Supporting Information

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SI Materials and Methods

The findings reported here were generated through research in Peru, Ecuador, and Bolivia on the relationships among extractive industry expansion, livelihoods, institutions, and environmental change. This research has been conducted through three separate, but linked projects over a period of 10 years. The first project was conducted in Cajamarca, Peru, one of the very first examinations into the human-environmental effects of mining expansion in the Andean region under conditions of neoliberal policy. That project served to refine research questions for the subsequent research projects. These broadened the scope of the research to Piura and Ancash in Peru, as well as to three sites in Ecuador and two in Bolivia.

The projects share common approaches and techniques. They each take a case study approach in which the spatial boundary of the case is defined by the geographical area affected by extractive industry. These units typically cover several local government jurisdictions, and include within them communities and small towns. The temporal boundaries of our cases begin just before the onset of extraction and run through to the present. Therefore, each case involves research at different geographical (in particular, households and communities) and temporal scales within the case. Thus, although the case is itself an N of 1, within-case units exceed 1.

Among the three projects, there are eight case studies. In this article, we report on the three from Peru, although insights from the other cases constitute context for the analysis and interpretation of the Peruvian data. The selection of a case study approach reflects a particular conception of causality. Bennett and Elman (ref. 2, p. 457) distinguish between a neo-Humean regularity approach to causality, which "lends itself to large-n regression analysis," and the approach in many "case studies [which] have a relative advantage in the search for mechanisms and capacities." In most case study analysis, this search is for the pathway that leads from a cause to an effect, although in some instances (3), the case study may be used to trace the pathways from an event to its causes, which are often multidimensional and interrelated [there is some similarity between this event based approach and Gerring's (1) conception of single outcome studies]. However, case studies do not exist in isolation. They are always conducted in implicit or explicit comparison with broader populations (ref. 1, p. 13). This is the case for the research reported here, which focuses on cases of human-environmental systems affected by extractive industry, and in which each case is considered in relation to the other cases studied as well as on its own terms.

As noted by Gerring (1), a case study approach is particularly suited to research that seeks to identify causal mechanisms, rather than causal effects under conditions in which there are no clearly distinct dependent and independent variables, but rather causal pathways characterized by sequences of factors, which, when studied, can individually often have an N of just 1. Indeed, a similar rationale partly underpins the National Research Council's (4) and other efforts to guide research in sustainability science (5). Case studies and qualitative analysis "do not look for the net effect of a cause over many cases, but rather how causes interact in the context of a particular case or a few cases to produce an outcome" (ref. 2, p. 458). They typically do this causal analysis through in-depth comparison against independent and dependent variables and/or through within case process tracing (1–3). Although a drawback of case studies is that they are more suited to hypothesis generating than hypothesis testing (1), they are a more appropriate instrument for addressing hypotheses that posit context specificity in the relationships addressed. Such context and time-space specificity characterizes many relationships within complex socio-ecological systems (5, 6). Therefore, it is advisable to approach such systems through in-depth study, and to be cautious before drawing generic conclusions and making blueprint recommendations as to how to govern them (6).

Case studies are also suited for the study of path-dependent processes in which earlier system states system influence (and reduce the degrees of freedom) for its future trajectory. Understanding such trajectories requires study of a system in depth and over time, and may often imply different types of explanation for system states at different points in time. This approach is particularly relevant for trajectories in which institutional change occurs and then affects subsequent system dynamics. Moments of institutional change more typically require agent based explanations, whereas periods of institutional stability likely involve more structural explanations (2, 7). This observation is especially relevant for the study reported here, in which one of our main purposes is to explain institutional change, and in which path-dependent effects are likely.

