Linking changes in knowledge and attitudes with successful land restoration in indigenous communities

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Successful land restoration in impoverished rural environments may require adoption of new resource management strategies; however, feedbacks between local knowledge and introduced restoration technologies have rarely been articulated. We used interview scenarios to analyze the role of local knowledge in land restoration at a large-scale, long-term watershed rehabilitation and wet meadow restoration program in the highland Andes. Indigenous communities built over 30,000 check dams, terraces and infiltration ditches, and the density of erosion control structures and visible restoration varied greatly across participant communities. We developed a survey reaching across the highest restoration management intensity, lowest restoration management intensity, and non-project (control) communities. We interviewed 49 respondents using 14 scenarios based on photos depicting biophysical phenomena related to land degradation and restoration. The scenarios generated 5,828 statements that were coded into 964 distinct concepts. As expected, respondents that built more erosion control structures had more detailed knowledge of check dam construction and ecosystem development following physical interventions. More significantly, there was a shift in the conceptualization of and attitudes toward land degradation and restoration. Respondents who built more erosion control structures were more likely to: attribute wetland hydrology to groundwater recharge rather than myth constructs about seeps and springs; attribute land degradation to human rather than mythological causes; and have more proactive attitudes regarding land restoration. Evidence suggests that when addressing severe land degradation or restoring ecosystem processes not readily observable by indigenous people, such as groundwater flow and wetland recharge, restoration success will depend on combining local and scientific knowledge.

Key words: Aymara, bofedales, check dams, coupled human-environment systems, land restoration, local knowledge

Implications for Practice

- Although local knowledge is often assumed to be a foundation for developing restoration technologies, there may be knowledge gaps that need to be addressed when restoring severely degraded lands or ecosystem processes not readily observable by indigenous people.
- Combining local and scientific knowledge can enhance land restoration success. Given the opportunity indigenous people can incorporate introduced restoration knowledge with traditional biophysical and cosmological concepts to create new knowledge that is empirically effective and culturally supportive.
- Experience with land restoration can lead to a profound shift in conceptualization of and attitudes toward land degradation and restoration, which are typically resistant to change. Perceptions of self-determination that evolve from land restoration are vital to confronting environmental change and enhancing sustainability.

Introduction

Land degradation is a threat to many rural agrarian communities (Gisladottir & Stocking 2005). Local and indigenous peoples can be effective in restoring degraded lands, and local knowledge is often valued as a source of restoration technology (Walters 2000; Long et al. 2003; Mingyi et al. 2003; Badola & Hussain 2005; Walton et al. 2006; Amede et al. 2007; Stringer et al. 2007; Blay et al. 2008; Botha et al. 2008). However, we argue that the extent to which local knowledge can in fact form the foundation for land restoration depends on (1) how much local knowledge remains extant in changing and modernizing societies, (2) the extent to which local knowledge and practices can adapt to changing contemporary conditions, (3) the degree to which effective restoration technologies are developed through farmer–scientist interactions that integrate local and introduced knowledge, and (4) how well novel technologies are successfully adopted and integrated by local people.

Local knowledge is comprised of empirical observations, generalized concepts, and attitudes. It is adapted to local environments over many generations, is embedded within local
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Figure 1. Study area, watershed rehabilitation, and wet meadow (bofedal) restoration program in the highland Andes.

cultures and mythologies, and is passed down through oral traditions (Agrawal 1995; Sillitoe 1998). Knowledge systems also respond to social and environmental change, which may lead to some loss of traditional knowledge and generation of new knowledge. For example, medicinal plant knowledge decreased with proximity to roads and larger towns in the western Amazon, indicating that accessibility of western health care decreased the dependence on traditional medicine (Vandebroeck et al. 2004). Another example relevant to the geographic region of this study is the large-scale terracing, irrigation and aquaculture systems, and reforestation carried out by the Inca and Tiwanaku civilizations (Erickson 1992; Chepstow-Lusty et al. 1998). However, much of this knowledge has been lost over time, to varying degrees across the Andes.

Indigenous societies may have little context for addressing the type and extent of land degradation resulting from modern road construction, mining, dams, high-population densities, and extensive land cover change. Most indigenous restoration practices are based on revegetation, species enrichment, wildlife management, and/or passive restoration after removing stressors (Uprety et al. 2012). Such practices can draw from traditional planting techniques, fallows or semi-nomadic lifeways that allow regenerative periods, and cultural taboos that restrict hunting or harvesting in certain areas or during certain time periods (Posey 1983; Decher 1997; Upadhaya et al. 2003). These strategies work well when impacts are limited to vegetative structure, plant and animal composition and abundance, or depletion of stores of soil nutrients and organic matter (Brown & Lugo 1994; Hobbs & Norton 1996; Lamb et al. 2005). However, when systems have been severely degraded by soil compaction, gully erosion, altered hydrology, contamination, or impairment of productivity and ecosystem function, restoration requires more significant investments in time, energy, and resources (Brown & Lugo 1994). Addressing severe land degradation may require new knowledge and restoration technologies that are not part of the store of traditional knowledge. This suggests that successful land restoration in many rural development settings may require interactions with outsiders leading to the development of hybrid knowledge systems (Thomas & Twyman 2004). The characteristics of each interaction will influence the degree to which restoration technologies are endogenously developed or adapted, are appropriate to local priorities and management systems, and are incorporated into indigenous cultures. Clearly articulating how feedbacks between local and introduced knowledge and technologies influence restoration success is vital to addressing land degradation in impoverished rural environments.

