Andes, Bofedales, and the Communities of Huascarán National Park, Peru

Article *in* The Society of Wetland Scientists Bulletin · November 2020

WETLAND RESEARCH

Andes, Bofedales, and the Communities of Huascarán National Park, Peru

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ABSTRACT

Mountain wetlands are abundant in the high elevations of the tropical Andes. Wetlands occupy ~11% of the total park area and are mostly found in the large mountain valleys. Wetlands occur up to 5000 m asl, but most occur between 4,000–4,700 m asl. The highest elevation wetlands are typically dominated by cushion plants, while lower elevation wetlands are more commonly occupied by graminoids. About 60% of all wetlands are peatlands and the remainder are mineral soil wet meadows. The peatlands are up to 11 m deep and 12,000 years old, storing an average of 2,101 Mg C ha^{-1}, which is comparable to lowland tropical peatlands. Our work in Huascarán National Park in Peru is also showing the importance of wetlands in a coupled natural-human system. These wetlands and alpine landscapes are shaped in part by legacies of past human land use, including ancient pastoralism and farming, and are also affected by millions of downstream users dependent upon wetlands and glacier-fed streams for water and energy production. Biodiversity and endemism is high among taxonomic groups such as plants, birds, fish, amphibians and insects. Currently the tropical Andes are in ecological flux due to rapid land cover changes caused by both biophysical and socioeconomic drivers. In addition, the high Andes are experiencing warming and rapid glacial retreat that is resulting in hydroecological changes and socioeconomic changes to the traditional Andean societies that feed back to changes in wetland sustainability.

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INTRODUCTION

The tropical Andes are rich in biological diversity and have been utilized for millennia by human communities (Young and Lipton 2006). When the Spanish conquistadors arrived in the 16th Century, bringing horses and cattle and a different land management scheme with them, cultural resources dramatically changed and many unique ecosystems were transformed by the introduction of new grazers and browsers and the abandonment of maintenance of water systems and much of the original land use practices shifted and adapted. Dramatic transformations are once again occurring with rapid climate change and glacial retreat in the Andes of Peru that is further transforming water and biological resources, changing biodiversity as species shift, livelihoods adapt by changing agriculture, livestock husbandry, and other economic activities, and new species are introduced (Anderson et al. 2011; IPCC 2019; Hock et al. 2019). In Peru, these problems are exacerbated by growing demands for water and other mountain natural resources associated with economic growth (Mark et al. 2017; Hock et al. 2019).

The high Andes of Peru have received worldwide attention due to rapid glacial retreat and socioeconomic changes to the traditional Andean societies. These changes could cause the collapse of traditional societies altering human well-being and cultural heritage, coupled with ecological collapse in one of the most biologically diverse landscapes in the world (IPCC 2019). Such dramatic shifts may be mirrored in other ecological systems and traditional societies throughout the world especially where wild pollination is tied to traditional food crops and small-scale agricultural systems (IPBES 2018; Villagra et al. 2020). A multidisciplinary research team including U.S. and Peruvian institutions, Peruvian National Park managers, agropastoralist communities and a local non-governmental organization with funding from National Science Foundation-Coupled Natural Human Systems are examining these issues in Huascarán National Park (HNP) as a case study of how communities, biodiversity, protected area management, and rapid climate change all intersect in a wetland rich mountain environment.

Natural Protected Areas (NPAs) provide critical environmental services in an increasingly anthropogenic world. High elevation NPAs protect both the alpine species and essential watersheds needed by local communities within and below alpine systems. Because the tropical Andes is one of the global biodiversity hotspots (Myers et al. 2000) and high elevation endemism among taxonomic groups such as plants, birds, fish, amphibians and insects, a series of protected areas were created to attempt to conserve that biodiversity (Rodríguez and Young 2000). HNP (340,000 ha) was created in 1975 to conserve the ecosystems of the Cordillera Blanca, which is in the central Andes of Peru with high peaks ranging from 5,000 to 6,768 masl (including Peru's highest peak, Huascarán Sur). The United Nations Educational, Scientific and Cultural Organization declared HNP a Biosphere Reserve in 1977 and included it in the list of Natural Heritage of Humanity in 1985. As of 2016, the Cordillera Blanca contained approximately 755 glaciers (25% of all tropical glaciers) and 830 lakes of glacial origin (Mark et al. 2010; Autoridad Nacional del Agua 2016). These mountain glaciers are an important source of water, and they regulate water quantity by buffering the temporal precipitation variability that supplies water for domestic, agricultural and industrial uses during the dry season for both locally and in the arid coast of Peru (Rabatel et al. 2013). HNP is surrounded by 30 agropastoralist communities that existed before park creation. Cattle and sheep are numerous and free ranging in HNP, with limited numbers of horses and burros allowed to graze in peripheral park areas. Some communities continue to have access rights to HNP land, and their animals can use grasslands and wetlands under specific agreements and arrangements with the HNP.