Given these methodological strengths, Gerring (1) suggests that there is a move in some portions of the social sciences away from variable-centered approaches to causality toward case-based approaches. Certainly, case study approaches have dominated work on coupled social and natural systems, as, for example, on collective action around natural resources, common property regimes, and studies of localized human environment interactions (8, 9). However, the very large number of case studies of coupled human-environment systems presents the challenge of how to read across them or construct large-N data bases on which hypothesis can be broadly tested. This is the challenge taken up by Poteete and Ostrom (8) and Rudel (9). Each article argues that case studies are essential to understanding the causal complexities in human-environment relationships, and that constructing large Ns is a possible, although also difficult endeavor that is plagued with problems. Rudel (9) builds a large N through a metaanalysis of case studies of forest cover change, whereas Poteete and Ostrom (8) discuss the possibilities both of building large N databases on the basis of existing case studies and of constructing research partnerships that would allow the conduct of many case studies in ways that facilitate comparative case analysis (for a similar sort of exercise in economics, see Angelsen and Kaimowtiz, ref. 10, who conduct a metaanalysis of 140 economic models of the causes of deforestation, while various studies in land change science conduct similar sorts of exercises).

Research on socio-ecological systems in which extractive industries occupy an important place is still at an early stage. This situation strengthens the argument for approaching the topic through a case study approach. Poteete and Ostrom (ref. 8, p. 178) note that "Case studies of natural resource management helped reset the terms of debate about collective action." Therefore, it is important at this stage to conduct case studies of extractive industries to (re)set the terms of debate, generate hypotheses that can be taken up in future research, and to begin to assess how far hypotheses generated for other types of socio-ecological system are relevant or not for this domain of study. We do not argue that such adoption of a case study approach is a second best response to the impossibility of large N regression approaches, but rather that at this stage of the endeavor, a case study approach is the only sensible option to studying such socio-ecological systems. The early stage of this research also means that the existing number of case studies is still small, and as a result, the challenge of building large N databases lies ahead. The research reported on here has nonetheless been designed to allow some comparative analysis across a small body of case studies built up progressively across separate research projects. We have built a base for comparison across the cases in three main ways.

First, as recommended by Ostrom and Nagendra (6), we have analyzed elements of the socio-political setting within which the cases exist and with which they interact by conducting analysis of policy and the spatial analysis of mineral concessions on a national scale. This approach allows the research to understand the interactions between system (case) and setting (context) and the ways in which causality has run in both directions at different points in time (sometimes, from setting to system; at other times from, system to setting). Fixed categorizations of variables as either dependent or independent would not have allowed such analysis.

Second, we have chosen cases in which the process of extractive industry expansion has advanced differentially. Thus, although the three cases in Peru are each of extractive industry expansion within existing socio-ecological systems, each reflects different intensities of expansion: In Cajamarca, the process of expansion has been the longest and is the most consolidated; in Piura, it is the least advanced; in Ancash, expansion is relatively consolidated, but on a still smaller scale than in Cajamarca. Following Gerring's dictate (ref. 1, p. 149), the cases are selected for both representativeness (mining affected socio-ecological systems) and variance (different intensities of mining). This tactic allows us to ask whether the same patterns are reproduced in the process of mining expansion, and to ask how cases within a country interact with each other. Note this approach to case selection remains consistent with King, Keohane, and Verba's (11) recommendation against qualitative approaches selecting cases on the basis of their dependent variable. To the extent that independent (mining) and dependent (e.g., levels of conflict) variables can be separated in such socio-ecological systems (and as we have noted, this is only partially so), the three cases are selected on the basis of the presence of the ostensible independent variable (mining). Thus, the three cases allow for (and have been conducted through) a mix of cross-case comparison and within-case process tracing (1).

Third, Poteete and Ostrom (8) note that one vehicle for building large N field studies is to work through partnerships, research alliances, or international research networks on the grounds that these relationships allow for sharing of data, of experiences with techniques, of selection of indicators, and ultimately, for standardization of design (although they also note the institutional and professional factors that militate against such standardization among different projects). Although our work is on a far more modest scale than the cases that Poteete and Ostrom (8) describe, we have followed closely the principles of working in partnership as a small network. In interaction among the different studies, the principal investigators (PI)s and some of the co-PIs has been continuous over this 10 year period, allowing sharing of data and experiences with research techniques, and collaboration in interpreting causal pathways.