We analyzed the following questions about the role of local knowledge in land restoration: Does local knowledge of basic soil–water–plant relations, land degradation, and land restoration vary in relationship to land restoration activities and outcomes? In what ways do local knowledge and attitudes influence decisions about investing in land restoration? We answered these questions through research on a watershed rehabilitation and wet meadow (bofedal) restoration program in the highland Andes (Fig. 1). Severe gully erosion had impaired local livelihoods, and restoration efforts were initiated in 1992 as part of an effort to enhance water security and grazing sustainability. Local
communities built over 30,000 check dams, terraces, and infiltration ditches. This resulted in large-scale restoration (approximately 50 km²), as indicated by increased bofedal vegetation in gullies with check dams (36.5% cover) compared to gullies without check dams (7.3% cover), and a long-term increase in vegetation measured by normalized difference vegetation index (NDVI) (Hartman et al. 2015). There is a high degree of variability in the density of erosion control structures in project participant communities, and we compared the knowledge and attitudes of respondents in the four highest restoration management intensity, four lowest restoration management intensity, and four non-project control communities. We elicited knowledge about basic soil–water–plant relations, land degradation, erosion control structures, and bofedal restoration using scenario methods (Soleri & Cleveland 2005; Cleveland & Soleri 2007). As expected, respondents who had built more erosion control structures had more detailed knowledge of check dam construction, hydrology, and ecosystem development following physical interventions. However, respondents with greater empirical experience also exhibited a fundamental shift in the conceptualization of and attitudes toward land degradation and restoration. This is significant because the beliefs that form the cognitive structures that support environmental attitudes are highly resistant to change (Heberlein 2012). Enhanced understanding of what can cause a shift to more proactive resource management attitudes in indigenous communities has implications for land restoration, sustainability, and perceptions of climate change.

Methods

Study Area

This study analyzes a watershed rehabilitation and wet meadow restoration program located in the highland Andes. The study area is a traditional indigenous territory (Ayllu Majasaya-Aransaya-Urunsaya) in the Tapacarí Province, Department of Cochabamba, Bolivia. The main cultural group is Aymara, with a very small Quechua minority. Situated along the Cochabamba-Oruro Highway on the Eastern Cordillera of the Andes, elevations range from 3,800 to 4,650 m. The climate is semiarid, with 90% of the rain falling between November and March. Population densities are low (14.7 people/km²), with people living in isolated ranchos. Land management is based on grazing Puna grasslands (semiarid bunchgrass steppe) and bofedales (wetland systems with characteristic herbaceous vegetation that develops in seeps, springs, wet meadows, and floodplains, Squeo et al. 2006), with agriculture in the mesic valleys. Herd size ranges from 5 to 116 animals/family, mostly sheep and llamas.

There is a long history (7,000–8,000 bp) of human occupation in the Central Andes (Ellenberg 1979; Baied & Wheeler 1993; Chepstow-Lusty et al. 1998). Modern land degradation resulted from population growth, infrastructure development, overgrazing, and cultivation on steep slopes, which led to gully erosion, bofedal degradation, reduced agropastoral production, and deforestation of Polylepis woodlands (Siebert 1983; Harden 2001; Brandt & Townsend 2006). Bofedales provide vital dry season grazing, and degradation or destruction of this resource severely impacts local livelihoods. Land restoration efforts were initiated through a partnership between the Ayllu Majasaya-Aransaya-Urunsaya and the Dorothy Baker Environmental Studies Center (CEADB). The project grew to encompass over 30 communities and additional governmental and non-governmental organizations. CEADB training was based on a discussion of values, including local community responsibility for land degradation, the Andean value of reciprocity as a justification for land restoration, and land restoration as an investment in wellbeing. Information on erosion control construction techniques and soil–plant–water relationships was introduced in later stages. Resolving land tenancy disputes and revaluing traditional rites, customs, and social norms (described below) were central to project implementation. Local communities typically built check dams in community work groups (aines), starting at the headwaters and working downstream as gullies stabilized. In later stages, communities built terraces and infiltration ditches on slopes. Local communities built a total of 15,000–20,000 check dams, 9,100 terraces, 5,300 infiltration ditches, 36 gabions, 35 grazing exclosures, and 12 stock ponds, and planted 1,670 trees.

