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Global consumption continues to generate growth in mining. In lesser developed economies, this growth offers the potential to generate new resources for development, but also creates challenges to sustainability in the regions in which extraction occurs. This context leads to debate on the institutional arrangements most likely to build synergies between mining, livelihoods, and development, and on the socio-political conditions under which such institutions can emerge. Building from a multiyear, three-country program of research projects, Peru, a global center of mining expansion, serves as an exemplar for analyzing the effects of extractive industry on livelihoods and the conditions under which arrangements favoring local sustainability might emerge. This program is guided by three emergent hypotheses in human-environmental sciences regarding the relationships among institutions, knowledge, learning, and sustainability. The research combines in-depth and comparative case study analysis, and uses mapping and spatial analysis, surveys, in-depth interviews, participant observation, and our own direct participation in public debates on the regulation of mining for development. The findings demonstrate the pressures that mining expansion has placed on water resources, livelihood assets, and social relationships. These pressures are a result of institutional conditions that separate the governance of mineral expansion, water resources, and local development, and of relationships of power that prioritize large scale investment over livelihood and environment. A further problem is the poor communication between mining sector knowledge systems and those of local populations. These results are consistent with themes recently elaborated in sustainability science.

institutions | extractive industry | conflict | livelihood

Long-term global change trends drive the continuing expansion of mining (1–5). Among Organization for Economic Cooperation and Development (OECD) countries, predictions that mineral demand declines at higher levels of national economic development have not been borne out (1). Demand for minerals continues to grow rapidly in emerging economies. Innovations in mining technology make it economically possible to recover minerals from low grade deposits (6, 7). Meanwhile, new technologies, including those intended to enhance sustainability, increase demand for certain minerals. For example, battery-based automobiles will lead to increased demand for lithium, 49% of the reserve base of which is estimated to lie in the salt flats of Bolivia (8), whereas policies that seek to substitute fossil fuel with nuclear energy will require increased uranium mining.

These trends present serious challenges to sustainability. Extractive industry involves the permanent draw down of nonrenewable resources, accounts for ≈20% of global greenhouse gas emissions (9), and generates numerous local human-environment challenges. We have examined these challenges since 1999 through sustained field research on the relationships among extractive industry (mining and hydrocarbons), environment, livelihoods, and institutional change across eight case study regions (including 43 localities) in Peru, Ecuador, and Bolivia. Here, we focus on findings from Peru, an exemplar for mining-sustainability themes. Drawing on work on institutions, knowledge systems, and environmental change (10–13), we ask: What are the human-environment impacts of mining? What institutional factors help explain these impacts? Under what conditions might institutional arrangements and social learning foster local sustainable development in the presence of mining?

Our research was carried out in the three case study regions of Southern Cajamarca, Cordillera Huayhuash in Ancash, and the highlands of Piura (for further details on research sites, methodology, and instruments, see Tables S1–S3). Between 1990 and 2007, Peru received US$12.35 billion in mining investments. It is the leading silver producer of the world, second for copper and zinc, fourth for lead, and sixth for gold. Peru ranked sixth in the world in levels of investment in exploration in 2007 (4), and although the financial downturn in 2009 has slowed the growth of some foreign investment, the underlying drivers of global demand have not changed, and copper, silver, and gold production are still growing (14).

This level of activity could be an important vehicle for improving Peruvian livelihoods. However, the evidence of positive effects is weak, especially in rural areas (15–17). Indeed, mining has led to increased social conflict. In 2007, the Peruvian Ombudsman's office recorded 78 conflicts in the country, 37 of which were socio-environmental in kind, and 33 related to mining; by 2009, it recorded 250 conflicts, of which 125 were socio-environmental in kind, and 89 related to mining (18, 19). These conflicts are linked to the mining-sustainability relationship, and are motivated by concerns about livelihood security, environmental degradation, and by the perception that well-being has not increased in proportion to the profits of mining companies (20).

