol must also be provided in the manuscript.