The Importance of Traditional Ecological Knowledge in Agroecological Systems in Peru

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The importance of traditional ecological knowledge in agroecological systems in Peru

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ABSTRACT
This study argues that a critical element in the success of an ecosystem service (ES) approach at any level is the higher qualitative valuation of local traditional ecological knowledge (TEK). As such, the objectives of this research were to illustrate the role of TEK in agroecological systems in Peru and to develop recommendations about this type of knowledge acquisition. The data were gathered using interviews and focus groups with subsistence farmers along with key informant interviews to elicit TEK at local and regional scales in five provinces in the Lake Titicaca region of Puno, Peru. Qualitative analysis revealed dominant themes of TEK provided by farmers and key informants, and how this knowledge can enhance the application of an ES approach for environmental management. Climate variability, predicting the timing of seasonal changes, water availability, and adapting the agricultural calendar and agricultural techniques were all central themes. This research concludes that environmental management decisions in the Puno region of Peru are being informed and improved through the use of TEK. Supporting previous research, we propose that agroecological systems, at their core, need to respect the integrity and sanctity of TEK and value it properly within any practical solution for environmental resource management.

1. Introduction
The modern-day concept of ecosystem services (ESs) initially emerged in the 1970s through a dialogue between biology and economics, in an effort to better manage the relationship between humans and nature (Lele et al. 2013). The Millennium Ecosystem Assessment (2005) defines ES as ‘the functions and products of ecosystems that benefit humans,’ and categorizes these services into four broad types: provisioning (e.g. the production of water and food), regulating (e.g. the control of climate and flood), cultural (e.g. spiritual and recreational benefits), and support services (e.g. soil formation, primary production). Since its emergence, this concept has become the foundation for a diversity of literature that measures, assesses, and values aspects of human reliance on nature for the sake of conservation and sustainable resource use (Lele et al. 2013).

The increasing global acknowledgement of the value of ES approaches for sustainable development is evinced by recent developments such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), an intergovernmental body comprised of over 120 governments whose mission is ‘to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development’ (IPBES 2016). Despite the growing popularity of ES approaches, there are still a number of limitations, particularly when it comes to integrating traditional ecological knowledge (TEK) to reflect social, cultural, and other nonmaterial values assigned to local resources (Chan et al. 2012b).

TEK refers to any type of context-specific knowledge held by a society or culture that references their local environment (Boafo et al. 2016). Berkes et al. (2000) distinguish TEK from Western science in that the former is often passed down through everyday rituals and cultural practices, rather than through formal reports or peer-reviewed publications. Yet, in recent decades, research has shown that TEK has the capacity to contribute meaningfully to topics such as biodiversity conservation, ecosystem dynamics, community resilience, and sustainable resource use (Berkes et al. 2000; Gadgil et al. 1993; Gómez-Baggethun et al. 2012; Ruiz-Mallén & Corbera 2013); hence, it ought to be considered in any assessment of ESs. The IPBES even highlights the importance of TEK in its fourth operating principle: ‘Recognize and respect the contribution of indigenous and local knowledge to the conservation and sustainable use of biodiversity and ecosystems’ (IPBES 2016).

However, there is still a struggle for practitioners to meaningfully integrate social and cultural
perspectives gained from TEK into on-the-ground ES approaches (Fisher et al. 2009; Lele et al. 2013). In fact, a 2012 survey of ES studies in Latin America revealed that there was no significant analysis of the role of TEK (Balvanera et al. 2012). Current application of the ES approach still emphasizes the monetary valuation of tangible services, which is much more amenable to measuring provisioning-type services, such as food production. As a result, cultural services, which are less tangible and require an understanding of TEK, may be absent from the approach or their valuation is relatively discounted compared to tangible services (Winthrop 2014). This could lead to the exclusion or underrepresentation of cultural services in any resulting decision-making framework (Chan et al. 2012a; 2012b).

Practical applications of ES approaches can gain more practitioners through the proper inclusion of TEK. For example, the traditional practice of combining water and land management techniques was an essential agroecological adaptation that led to the expansion of the Tiwanaku civilization in the Lake Titicaca basin (Brush & Guillet 1985; Erickson 1988; Janusek 2004). Such historic systems of land management compose a portion of modern TEK in the Lake Titicaca region. The local adaptations in soil and water management that can be observed today in this region were pioneered by the ancestors of the modern dwellers of this area. Through such historic and highly cultural perspectives, environmental managers, ecologists, and anthropologists can develop contextualized solutions to environmental issues in the Andes and elsewhere.

