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# The System Nobody Sees: Irrigated Wetland Management and Alpaca Herding in the Peruvian Andes

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Increasingly, attention in regional, national, and international water governance arenas has focused on high-altitude wetlands. However, existing local water management practices in these wetlands are often overlooked. This article

looks at the irrigation activities of alpaca herders in the community of Ccarhuancho in the Central Andes of Peru. For more than two centuries, they have been constructing small-scale irrigation canals to maintain and expand the local wetlands, called *bofedales*. The seminomadic character of alpaca herders complicates irrigated wetland activities, such as operation and maintenance. Climate change and human and animal population pressure have increased not only the importance of these irrigation systems but also of local conflicts and communal decision making. Local irrigation activities in Ccarhuancho go unnoticed in broader water

governance arenas because of its remoteness, limits to what popular new analytical tools can measure, a general undervaluation of wetlands, and a tendency of the canals to merge over time with the surrounding *bofedales*, making them less visible. Nevertheless, these man-made systems account for 40% of the wetlands in the study area and risk being seriously degraded or destroyed without local water management. With climatic changes affecting existing natural wetlands, the local herders were the first to recognize and respond to these changes and to defend the wetlands against degradation. Their efforts are, however, largely overlooked, even though such local water governance practices are crucial for the success of regional and national water governance in the Andes and other mountain areas. (Note: The title of this paper is an adaptation of Netting's [1974] paper "The system nobody knows" about small-scale irrigation in the Swiss Alps.)

**Keywords:** Water governance; irrigation; *bofedales*; pastoralism; Ccarhuancho; Peru; Andes.

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## Introduction

High-altitude wetlands are increasingly attracting attention in regional and national water governance arenas (Ramsar 2008; see also Budds and Hinojosa 2012), but in many of these environments, local water governance arrangements have been established for centuries (Fairley 2003; Lane 2009). This article describes the irrigation activities of a group of alpaca herders on the Andean *puna* of Peru, with common access to pastures, wetlands, and water resources. The *puna* is often considered a natural grassland environment, including bogs, small lakes, and rivers, located at or beyond the agricultural frontier. Demarcations of the *puna* ecological zone are often based on altitude (Baied and Wheeler 1993; Lane 2009). However, we follow Mayer (2002), who defines the *puna* in relational terms as the high, cold, and treeless areas in comparison to the lower potato and maize lands (*quechua* zone). Although cultivation of Andean tubers often occurs in the *puna* and drained wetlands (Zimmerer 1991, 1994), in the region of this case study, the *puna* is

more associated with animal husbandry, such as camelid and sheep herding (cf Browman 1974; Orlove 1977; Flannery et al 1989). Throughout the *puna* there are patches of wetlands, known as *bofedales* (Squeo et al 2006). Much of the ecological literature about the *puna* and *bofedal* environment portrays it as a fragile ecosystem (Messerli et al 1997); a domain of nature with great biodiversity and a productive life-support system, rich in natural resources and ecosystem services (Halls 1997; Ramsar 2008; Buytaert et al 2011). The local, regional, and global importance of these ecosystems is underlined in recent studies that use geographic information system (GIS) and remote sensing tools to catalog *punas* and *bofedales* (Postigo et al 2008; Otto et al 2011).

Despite these studies, the prevailing perception of high-altitude wetlands is one of wastelands or *tierras eriazas*, with a harsh climate and difficult access, that are unfit for agricultural production (Halls 1997; Ramsar 2008). Viewed as an obstacle to progress, they are often drained or degraded for economic gain, mining, or hydraulic works (Boelens et al 2002; Sosa and Zwarteveen

2012), a common occurrence in wetlands worldwide (Zedler and Kercher 2005; Joosten et al 2012). Against this backdrop, a management discourse of conservation and protection of pristine and valued nature that offers crucial environmental services is emerging (Messerli et al 1997; Joosten et al 2012). The problem with this discourse is that it views local human activity as separate from the ecosystem, often portraying it as an external threat (Zedler and Kercher 2005). Consequently, local water governance practices that conserve wetlands tend to be overlooked.

This article aims to contribute to changing this marginal image of wetlands by presenting human–*bofedal*–water resource interactions that extend and maintain this mountain environment. This is largely absent in general descriptions of *bofedales* as ecosystems or production zones (Gelles 2000; Mayer 2002; Squeo et al 2006). In contrast, this article argues that human actions profoundly shape and expand these environments through water management and irrigation of wetland pastures. Too few studies have documented how the availability, quality, and productivity of these wetlands are controlled by people to alter inundation and drainage of land and transform plant growth, thus shaping the *bofedales* as irrigated wetlands. One interesting exception is the work of Palacios Rios (1977), who details local access rights and irrigation activities such as canal construction, maintenance, and scheduling.

The irrigation of permanent pasture or meadowlands under native and seeded grasses for direct grazing is a less well-known and debated area of irrigation management in the Andes. For many, irrigation is associated with intensive crop and cut fodder production (Guillet 1987; Guillet and Mitchell 1994; Boelens 2008). Although some scholars have acknowledged the threats to and struggles for local water security and access, as well as multiple water uses in the headwaters of the Andes (Boelens et al 2002), the interrelation of irrigated practices, water control, and pasture management is largely unexplored. Historically, there is extensive contact between camelid herders in the *puna* and peasant irrigators in the lower *quechua* zones through kinship ties (*compadrazgo*) and trade (Flores Ochoa 1979; Mayer 2002). Social organization regarding natural resources is based on similar cultural institutions such as reciprocity (*ayni*), collective user investment (*minga* or *faena*), and communal authority (*asamblea*), whether the task is canal construction, land preparation, village upkeep, or wetland conservation (cf Beccar et al 2002; Urteaga 2006; Verzijl 2007). The management of *bofedales*, including water control, access, and use rights, therefore rests on principles similar to those in other Andean ecological niches.