The importance of institutions in determining the quality of development and natural resource management is well established (5, 10, 21–24). However, in many cases, mineral expansion occurs before adequate institutions are in place. Mechanisms to ensure transparent use and distribution of money generated by mining are often weak (24, 25), as are arrangements for transforming mineral wealth into human development and environmental quality. These institutional constraints help explain the social unrest driven by the greed, grievance, uncertainty, and fear that often accompany mining expansion (26). That such arrangements persist reflects the political power of those who benefit from them, as well as central government commitments to prioritize institutions that promote foreign direct and large scale investments as a pathway to economic growth (27). The presidents of Peru, Ecuador, and Bolivia have each made these commitments clear over the last 2 years (28).

Boundaries among knowledge systems also undermine sustainability (12, 29). As mining expands, modern knowledge systems responding to national and international objectives encounter livelihood-based knowledge grounded in local objectives (13). These

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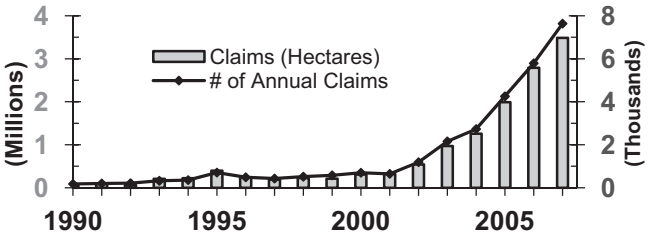

Fig. 1. Mining claims in Peru 1990-January, 2008.

knowledge systems have distinct criteria of credibility and legitimacy, and distinct normative conceptions of how things should be. Managing the boundaries between these systems is essential for local sustainability, and is a particular challenge given that some actors involved possess far more information and power than do others.

Boundaries have to be managed not only for purposes of mediation, but also for learning and performance (12, 13). For local knowledge systems aiming to understand, adapt to and take advantage of change, "learning from experience is particularly slow, so identifying new alliances of local and science-based knowledge systems to speed up this acquisition is particularly important" (refs. 13 and 30, p. 850). The mining sector also needs to learn from local systems as it enters new and complex environments for which its knowledge may be inadequate. One study concludes that in 19 of 25 United States mines studied, model-based assessments failed to predict that water sources would be contaminated at levels exceeding United States standards. This inaccuracy was due to mitigation failures, as well as errors in geochemical and hydrologic characterization of mined materials and mine areas (31).

Research on these boundaries has generated a set of quasi hypotheses about institutions, knowledge, and learning that cross-cut the various communities engaged in human-environment and sustainability themes. These are: (*i*) sustainability enhancing, resource governance institutions have to be built before resource based growth occurs (24); (*ii*) where asymmetries of power exist, social conflict is often the catalyst for the crafting of institutions that foster more sustainable resource management (20); and (*iii*) institutions of resource governance that allow local participation are more likely to succeed than institutions imposed from outside (32).

This study undertakes an empirically based, qualitative assessment of these hypotheses for mining in Peru. It does so by addressing which institutional arrangements need to be created to increase synergies between mining, environment, and livelihoods, whether such institutions can be crafted if mineral expansion has already begun, and what role sustainability science might have in building these institutions and enhancing synergies. We emphasize mining and Peru because there are no single-model panaceas for resource management and arrangements must be crafted to fit particular contexts (10, 11). The Peruvian example allows us to ask, under conditions of conflict: Can feasible institutional arrangements emerge for managing the relationships between mining and livelihoods, and between expert and local knowledge systems, and what would these arrangements be?