Utilizing a case study approach in Puno, Peru, this research had two major aims: (1) to document the relationship between TEK and the management of agroecological systems in the context of ES approaches (2) to provide recommendations on elicitation of TEK and how this can benefit the practical application of ES approaches.

2. Using TEK to assess social and cultural values in agroecology

The practice of assessing social and cultural values using TEK in an agroecological context has been documented in numerous research studies (e.g. Vedwan 2006; Von Glaserapp & Thornton 2011; Calvet-Mir et al. 2012; Tengberg et al. 2012; Mohri et al. 2013; Celentano et al. 2014; Gould et al. 2014; Landreth & Saito 2014; Boafo et al. 2016). Each of these studies demonstrates in some way that using TEK to assess social and cultural values is integral to informing environmental management decisions.

For example, in a case study of four rural communities practicing rain-fed agriculture in Ghana, Boafo et al. (2016) concluded that the loss of TEK transmission through successive generations in Ghana could negatively affect ES management, and that Ghana should mainstream TEK into the formal education system starting at a primary level. In another example, Calvet-Mir et al. (2012) conducted an assessment of ESs supplied by home gardens in northeastern Spain, noting that – according to informants’ local knowledge and perceptions – cultural services were the most valued category provided by these agroecosystems. Moreover, the contribution of home gardens to the enhancement of cultural identity and development of sense of place generated opportunities for knowledge building practices that improved ES management (Calvet-Mir et al. 2012). The value of these cultural services likely would not have been reflected in traditional, more quantitative ES approaches. Hence, it is necessary for ES approaches to use TEK to assess social and cultural values in agroecology to increase the awareness about local conditions and to improve the management of the natural resources.

In the Lake Titicaca basin of the Andes, traditional agroecological methods have been recently reemerging to conserve soil and water resources, including the use of q’oñañas (form of water harvesting using clay layer of soil to maintain water level in small ponds), q’ochas (superficial depression to capture water in rainy season and cultivate in dry season), waru waru (also known as camellones, these are raised fields with canals on both sides, used throughout pre-Hispanic Latin America), and andenes (teraced hillsides used for planting surface). Considering the prominence of these traditional approaches and the interconnectedness of humans and nature in the Andean worldview, there is a need for more research about how to utilize TEK to better integrate social and cultural values into ES approaches.

Furthermore, various researchers have pointed to the lackluster treatment of ethno-ecology and its corollary cultural services within the approach of ESs (e.g. Chee 2004; Hodgson et al. 2007; Bryan et al. 2010; Fish 2011; Seppelt et al. 2011; Luck et al. 2012; Chan et al. 2012a, 2012b). Martin et al. (2010) advocate for the inclusion of TEK for environmental management and ecological engineering. It is within this gap, in an attempt to integrate TEK into ES assessments, that this research falls.

The operational model upon which the current study is based was designed by Cowling et al. (2008) to institutionalize the use of ES assessment, planning, and management within daily decision-making processes of natural resource management organizations. Cowling’s three-phase model was an attempt to avoid...
the ‘societal irrelevance’ (Cowling et al. 2008, p. 9483) of technological elitism that so often characterizes the bandwagon approach to water and land management. The first phase of their model – the assessment phase – is what this research built upon to create recommendations for the inclusion of TEK within ES assessments in order to improve planning and management decisions. Central to this study’s goal of formalizing the integration of TEK into ES approaches in Puno, Peru, is the idea that regional planning language should reflect the need to listen to community values and integrate them with other forms of knowledge within the construct of ESs for environmental management (Raymond et al. 2009).