Although case studies may have an "affinity" with qualitative data and approaches, they do not necessarily use only them; likewise the technique of process-tracing (reconstructing causal sequences and pathways) can also use both qualitative and quantitative data (refs. 1, 10, and 11, p. 179). The case studies we report on here, as well as those from Bolivia and Ecuador, mix qualitative and quantitative approaches to data generation. The contributions of quantitative data need not always be through statistical analyses. In many instances (as in the research we report on), it provides understanding of the details of the causal pathways and their outcomes. We have used or generated quantitative data for the study of household level effects of mining, water quality and quantity, and the extent of mineral concessions and of their overlap with drainage basins. We used qualitative techniques to examine institutional change, to reconstruct causal pathways and sequences of events, to understand relationships between actors, and to trace processes across scales of analysis.

Table S1 provides a summary of the mix of quantitative and qualitative methods used across the eight case studies in Peru, Ecuador, and Bolivia between 1999 and 2009. These eight case studies involved research in 43 communities, and extensive interviews with representatives from government, nongovernmental, commercial private sector, church, and other entities. Following the table, we describe in more detail aspects of the household research and of the qualitative techniques used.

All human subjects protocols were observed during the studies and approval was received from the Institutional Review Boards or Research Ethics Committees of the University of California at Santa Cruz, the University of Manchester, San Francisco State University (San Francisco, CA), and the University of Colorado (Boulder, CO).

Household Level Analysis. The household level research was guided by specific research questions and methodologies that sought to examine shifting household access to resources in the presence of mining expansion under conditions of the new neoliberal institutional arrangements that have swept across Latin America over the past two decades (12). These new institutional formations have integrated the countries of the region into the global economy by dismantling national barriers to international capital investment, and have reorganized their internal economies through the privatization of production, the elimination of state subsidies to many sectors, and the decentralization of political authority. Alongside these changes, new institutional formations have also been promoted through voluntary private sector initiatives, which include a host of activities referred to as socially and environmentally responsible programs. These programs have been particularly important for many large international extractive operations, because they have often been the most influential governance institutions in remote areas in the Andes traditionally neglected by highly centralized state institutions.

To link these new institutional arrangements with questions of livelihood transformations and sustainability, the case-study research drew on theoretical and conceptual approaches in interdisciplinary and development studies focused on reconceptualizing relationships between poverty, livelihoods, and access to resources. These approaches, which are frequently referred to as sustainable livelihoods frameworks, provide a rigorous analytical approach for understanding how resource access, household livelihoods, and resources interact (13–18).

Sustainable livelihoods frameworks offer a number of important conceptual and methodological advantages for household level research. First, they intentionally seek to link questions of local environmental and social change with larger institutional and political-economic changes such that particular geographic areas, actors, and processes can be clearly specified and rigorously examined. Second, because they broaden the scope of investigation at local scales of analysis, they provide for more comprehensive specification of causal relationships between independent and dependent variables. They also provide for the generation of higher amounts of observable variance in dependent variables, which in this research, was conceived of as capital resources. Following King, Keohane, and Verba's argument (11), our case study research was designed to provide for a maximum amount of variation in our dependent variables such that a diverse set of observable implications about the relationship between institutions and local change could be generated.

Sustainable livelihoods frameworks focus on a larger array of resources that household member's access to construct livelihoods. Drawing on the heuristic of capital terminology, scholars have identified several important types of capital resources that are involved in livelihood production. The conceptual categories for this research that were derived from sustainable livelihoods frameworks were financial, physical, natural, and social capitals. Financial and physical capitals were defined as infrastructure, transportation, electrical services, savings, and convertible liquid assets, as well as regular flows of money such as earned income, pensions, transfers from the state, and other remittances. Human capital was defined as human capabilities such as skills, education, knowledge, ability to labor, and health. Natural capital was defined as both nonrenewable resources such as minerals, forests, and soils, and renewable resources such as ecosystem services and nutrient cycling. Last, social capital was defined as relational structures (both horizontal and vertical) that facilitate action and as the relations between people that provide a flow of resources that enables both solutions to problems and the pursuit of economic and political activities.