Results

Mining and Sustainability Challenges in Peru. Minerals account for 62% of the exports of Peru, and the mining boom of the country has helped foster sustained economic growth, running at 8% growth (per annum) by 2008 (4). Fig. 1 illustrates the effects of this growth on the long-term trend of mining concessions. Since 1990, 89% of all of the area ever claimed for mining has been given over as concessions (33). Currently, there are 33,963 active mining claims that cover 13,997 km^2, 11% of the country (for entire time series, see *SI Materials and Methods* and Fig. S1). Certain regions have

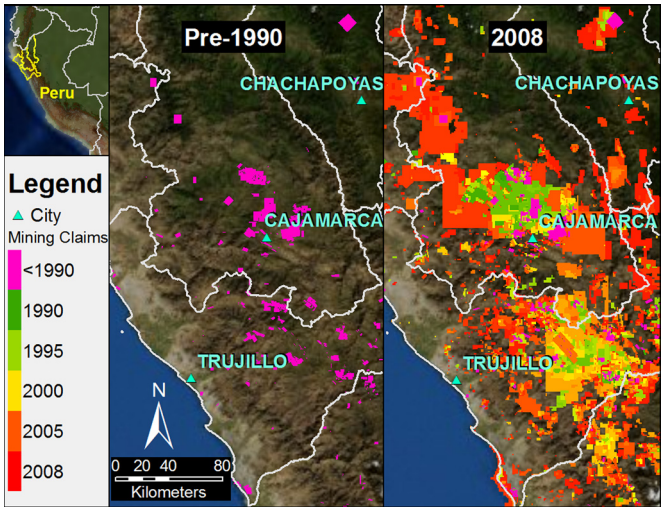

Fig. 2. Mining claims, Cajamarca, 1990–2008.

witnessed particular acceleration in the area affected by claims (Fig. 2; Fig. S2). Although only some concessions become active mines, the extent of concessions indicates: (*i*) the types of mining-livelihood-environment relationships that central government is willing to countenance; (*ii*) the distribution and location of potential mining activities in relation to other social and environmental factors; and (*iii*) the predisposition of the mining sector to invest.

This growth has occurred in an institutional context that hinders the alignment of mining and sustainability. Until 2008, Peru did not have a Ministry of Environment, and responsibilities for granting concessions, promoting mining, regulating its environmental and social impacts, and approving the Environmental Impact Statements of companies were all vested in the Ministry of Energy and Mines (MEM), creating an evident conflict of interests. There has been no requirement that concessions are aligned with local government plans for development, land use, ecological zoning, or water management. Nor has there been consultation with local populations before the granting of concessions, even though Peru is signatory to the International Labor Organization Convention 169, which stipulates the right of indigenous people to prior consultation and to free, prior, and informed consent before any relocation from their lands. Existing institutions favor promotion of mining over its regulation or its synergy with local livelihoods and environment. Similar arrangements have been documented in Africa (34).

The surge in mining concessions has been accompanied by mergers and takeovers among transnational mining companies and the use of new technologies that require large capital expenditures, leading companies to request larger concessions (35). Companies with 20,000 or more hectares account for >46% of all mining claims, and 10 operators control 3,486 km^2 of concessions in Peru (Table S4). This concentration introduces immense imbalances of power in the countryside between companies and communities, and raises issues about land use change and water resources.

Mining, Water, and Livelihoods. Concessions have been granted in the upper reaches of watersheds, with 33% of claims located at ≥4,000 meters above sea level (masl) and 58% at ≥3000 masl (Table S5). Table 1 shows the extent of concessions in watersheds that supply water to most of the major cities in Peru and its coastal agriculture. Watersheds supplying the cities of Lima, Trujillo, Chiclayo, and Ica each have 30% or more of their surface under concession. Fig. 3 shows the concentration of concessions in the headwaters of the rivers supplying greater Lima. Larger portions of watershed surfaces are affected in Cajamarca (Fig. S3). This expansion occurs in a context in which water resources are already