3. Description of study area

The Puno region of Peru is located in the northern portion of the Lake Titicaca water basin (Figure 1). The Lake Titicaca basin encompasses an area of 57,000 km² in the southernmost portion of Peru. The Lake itself shares an international border with Bolivia, and it is divided almost evenly between both countries (Erickson 2000). This area is characterized by its high elevation and small villages dotting the valleys between the peaks that make up the Andes. Further characterization of this Andean region includes a unique type of environment called the altiplano or high plains. At night, frigid temperatures can prevail caused by loss of heat through low atmospheric density, an absence of clouds, and low vapor pressure. Nighttime temperatures can fall below freezing any time of year, especially at higher altitudes (Thomas & Winterhalder 1976). Daily average air temperatures can range from −10°C to 23°C ([UNESCO] United Nations Educational, Scientific and Cultural Organization 2015). The climate in the Lake Titicaca basin is marked by great hydrological interannual irregularity ([UNESCO] United Nations Educational, Scientific and Cultural Organization 2015). Precipitation can vary between 200 and 1400 mm per year. Winters are dry and summers are wet, with the rainy season lasting from December through March ([UNESCO] United Nations Educational, Scientific and Cultural Organization 2015).

The field portion of this research was conducted in 12 villages, located in five culturally and biophysically similar provinces in the Puno region of Peru: Puno, San Antonio de Putina, El Collao, Huancane, and Moho. Over 41% of the Puno region’s inhabitants are Quechua-speaking and more than 30% are Aymara speakers (RNIEC 2016). Quechua families represented the majority ethnic group in each of the five provinces in which fieldwork was conducted.

Subsistence farming is the main socioeconomic activity in this area, with crops including common highland cultivars such as potatoes, barley, oats, quinoa, broad beans, and minor tubers (Painter 1984). While most of the year is spent preparing the ground for sowing, tending to crops, or reaping, some inhabitants may spend spare time and money producing livestock for market. Alpaca, chickens, cows, sheep,

![Figure 1. The Puno Region is located in the southeastern most part of Peru, in the Lake Titicaca Basin.](image-url)
and guinea pigs are raised for meat, milk, and other products for both personal consumption and for sale at local markets (FAO 2006). Guinea pig management is the current focus of several nongovernmental organizations (NGO) working in the Puno region due to the ease of care, the increasing local market demand and the small cash expenditure required for maintenance. The basic unit for production is the household, consisting of extended family members. Running water and electricity are not available in households, but sometimes in communal properties such as municipal offices.

The prominent religion is syncretic, consisting of traditional animism and spiritualism blended with Catholicism (Di Salvia 2011; Sigl 2011). For example, both the Quechua and Aymara cultures worship the Pachamama, or Mother Earth, which has been superimposed with the Catholic belief in the Virgin Mary. However, many traditions and rituals have survived and are commonly practiced as part of the agricultural calendar. These rituals are a way of showing respect to the Earth and the crops that sustain the communities. Observed biophysical signs in the environment are used as a way of determining the best time to plant, how the weather will affect the crops, and whether it will be a productive season (Wust & Solano 2005).

4. Methodology

4.1 Data collection and analysis

Qualitative data were collected from 6 May through 19 June 2013 during an internship with a nongovernmental organization called El Instituto Peruano de Investigación Quechua Aymara, ‘JATHA-MUHU,’ whose mission is to promote local sustainability and self-sufficiency through strengthening organizational networks and providing training for young Quechua and Aymara leaders. Data collection methods included (1) semi-structured interviews with key informants from local nonprofits and municipal government agricultural and development organizations; (2) focus groups with local citizens including both male and female indigenous Quechua and Aymara subsistence farmers; (3) individual semi-structured interviews with male and female indigenous Quechua and Aymara subsistence farmers; and (4) participant observation.

A total of 15 key informant interviews were conducted, beginning with sponsors at JATHA-MUHU who then recommended other key stakeholders from local nonprofits and municipal government agencies. These interviews took place at the respective institution of the informant being interviewed. Key informants were asked questions about their background knowledge regarding ES approaches (in general), and how they perceived such approaches to fit in with Quechua and Aymara worldviews and practices related to environmental and natural resources. Each interview lasted about 30 min.

In addition to the key informant interviews, 26 individual semi-structured interviews were conducted with local Quechua subsistence farmers in the Puno region. Participants were selected based on current involvement and survey activity with JATHA-MUHU. During the NGO’s survey activities with individual farmer households, participants were asked if they would also be willing to participate in an interview about TEK. Interviews usually took place in the farmers’ homes, and these interviewees were asked a different set of questions from the key stakeholders in order to learn about their farming practices, the significance of local natural features and resources and their perceptions of conservation and sustainability. After feedback from initial farmer interviews, the questionnaire was modified with help from fellow investigators at JATHA-MUHU for the sake of time and comprehension.