The following two sections explain the research methods and introduce the case study area. The fourth section focuses on the importance of water, the external threat that the herders face, and the relation of water to

other resources. The subsequent sections present some general characteristics of *bofedales*, elaborate how canal construction has created and extended them, and give further details on irrigation activities. The conclusion highlights the interconnectedness of resources to show the value of existing local governance principles and sustainable practices that integrate wetlands, herders, and animals.

## Methods and data collection

To visualize the intimate connection among irrigation practices, *bofedales*, and camelid herding, we chose as our study area the sector of Ccarhuancho Centro, which is part of the indigenous Ccarhuancho community in the Huancavelica region (13°13'09"S, 74°57'45"W) of Peru. We gathered data about irrigation practices and *bofedales* in Ccarhuancho and Huancavelica city during a dozen field visits between 2007 and 2011. The methodology was twofold. First, information was collected regarding irrigation activities. More than 30 in-depth interviews were conducted (17 with women); 21 of the interviewees lived principally in Ccarhuancho, and the others traveled back and forth from Huancavelica. To understand the communal dimension of the upkeep of *bofedales*, the research included observations of festivities, collective workdays, village assemblies, and meetings with local and regional government officials. During these events, informal interviews produced insights into both local resource governance arrangements and organization of communal opposition to external threats to water security.

The second part of the research involved cataloging the irrigation canals, *bofedales*, and grasslands. We surveyed some herders in Ccarhuancho Centro to list the canals and *bofedales*. Initially, we attempted to collect location data using a global positioning system, but this proved too strenuous due to the altitude and time constraints. We then resorted to Google Earth, ArcGIS, and AutoCAD to indicate and analyze the irrigation canals and grazing grounds.

## Study area

An association is infrequently made between transhumance and irrigation. Herders generally rotate the *puna* grasslands (Flores Ochoa 1979) and do not concern themselves with activities such as canal construction and field irrigation. In Ccarhuancho, herders move around but nevertheless give the necessary year-round attention to water management activities linked to specific canals or fields.

*Bofedales* are paradoxical in that they are wetlands in an arid or semiarid grassland environment: rainfall in the study area averages 800 mm, with 90% falling in the 6 months between October and April (Lahmeyer 2007).

**FIGURE 1** Landscape in the community of Ccarhuancho. (Photo by A. Verziji)



The *bofedal* vegetation is a valuable grazing resource, and irrigation is essential for the upkeep of these wetlands, especially because contributions from snow and glacier melt have disappeared in recent decades (Messerli et al 1997; Boelens et al 2002; Vuille et al 2008). The importance of these wetland grasslands to the Ccarhuancho herders is underlined by their significant attempts to maintain and extend them and to exclude outsiders from their benefits. Like the grazing pastures, wetlands and water fall under communal authority and collective decision making.

The communal landscape is made up of more than 38,000 ha of rocky mountain peaks, pastures, rivers, *bofedales*, and shallow lakes; hundreds of herders; and thousands of animals (Figure 1). The term *community* used in this paper refers to a group of people linked to a land unit whose territorial boundaries are locally recognized and contested. Historic documents and modern land titles exist but often differ from local day-to-day practices and governance. Community resembles Orlove's (1977: 80) system in which herders and animals, together with plant communities and abiotic factors, all interact. This interaction means that boundaries, outer and inner, are dynamic and constantly debated.

For centuries, Ccarhuancho herders have roamed the *puna* with their animals, all the while redirecting small water flows to improve forage lands. Current challenges such as climate change and population pressure (human

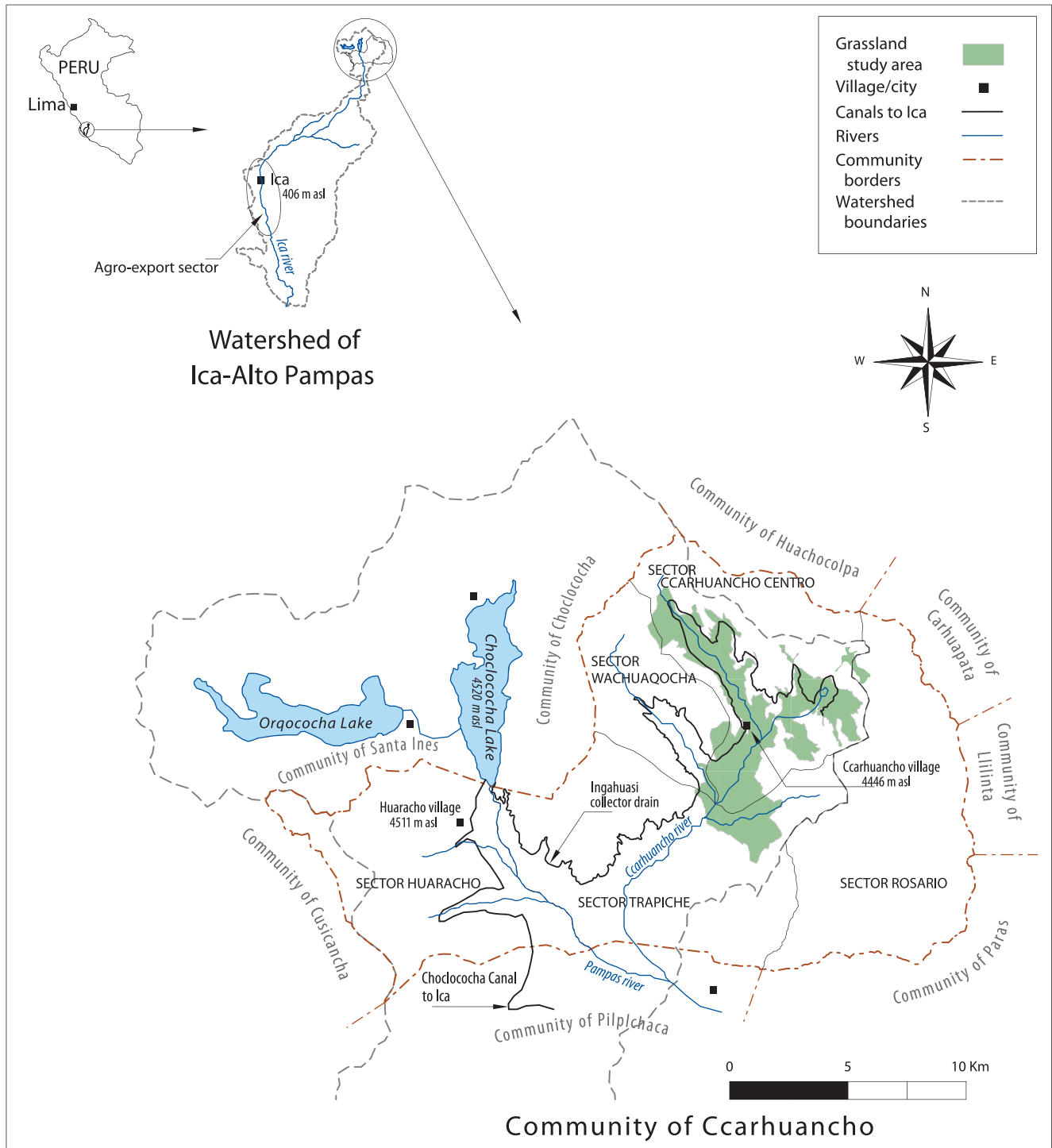
and animal) make irrigation more important. More canals are being constructed, and technologies such as sprinklers and small tanks are being introduced. Existing governance arrangements keep intracommunity conflicts in check and enable the community to defend itself against claims from downstream agroexport interests.