WETLANDS

Mountains are often areas of high wetland abundance due to excess water from high rates of orographic precipitation, and these wetlands provide many benefits, including high-quality habitat, nutrient sinks and transformations, carbon and water storage, and areas for pasture (Chimner et al. 2010, Cooper et al. 2012). The Andes are no exception, with wetlands common across the entire range from the northern páramo region of Colombia, Venezuela, and Ecuador through the humid and dry puna of Peru and Bolivia all the way down to southern Argentina (Chimner et al. 2011).

Bofedales (singular bofedal) is a commonly used term in Peru to refer to mountain wetlands (Maldonado Fonken 2014). One of the unique aspects of bofedales in the Andes is the dominance of cushion plants (Figure 1). The compact growth form of cushion plants is an adaptation to arctic and alpine conditions as it traps heat and minimizes wind shear (Billings and Mooney 1968). In the Andes, cushion plants are mostly in the family Juncaceae, Asteraceae and Plantaginaceae (Cooper et al. 2010).

FIGURE 1. High elevation cushion plant peatland in Pastoruri, HNP. (Photo by Rod Chimner.)

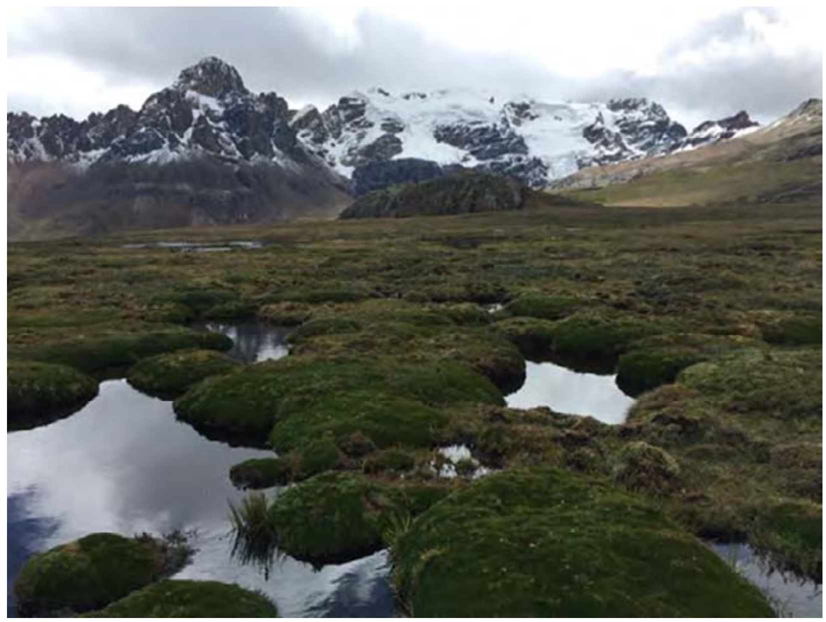
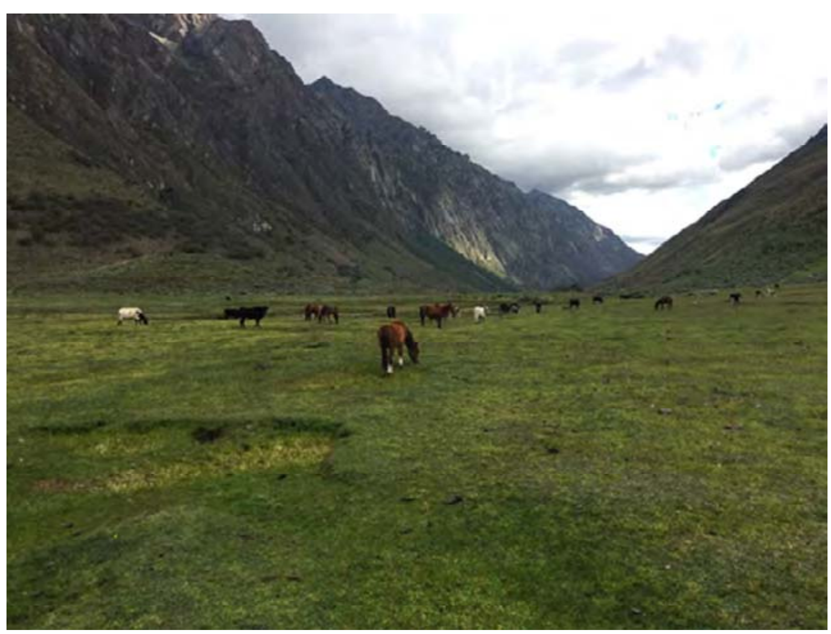