Table 1. Percentages of major populated watersheds subject to mining concessions

Major river (region)	Size of watershed, km²	Percentage of watershed claimed by concessions
Cajamarca (Cajamarca)	4993	64
Chancay (Chiclayo)	4960	45
Jequetepeque (Cajamarca)	4726	41
Santa (Huaraz)	11789	41
Lurin (Lima)	1738	41
Moche (Trujillo)	2423	41
Rimac (Lima)	3584	40
Moquegua (Moquegua)	3516	38
Cutervo (Cajamarca)	2719	34
Chicama (Cajamarca)	6181	32
Apurimac (Huanuco)	41474	31
Chillon (Lima)	2566	30
Ica (Ica)	6930	29
Madre de Dios (Madre de Dios)	19011	27
Mantaro (Huanuco)	34307	26
Apurimac (Andahualyas)	23405	21
Marañon (Northeastern valleys)	43411	20
Chotano/Marañon (Cajamarca)	14750	18
Chiria (Piura)	10948	18
Piura (Piura)	11718	17
Chili (Arequipa)	12657	17
Totals	267805	

under pressure. Lima and other cities face serious long-term water supply constraints after a decade of precipitation deficits and the disappearance since 1970 of approximately one-quarter of the glaciers supplying coastal watersheds (36). Water-dependent export agriculture is also increasing rapidly on the coast. Meanwhile, 29% of the population has no access to piped water, and more than half of the major rivers used for water supplies are contaminated by accumulated mining, hydrocarbons, and human waste (37).

Mining has potential adverse effects on livelihoods primarily through its impacts on land and water resources. In Piura, Cajamarca, and Ancash, land rights were initially held individually or collectively by peasant communities. These rights gave access to natural resources that served as livelihood assets, reserves for future use, items of consumption, and sources of cultural identity. To conduct exploration and install operations, companies need access to these surface land rights. The impact that this transfer of rights has on livelihoods is compensated through the price paid for the land, offers of employment, and community development programs. In Cajamarca, 59 randomly sampled households from three communities (23% of total community population) affected by mining activities experienced significant, although short-term, increases in access to medical and educational services through community development programs. Between 1992 and 2000, US$5 million was paid to >250 households in 44 communities in return for land transfers to mining companies (15, 38). Such payments can have positive short-term effects, although rarely enhance the sustainability of livelihoods because of shifts from durable natural assets to less durable (if more flexible) financial assets. Our 2005 follow-up case-study research with 52 randomly sampled households from four communities (13% of total community population) affected by mining activities indicated that although almost all households either sold land to the mine or were involved in many of the community development programs the mine administered, only 56 and 29%, respectively, of households reported increased access to health services and schooling. Also, 45% of households indicated that their overall annual financial incomes had declined, and 86% reported no increase in cattle and sheep holdings, the primary sources of household income.

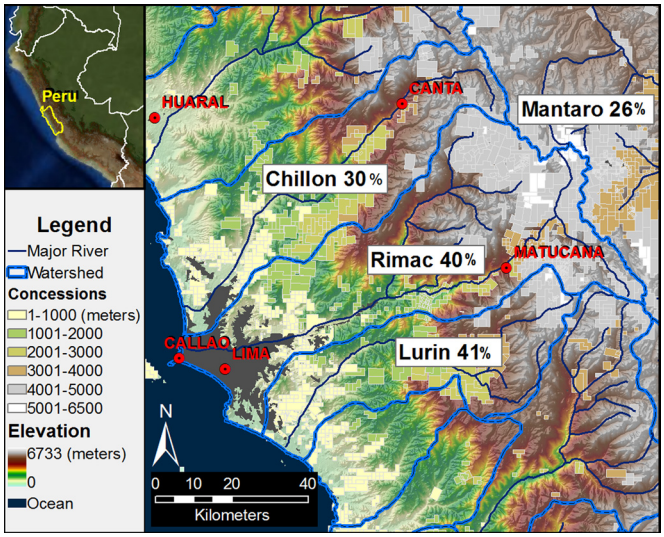

Fig. 3. Mining claims in watersheds feeding Lima.

Mining activities have fundamentally altered the spatial extent of livelihood resource bases, leading to unsustainable intensification and increasing livelihood insecurity. Our 2005 research shows households struggling to maintain livestock herds because high elevation grazing lands are now occupied by mining activities (Fig. S3); 61% of households temporarily intensified agriculture to compensate for loss of grazing lands. This intensification has reduced fallow periods and, respondents believe, decreased soil fertility. In 2003, 95% of interviewees in the two communities most affected by mining operations indicated that fallow periods have shortened considerably because of the need for fodder crops.