The case study research sites are the upper 2 valleys in the Ccarhuancho Centro sector, which will be affected by a proposed interceptor drain project. The valleys cover some 3900 ha of pasture, supporting 59 families and more than 11,000 animals. The system in place has evolved over centuries. Ccarhuancho received land rights in 1712, when the Spanish crown granted to "the community [of Indios] and their children: their lands, pastures and mountains, their waters and splendors enough to live from and herd their cattle" (Guerrero and Pacheco 2007). These local waters, which are vital for the *bofedales*, are imperiled by the proposed water transfer project.

### **Water security, external threats, and internal complexities**

Agribusiness in the irrigated coastal desert valley of Ica constitutes the biggest agroexport sector in the country (Rendon 2009; Hepworth et al 2010; Oré 2011). This sector proposed new hydraulic works in the area of Ccarhuancho to capture and transfer water to the coast.

FIGURE 2 The community of Ccarhuancho. (Map by A. Verziji and S. Guerrero)



The plan was to construct within community territory a 70-km-long interceptor drain, Ingahuasi, that would capture all streams and runoff that it intersected, an estimated 50 million m<sup>3</sup>, en route to the Choclococha

Lake and continuing farther downstream to Ica via the Choclococha canal, which was constructed in the 1950s (Guerrero and Pacheco 2007; Lahmeyer 2007). Ingahuasi would deprive community wetlands of water influx and

TABLE 1 Herds, *estancias*, and *echaderos* in Ccarhuancho Centro. (Table extended on next 3 pages.)

Combined herd <sup>a)</sup>	Families	Alpaca	Llama	Sheep	<i>Estancia</i> (farmstead)
I	3	350	20	160	Llamapawasi
					Pukamayo
II	4	650	4	241	Aqowasi
					Yuraqorqo
					Otorongo
III	6	550	60	220	Uchqupuqio
					Tola
IV	3	600	30	120	Oqemoqo
					Tayapata
					Pampawasi
V	4	288	6	40	Taqrapampa
VI	3	480	53	196	Tulamoqo
					Ayapa-uman
VII	1	180	17	76	Laqaypampa
					Qello esquina
VIII	1	236	26	29	Aqchimachay
					Llaqta (village)
IX	2	305	35	100	Soraqocha
					Patahuasi
X	3	265	50	57	Waqtaqasi
					Soraqocha
XI	1	239	28	21	Chaupiqasa
XII	3	418	36	161	Uñawasi
					Cachipucro
XIII	3	450	60	150	Pampawasi
XIV	3	236	36	86	Waqtakoral
XV <sup>d)</sup>		500	0	0	Qatunmachay
					Trapiche
XVI	1	203	11	67	Yuraqcerca
XVII	3	555	47	192	Tukuqaqa
					Carneceria
XVIII	7	860	75	365	Tuqramachay
					Mollepunku
XIX	5	304	67	171	Ingahuasi
					Machaypampa

TABLE 1 Extended. (First part of Table 1 on previous page, next parts on next 2 pages.)

Combined herd <sup>a)</sup>	Echadero (grazing area) (ha)	Exclusive access (ha)	Occupation
I	260	185	Dec–May
	Carhuapata <sup>b)</sup>		May–Nov
II	490	60	Dec–May
	140	0	Nov
	210	50	May–Dec
III	290	245	Year round
	Rosario		June–Aug
IV	130	45	c)
	120	50	May–Dec
	130	65	Dec–May
V	110	85	Year round
VI	160	13	Dec–April
	Rosario		April–Dec
VII	200	140	Year round
	Same echadero		
VIII	80	42	Year round
	Same echadero		
IX	100	20	Year round
	Same echadero		Aug
X	130	70	Year round
	Same echadero		Aug
XI	70	36	Year round
XII	160	150	Year round
	Same echadero		May
XIII	140	85	Year round
XIV	230	170	Year round
XV <sup>d)</sup>	350	350	Jun–Dec
	Trapiche		Jan–May
XVI	35	35	Year round
XVII	370	42	Jun–Dec
	Wachuaqocha		Dec–May
XVIII	830	830	Year round
	Same echadero		
XIX	180	105	Dec–May
	Rosario		May–Dec

TABLE 1. Continued. (Table extended from previous 2 pages and continued on next page.)