FIGURE 2. Cattle and horses graze in cushion plant wet meadows and peatlands in Ulta Valley, HNP. (Photo by Rod Chimner.)



Cushion plant dominated bofedales are common in HNP, and many of them are organic soil peatlands or fens (Figure 1). However, other cushion plant bofedales are actually mineral soil wet meadows (Figure 2: Chimner et al. 2019). Cushion plant peatlands can have high biodiversity for species assemblages of endemics such as anurans (Lescano et al. 2020) and wet meadows often support mixed avian flocks that include rare and new-to science species (Schulenberg et al. 2020). Because cushion plant-dominated wet meadows and peatlands can look superficially similar (Figure 2), there can be confusion in the literature and with management as they are both called bofedales (Chimner et al. 2019).

While cushion plants are common, there are many other plant species found in wetlands. The most recent floristic analysis that focused on bofedales in HNP documented relatively low alpha diversity, but potentially high beta diversity. Polk et al. (2019) sampled three valleys (Llanganuco, Quilcayhuanca, and Carhuascancha) and identified 112 vascular plant species in 29 families. The most species rich families were Poaceae, Asteraceae, and Cyperaceae. The most frequent species were *Plantago tubulosa* Decne., *Eleocharis albibracteata* Nees & Meyen ex Kunth, *Juncus ebracteatus* E. Mey., *Gentiana sedifolia* Kunth, and *Calamagrostis rigescens* (J. Presl) Scribn. Rarity was common in the inventory - 37% of all species occurred only once. Mean alpha diversity was 12.6, which is what might be expected for high mountain vegetation. The survey design used by Polk et al. (2019) allowed for a valley-to-valley analysis, which showed that vegetation in the three valleys are more dissimilar than they are similar, sharing only 35% of the species on average. This finding suggests that there is high beta diversity among plant species in bofedales in HNP and more vegetation surveys should be completed to further document plant diversity.

FIGURE 3. Graminoid peatlands and graminoid wet meadows in Rio Negro, HNP. (Photo by Rod Chimner.)