Five focus groups with subsistence farmers were then conducted, and these took place in various locations across the five provinces in the study area where the host institution had already arranged group meetings. The smallest focus group had 6 participants, whereas the largest consisted of 22 community members and subsistence farmers from the village of Calacala. Individual interviews lasted 30–45 min, while focus groups tended to last slightly longer because of their interactive nature.

All participants from both the key informant interviews and subsistence farmer interviews/focus groups gave verbal informed consent to participate in the research. The research was approved by the Institutional Review Board (IRB) office at the University of South Florida. For stakeholder interviews, citizen interviews, and focus groups, questions were asked in Spanish and responses were documented in field notes and audio-recorded with consent.

Once transcriptions from stakeholder and farmer interviews and focus groups were translated to English, the content was inductively analyzed by drawing out recurring themes and key words. During this qualitative content analysis, information on local values and useful concepts related to TEK was extracted and synthesized. Section 5 presents and discusses four predominant themes that arose during data analysis.

While the bulk of data were collected through focus groups and semi-structured interviews, participant observation was also a critical aspect of the research design. These three data sets were cross-referenced during analysis to ensure that there were no contradictions in accounts of existing cultural norms and traditions, though people’s perceptions of those norms
might vary. Observations took place in the field on a weekly basis in two provinces of Puno: Puno and San Antonio de Puntina. Local narratives and empirical evidence were collected to assess how local ethno-ecology can contribute to the improvement of a practical approach to ESs and its applicability to other locations and natural resource management projects.

### 4.2 Methodological limitations

Although most inhabitants of the provinces in the study area speak Quechua or Aymara in their communities, Spanish is commonly spoken as a second language; however, language barriers may still have been present to some extent. Audio-recordings were transcribed by a student at the University of the Altiplano and then translated into English. As with any translated text, some intricacies of respondents’ statements may have been altered.

Also, due to the short time frame of the field investigations, the internship host institution and project sites served as platforms from which to conduct investigation. As a result, responses may more prominently reflect the views of communities which are actively involved with JATHA-MUHU projects rather than the views of the Puno region as a whole. Another limitation is that the interview was not pilot-tested with a community not participating in the study, but rather adjusted after the initial interviews took place. So, the same questions were not asked to all informants.

There was also a marked lack of participation among women. Because gatherings for focus groups were prearranged by JATHA-MUHU, there were logistical barriers to separating the groups by gender. In focus groups, men were noticeably more apt to speak up first and contribute answers than women. However, women do participate in planting and harvesting activities, so traditional knowledge also resides with them.

Finally, in the 6 weeks of field investigation, the elicitation of more expressive answers or more explanatory information about TEK was slow to advance. Key informants explained that this was likely due to a lack of trust on the part of the indigenous community members that comprised focus groups. Subsistence farmers were hesitant to be entirely forthcoming with this type of knowledge for a foreign researcher they had only known for a short period of time.

### 5. Results and discussion

#### 5.1 The complexity and necessity of TEK

Trying to understand how TEK relates to the practice of local environmental management is extremely complex. There are two basic reasons for this, gleaned from the data. The first is that assessing the benefits of ESs requires a multidisciplinary and detailed understanding of the ecosystem and its host culture. This emphasizes the value of an ethnographic approach to qualitative research that is time-intensive. The second is that it is often difficult to create a mutually exclusive category for any single ES. One ES may have multiple layers of value or meaning in social, economic, and ecological realms.

While Millennium Ecosystem Assessment (MA) (2005) and other proponents of ES approaches have identified four types of services provided by an ecosystem, they tend not to address the fact that ESs can fit more than one category at a time. For example, in Peru, the Lake Titicaca ecosystem has provisioning benefits, supplying material resources such as fish, drinking water, and reeds for construction. At the same time, the ecosystem provides nonmaterial, cultural benefits such as the spiritual belief that the Lake was the fount of mankind from which the Inca God Viracocha rose and made the first Inca, Manco Capac and Mama Occllo. The lake is still considered a sacred place today.