Combined herd <sup>a)</sup>	Families	Alpaca	Llama	Sheep	Estancia (farmstead)
XX	3	450	25	40	Yuraqkancha
Total	59	8119 <sup>e)</sup>	686	2492	

Source: Based on the 2012 community livestock census, which is used to determine the tariff (50 centavos per head).

<sup>a)</sup>A combined herd consists of one or more private herds of different families that occupy an *estancia*.

<sup>b)</sup>Herds migrate out of the study area (such as the sector Rosario or another community).

<sup>c)</sup>Herders are too old to move to Oqemoqo and stay in lower *estancias*.

<sup>d)</sup>Community herd (used for covering expenditures or festivities).

<sup>e)</sup>*Crias* (newborns) and *maltones* (born the previous year) are not counted, so the real herd size is 30% bigger.

<sup>f)</sup>3900 ha is not the sum of the *echaderos* (as these overlap) but the total study area. Carrying capacity, derived from e + f, is 3.75 animals per hectare.

would be an unbridgeable obstacle to transhumance (Figure 2).

According to the engineers in Ica responsible for the environmental impact assessment, negative social and environmental impacts were minimal. They recalled finding abandoned settlements, sparse and scattered populations, barren lands, and no local infrastructure in the upper valleys of Ccarhuancho Centro. The assessment argued that the few people in the area would welcome the labor opportunities resulting from the project (Lahmeyer 2007). This visualization and evaluation of the wetlands hid a complex array of irrigation activities and pasturing arrangements—a system that nobody sees, including the Ica engineers. Ccarhuancho fiercely resisted this project, right up to the Latin American Water Tribunal, whose verdict was in favor of the community. However, the negative images remain of wetlands, of the people who defend such “wastelands,” and of their reasons for doing so.

The central village of Ccarhuancho can appear deserted. Herder families live dispersed in *estancias* or farmsteads with surrounding grasslands called *echaderos*. Because many families migrate with their herds, alone or in groups, many *estancias* appear unused for months. There are no fixed boundaries to *echaderos*, but they often follow natural markers such as mountain ridges, rivers, or vegetation lines. When *echaderos* overlap, families adjust the rotation of their herds on an ad hoc basis. Often, overlapping *echaderos* are separated by time: when one herd moves out, a second one moves in. However, pasture areas nearest to a family *estancia* are considered exclusive to that family. Table 1 lists the herds, *estancias*, and *echaderos* in Ccarhuancho Centro, showing herd composition, *estancia* occupation, exclusive pasture land, and movement between them. Figure 3 gives a spatial overview of the case study area with *estancias*, *echaderos*, and migration routes.

Families with access to multiple *echaderos* move their herds twice a year, usually in December (before the alpaca breeding season) and in May (after the rains). However, some move them several times a year to revitalize the pasture ground they leave behind. Access often rests on inheritance rights and established family connections

with pasture areas. Yet the *echadero* boundaries tend to shift according to herd behavior, as well as local negotiation. Villagers indicate that if a person's herd becomes smaller, so automatically does the *echadero* that person accesses; when the herd becomes bigger, so does the grazing area. If a herd becomes too big, and would claim too large a grazing area, the community assembly urges that family to reduce the herd. Animals are private property but subject to communal authority.

Herders indicate that for a long time, sheep were more commercially valued and more numerous, but today alpacas are favored and outnumber both sheep and llamas. According to the villagers, alpacas consume less pasture than sheep, despite their larger size. Also, their cushionlike feet are less destructive of *bofedales* than the sharp hooves of sheep (Baied and Wheeler 1993: 149). Today, the carrying capacity of animals in Ccarhuancho Centro is 3.75/ha (Table 1), higher than the estimate for *puna* grasslands in Peru (Browman 1983). Key to this, as the herders know, is the creation and upkeep of the *bofedales* with irrigation.

### Bofedales and canal construction

*Bofedales* are pockets of peat saturated with groundwater and surface water. They are fragile ecosystems that arise when hydrological and geological elements combine favorably (Squeo et al 2006: 246, 252) and are sensitive to climate variations and human interventions, such as mining and farming. In this, they resemble wetlands in lower areas (Zedler and Kercher 2005) and the Ecuadorian *páramo* (Buytaert et al 2011; Buytaert and De Bièvre 2012). Rather than benefiting from perennial rain, *bofedales* flourish more when fed through subsurface flow coming from glacier or snowmelt. These two water sources, according to the herders in Ccarhuancho Centro, vanished in the 1970s.

In Ccarhuancho, natural *bofedales* are often found where groundwater surfaces via a spring and where flow assures a constant influx of water into the peat. It takes years to revitalize dried-out wetlands or to develop new ones from parched peatland (Palacios Rios 1977; Orlove 1982). Their size varies from less than 1 ha on slopes to



TABLE 1. Extended Continued. (First part of Table 1 on previous 3 pages.)