Quantitative data on the relationships between livelihood resources, institutions, and extractive activities were generated through formal semistructured surveys that included unstructured verbal responses and structured ordinal, categorical, and interval variables. Table S2 summarizes the case-study research methodology used in Cajamarca, Peru, between 1999 and 2005. Table S3 presents a summary of the findings generated from the 2005 component of the case-study research in Cajamarca.

Water and Spatial Analysis. The spatial analyses for watersheds and mining concessions were generated using SRTM 90-m digital elevation model data, LANDSAT imagery, Blue Marble Next Generation data from National Aeronautics and Space Administration, and publicly available vector and raster data. The mining concessions data were acquired from the Peruvian Ministry of Energy and Mines (MEM). The water data (Table S6) were collected from Environmental Impact Assessments archived in the MEM. Water sample data were collected for 26 different elements across the >100 water monitoring locations. The baseline data were compiled from samples between 1991 and 1993, and the comparative data were collected from samples taken between 1994 and 1999. The entire water sampling database includes information for 36,000 water sample points.

Qualitative Data Generation. Qualitative techniques were used in each case study to examine institutional change, to reconstruct causal pathways and sequences of events, to understand relationships between actors, and to trace processes across scales of analysis. The use of qualitative techniques differed from techniques oriented toward the generation of quantitative data in that the purpose here was both to generate data and to trace causal pathways. Therefore, qualitative techniques were oriented both to data generation and causal analysis. The rationale for this analytical strategy has already been laid out above, and is consistent with approaches to the analysis of socio-ecological systems laid out by authors such as Ostrom (6, 19) and Rudel (9), as well as the analysis of political and institutional change as laid out by authors such as Collier (20) and Mahoney (21).

The qualitative techniques used for the purpose of data generation and process tracing, which are also summarized in detail in Table S1, include unstructured key informant interviews with extractive industry representatives, government officials, nongovernmental organization representatives, civil society leaders, and households to provide background and context to the research and to elaborate on the key factors driving institutional change. Focus groups were conducted with communities and stakeholder representatives to evaluate social interaction, group perceptions, informal institutional dynamics, social conflict, and the impacts of extractive industries within communities. Participant observation, a common qualitative research methodology in fields such as anthropology and environment-society studies that involves the researcher in activities such as meetings, negotiations, or livelihood activities, was conducted in some of the case studies to examine intracommunity relationships and broader processes of social conflict and institutional change. Our examination of conflict dynamics in all of the case-studies was qualitative in nature due to the sensitivity of the topic and the need for in depth analysis to probe people's concerns and motivations. The research aimed to contribute to the information base on which stakeholders approach relationships between mining, livelihoods, and development. This objective required that we sustain relationships with organizations over several years in the hope that this would give our findings progressively greater credibility with these organizations.

Reliability. The plausibility of the interpretations offered in the article resides in part in the in-depth knowledge derived from the sustained interaction of the researchers with these cases and the topic of which they are cases. This interaction has meant that we have been able to elaborate interpretations iteratively in line with the accumulation of evidence. The progressive accumulation of evidence is the mechanism through which the internal validity of the analyses and interpretations has been sought. At the same time, the research process has sought external validity for the findings not through the route of statistical inference against large-N samples, but through the subjection of the findings to critique in various public and professional forums. Some of these forums have been of an academic nature, but the more important for our purposes here have been with the actors involved in discussions of extractive industry, environment, and development in the three countries. These interactions include discussions with companies, the Ombudsman's office, nongovernmental organizations, social movement organizations, and activists; and they range from small scale discussions to presentations to the Ecuadorian Constituent Assembly. This is not to say that all actors agree with these interpretations, although many have done so; there is debate and critique, rightly so. However, our interpretations are a result of that debate and critique.