Andean Cosmology and Land Management

The Aymara system of land management is based on local knowledge that includes Aymara cosmology, which is animistic and is characterized by reciprocal relationships between entities in the human, natural, and supernatural realms (Van den Berg 1989; Delgado Burgoa 2001). An example of entities in the supernatural realm are the Apus, deities associated with mountains or mountain ranges which are considered essential to the maintenance of rain, water flows, and soil fertility. The relationships between the human, natural, and supernatural realms are maintained through adherence to behavioral norms, respect for natural law, and by practicing a complex series of rites, customs, and festivals (Delgado Burgoa 2001).

Aymara cosmology plays a strong role in shaping local perceptions of the root causes of land degradation and the potential for land restoration (Zimmerer 1993; Rist et al. 2003). At project inception in the early 1990s, gully erosion was attributed not only to heavy rains, overgrazing, and cropping on marginal slopes, but also to aspects of Aymara cosmology. According to CEADB project records (described below) and La Fuente (1997), local people perceived that social change and modernization had led to (1) the younger generations not performing the traditional rites and customs, (2) people not knowing how to read natural signs and “listen to the land,” (3) a proliferation of conflicts in the community, and (4) violations of natural law (e.g. abortions). The net effect of these changes was a disruption or disturbance to the reciprocal relationships within the human-natural-supernatural realms, with the consequence being that humans were “punished” with frosts, hail, erosion, and a loss of livelihood. In addition, Aymara cosmology holds that seeps, springs, and wet meadows come from deep inside the earth, rising up from the ocean through
veins in the mountains, or that springs come from frogs that congregate and urinate, therefore creating a puddling effect (Van den Berg 1989). In this conceptualization, humans cannot physically influence the function of seeps and springs, either positively or negatively. Therefore, erosion control structures were rejected as a viable option to restore the land. According to community members, the best restoration strategy was to revalue the rites and customs, teach the younger generations how to listen to the land, resolve disputes, and restore respect for natural laws. These approaches were conducted parallel to building some check dams on a trial basis see how well they worked. As people saw the efficacy of the check dams, they continued to build them, eventually adding terraces, infiltration ditches, grazing management, and reforestation.

In the Andes, there is a rich and effective tradition of pastoralism, terracing, irrigation systems, and reforestation dating back to pre-Inca civilizations (Erickson 1992; Chepstow-Lusty et al. 1998; Preston et al. 2002). Although the land restoration program in the study area used some technologies that are traditional in the region, others were novel. The Ayllu Majasaya-Aransaya-Urunsay was settled 250 years ago through internal migration by people who built homes in and around the rest areas (tambos) along the highland pass between what is now Oruro and Cochabamba. Modernization, land reforms in 1952, and western education confronted community members with new concepts, technologies, and institutional frameworks. In sum, a history of Spanish colonization, internal migration, and modernization induced a substantial loss of local knowledge. The knowledge system that survived these transformations included agropastoral traditions and practices, a system of weather and crop forecasting, cultural practices that contribute to sustainability, and a robust cosmology. However, the extensive terracing and irrigation systems of the Tiwanaku civilization and Inca civilizations were not extant in the region. When confronted with land degradation, local people were faced with the following choices: (1) become increasingly reliant on off-farm labor, (2) move to the city or to the lowland tropics, (3) reestablish traditional cosmological behaviors to restore the land, or (4) invest in the new land restoration being offered.

Sample Frame

The sample comprised the four highest restoration management intensity (HighRMI) communities, four lowest restoration management intensity communities (LowRMI), and four non-project control communities (NonProject) with negligible restoration management. Restoration management intensity (RMI) was defined as the density of erosion control structures (ECSs) (RMI = No. of ECSs/km²), which ranges from 14.7 to 225.3 ECSs/km² in project participant communities (CEADB project records). Study communities with similar geology soils and topography were identified in the Puna grassland zone (above 3,800 m). They were all part of the Ayllu system of organization, and adhered to similar social institutions, cultural norms and practices, agricultural production methods, and grazing management practices. However, control communities were not immediately adjacent to the study area to reduce the potential for spatial auto-correlation and ensure independence of the NonProject communities from the HighRMI and LowRMI communities. Respondents were male heads of household, because men build and maintain erosion control structures in the Aymara culture. All respondents had a similar background in agropastoral management, and typically spent up to 2–3 months in off-farm labor (e.g. construction worker, taxi/truck driver, merchant, and tailor). Within the HighRMI and LowRMI communities, respondents were selected from a household survey (n = 237) that was conducted in 2011 (Hartman 2014). The number of check dams, terraces, and infiltration ditches constructed in survey households were documented. HighRMI respondents were selected from the upper quartile of ECSs/family (58–501 ECSs), and LowRMI respondents from the lowest quartile (0–4 ECSs). The distribution of the respondents across the study communities is shown in Appendix S1.