Mining activities in Cajamarca have also led to outmigration. In 2003, >75% of households in the 44 communities that sold land to mines between 1992 and 2000 had moved to neighboring communities at lower elevations. Also, 17% of households that sold parcels of land moved to the city of Cajamarca. According to interviews with a 10% sample of households from nine communities who sold land to the mine, more than half were unable to purchase new lands equal to their previous holdings due to price inflation, forcing them to migrate in search of housing and new livelihoods (38).

Water is needed in large quantities for mineral production and processing. The adverse impacts on water quality early on in the life of several post-1990 mines in Peru have generated particular concern and conflict. A synthesis of several years of water chemistry findings from environmental impact and water monitoring studies in Cajamarca show water quality downstream of the largest gold mine in Peru often failed to meet company, MEM or Ministry of Health standards (Table S6). Community respondents report increased problems of human, animal, and fish ill-health, and deterioration in water smell, taste, and cloudiness.

At all our sites, a recurrent issue in debates on water quality and quantity is the difference between indicators used by residents and by the mining sector. Residents' indicators are typically vernacular and based on everyday monitoring of the landscape; the indicators of the mining sector are quantitative and based on structured monitoring programs (30). Although residents distrust quantitative indicators, because they do not understand them and the data are often produced by scientists contracted by mining companies, the mining sector has no faith in vernacular indicators. Although the mining sector insists that the use of new technologies means that the negative impacts of twentieth century mining will not be repeated, residents remain skeptical given historical associations between mining, contamination, and poverty, as well as more recent mitigation failures.

Concerns about impacts on water also underlie resistance to mining in Piura. Interviews in four sectors of the community

Segunda y Cajas showed that residents' primary concerns regarded the effect that mining would have on the quality and quantity of water. Civil society and church organizations expressed the same fear. In 2003, 60% of irrigating farmers from the four case study communities in Cajamarca reported reduced water availability, believing that this was due to new mining operations. Rural and urban interviews since 1999 consistently show the dominance of water concerns.

Responding to these pressures, some companies adopt technologies to reduce impacts on water. A proposed large copper mine in Piura says it will use technologies that maximize water recycling and avoid use of inorganic reagents. In Cajamarca, mines have responded to conflicts over deteriorating water quality and a large mercury accident by instigating drinking water programs. In 1996, only 3% of households in the 2003 case study communities had access to piped water resources; by 2005, 85% of households had received new piped water connections over half of which were installed by the mining company. Companies also aim to offset negative effects on land and water by creating new assets through agricultural production, education, and infrastructure programs. The effects on livelihood sustainability are mixed. One transnational company in Cajamarca is thoroughly rethinking its program on the grounds that, over its 15 years of operation, it has had little success in enhancing livelihood sustainability (39). Repeat interviews since 2004 with the community relations team reveal growing staff recognition that these programs have encouraged clientelism, increased inequality, and failed to mitigate conflicts.

Therefore, other mechanisms are required to translate the value of extracted natural capital into new livelihood assets and opportunities. Since 2004, the main instrument has been a tax transfer arrangement, in which a proportion (currently, 50%) of tax paid by the mine returns to the mine-affected region. However, most local authorities have inadequate staff and skills to establish priorities or implement significant investment projects, and Ministry of Finance rules have prevented use of mine-tax transfers to strengthen technical capacity of municipal government. At a national level, tax transfers are associated with increased conflict because of these problems. In response, the International Finance Corporation (IFC) aimed to develop this capacity in Cajamarca. In 2008, local mayors reported improvements; other elected officials interviewed were less sanguine.

Mining and Conflicts. Maps of mining concessions can be viewed as maps of uncertainty. Once communities become aware that a concession has been granted on their land, their future becomes unclear. People possess inadequate information regarding the implications of such concessions, and the information they do receive has problems of salience, legitimacy, and credibility (12). Interviewees have often requested information from us, because often they neither understand nor trust information given to them by mining companies, the MEM, or environmental groups.