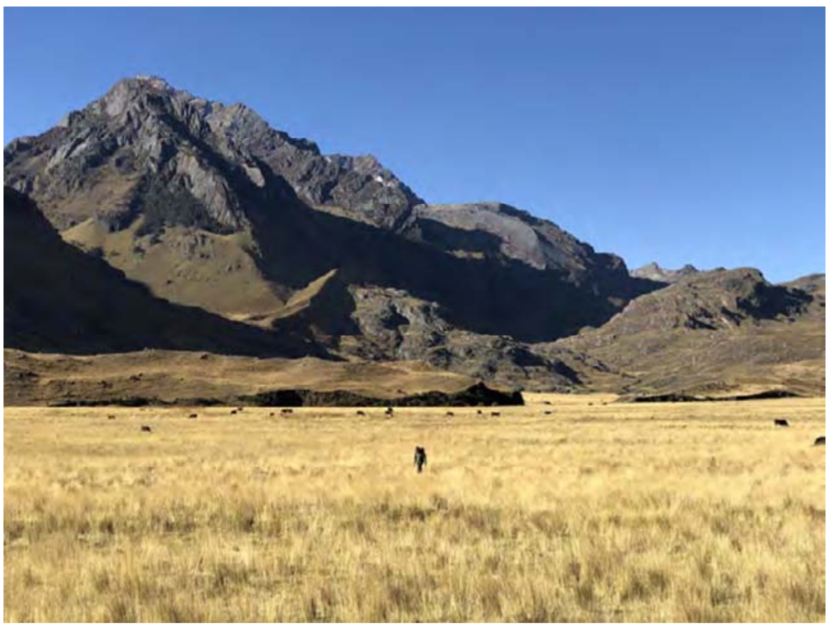
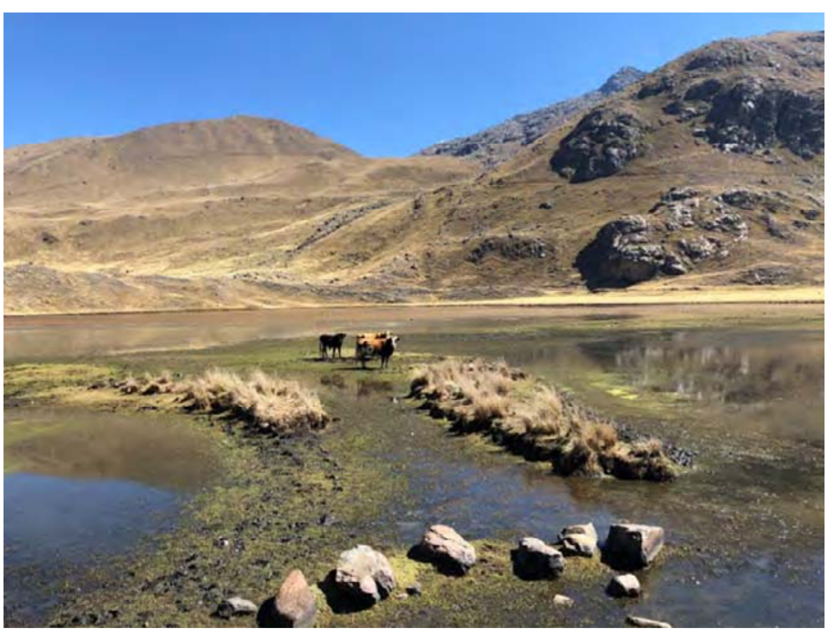


FIGURE 4. High elevation clear water lake in Rio Negro, HNP. (Photo by Rod Chimner.)



Previous research identified four wetland types based on hydrophytic plant species that co-occur in Peruvian bofedales (Weberbauer 1945; Maldonado Fonkén 2014). Polk et al. (2019) identified five plant assemblages or groups with one cushion plant-dominated assemblage: 1) *Plantago tubulosa - Oreobolus obtusangulus*, and four graminiod dominated assemblages: 2) *Werneria pygmaea - Pernettya prostrata*, 3) *Juncus ebracteatus* - *Carex bonplandii*, 4) *Eleocharis albibracteata* - *Calamagrostis rigescens* - *Lachemilla pinnata*, and 5) *Werneria nubigena* - *Oritrophium limnophilum* - *Phlegmariurus crassus* These five groups could be conceived of as subgroups of the system published previously by Weberbauer (1945) and Maldonado Fonken (2014). Cation exchange capacity, organic matter, bulk density, and elevation were factors associated with structuring bofedal vegetation in the three valleys sampled. At the scale of HNP, subsequent mapping work by Chimner et al. (2019)

showed that elevation and latitude are additional organizing factors and they classified bofedales as cushion plant peatlands, cushion plant wet meadows (Figure 2), graminoid peatlands (Figure 3), and graminoid wet meadows (Figure 3).