Scenario Methods

Scenario methods were used in this study to quantitatively explore knowledge and attitudes in an indirect, rather than direct way (Soleri & Cleveland 2005; Cleveland & Soleri 2007). The scenario method is based on the assumption that it is possible to define an ontological comparator that is an unbiased description of basic biophysical phenomena and which forms the basis for eliciting knowledge and attitudes. One way to do this is by showing respondents a series of photos that depict biophysical scenarios and asking a series of questions about them, including what would happen in response to specific variables. Thus, scenarios serve as a platform for asking questions and engaging in a targeted and structured discussion. The scenarios used in this study consisted of 14 steps that transitioned through basic soil–plant–water relationships, erosion and land degradation, erosion control techniques, and bofedal restoration (Appendix S2). Field work was conducted from September 2012 to January 2013. A total of 49 respondents were interviewed in the HighRMI, LowRMI, and NonProject groups. Once a respondent was selected, if the respondent was not home at the time of survey the interview team returned multiple times to ensure the person was interviewed, was confirmed out of town up until the study period ended, or declined to conduct the interview. Compliance rate was high (96.1%). Support for the study was secured through the Aymara authority structure, and we conducted the interviews with one of three promotores recommended by local leaders, who helped facilitate the interviews and translate when necessary (see Appendix S2 for further information on interview protocols).

Data Coding and Analysis

Data coding was based on identifying response units that consisted of small, self-contained concepts (Appendix S3). Each concept was assigned to a knowledge category relevant to scenario topics, and themes were identified relevant to the research questions. Data were analyzed by knowledge categories, themes, and individual questions (Appendix S3), which allowed analysis based on larger number of responses (see
Table 1. Sample size and response rates for the scenario methods conducted at the study area, a watershed rehabilitation, and wet meadow (bofedal) restoration project in the highland Andes. The total number of responses (5,828) refers to the total number of individual statements made in the scenario interviews. These statements were then coded into 964 discrete self-sustaining concepts (response units) for the entire survey. See the Supporting Information for a description of the coding process. The total number of responses/person (mean ± SD) was calculated for the HighRMI, LowRMI, and NonProject respondents based on the number of discrete coded concepts, and the difference between groups was statistically significant (*p < 0.0001).

|                | Total No. of Respondents | Total No. of Responses/Person | Total No. of Responses | Total No. of Coded Concepts |
|----------------|--------------------------|-------------------------------|------------------------|-----------------------------|
| HighRMI        | 16                       | 134.2 ± 21.5                 | 1342 ± 215             | 964                         |
| LowRMI         | 15                       | 120.1 ± 16.8                 | 1201 ± 168             | 964                         |
| NonProject     | 18                       | 104.4 ± 16.8                 | 1044 ± 168             | 964                         |
| TOTAL          | 49                       | 118.9 ± 16.8                 | 5828 ± 168             | 964                         |

Appendix S3 for additional information on the coding process and how knowledge categories, themes, and individual questions were defined. Data were analyzed through one way analysis of variances (ANOVAs) assuming equal variance or a Browne–Forsythe one way ANOVA assuming unequal variance following a Levene’s test for equality of variances. In some cases, a least significant difference or Games-Howell post hoc multiple comparison of means was used and reported when statistically significant. One individual question (“how did you learn about nature and how to manage the land”) was analyzed through a 3 × 3 contingency table using Fisher’s exact test.

CEADB Project Records and Other Data Sources

The project history had been documented in CEADB project records that include community sketch maps, erosion control construction records, quarterly progress reports, annual evaluation reports, and results of participatory workshops. We also reviewed relevant working papers and thesis, conducted prior research in the area in 1996, and conducted semi-structured interviews in 2008 which provided background material for the scenario methods.

Results

Land Restoration Response Rates

There was a positive correlation between the number of responses/person and restoration management intensity, with the highest response rates for HighRMI respondents and the lowest response rates for NonProject respondents (Table 1). Moreover, the increased response rates were limited to knowledge categories relevant to watershed rehabilitation and bofedal

Figure 2. Knowledge about land restoration and management in the Ayllu Majasaya-Aransaya-Urunsaya. Responses are analyzed by the following knowledge categories: (A) SPW (soil-plant-water) includes statements about basic soil–plant–water relationships, (B) ErosCont includes statements about erosion control, including statements about the need for erosion control and construction techniques, (C) LandDeg includes statements about soil desiccation, destruction of vegetation, impacts to grassland productivity, and so on. (D) LandRest includes statements about land restoration, including restoration techniques and the effect on ecosystems following management interventions, (E) DescrEval includes descriptive statements and evaluation of the condition of the land, (F) AgroPast includes statements about agricultural and pastoral management, (G) GralMan includes general management statements, such as perceived consequences of land degradation, motives and perceived benefits for restoring the land, and general attitudinal statements, p values from a one way ANOVA assuming equal variance following a Levene’s F test for equality of variances, with (*) denoting a Browne–Forsythe one way ANOVA assuming unequal variance; error bars indicate standard error.
restoration (Fig. 2). There was a significant between-group difference in response rates about erosion control, land degradation, and land restoration. However, there was no difference in response rates in knowledge categories considered part of the local store of resource management knowledge, such as basic soil–plant–water relationships, descriptive statements about the condition of the land, and agropastoral management.