Combined herd <sup>a)</sup>	Echadero (grazing area) (ha)	Exclusive access (ha)	Occupation
XX	90	90	Year round
Total	<b>3900<sup>b)</sup></b>	<b>2963</b>	

several hundred hectares on plains. Peatland vegetation is determined by 4 main ecological factors (Squeo et al 2006: 251): water quantity and seasonal availability; temperature and incidental frost; water quality, including pH balance, nutrients, and toxic elements; and biotic factors, such as seed dispersion by animals and grazing (see also Zedler and Kercher 2005: 49). These factors reveal the management challenges for the herders in Ccarhuancho. In response, they have constructed a vast network of canals that turn dry peat into lush wetlands. These canals differ in length from several kilometers to 100 m and in width from 0.8 m to the size of a *sapa-pico*, a shovel with a 0.15-m blade.

At least 3 types of canals can be distinguished. The first is constructed parallel to the border of an existing *bofedal*, several dozen meters away, to irrigate the area between. Once this extended area is in production, which can take years, the procedure can be repeated. *Bofedales* operate like huge sponges, so once the peat is saturated, maintaining it requires only a percentage of the water stored in it. The second type of canal runs through the larger *bofedales* and is used to irrigate areas that have lower retention capacity or to which the underground flow is blocked. These canals are found in the plains that flank the Ccarhuancho River and are used for maintenance rather than extension. With the disappearance of snow and glacier melt, the increase in torrential showers, and the erosion of the riverbed, these maintenance canals are vital for wetland sustainability. The third type of canal is used strictly to transport water, without extending or maintaining *bofedales* along its course, like the main canal to the village or the closed conduits that transfer water from the newly constructed tanks.

More than 100 canals have been identified in Ccarhuancho Centro, with a total length of more than 36 km. Figure 4 presents the canals and artificial and natural *bofedales* in the middle part of Ccarhuancho Centro (for additional data and dimensions, see *Supplemental data*, Tables S1 and S2; <http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00123.S1>). Although it is difficult to give an approximation, the location of canals and the topography suggest that more than 40% of the *bofedales* in Ccarhuancho Centro would be degraded or destroyed without this canal network.

This local form of water control goes unrecognized in current debates on Andean wetland management, partially because of the new satellite and remote sensing technologies used to analyze these often vast and isolated

areas. Land Satellite data, with a resolution of 30 m (Quiroz et al 2001; Postigo et al 2008; Otto et al 2011), are too crude to reveal local complexities and thus help create the image of wetlands as natural expanses. Another reason that nobody sees these irrigation canal systems is that over time, it becomes hard to distinguish between peatland produced by human intervention and that produced by natural processes. Because canals are constructed parallel to the *bofedal*, older ones become nearly invisible and can lose their transport function. The history of a *bofedal* is known only to its makers.

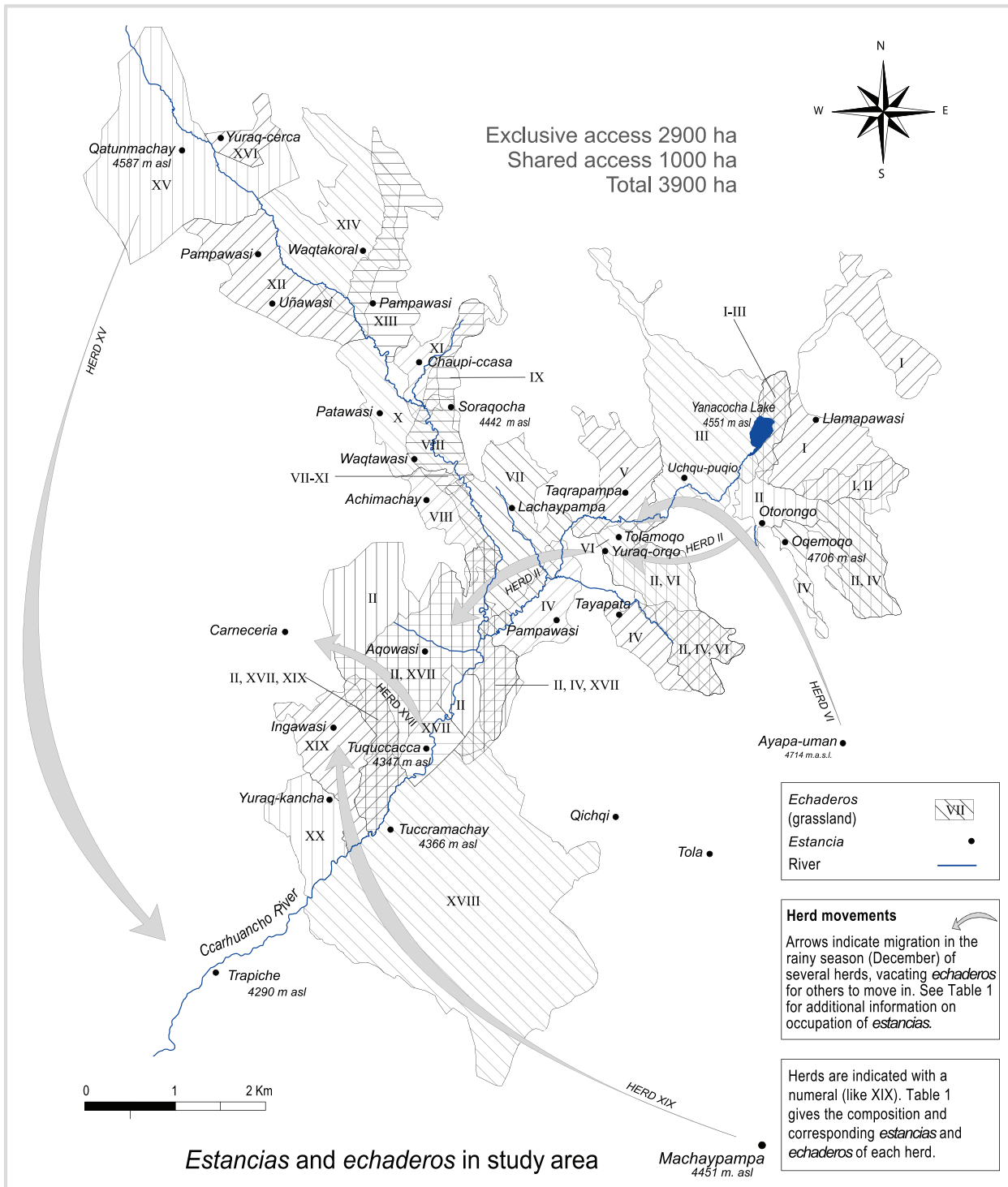
The example of the 7-ha Uchqu-puqio *bofedal*, with current and old canals, is highlighted in Figure 4. It pertains to a single *estancia* within the larger *echadero* of the same name. Maintenance and extension are undertaken by the corresponding families only. However, in the process of amplification, canals and *bofedales* become interconnected. This is happening in the areas below Uchqu-puqio. In the past, these canal sections were shorter and maintained by the families from 4 *estancias*. However, the herders indicated that, in the future, the area from Uchqu-puqio to the valley floor might become one large *bofedal* (potentially 60 ha) with shared water distribution.