There is normally little information about mountain wetland abundance, because they are often small and located in remote and rugged settings that make them difficult to map (Bourgeau-Chavez et al. 2017). Mapping work by Chimner et al. (2019) in HNP has found that wetlands are numerous and occupy ~11% of the total HNP area, mostly found in the large mountain valleys. For context, grasslands comprise 17% and woodlands 8% of the HNP area. Cushion plant peatlands were the most abundant wetland type occupying 6.2% of HNP, followed by graminoid wet meadows (3.5%) and cushion wet meadows (1.3%), and graminoid peatlands (0.1%).

Wetland type and abundance varied with elevation. Wetlands occurred up to 5,000 masl, but were most abundant between 4,000–4,700 masl with about three-quarters of all mapped wetland area occurring within this elevation zone. At the lower elevations, wetlands were mostly graminoid wet meadows and at higher elevations wetlands were mostly cushion plant peatlands. Cushion plant wet meadows were most common in mid-elevations. Wetland type and abundance also varied north to south, with more wetlands found in the south (mostly cushion plant peatlands) compared to the northern part of the park (cushion wet meadows) (Chimner et al. 2019).

Wet meadows and peatlands have large differences in soils, hydrology, chemistry, and often respond very differently to grazing. Wet meadows are often preferred for grazing because they are seasonally wet and have stable soils compared with peatlands, which makes it easy for livestock to utilize. Wet meadows can still be overgrazed leading to vegetation loss, erosion, nutrient losses and soil carbon declines (Enriquez et al. 2014, 2015). In contrast to wet meadows, mountain peatlands are very susceptible to grazing impacts due to their thick and soft organic soils, which are easily trampled (Chimner et al. 2010, 2011; Cooper et al. 2012) and can significantly reduce or reverse carbon storage and increase emissions of the potent greenhouse gas methane by an order of magnitude (Sánchez et al. 2017). In HNP, Calvo (2016) assessed bofedal condition in Quilcayhuanca Valley and found that bofedales in good condition had >70% cover of native species with abundant litter, high soil infiltration and water quality, high plant diversity, no bare soil, and no sign of erosion. Whereas bofedales in poor condition had < 25% of native species, poor soil infiltration and water quality, high percent cover of bare soil, and signs of erosion.

Peatlands in HNP range in age from 3,200 to 12,000 years (Hribljan unpublished data) and have an average depth of ~ 5 m, with maximum depths reaching ~11 m (Hribljan unpublished data; Chimner unpublished data).

FIGURE 5. Interdisciplinary team in the field with Peruvian and US students and local partners in Ulta, HNP. (Photo by Molly Polk.)

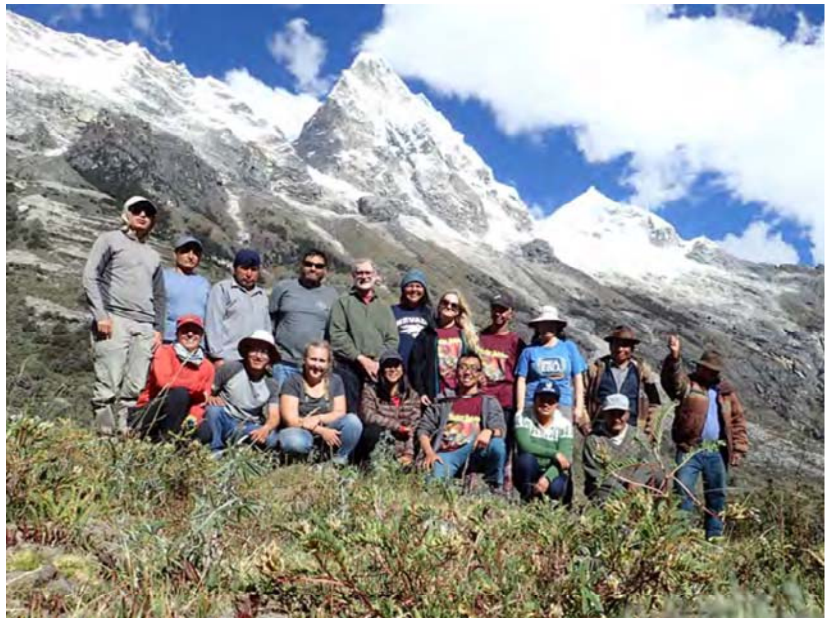
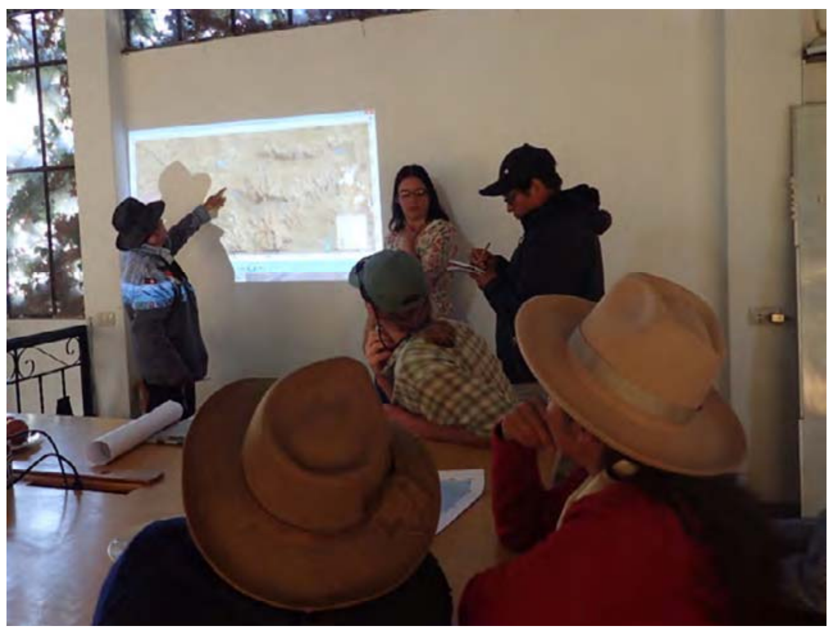