The HighRMI responses within knowledge categories revealed an in-depth and highly specific knowledge. For example, respondents provided detailed engineering specifications and design criteria for check dam construction (e.g. “check dams need to be protected with a V-notch to accommodate strong flows”; “check dams are more durable if we plant bunchgrasses and shrubs, the roots help hold the check dams in place”; and “check dams need to be built with flat stones placed at the base so the gully is not scoured out”). The total number of responses and the diversity of check dam design criteria cited were significantly higher in HighRMI respondents compared to LowRMI and NonProject respondents (Table 2). Some HighRMI respondents also cited restoration management recommendations that went beyond erosion control construction and grazing management techniques promoted as part of the land restoration program (e.g. “to improve the bofedal, dig ditches in the rocks on the slopes so the wind can bring seeds and the grass and other plants will grow”; “to improve the bofedal, plant bunchgrasses in rows or around the edges to retain water and trap sediments”).

### How Land Restoration Knowledge is Generated

The mean number of days/person spent in courses and working with promoters was significantly higher in HighRMI and LowRMI respondents compared to NonProject respondents (Table 3). When asked how they learned about nature and resource management, responses differed by group (Table 4).
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Figure 3. Conceptualization of the root causes of land degradation. Responses are analyzed by the following themes: (A) HumanCause includes statements attributing land degradation to overgrazing, vegetation removal, etc.; (B) NaturalCause includes statements attributing land degradation to heavy rains, hail, steep slopes, etc.; (C) MythConstr includes descriptions of the structure of nature derived from the traditional Andean worldview, in which the health of the land is determined by the relationship between the human, natural, and supernatural realms; (D) ClimateCh includes attribution of land degradation to human-induced changes in climate, including stronger rainfall events; (E) NoAgency includes statements about land degradation where no particular causal agency was specified. The \( p \) values from one way ANOVA assuming equal variance following a Levene’s \( F \) test for equality of variances, with (*) denoting a Browne–Forsythe one way ANOVA assuming unequal variance; error bars indicate standard error.

HighRMI respondents cited learning through empirical experience at significantly higher rates (e.g. “I learned in practice or by doing”; “we have been working the land and building erosion controls for years and that is how I learned”), and LowRMI and NonProject respondents cited ancestral knowledge at significantly higher rates (e.g. “I learned from my ancestors, this is an inheritance for us”; “I learned because I was born here and live here, with my neighbors”). The frequency with which “participation in courses and workshops” or “watching and observing the land” was cited as a source of knowledge did not vary among groups.

**Perceptions of the Root Cause of Land Degradation**

Response rates for conceptualization of the root causes of land degradation were evaluated by themes (Fig. 3). There was a
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Figure 5. Attitudes toward land degradation and management. Responses are analyzed by the following themes: (A) Proactive, self-determined attitudes include statements about the need to take care of the land and the local ability to build erosion controls; (B) Passive, fatalistic attitudes include statements reflecting the lack of care for the land and the lack of hope that anything can be done to address erosion; (C) Dependent attitudes include statements that institutional support is needed to address erosion. The \( p \) values are from one way ANOVA assuming equal variance following a Levene’s \( F \) test for equality of variances, with (*) denoting a Browne–Forsythe one way ANOVA assuming unequal variance and (**) denoting significant difference between HighRMI and the LowRMI and NonProject groups only.

Table 5. Perceptions of appropriate stocking rates for a 4 ha bofedal. Respondents were asked to evaluate conditions in a bofedal impacted by erosion and sediment deposition, and to make management recommendations. In order to measure perceptions of the effect of management recommendations, respondents were asked to indicate llama stocking rates before they made the management recommendations, and then estimate stocking rates after they made management recommendations. The \( F \)-scores and \( p \)-values from a one way ANOVA assuming unequal variance following a Levene’s \( F \) test for equality of variances \( (df = 46) \); data presented as mean ± SE.