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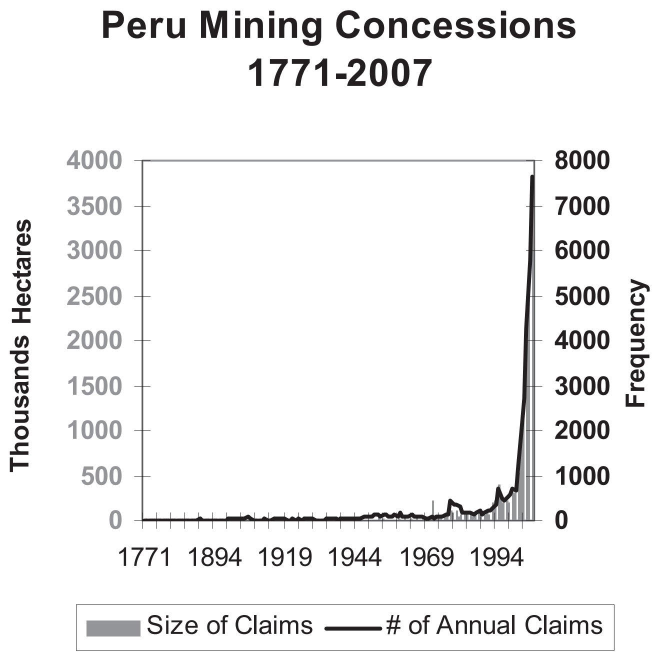

Fig. S1. Active mining concessions in Peru 1771-January, 2008.

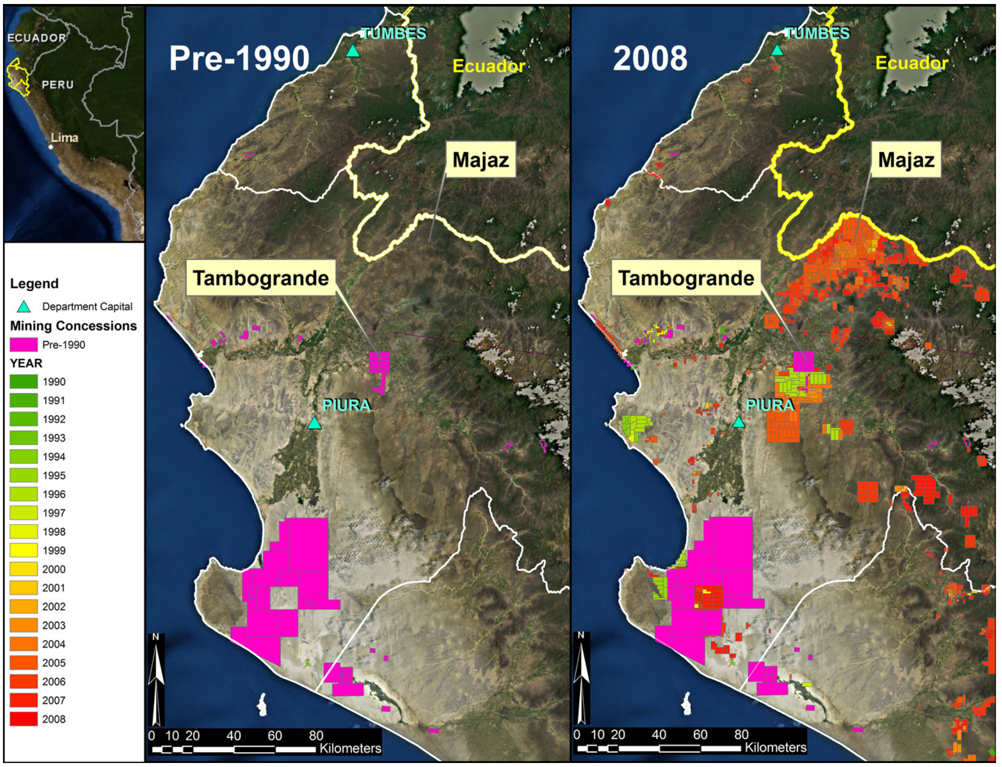

Fig. S2. Mining concessions, Piura, 1990–2008.