FIGURE 6. Research team collaborating with community members at The Mountain Institute in Huaraz, Peru. (Photo by Molly Polk.)



The thick peat deposits combined with dense peat (average bulk density = 0.26 g cm^{-3}) result in these peatlands containing very high belowground carbon stocks (average = 2,101 Mg C ha^{-1}) compared to most peatlands globally. For instance, high elevation peatlands in HNP have carbon stocks on an areal basis that are greater than average carbon stocks of 1,421 Mg C ha^{-1} from peatlands in the Peruvian Amazon Pastaza-Marañon basin, which is the second largest continuous peatland complex in the tropics (Lähteenoja et al. 2012).

Although little water table data exists, peatlands in HNP appear to be similar to other peatlands in that they require continuous high water tables to slow decomposition rates (Planas-Clark et al. 2020). For example, even though there were large differences in total precipitation between the wet and dry seasons, water table levels were relatively stable throughout the year and stayed near the soil surface in reference peatlands (Planas-Clark et al. 2020). This stability of water also provides fresh water during the long dry season for local agropastoralists (Maldonado Fonkén 2014). In addition to providing water, wetlands in HNP are also being used to improve water quality from heavy metal pollution from mines and glacial melting exposing geologic formations that are weathering metals.

BIODIVERSITY

The high Andean landscape is considered one of the world's hotspots of biodiversity but much of that diversity is largely unknown and includes taxa that provide critical ecosystem services. High elevation wetlands and clear water lakes (Figure 4) have high diversity levels of aquatic macroinvertebrates (Nieto et al. 2020), endemic avian species (Schulenbuerg et al. 2020), amphibians (Lescano et al. 2020), and wild pollinators (IPBES 2018). Endemic species are still poorly known with new species of birds (Schulenberg et al. 2020) and insects still being discovered (Figure 5). On the landscape level, HNP provide habitat to over 780 vertebrate species, many of which are considered threatened or near threatened by the IUCN Red List of Threatened Species, including the larger animals like the puma (*Puma concolor*), Andean fox (*Lycalopex culpaeus*), and Andean bear (*Tremarctos ornatus*) (Fjeldså 1993; Yensen and Tarifa 2002; Lloyd 2008; Gareca et al. 2010). Many of these species are impacted by current park management. For example, the South American deer or taruka (*Hippocamelus antisensis*), a high altitude specialist listed as vulnerable by the IUCN Red List of Threatened Species (Barrio et al. 2017), shares habitat with domestic livestock leading to the displacement of taruka (Merkt 1987; Barrio 1999, 2006; Gazzolo and Barrio 2016).