Differences exist not only regarding knowledge claims about how things are, but also how things should be. Conflicting views exist regarding the rights that mining companies and residents have, and the relative weight of these respective rights. Such discrepancies manifest themselves in different claims on the landscape. Fig. 4 shows mining rights in the Huayhuash region of Ancash, and their overlap with community controlled private conservation districts, which reflect a quite different view of how the landscape should be managed. According to our interviews in four communities in the region, this spatial disjunction has led to conflicts between different legal, constitutional, and cultural interpretations of rights.

Across all of the case studies, residents' ability to express their views during exploration and exploitation is often obstructed, because key decisions are made far away in Lima, and local actors feel far less at ease in the formal environments of Lima than do mining officials. Also, grievance procedures do not work well for local populations (18). Feeling that there are few or no possibilities

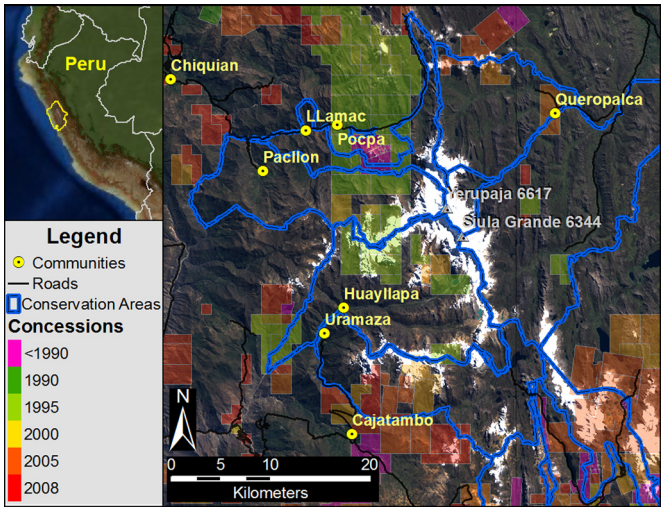

Fig. 4. Mining claims and community level private conservation areas in the Cordillera Huayhuash, Ancash.

to elicit government response to their concerns, local populations frequently conclude that violent conflict is the only way to make their knowledge count. Each of our research sites has seen such violence, with loss of life in Cajamarca and Piura.

This situation makes the work of communication, translation, and mediation at the boundary between mining and livelihood knowledge systems at once important and difficult (12). In each of Piura and Cajamarca, individuals and groups attempting to have this role have done so from already established positions of leadership and legitimacy. Several of these "boundary mediators" have been linked to the Church, some to nongovernmental organizations (NGOs), and others to research and educational institutions. However, in an environment of "if you are not for us you are against us," it is difficult to sustain this role. Interested parties have actively undermined mediators' legitimacy with public and private claims that they are biased. When church related groups in highland Piura have posed the question "might it be possible for mining and livelihoods to coexist?," activists criticize them for being "pro-mining." Meanwhile, in both sites, NGOs and religious figures aiming to mediate while at the same time raising concerns about mining's adverse effects on the environment or human rights have been publicly criticized by government, companies, and the media as antidevelopment and even terrorists. The most effective mediator between these different views on rights and knowledge has been the Ombudsman's office, a state institution that is independent of the Executive and answers directly to Congress. Although some companies (as in Piura) question the credibility and impartiality of the Ombudsman's analysis, it has greater legitimacy with the different parties than do any of the other potential boundary managers.

Discussion

The local sustainability challenges generated by mining expansion depend on: the effects on residents' access to land and water; the effects on water quality; whether lost livelihood assets have been compensated by new, durable assets; and the effects on residents' belief in the legitimacy and credibility of information. As literature on institutions and the environment would suggest (10, 11, 13, 17, 40), to secure such sustainability requires social processes that lead to the creation of more effective institutions for managing relationships between mining, land, water, and people, and between mine-based and livelihood-based knowledge systems. The Peruvian case suggests elements of such processes.