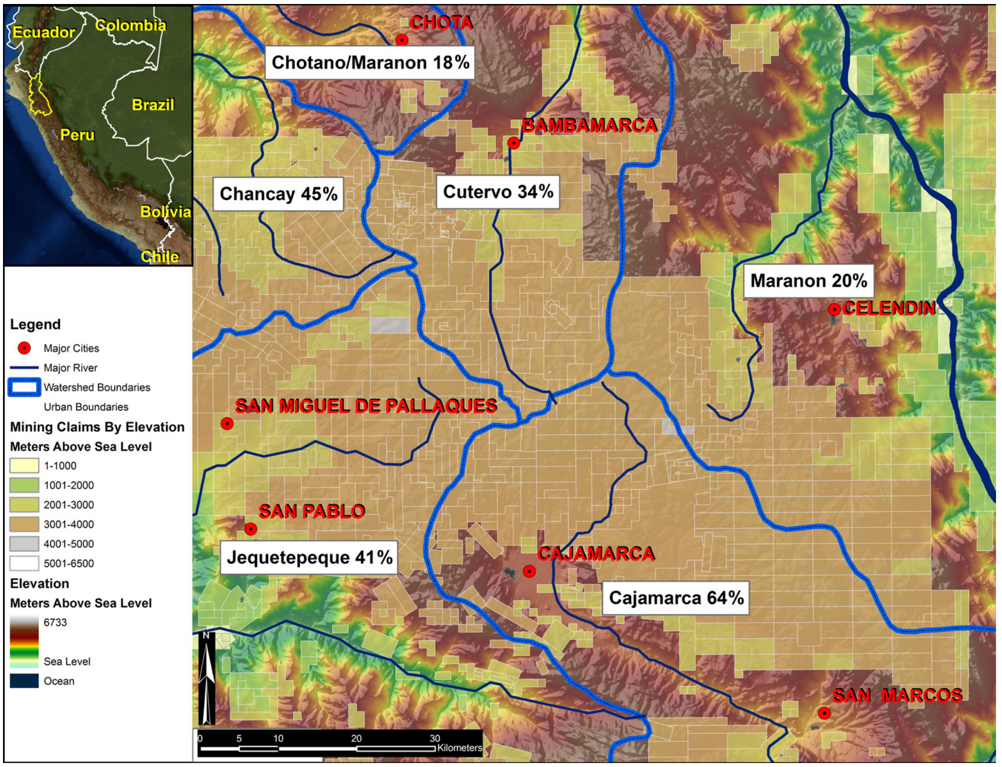

Fig. S3. Mining concessions in watersheds in Cajamarca.

Table S1. Summary of research populations and methods in Peru, Ecuador, and Bolivia