Biodiversity research has been limited to a few localized studies (Fjeldså 2002; Yensen and Tarifa 2002; Lloyd and Marsden 2008; Renison et al. 2018; IPCC 2019). The lack of biodiversity assessments has left gaps in understanding how change and disturbance will affect the biological communities that inhabit these systems in the future (Fjeldså 2002; Lloyd and Marsden 2008; Dangles et al. 2020). For instance, macroinvertebrates may have reduced functional diversity as glaciers retreat in high elevation systems. Most wild pollinators are poorly studied with little known about high elevation bombus species, which are of particular concern due to the introduction of non-native bombus species such as *Bombus terralis.* The impacts of non-native bombus introductions may be linked to the declines of the IUCN listed species such as *B. dahlbomii*, one of the largest bombus species (Singer and Sanguinetti 2014), and the Andean Bumble bee (*B. coccineus*). In addition, several species of honey producing bees such as *Apis mellifera* have been introduced in many high elevation communities, leading to the introduction of parasites and pathogens that appear to impact native pollinators especially, the rarer bombus species such as *B. dahlbomii* (deLanda et al 2020).

WETLANDS AS COUPLED NATURAL AND HUMAN SYSTEMS

Wetlands of the high Andes Mountains can be conceptualized as coupled natural-human systems because their characteristics and dynamics are only in part regulated by biophysical processes pertaining to the water cycle and to the dynamics of ecological succession. An important additional component is the conspicuous human dimension, such that wetland ecosystems cannot be understood without reference to interactions among the various biophysical and social processes. For instance, many Andean bofedales have been managed since pre-hispanic times by using water management technology (Morlon et al. 1996; Lane 2006, 2014).

In the case of our study areas this is true even for the most remote and "pristine" parts of HNP. The human influences are ancient: one of our study sites is located along a hiking trail used by trekkers going to the Chavin archaeological site for tourism - they move along routes where pilgrims came to participate in rituals 3,500 years ago. Agropastoralists have also created and modified wetlands for livestock by diverting surface water to maintain or enlarge wetlands (Lane 2006). Similarly, farmers use canals to extend the irrigation of their crops. The sizes of these water reservoirs are 10 - 15 m in diameter and hold between 100 - 300 m^3 of water (Lane 2014). The expansion of the wetland area not only improves the water provision service, but also regulates water flow during the dry season, increases water quality, and contributes to soil carbon sequestration (Lane 2014). Understanding the deep timeline of human influences will be an important complement for understanding the complex couplings in this system.