Sources and Qualities of Institutional Innovation. Since 2004, there have been national and local institutional innovations that have the potential to enhance environmental quality and allow the conversion of subsoil natural assets into local development. Four national changes are important. First, since 2004, mining tax and royalty systems have changed in ways that ensure significant fiscal transfers to mine affected areas. These changes generated a new challenge, increasing local conflict due to the ways in which local governments managed these resources (16). The challenge led to a pilot program to strengthen municipal capacities, although this program has not been rolled out on a national basis, and Ministry of Economy and Finance rules prevent municipalities from using tax transfer resources for capacity building.

The third and fourth changes constitute steps, if incomplete, toward improving environmental regulation. In 2008, a Ministry of Environment was created, potentially a significant change for natural resource governance. However, the Executive, the MEM, and the mining sector have each resisted giving it the role of regulating the environmental impacts of mining. Consequently, Environmental Impact Statements are still approved by the MEM. Although the role of monitoring the environmental effects of operating mines has recently been passed to a third party, this body is the regulatory authority for the energy sector, which has no prior expertise on environmental issues.

Each of these changes has occurred in contexts of social conflict. Conflicts with communities led mining companies to favor the first change; local conflicts over the use of tax transfers led to the second change; international conflicts over the Free Trade Agreement with the United States and over gas development in the Amazon preceded the creation of the Ministry of Environment; and growing public criticism of the partiality of the MEM preceded the fourth. Although social conflicts encouraged change, actual innovations occurred because of lobbying by specific actors, in particular NGOs, the Ombudsman's Office, International Financial Institutions, and certain mining companies. The Ombudsman's Office has recognized in interviews that the existence of social conflict has made it possible for them to promote specific institutional innovations. However, these changes remain incomplete because of resistance from the mining sector, Ministry of Economy and Finance, and the Executive.

Local institutional changes have also occurred. For example, participatory water monitoring has advanced in Cajamarca. This change originated in conflicts that led the Compliance Advisor Ombudsman (CAO) of the IFC to intervene. Given that the IFC is a part owner of the Yanacocha mine, the impartiality of the CAO has been questioned by local groups. Nonetheless, many stakeholders recognize the value of the water monitoring system that it initiated through an external consultant. In response to subsequent conflicts, the company has established additional participatory monitoring of water courses (often, again, with the mediation of third parties). The weakness of such initiatives is that they emerge in response to conflicts, rather than before the onset of mining activity, and were initiated by the company and its owners. However, they do allow for the joint involvement of scientists and stakeholders to monitor against both technical and vernacular water indicators. In some instances, this effort has identified contamination, providing a modest measure of local recognition. Over the last 2 years, there have been attempts to build from such experiences and link participatory water monitoring initiatives across Peru. Although many mines believe that their technological innovations have genuinely reduced water resource impacts, they do not view such monitoring as threatening. Also, if monitoring were to identify problems, the mines can respond to them iteratively with additional treatment and infrastructural investments (as has happened in Cajamarca). For the most part, monitoring identifies tensions between mining, livelihoods, and environment that can be resolved.

In another example, participatory ecological zoning allows the combination of local and expert assessments of the functions and appropriate uses of land, and is essential if mining expansion is to be better aligned with existing livelihood and watershed geographies. Our interviews with mining companies show that the industry is resistant to this type of institutional change, and views zoning as an unacceptable attempt to place areas off-limits to mining. Zoning initiatives have begun in both Piura and Cajamarca. However, they have been promoted by NGOs in conjunction with allies within district and regional government, unlike water monitoring, which has often been enabled by the industry. The NGOs involved have been careful to avoid the label of being "anti-mining." Although they speak out on issues of environment and human rights, some senior staff members also participate in off-camera working groups with the industry and the Prime Minister's office. They also struggle to persuade other activists that zoning should be viewed as a planning tool and not an instrument to stop mining. Between the hostility of mining companies and the zeal of activists, it is difficult to protect ecological zoning as a process that mediates between divergent interests and knowledge systems rather than simply reaffirming already established boundaries.