For the upkeep and water management of larger wetlands, the families might look to the valley floor below. Here, *bofedales* up to 100 ha can be found. The intensively used Ccarhuancho *bofedal* in front of the village (103 ha) consists of canals constructed and maintained during collective *faenas* or workdays. This *bofedal* is old and was in part formed naturally, but it requires upkeep. The families that have access to this *bofedal* must maintain it and invest in it. They do not migrate like their neighbors downstream. As populations of both animals and herders are increasing, villagers indicate that this *bofedal* is under the most stress from overexploitation and conflict.

### Other *bofedal* irrigation activities: application, operation, and decision-making

Local canal construction and maintenance are often considered activities of small-scale mountain irrigation (Vincent 1995; Crook and Jones 1999; Verzijl 2007). This section explores other irrigation activities important to *bofedal* conservation. In Ccarhuancho, there is no central management of the network of canals, springs, and rivers. It has no recorded water rights, and many

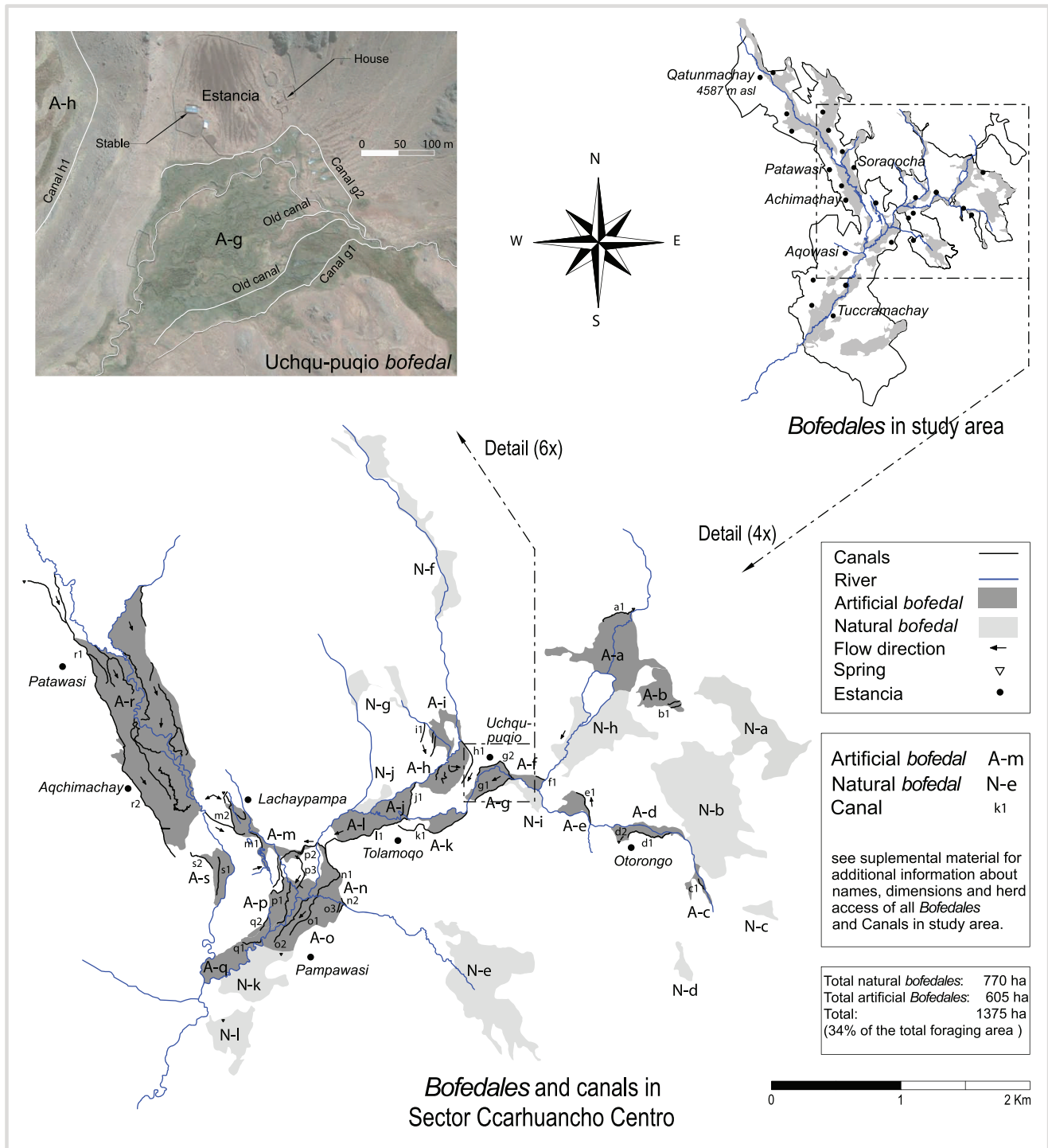
FIGURE 3 Estancias and echaderos in the Ccarhuanchu Centro sector. (Map by A. Verzijl and S. Guerrero)



conflicts are still settled in situ between stakeholders. Much like the Swiss mountain irrigation system described by Netting (1974: 69), the system appears to run itself. Netting states that “central control and

direction of work is unnecessary if upkeep is minimal and routine” (1974: 73). However, scholars like Palacios Rios (1977) state that *bofedales* need constant upkeep and abundant water; and Ccarhuanchu herders mentioned