Furthermore, within the ontology of indigenous relationships with their ecosystems, spiritual, social, and ecological domains are integral parts of the long-term management of life on earth, as opposed to ‘contemporary western conventions of thought and practice [which] seek to separate the spiritual, the social and the ecological and to separate rights and responsibilities.’ (Jackson 2006, p. 27). This particular worldview holds true for the Aymara and Quechua people that were interviewed as part of this research. Quechua and Aymara see themselves as keepers of the Earth and look at the Earth or its anthropomorphic symbol, Pachamama (Mother Earth) as the keeper of all living and nonliving things on Earth. This is an intimate relationship in which social, cultural, and ecological are all part of a single web of knowledge, symbols, meanings, and survival. Thus, it is only through this traditional worldview that an environmental manager can come to understand the ecological backdrop against which they will find the best solution that will both last and be acceptable to the people.

#### 5.2 The chacra, where all life and knowledge resides

The reciprocal nurturing relationship between the Earth and Quechua and Aymara people in the altiplano was central to respondents’ understanding of ecosystem management. Every activity is seen as an act of creation, an act of rearing. Even water management is perceived as an act of nurturing and rearing water. Without considering this relationship between
culture and ecology in ES approaches, the water or natural resources manager cannot provide an appropriate solution to water scarcity and other water management challenges, as such intimate, traditional knowledge ‘is a summation of millennia of ecological adaptation of human groups to their diverse environments’ (Berkes et al. 1995).

This nurturing relationship was evident in respondents’ discussions of the chacra, or cultivated fields. The soul of the Andean altiplano man and woman lives in their chacra (Ishizawa 2006). A typical sized chacra is illustrated by the photo in Figure 2.

The chacra represents more than a livelihood for subsistence farmers; it is a symbol for Mother Earth, as are the seeds that are planted in it. Seed, woman, and Earth are seen as one and the same. They are all symbols of fertility, and they all give birth to life (Tauli-Corpus 2010). This was clear during all of the interviews and focus groups, since respondents tended to focus on the chacra as the reference point for all questions about their environment, perceived climate change, and water scarcity.

Every single subsistence farmer interviewed mentioned the chacra at least once in response to the question, ‘What types of activities do you do in nature?’

One farmer’s response – ‘Our only activity is tending to our fields’ – is a clear representation of the organizing principle of their lives and the ecological knowledge and experience that is part of that existence. This answer was both commonplace and tantalizing. It was the beginning of a larger explanation for how respondents use TEK every day to ensure the well-being of their crops and cope with climatic variability.

5.3 Local variability, climatic observations, and adaptation

Focus groups showed that adaptability and customization were integral elements of crop production and pest management in the Puno Region, and farmers relied on certain cosmological and ecological signals to tailor their crop profiles each year. The customization of farming practices each year – based on local knowledge of climatic changes and crops’ response to moisture in the soil – is telling of the intimate ecological knowledge residing within each farmer. This is also evident in a colloquialism that often followed responses about how the farmer ensured a good crop. Whenever they described their particular practices, they followed up with, ‘Well that’s how I do it.’ This expression symbolizes farmers’ awareness of microclimates and hyper-local variability of weather and moisture conditions and their ability to cope with those conditions through the use of TEK.

Historical adaptability to these conditions is resident within physical remains of previously explained mechanisms such as camellones, qotañas, q’ochas, and andenes.

The altiplano farmer depends on other forms of life to give him signals regarding weather, the climate, the changing of the seasons, and ultimately when to plant his crop. Because subsistence farming is rain-fed, the appropriate timing of planting season is calibrated with all the cultural and natural signs of the onset of the rainy season.

The toad is a perfect example of the multiple meanings and layers of knowledge that can be gained by integrating TEK into ES approaches. In Andean mythology, the toad is equated with reproduction, fertility, and Pachamama herself (Urton 1981). The toad is also an indicator of future or prevailing weather conditions, so, now the disappearance of the toad in the altiplano environment is taken as an overall indicator of ecosystem health. Weather predictions using the toad rely on the observation of increased numbers of toads to signal the onset of the rainy season (Urton 1981). Toads inhabit rivers, marshy areas, swamps, and bofedales, but they often find their way into agricultural fields and the timing of their presence in the fields signifies wet and fertile conditions (Urton 1981).