| Question                                                                 | HighRMI          | LowRMI           | NonProject       | F Score | p Value |
|--------------------------------------------------------------------------|------------------|------------------|------------------|---------|---------|
| How many llamas can be grazed in the bofedal in its current condition?   | 15.6 ± 3.3       | 32.0 ± 8.3       | 116.4 ± 31.2     | 7.73    | 0.001   |
| How many llamas can be grazed in the bofedal after implementation of     | 23.2 ± 3.3       | 48.2 ± 9.5       | 124.2 ± 30.3     | 9.11    | 0.001   |
| management recommendations?                                              |                  |                  |                  |         |         |

statistically significant increase in the mean number of statements attributing land degradation to human causes, with response rates highest in HighRMI respondents and lowest in NonProject respondents (e.g. “If there are too many animals, the bofedal will dry out and become bare”; “this land has been eroded or washed away because we have removed so many trees”). This is contrasted with an increased rate at which myth constructs were used to explain natural phenomena and land degradation in NonProject respondents (e.g. “The water in the spring [juturi] flows like a vein from deep inside the earth or from the heart of the mountain”; “the water is transported through veins from the sea as we live over the ocean”; “the water in the spring comes from the frogs that have urinated there”). There was no between-group difference in the rate at which land degradation was attributed to natural causes (e.g. “the erosion is caused by hail and heavy rains,” “this land is eroded because it is very steep”), or human-induced climate change (e.g. “this land is eroded because the rains are heavier with this new climate change”). The most common theme for all response groups was land degradation due to natural causes. However, statements about land degradation sometimes were made where no causal agency was specified. In this case, response rates were highest in HighRMI respondents and lowest in NonProject respondents.

Management Approaches to Land Restoration

Response rates for approaches to land restoration were also evaluated by themes (Fig. 4). HighRMI respondents discussed land restoration as a process of building erosion control structures or in terms of revegetation and ecosystem management at significantly higher rates (e.g. “for this land to improve or recover, we need to plant grasses and bunchgrasses”; “in check dams, if there is black soil the bofedal vegetation can appear quite rapidly”; “to improve the bofedal, build infiltration ditches to maintain water and the green vegetation”). NonProject respondents discussed land restoration in terms of agricultural intensification to improve the land at a higher rate (e.g. “we need to build irrigation canals and bring water to the bofedal”; “we need machinery to do erosion control, we can level out the gullies
and then plant”; “the bofedal can improve or recover if we plant improved Phalaris grass”). The most common land restoration themes across all response groups were related to erosion control and ecosystem development.

Hydrology, Check Dam Construction, and Bofedal Vegetation

Community members were asked to evaluate the influence of check dams on hydrologic flows and bofedal growth in gullies (Table 2). HighRMI respondents were more likely to attribute standing water in gullies to check dams than LowRMI and NonProject respondents (e.g. “the water in the gully comes from the check dam that has detained or impounded the rainwater; the check dam acts like a filter and water always flows out of the bottom”). HighRMI respondents were also more likely to attribute bofedal vegetation in gullies to check dams (e.g. “the bofedal is growing in the gully because there is a check dam, it detains water and a bofedal is created, and the grasses stay green all year long”; “the bofedales in the gullies are protected and maintained by the check dams, if not the rain washes them away”). This is contrasted with the increased rate at which LowRMI and NonProject respondents attributed standing water and bofedal vegetation in the gullies to a “‘vein’ in the mountain that has created a spring (e.g. “the water in the gully comes from a spring [jatuter], the gully must have cut through a vein that transports the water from the ocean”; “the bofedal is growing in the gully because there is a vein that brings water up from deep inside the earth”). Water flows in bofedales were attributed to a combination of river flows, runoff from the slopes, and the presence of a larger vein (or multiple smaller veins) in the bofedal by all groups.

Bofedal Restoration

Community members were asked to evaluate the condition of a degraded bofedal and make management recommendations. There was a significant difference in the management approaches between the groups (Table 2). The HighRMI respondents more frequently cited restoration approaches that rely on erosion control (e.g. “check dams in the gullies and terraces on the slopes maintain the bofedal; the water is retained and filters in bit by bit, so the bofedal will be green like it is full of springs”; “to improve the bofedal, build check dams so the sand does not wash down and cover the bofedal”), revegetation techniques (e.g. “to improve the bofedal, plant grass in the bare areas”; “we need to plant grass and kiswara (Buddleja incana) in the rocks so that they can receive the water and create more bofedal”), and grazing management (e.g. “we have to protect this bofedal from grazing for some time, so it can recover, it will be nice and green if we don’t put any more animals on it”; “to improve the bofedal, we need to organize to do grazing management, we can fence it off and do rest-rotation grazing”). In contrast, NonProject respondents more frequently cited management strategies based on agricultural intensification methods such as mechanization, irrigation, and building engineered structures (e.g. “to improve the bofedal, we need to find water and irrigate or store water with a dam”; “to improve the bofedal, we can raise more llamas, alpacas, and sheep, this bofedal needs more animals”).