FIGURE 4 *Bofedales* and canals in the Ccarhuancho Centro sector. (Map by A. Verzijl and S. Guerrero)

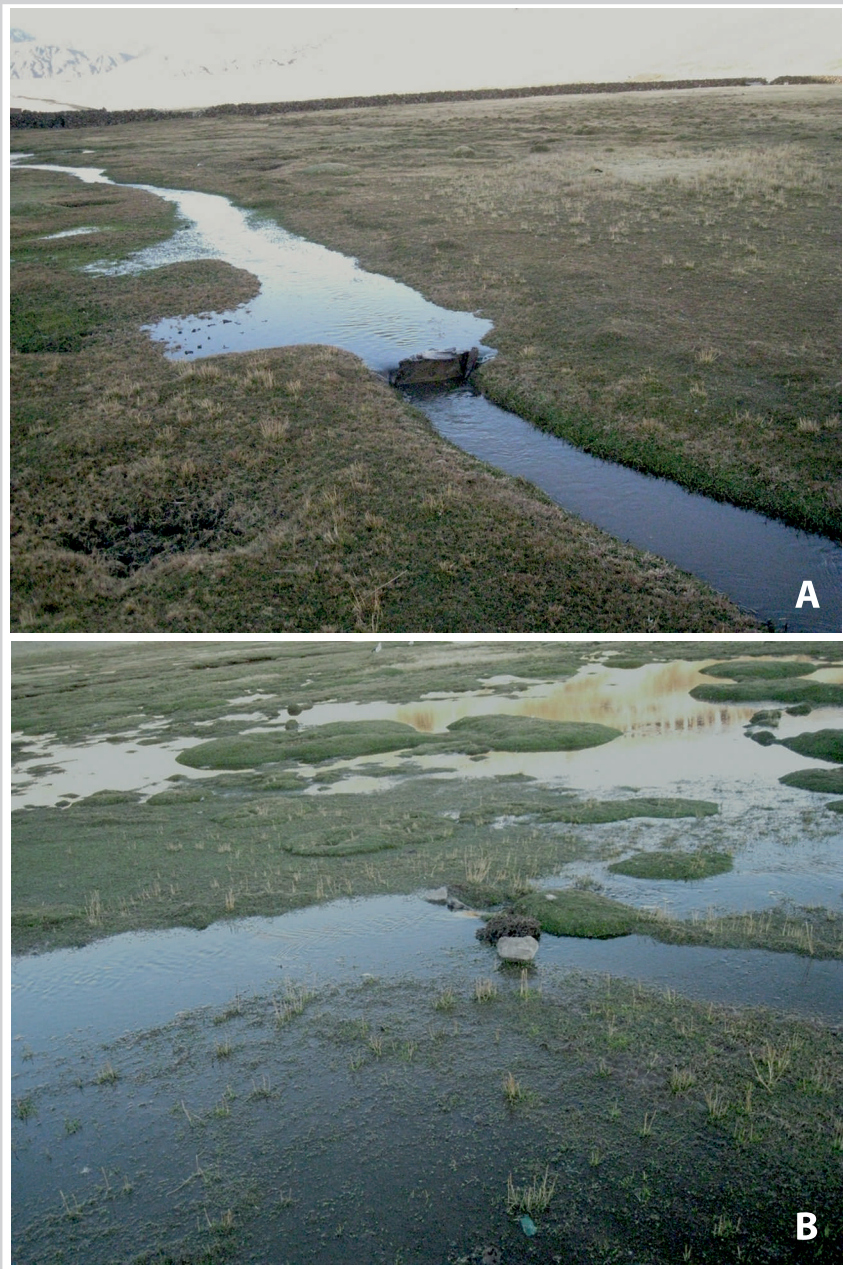


that operation and monitoring of *bofedales* are on a local scale but complex, as outlined later.

There are two principal ways to irrigate wetlands. Both involve partially blocking a canal with a flat stone,

called a *tranqa*, or a piece of turf, which is placed at the tail end of a ditch, causing water to spill over the edge (see also Netting 1981: 45). In the first method, when the water has inundated the area, the *tranqa* is removed, and others

**FIGURE 5** (A) Wetland irrigation with *tranqa*; (B) irrigation field application and inundation of a canal. (Photo by S. Guerrero)



are placed at different locations along the canal to control overflow points. Because canals are often hundreds of meters long, stones are normally not carried but left along their course. In the *bofedales* on the valley floor, the canal water spills over on both sides, submerging part of the land. This method is used mostly in the second type of canal used, as discussed earlier, to prevent existing *bofedales* from drying out. Whereas in traditional irrigation systems control stones have to be removed after a couple of hours depending on the irrigation rotation, in

*Ccarhuancho* stones can stay in a single place for much longer. Figure 5 shows irrigation techniques that use *tranqas*.