The critical role of the toad in Andean agroecology was reinforced by our data. Each focus group stated their belief that toads contribute to the increased

Figure 2. Focus group participant harvesting potatoes in her chacra, Carpa, Peru.
fertility of the *chacra*, and two of the interviewed farmers mentioned the disappearance of the symbolic toad in response to a question about their relationship with nature, and whether they had witnessed changes in climate.

Many other farmers confirmed the mysterious disappearance of the toad and blamed it on water scarcity, climate change, and local pollution. While the prevailing scientific explanation for the disappearance of toads is the use of agrochemical fertilizers by these farmers, not a single farmer made this connection in our interviews or focus groups. Farmers who were interviewed said chemical fertilizer ‘killed the land’ and ‘attracted potato worms,’ but they did not make an explicit connection to the disappearance of the toad.

The multiple meanings given to the toad by the Quechua and Aymara people demonstrates the power of local, customary, and traditional ecological knowledge to inform water management decisions. The toad has the potential to be an ecological red flag to indicate the declining health or changes within an ecosystem, and might even be considered a ‘cultural keystone species’ (Garibaldi & Turner 2004), since it forms the contextual base of water management decisions. Understanding the value of the toad or any other culturally symbolic and biologically significant species within ES approaches can enhance and improve the resiliency and sustainability of natural resource management within this approach. There is also a potential to monitor the fluctuation in the toad population as part of a postwater intervention follow-up assessment. The benefit of these uses is that they fit easily within the rationality of the Andean cosmology and local understanding of ecosystem functions. The key to unlocking this critical knowledge is an investment of time, effort, and cultural openness.

### 5.4 Variations in water availability and management techniques

When discussing water resources, many interviewees, both key informants and subsistence farmers, frequently repeated the slogan painted on the Vilquechico municipal water tower when discussing their relationship to nature: ‘Water is life.’ The social and technical aspects of local water management and water availability are tied closely to the subsistence lifestyle and, thus, local TEK. Prevailing themes in the interviews included climate change, water scarcity or unpredictability, and related declining crop yields. All of this revolved around the need for water and a local understanding of the water cycle and seasonal water availability.

Focus groups revealed the rhythm of life in the Puno region depends on the predictability of climate and rainfall patterns. Ecological indicators and predictors for the coming of the rains, learned through generations of practice, signal when it is time to prepare the fields and the seeds for planting. However, strong indications from the focus group respondents suggested seasonal rainfall has become less predictable over the past two decades. All of the focus groups told the interviewers there used to be a clear dividing line between the wet and dry seasons. Now, it rains after the wet season has ended. Frost comes early and stays late into the dry winter season, when it used to consistently frost after the May/June harvest. Also, the rains may not arrive until later into the planting season. All of this leads to an unhappy ending for the year’s harvest. These findings demonstrate that TEK can play a vital role in ES approaches by providing insight into predicting climate and identifying climatic changes. Many other studies have also noted the role TEK can play in predicting and coping with climate and weather patterns and its importance in both indigenous and modernizing communities (Stigter et al. 2005; GómezBaggethun et al. 2010; Lefale 2010).

Yet, ironically, when asked what they could do to make sure that the crop yield improves from year to year, the focus group participants honed in on technological solutions, possibly reflecting the wider tendency to undervalue TEK. Technical irrigation solutions were a popular perceived fix to their water management challenges.

The only focus group respondents who suggested reviving local knowledge and coping mechanisms to deal with water scarcity or climate insecurity was a group that was already working with a local nonprofit that favors the use of TEK. All other focus groups pinned their hopes to a proposed ‘irrigation project,’ even though they knew the project would be costly, and they already felt isolated from the municipal and regional government charged with implementation. They expressed that this made it all the more unlikely that they would receive an irrigation project in their area. One focus group respondent in Carpa stated he felt people should be responsible for themselves instead of waiting for a handout. Others shook their heads in agreement. However, the reliance on modern technology as a solution to basic water availability problems was still quite evident.