Respondents were shown a picture of a 3–4 hectare bofedal, and asked how many llamas they would recommend grazing there. NonProject respondents recommended significantly higher stocking rates compared to HighRMI and LowRMI respondents (Table 5). Some HighRMI and LowRMI respondents explicitly stated that stocking rates should be determined based on ecosystem condition (e.g. “if we graze any more animals than that, the bofedal will be left bare”), suggesting increased recognition of the role of grazing in land degradation. All groups indicated stocking rates could increase following restoration management, but the magnitude of suggested stocking increase was similar across all groups.

Attitudes Toward Land Degradation and Restoration Management

Attitudes toward land management reflecting community members’ willingness to act in response to erosion and land degradation were evaluated by themes (Fig. 5). HighRMI and LowRMI respondents made more statements about the need to protect or maintain the land over time (e.g. “we can do something to maintain the soil, a lot depends on just taking care of the land”; “we have to follow up and monitor erosion controls, check dams need to be maintained every year”). In contrast, LowRMI and NonProject respondents made more statements about the local inability to address land degradation (e.g. “there is nothing we can do to fix the erosion, there is no hope, we just have to endure until we die”; “we look at the erosion in vain, even though people complain about it we don’t do anything to control it”) and the need for outside support to address land degradation (“we need help from the institutions to face the erosion, we need projects, training, materials, funds”).

Discussion

The results suggest that local knowledge has evolved in response to land restoration initiatives. There was a positive correlation between restoration management intensity and response rates related to watershed rehabilitation and bofedal restoration, but not in response rates related to basic soil–plant–water relationships or agropastoral management. Contact with outside scientific concepts did not explain all of the increased response rates, as the difference in the number of days spent in courses and working with promoters is only statistically significant when comparing the project area with the non-project area, not between LowRMI and HighRMI. Based on the answers to the question “how did you learn about nature and resource management,” direct experience with constructing erosion controls and observing ecosystem responses likely played a stronger role in increasing land restoration response rates. We suggest that new land restoration knowledge has grown out of feedbacks between doing and learning, and observing the biophysical effect of erosion control structures.
The scenario responses show that HighRMI respondents have a greater understanding of how check dams affect water flows and bofedal vegetation. HighRMI respondents more commonly attributed the presence of standing water and bofedal vegetation in gullies to check dams. In contrast, the NonProject and LowRMI respondents more commonly cited myth constructs in describing how seeps, springs, and bofedales function. As previously discussed, Aymara cosmology plays a strong role in shaping perceptions of the root cause of land degradation (Zimmerer 1993; Rist et al. 2003), and originally created a disincentive for building erosion control structures to restore the land. We suggest that the Aymara were not historically able to observe groundwater flow, and that missing information was filled in by a myth construct explaining the function seeps, springs, and wet meadows. Construction of erosion control structures induced observable ecosystem changes such as sedimentation, increased infiltration, and water retention, and establishment of bofedal vegetation in gullies (Hartman et al. 2015). Empirical experience and direct observation of gully incision and the hydrologic effect of check dams led to a greater understanding of wetland recharge. Direct observation also led to a greater appreciation for the role of erosion control structures in restoring bofedales. The Aymara integrated these observations with traditional biophysical concepts, agropastoral management systems, and myth constructs to generate new knowledge that enabled restoration success.

It is important to note that local knowledge and myth constructs can be compatible with sustainable resource management (Berkes et al. 2000), and will not invariably conflict with land restoration. For example, Orlove et al. (2000) documented traditional Andean drought forecasting based on observations of the brightness of the Pleiades made during the solstice festival of San Juan, which is correlated with high altitude cirrus clouds during warm El Nino years. Myths supporting the establishment of sacred groves led to enhanced plant and wildlife diversity in West Africa (Decher 1997) and in India (Upadhyaya et al. 2003). Finally, ancestral knowledge and myth constructs provided a foundation for developing riparian restoration strategies with the White Mountain Apache (Long et al. 2003) and the Zuni (Norton et al. 2002) of the southwestern United States. We found some evidence of an alternate pathway for evolution of restoration knowledge based on Andean cosmology. One respondent described how check dams impound water from the “veins” (e.g. “the check dams capture the water from the veins, like a cup”). Respondents also cited mechanisms by which “veins” could be damaged by human activities (e.g. “without check dams the vein will be washed out and eroded, and the bofedal will dry up”). Aymara cosmology was also invaluable in calling attention to conflict resolution and restoring social norms and institutions as essential elements of land restoration (Rist et al. 2003; Hartman 2014). This was facilitated by the willingness of CEADB to listen to local voices, plan collaboratively, and include all perspectives so that a complete understanding of the restoration process can emerge. In other words, effective communication that highlights similarities and resolves tensions between local and scientific knowledge can lead to more effective land restoration interventions (Briggs 2005; Fairhead & Scoones 2005; Cleveland & Soleri 2007; Sillitoe & Marzano 2009).