Location and duration	Research subjects	Methods utilized
Peru		
Cajamarca 1999–present Gold mining	Mining company representatives	Interviews (Cajamarca, Lima, London, United States), workshops, public meetings, participant observation
	Key informant interviews	Government officials: Mayors, Peruvian Ministry officials, Ombudsman; Councilors, Regional Government-President, Advisors
		NGOs-Cajamarca, Lima, United States, Canada, Switzerland, United Kingdom
		International institutions: World Bank, IFC, UN
		Civil Society: Church representatives, peasant organization leaders, university organizations, urban organizations
	Communities (n = 17)	Formal meetings, focus groups, participant observation
	Households	Structured surveys, unstructured interviews, participant observation
Piura 2007–present Copper mining	Mining company representatives	Interviews (Piura, Lima, United Kingdom); public meetings and public debates; observation
	Key informant interviews	Government officials: Congressional representatives, Ministers, Regional government Department Directors, Ombudsman, local mayors; House of Parliament in United Kingdom
		NGOs-Piura, Lima, England
		Civil Society: Church representatives, peasant organization leaders, urban representatives
		Business leaders
	Communities (n = 4)	Formal meetings, informal interviews, participant observation, direct observation of local referendum on mining
Ancash 1999–present polymetallic mining	Key informant interviews	Government officials: Congressional representatives, Ministry representatives
		NGOs-Huaraz, Lima, United States
		Civil society-peasant organization leaders
	Communities (n = 4)	Informal interviews, semi-structured surveys
		Community meetings
Ecuador		
Cotacachi 2005—present, Cuenca 2007–present, Zamorra 2007–present Proposed copper mine	Mining company representatives	Interviews (Pichincha, Azuay, Loja); participation in Constituent Assembly forum on mining
	Key informant interviews	National Government: MEM; National Planning Council; representatives on Constituent Assembly
		Municipal and provincial government: Councillors, Water Boards, Environmental Directors, Protected Area coordinators
		NGOs-Pichincha, Imbabura, Azuay, Zamorra
		Civil Society: Pichincha, Imbabura, Azuay, Zamorra. National and subnational activists; cantonal assembly; national coordinator committees on environment and human rights
		Participation in Constituent Assembly forum on mining
	Communities (n = 5)	Participant observation; focus groups; household interviews; informal interviews; interviews with community leaders
Bolivia		
Oruro 2007–present, Tarija 2007–present Hydrocarbons and mining	Hydrocarbon and mining company representatives	Interviews: La Paz, Santa Cruz, Villa Montes, Palos Blancos, Oruro, London, Manchester; participation in public meetings; observation, site visits
	Key informant interviews	International organizations and networks: United States, Peru, London
		Departmental government: Current and former advisors to President, Department Secretariats
		Municipal government: Elected leaders and staff
		Government offices: National Hydrocarbons Agency; Ministry of Energy and Hydrocarbons, Ministry of Mines
		Parliamentary officials: Senators, representatives
		National and regional indigenous peoples' organizations: Santa Cruz, Tarija, Villa Montes, Yacuiba, Entre Rios, Caiparendita, Carapari; direct participation in activities of the organizations
		NGOs: Tarija, Santa Cruz, Camiri, Cochabamba, La Paz, Entre Rios, Villa Montes, Yacuiba; direct participation in activities of the organizations
		Business leaders and Civic Committees: Tarija, Santa Cruz
	Communities (n = 11)	Participant observation; focus groups; household interviews; informal interviews; interviews with community leaders; direct participation in activities of the communities

Table S2. Cajamarca case-study research methods 2000–2005

Research community Cajamarca (code)	Household sample size	Sample as percentage of community	Sampling method	Research activity
2000				
Ladera	19	18	Random	Quasiexperimental research design based on levels of impact from mining activities. Semistructured survey (112 questions) livelihood assessment and impacts of mining activities on household access to resources.
Jalca	20	25		
Control	20	25		
2003				
Various (n = 9)	20	NA	Snowball	Semistructured survey (45 questions) impacts of mining land purchases on household livelihoods, changes in household migration behavior.
2005				
J1	10	9	Random	Semistructured survey (67 questions) livelihood assessment, institutional change, and impacts of mining on migration and access to resources.
A1	14	19		
Q38	13	21		
H1	15	4		

NA, not applicable.