The second method involves several stones placed in the canal to divide the flow so that part of it flows onward and part flows onto the *bofedal*, guided by small cutouts in the peat. These stones remain in place more permanently and are used to revitalize peat dried up over a long period. An alternative to this method is to have several smaller canals redirecting water over a designated area.

Such structures, which do not require frequent attention, may give the idea that no monitoring is needed.

Overirrigating can also be a serious problem in Ccarhuancho. It encourages growth of the unfavorable Cuncus grass (*Distichia muscoides*) in the vegetation that alpacas eat. According to herders, the increase in temperature, torrential downpours, and loss of snowmelt have allowed Cuncus to outcompete other vegetation. Careless irrigation enhances Cuncus growth as water is being supplied from above rather than from underground. Although it is difficult to balance flows, removing Cuncus by hand is nearly impossible. Another solution being tried is to leave a group of alpacas overnight for a week on a Cuncus patch. Their dung kills the Cuncus, after which more desired vegetation flourishes.

Monitoring is also needed as torrential rains bring rocks and mud (*lodo*) into the canal system that might bury wetland meadows under a layer of debris. This could destroy a *bofedal*, and during the months of heavy rains the canal intakes are closed. The consequences of transhumance and irrigation mean that community members must cooperate and trust one another for monitoring and maintenance. This is also important when, for example, a herder moves into an *echadero* and *bofedal* maintained for months by other herders who have now moved on. Moreover, herders rotating through their pastures might make adjustments to a canal to which they will not come back for maybe a week. If changes are needed, they rely on those moving in after them to make the changes.

Although these activities are not centrally managed, the role of the community assembly is increasing with current changes in climate and population. Hard data about population are difficult to obtain, but herders indicate that in the 1960s some 20 families lived in Ccarhuancho Centro with 80–150 alpacas per family. In the 1980s, the assembly agreed to ban the keeping of pigs, and the community is phasing out sheep because these animals have a more negative impact on the wetlands than camelids. These regulations are strictly enforced if individuals or families do not comply. Community control also exists with respect to the human population. Presently, there is a waiting list of community members requesting an *estancia*. Meanwhile, people migrate to the city for work, or several families reside on a single *estancia*. In the latter case, fewer animals per family can be kept because pasture size is the constraining factor, and many families combine herding with nonpastoralist work.

Because of these pressures, the need to control water and improve and extend wetlands is becoming a more communal issue. Plans to harvest more water are discussed in the assembly, as are conflicts relating to water allocation that cannot be resolved by the users. The last decade has seen the introduction of technologies to harvest water, such as the construction of small tanks and

pressurized systems, and with them new water-related conflicts. Conflict resolution is less often handled in situ than in the past, and the assembly intervenes, seemingly following an egalitarian principle. It would, for example, demand the demolition of a recently constructed tank today to assure water availability for downstream users who wanted to retain the option of developing their wetlands tomorrow.

## Discussion and conclusion

Despite the challenges, the Ccarhuancho herders are confident they can sustain their *bofedales* as long as they control their water sources. This article aimed to visualize and acknowledge the local human–*bofedal*–animal–water resource interactions and arrangements that together constitute the ecology of high-altitude wetlands long used for grazing and managed through transhumance and herd-size control. Simple irrigation practices are also well established and enhance the quality, spatial coverage, and incidence of vegetation to support livestock densities. However, technological simplicity and strong communal control mean that these systems are often invisible to the uninitiated.

There are thousands of communities like Ccarhuancho with similar peatland potential in the Andes (Postigo et al 2008). Not only have *bofedales* or peatlands the ability to store and purify water, regulate regional hydrology, and capture carbon (cf Zedler and Kercher 2005), but also, as this article has shown, their use and conservation are linked to and enhance local livelihoods. Wetland ecosystem services are recognized in other mountain areas, such as the Ruergai plateau in the Himalaya (Chatterjee et al 2010; Zhang and Lu 2010; Joosten et al 2012). However, local efforts at community resource management and simple maintenance practices need better recognition and research. This article has shown that sustainable use of wetlands for livestock herding is possible and that local community water governance is critical. Depending on the circumstances, there is great potential for restoration of peatlands, and current attempts by scientists and “restorationists” (Zedler and Kercher 2005: 60) reflect the centuries-old practices of Ccarhuancho herders and their Andean predecessors (Lane 2009). They are, and will continue to be, the first to recognize and respond to climate change and defend their wetlands against degradation.

Responsibility for the next step in appreciation of this local water governance and adaptive restoration of *bofedales* lies beyond the herders. Higher-level agencies with responsibility for water resources and wetlands need to recognize the productivity of these land-use systems and the existence and value of these wetland irrigation practices. This recognition involves a broader understanding of governance that goes beyond

institutional arrangements and generic blueprints for individual or common-property entitlements to pastures, land, or water rights. Critical to this is seeing how, in the agroecology of wetland resources such as those of Ccarhuanchu, natural and man-made resources are deeply interconnected and fluid: canals “melt” into the *bofedales*, which diffuse into the surrounding pastures, and all have interdependent relations with herd behavior and herders. Like Orlove (1977: 80), we seek to treat this entire system of interconnected entities as a community—a centuries-old body of sustainable governance that integrally manages natural resources, animals, people, and livelihoods.

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This study has shown, however, that this governance entity’s fluid boundaries and their relation to lands in use need further analysis. The *bofedales* analyzed here are part of this community entity, not a separate unit of natural landscape to which a community has access entitlements. Future pressures emerging from climate and population change make it important to maintain the capabilities of this community governance. It is hoped that this study will stimulate more comparative research of water management of *bofedales* in the Andes and in highland wetlands and pastures worldwide.

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## Supplemental data

**TABLE S1** Artificially improved *bofedales* and canals and herd access.

**TABLE S2** Natural *bofedales* and herd access.

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