The scenarios suggest that there are different bofedal restoration strategies in the HighRMI, LowRMI, and NonProject groups. Bofedal restoration is a highly complex undertaking that requires management of multiple variables, including vegetative cover, water flows, erosion, infiltration, and groundwater recharge. Knowledge of bofedal restoration implies a synthesis of information from several sources, including local or ancestral knowledge, empirical experience, training, and contact with promoters. The HighRMI respondents more commonly cited bofedal restoration based on erosion control structures, agropastoral management, and ecosystem development, suggesting a greater contribution from direct empirical experience, observation, and traditional pastoral management as a restoration tool. In contrast, NonProject respondents more commonly cited bofedal restoration as improvement through agricultural intensification. It appears that NonProject area perceptions of bofedal restoration are extrapolated from prevailing models of agricultural development, which includes increased material inputs, mechanization, and infrastructural development. The agricultural intensification knowledge likely grew out of a different type of interaction with extension agents and development professionals in the region. Although agricultural intensification plays a role in rural development in the Andes, it is distinct from the hydrology and ecosystem management knowledge required for bofedal restoration.

The respondent groups had different attitudes reflecting the local willingness to act in response to land degradation and invest in land degradation. HighRMI respondents were more likely to attribute land degradation to human causes rather than to myth constructs about the way the world is structured. With increased restoration management intensity, there was also an increase in statements reflecting the local ability to protect or maintain the land. In contrast, the LowRMI and NonProject respondents were more likely to make statements about the local inability to address land degradation, or to discuss the need for outside aid or institutional support to address land degradation. By delving deeply into responses to specific questions about environmental management, the scenario approach makes it clear that the restoration process has increased perceptions of self-determination and the local ability to address land degradation. These results suggest that direct experience, rather than training associated with technology transfer, is the key ingredient to changing environmental attitudes supported by a cognitive structure of observations, beliefs, and values (Heberlein 2012). Social variables that facilitate or constrain land restoration decisions, e.g. accessibility, conflict resolution, and institutional arrangements (Agrawal & Gibson 1999; Hartman 2014), may also be more important than training to promote land restoration in rural development settings. We speculate that social differences influencing the rate of adoption of novel technologies and erosion control construction eventually lead to positive feedbacks between doing and learning, which then amplify the differences in restoration management intensity over time.

In conclusion, indigenous people can be effective at land restoration, given sufficient social mobilization and adoption
of new management technology when necessary. Large-scale restoration was achieved in a highland Andean system using a combination of intensive erosion control techniques and extensive grazing management. The degree of gully erosion and system degradation in the study area did not historically exist in the Andes, and several restoration techniques were novel to the region. This study is an example of an indigenous group that incorporates introduced restoration knowledge with traditional biophysical and cosmological concepts to create new knowledge. We argue that combining local knowledge with outside scientific knowledge will be necessary when addressing severe land degradation, or when restoring ecosystem processes not readily observable by indigenous people, e.g., groundwater flow and wetland recharge. Other examples where such a knowledge gap exists can be identified in future research. For example, local oral traditions and scientific convention held that remnant *Polylepis* woodlands in the highland Andes were restricted to microclimates in ravines and on talus slopes, and therefore could not be restored (Ellenberg 1979). Advances in plant propagation, systematic surveys of *Polylepis* woodland distribution, and observations of successful reforestation on till slopes where seedlings were protected from grazing and fire induced a paradigm shift that facilitated restoration efforts (Kessler 2002). The need to fill knowledge gaps has implications for other fields, such as perceptions of climate change in traditional societies not able to observe all portions of atmospheric processes. We also find that land restoration can be associated with a profound shift in attitudes toward land degradation to more proactive investment in land restoration. Moreover, proactive investment in land restoration translated to significantly lower rates of outmigration in HighRMI communities (29.1% families emigrated) compared to LowRMI communities (70.3% families emigrated) (Hartman 2014). Lower outmigration rates, combined with greater forage availability and water security from erosion control structures, can positively impact local livelihoods and contribute to the sustainability of a coupled human-environment system. This suggests that land restoration is a mechanism through which indigenous people can exert influence over environmental change, and potentially steer the trajectory of their own development and cultural evolution.

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Supporting Information
The following information may be found in the online version of this article:

Appendix S1. Distribution of respondents for the scenario methods.
Table S1. Geographic distribution of the respondents for the scenario methods, watershed rehabilitation, and wet meadow (bofedal) restoration project in the Ayllu Majasaya-Aransaya-Urunsaya.

Appendix S2. Scenario Interview protocols.
Figure S1. Scenario methods used in the study.

Appendix S3. Data coding.
Table S2. Examples of the coding process used for the scenarios used in the watershed rehabilitation and wet meadow (bofedal) restoration project, Ayllu Majasaya-Aransaya-Urunsaya.

Table S3. The knowledge categories, themes, and individual questions that were used to analyze the coded responses, watershed rehabilitation, and wet meadow (bofedal) restoration project, Ayllu Majasaya-Aransaya-Urunsaya.

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