Table S3. Summary of findings for 2005 Cajamarca case study research

	J1	A1	Q38	H1
Summary descriptive statistics for communities				
Total household sample population	50	70	65	75
Average age of interviewees	52	38	36	32
Gender of interviewee, %				
Male	80	30	38	53
Female	20	70	62	47
Percentage of interviewees who currently have access to piped water	100	93	62	100
Livelihood activities				
Percentage of interviewees who have access to irrigation	30	71	31	85
Average size of grazing parcels, ha (range)	9 (1.5–39)	12 (1–45)	2 (0.25–8)	6 (0.1–2)
Average number of cattle per household (range)	7 (3–10)	13(1–40)	4 (1–8)	7 (0–4)
Average number of sheep per household (range)	2 (0–6)	12 (0–28)	3 (0–6)	7 (0–5)
Average annual income-2005, US$ (range)	1,028 (295–2,585)	2,004 (200–7,877)	724 (74–1,846)	1,708 (92–7,384)
Household resource shifts				
Change interviewees indicated they have experienced in access to irrigation since 2000, %	More, 33 Same, 0 Less, 67	More, 10 Same, 10 Less, 80	More, 0 Same, 22 Less, 78	More, 0 Same, 0 Less, 100
Percentage of interviewees who indicated cattle holdings have increased since 2000	40	14	7	0
Percentage of interviewees who indicated sheep holdings have increased since 2000	50	18	7	0
Change interviewees indicated they have had in access to health post since 2000, %	More, 50 Same, 50 Less, 0	More, 50 Same, 29 Less, 21	More, 5 Same, 38 Less, 8	More, 67 Same, 33 Less, 0
Change interviewees indicated they have had in access to school for their children, %	More, 40 Same, 60 Less, 0	More, 30 Same, 50 Less, 20	More, 29 Same, 57 Less, 14	More, 23 Same, 62 Less, 15
Change interviewees indicated they have experienced in income since 2000, %	More, 30 Same, 50 Less, 20	More, 29 Same, 14 Less, 57	More, 8 Same, 31 Less, 61	More, 7 Same, 50 Less, 43

Table S4. Concentration of mining concessions by country of ownership, 2008

Company nationality	No. of companies	Total hectares held as concession	No. of mining claims	Percentage of all mining claims
Australia	6	241,065	176	1.57
Brazil	2	625,670	654	4.06
Canada	17	1,521,126	2532	9.88
Chile	1	35,498	52	0.23
China	1	65,545	84	0.43
India	1	75,400	101	0.49
Japan	1	82,848	224	0.54
Mexico	2	319,504	520	2.07
Peru	20	2,653,251	4802	17.23
South Africa	1	23,608	114	0.15
Switzerland	3	313,818	366	2.04
United Kingdom	2	228,234	315	1.48
United States	5	875,018	1185	5.68
Total	62	7,060,585	11,125	45.85

Table S5. Altitudinal distribution of all mining concessions in Peru

Elevation, m	Frequency, no. of claims	Total hectares	Percentage of total claims
1–1,000	7,078	2,637,859	17.10495
1,001–2,000	3,402	1,551,817	10.06261
2,001–3,000	4,816	2,232,555	14.47679
3,001–4,000	9,550	3,924,509	25.44811
4,001–5,000	12,031	4,784,466	31.02442
5,001–6,038	588	290,410	1.883136

Table S6. Water quality results for selected measures in Southern Cajamarca

Parameter concentrations (n = 45)	Baseline average 1991–1993, mg/L (n = 5)	Average discharge 1993–1999, mg/L	Maximum value, mg/L	Percentage of n above MYSA standards	Percentage of n above Class II standards	Percentage of n above Class III standards	Percentage of n above MEM standards
Dissolved solids	44.05	1,162	5,220	31	NA	NA	NA
Solids in suspension	NA	294	2,192	98	NA	NA	93
Copper	0.032	0.49	6.29	22	22	NA	22
Iron	1.24	23.76	93	76	76	76	76
Zinc	0.038	1.72	5.99	9	9	0	11
Manganese	0.04	5.10	17.56	80	80	76	NA
Potassium	0.85	2.48	9	NA	NA	NA	NA
Calcium	2.29	97	249	NA	NA	NA	NA
Sulfates	20.94	741	2,410	44	…	44	…
Sodium	1.81	154	1,560	NA	NA	NA	NA

NA, not applicable. Source, Bury (14).