The key informants expressed slightly different views in their interviews. Each key informant implied that they were willing to try any solution that worked, including an ES approach, as it was explained to them at the beginning of the interviews. When asked, ‘Do you think that ecosystem services approach is appropriate for application within local communities?’ one key informant’s reply was emphatic, but not in an expected way: ‘Yes, I believe it is adaptable because there is a necessity. The necessity for water is urgent right now, so, yes,
whatever technology that can be adaptable to a community…’ This was not an emphatic yes, but rather a willingness to try anything that would work at this point, almost in desperation.

In the case of this research, water availability and management were found to be highly localized expressions. Hence, solutions for water scarcity and water use should mirror this local knowledge. Any strategy or application of water management absolutely has to take into account both the local characteristics of ecology, environment, geology, soil, and sources of water and the sociocultural characteristics of the location. Without an adequate understanding of this mixed bag, any single water management technique is unlikely to stand the test of time. Participant observation and stakeholder interviews shed light on how TEK is utilized in local contexts to modify water management regarding bofedales.

The great variation of techniques and how they are uniquely suited to each small geographic area and founded on TEK can be seen in the example of the amplification of bofedales (i.e. the expansion of the area occupied by meadows thanks to irrigation), or high altitude wetlands, in the altiplano of Peru. Three different methods were observed being utilized within a radius of about 3 miles that each took advantage of a single local understanding and historical use of bofedales. Each local management solution took into account different micro-local variables resulting in unique management techniques. The micro-variables included water availability, the means and motivation of the people including communal efforts, and their understanding of how to manage the water to feed the bofedal. This type of management is based on the knowledge passed down through the generations regarding the use of the bofedal for high-quality camelid fodder production. In this region, bofedales are the only source of animal fodder of appropriate nutritional value during the dry season (Alzerreca et al. 2006).

The bofedal and its management is a local expression of water management techniques gained through TEK. One farmer interviewed in Conduriri stated that if you raise alpaca, then you have to have a bofedal somewhere on your property. In this way, ecology, local knowledge, pastoralism, and water management have become intertwined. This is a basic suite of understanding that a scientist would need to know in order to properly assess ESs, especially the services provided by water coursing through this unique landscape.

The first system for managing water within a bofedal uses an improved canal with sluice gate. The canal brings water from a natural spring 120 km away in the mountains, down to this area of wetland that is situated within the valley of Conduriri. The sluice gate, a rudimentary green metal gate, can be open or closed a certain amount according to small circles cut out of the handle that operates the vertical gate. The sluice gate can be opened or closed at predetermined times, and at different rates during either rainy or dry seasons in order to equally distribute the water to different bofedales. During a conversation with the current president of the local water association, he commented that before the gates were installed but the canal was in place the residents used to fight over the amount of water an upstream user would get. Now they can regulate the distribution of this water by opening and closing the gates. Also, the water association president determines the rate of distribution and is also responsible for checking to make sure nobody is cheating and using more than their prescribed rate of water. This is done through periodic checks on the gates and how far open they are during certain times of year.

The second system for managing water flowing into a bofedal is applied at a combination of individual and community level. This was implemented further up in the hills, closer to mountain spring sources of water. The research team drove about 20 min up a dirt road in Conduriri to observe the ‘capture’ of a natural mountain spring. This capture was done by creating a concrete basin around the origin of the natural spring, resulting in a small reservoir as seen in Figure 3. This is a masonry uncovered spring box with overflow pipes on two sides for discharge and distribution of water. The pipes are PVC pipes that regulate the discharge of water toward one side with less flow and toward the other side with a higher discharge rate. The discharge rates were determined by the amount of water required to maintain the bofedales during the dry season. Key stakeholders, the landowners in this area, determined how much water was needed during the year on each parcel of land. A group of these landowners then pooled their knowledge and decided on a system in concert with a local nonprofit supported by the office of the Secretary General of the Andean Community, to divide up the water flow emitting from the natural spring. One side of the
land has more residents, requiring more water to be discharged into natural canals to feed the bofedales, and the other side of the land has fewer residents, requiring less water to feed local bofedales. The maintenance required on this system is daily cleaning of the spring box and seasonal upkeep of the small canals that traverse each person’s land.

The third water management technique uses well water pumped into a seasonal reservoir with an electric motor. The water is then distributed to various portions of the property using gravity fed pipes and rubber hoses to water the bofedal and some field plots of indigenous shrubs and alfalfa. This was a pilot project carried out by Instituto Mallku, a sustainable development nonprofit, to enhance an existing on-site well with a reservoir and irrigation apparatus. Note that even during the dry season, the extent of the bofedal is considerable because of artificial watering.