These local institutional innovations mark steps toward sustainability. They also have emerged because of opportunities opened by social conflicts and have then been converted into institutional innovations by actors who, for distinct reasons, have had the power and legitimacy to do this. Once again, resistance to these innovations means they remain incomplete.

Sustainability Science and Incomplete Institutional Innovations. Analyzing the emergence of these institutional innovations helps understand the possibilities of fostering institutional change once expansion of extractive industry has already occurred. Likewise, understanding the roles had by mediators and institutional innovators illuminates the possible contributions of sustainability science. Like the mediating organizations and individuals that we have noted, practitioners of sustainability science would also operate at the boundaries between mining and livelihood based knowledge systems. Operating in these contexts, scientists are faced with a similar set of contradictory demands to those encountered by the mediators in Piura and Cajamarca.

First, information and knowledge must be salient, credible, and legitimate (12, 40) to be "truly useful" in regard to real-world practice. The problem must be deemed important, and its understanding come from trustworthy sources, based on accepted rules. Second, to achieve these characteristics, knowledge must be produced with stakeholders (12, 30, 41–43). Its effectiveness in mediating conflict depends on its legitimacy with a range of stakeholders (12), many of whom have opposed positions. If sustainability scientists are to produce knowledge that diverse actors accept as credible, then they must coproduce knowledge with these different actors at the same time as bridging conflictive relationships through the process of research itself. This challenge implies coproducing knowledge with stakeholders whose interests are opposed. However, some knowledge is simply too specialized to be coproduced. Therefore, great care must be taken to produce it in ways deemed independent, objective, and verifiable by independent third parties. In Peru, such specialist knowledge often fails to contribute to sustainability, because it is produced by, or under contract to, mining companies, and because it is too technical to be intelligible to most local stakeholders. Third, sustainability scientists face the challenge of combining independence with adherence to their own principles. Pursuing this combination requires finding a way to endorse specific institutional innovations while also retaining legitimacy with actors who disagree with them, a combination that mediators in Peru have sought by combining public commitments to institutional changes with off-camera roles to sustain relationships with all parties. Fourth, appropriate institutional innovations (and appropriate means of introducing them) cannot be blueprinted (11). They must fit with the context in which they operate

(10). This requirement means that, like Peruvian mediators, sustainability scientists will also require much local knowledge and field expertise.

These findings resonate with other research on institutions, knowledge, and sustainability, suggesting a way forward to meld research and practice. Following Ostrom (11), we conclude that there are no panaceas when it comes to institutional design. Following Young (10, 44), and Clark and coworkers (13), we conclude that institutions shape knowledge generation, and that to generate knowledge that is salient, credible, and legitimate (12, 40) requires institutions that facilitate dialogue among holders of different types of knowledge. Also, following Clark and coworkers (40), we conclude that such institutions can be built, although this will be a difficult process that encounters resistance.

Conclusions

The Peruvian case speaks to key hypotheses on institutions and sustainability. It suggests that, when resource based growth precedes institutional innovation, serious sustainability problems will emerge. However, it also suggests that, under certain conditions, sustainability enhancing institutions can be created even after resource booms have begun. One condition for this institutional innovation is the presence of social conflict that leads to demands for institutional change; the other is the presence of actors that can translate this conflict into specific institutional innovations. Conflict, adequately brokered, can offset asymmetries of power and allow institutional change. Even in conflictive situations, institutions that allow local ownership can progress and be more effective than centrally imposed institutions that are mostly designed to foster economic growth.

Materials and Methods

Our findings were generated through three linked research projects in Peru, Ecuador, and Bolivia examining areas affected by the expansion of new extractive industries in the Andes. The case study research combines qualitative and quantitative data collection and analysis techniques (for more details, see *SI Materials and Methods*).

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