All three of these techniques for water management are highly local and extremely dependent on the local understanding and use of bofedales for camelid-based pastoralism. The citizens of this area understand that bofedales are critical to the health of their alpacas and each landholder wants to have a healthy wetland ecosystem. They have found ways to amplify and extend these delicate ecosystems based on their needs and the needs of the ecosystem, demonstrating how ES can be enhanced through TEK. These techniques, it could be argued, also adhere to the Andean cosmology of reciprocity between living systems. This relationship between human and environment and the subsequent ethno-ecological TEK that developed from it have been adapted to create coping strategies that assist each village to maintain healthy contiguous ecosystems.

6. Recommended methodology to integrate TEK into an ES approach

The strategy of integrating social and cultural values into an ES approach at a macro-level demonstrates context and theory but fails to show practical application at the micro-level. This study argues that any practical intervention should be designed with a bottom-up, participatory process to elicit and integrate relevant TEK. The question is how do we get from strategy to application? A lot of ground was covered in the search for a methodology to help operationalize ES approaches, but examples of its application are few and far between (Cowling et al. 2008; Raymond et al. 2009; Seppelt et al. 2011; Luck et al. 2012; Nahlik et al. 2012; Plieninger et al. 2013).

TEK carries with it the advantage of its ability to counter risk and adverse climatic conditions (Gómez-Baggethun et al. 2012). In many instances, a long and disruptive colonial legacy is the only phenomenon that stands in the way of reviving and reconstructing these environmental technologies. Elicitation of TEK through an ethnographic case study approach can uncover the social values that underpin and provide the bulwark to these practices. This act in itself provides the social assessment and opportunities and constraints that Cowling et al. (2008) discuss and also helps to utilize and support Chan et al.’s (2012b) framework for integrating TEK in the characterization of ESs. Semi-structured interviews and focus groups that allow for a give-and-take narrative between interviewer and respondent are useful practices for eliciting buried, yet valuable, TEK and the values, perceptions, rituals, and perspectives that the revival of this knowledge brings with it. Such qualitative methods should be an integral and central part of any ES assessment. Without this, ES approaches will strew in the domain of theory and never progress to actual practice and implementation. We propose the use and study of social and cultural ESs as a valuable contribution to sustainability (Figure 4). Figure 4 demonstrates the conceptual difference between the top-down approach of many international ES implementations and the suggested bottom-up approach of this study.

![Figure 4. Current versus proposed socio-ecological approach to ecosystem services.](image-url)
ES approaches, at their core, need to respect the integrity and sanctity of TEK and value it properly within any practical solution for environmental resource management. In the context of the Puno region of Peru, environmental management decisions are being informed and improved through the use of TEK, and this practice also ensures that any intervention is culturally appropriate and adheres to social learning and adaptive management, both indispensable principles of environmental management. The inclusion of ethno-ecology and TEK into ES approaches is a matter of necessity, not of convenience.

7. Conclusions

The goal of ES approaches is to facilitate decision-making and foster implementation of interventions, policies, and management that integrate ecosystem functions and human well-being to ensure sustainability. When TEK is integrated into these approaches, it expands our understanding of the hallmarks and characteristics that environmental management projects need to be sustainable. The sustainable development of these communities and their cultural heritage programs need to be highly regarded and observed for their successful regeneration and cultivation of traditional, communal, and highly local ethno-ecological knowledge.

Within certain limitations (time and resources), this study concludes that just the act of considering and gathering detailed TEK for use in ES assessments and applications to natural resource management interventions is a vital initial step. The level of consideration granted to TEK within this study has not been part of the practical application of ES approaches in years past (Fisher et al. 2009; Lele et al. 2013). The contribution of this type of knowledge to the improvement of ES approaches appears to have vast potential. Six weeks of on-the-ground observation and elicitation has shown that the depth and breadth of this accumulation of detailed knowledge and perspective has much more to contribute to this area of environmental research. Demonstrating how TEK is used to inform and influence decision-making might lead more practitioners to see the potential value it has to improve sustainable strategies.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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