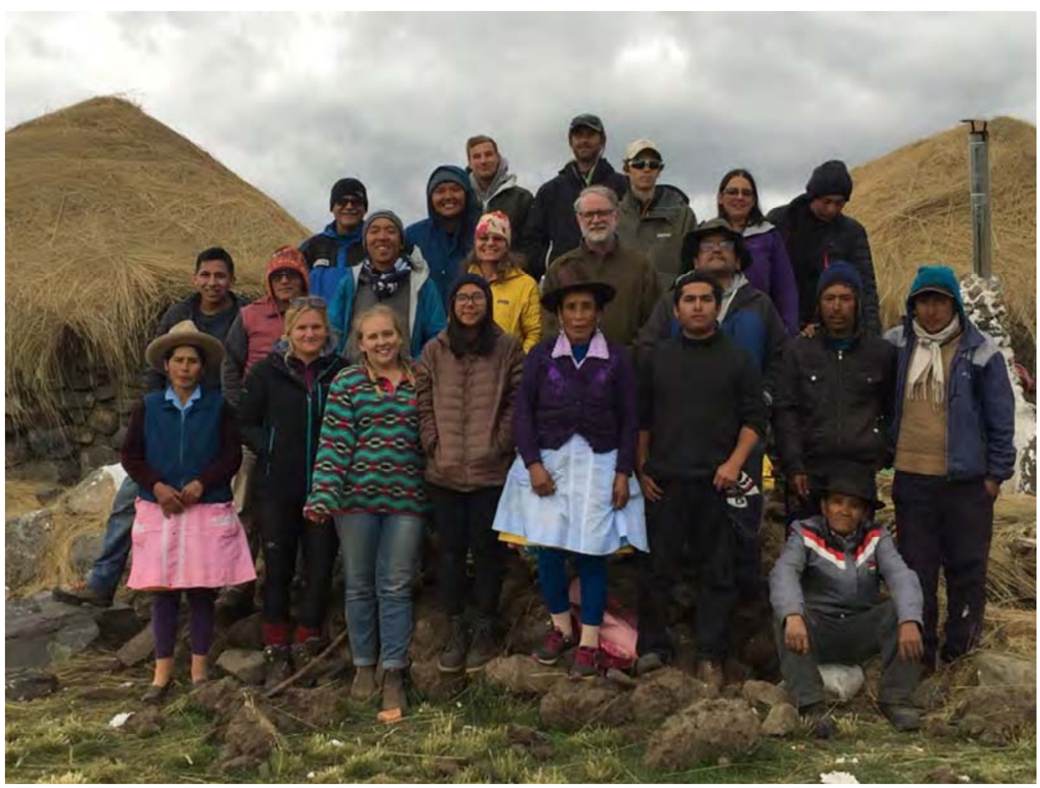
Inside the park today, it is not uncommon for cattle to navigate steep slopes above 4,000 m elevation. Livestock are far more visible in HNP than large wild mammal species, which are more commonly seen in landscapes outside HNP boundaries. The study of the pastoral systems not only provides needed information for park managers hoping to lessen damaging environmental impacts, but provides information to local communities who rely on wetlands for their economic and subsistence needs (Figures 6 and 7). This human-nature interaction exemplifies the historical cultural exchange between Western and Andean cultures, as they borrowed cattle from Western culture and incorporated and transformed their Andean human landscape. Cattle are so integrated into the local cultures now that local communities cannot understand life in the mountains without these animals. For local people, cattle are part of their natural landscape. It is like this in many parts of the Andes, however, there are still some remaining places where original livestock (camelids) are the main element of the landscape.

Areas within HNP has been heavily used for tours by school groups; the view of glaciers and other natural features was often the most direct experience Peruvian school children had of nature as seen in real life rather than on television. The glaciers provide critical runoff, especially during the five month long dry season, for maintaining surface water flows and for drinking water for the city of Huaraz. So, the park provides numerous educational and ecosystem services locally, regionally, and nationally. The park's wetlands provide unique biodiversity habitat, function in ways that store water and carbon, and are conspicuous landscape features visible to park visitors.

There are also important social roles filled by HNP, occupying the headwaters of valleys used by farmers for their crops downslope. The high elevations within HNP are accessible to traditional land use by the park's neighbors through agreements made with park managers, and as negotiated based on past land tenure. Our research suggests that the park-people interactions involve two archetypes of land use: a seasonal rotational livestock system that brings in cattle to the wetlands and sheep to the hillslopes of the park during the dry season, and a system that keeps cattle in the park year-round. The former appears to be less environmentally damaging (and more productive economically), but the latter is still common because cattle owners who remove their livestock risk losing access rights in the future. The wetlands thus are viewed as critical dry season production areas in some valleys, but can be sources of mortality for cattle that free range year-round, with only weekly or biweekly visits by the livestock owners. Our research has included detailed informant interviews by an anthropologist fluent in Quechua, the first language of many local people, to get their perspectives on the costs and benefits of wetlands for their livelihoods.

It is impossible to do research in this part of Peru and not be struck by social injustices having to do with past environmental and land tenure concerns. The Santa River, fed by glaciers within the national park, is littered by unmitigated mine tailings and contaminated with heavy metals. More than half of the high elevations of this part of Peru are within exploratory mining claims and several large mines are in active exploitation. The park provides an important protected space for natural environments, but

FIGURE 7. Project leaders in the field with community partners in Rio Negro, HNP. (Photo by Molly Polk.)



must also accommodate legitimate concerns about land tenure that date back to pre-park years when lands were controlled by large landowners in the form of *haciendas*. Some of the concerns mentioned by local people predate the park, but still drive emotions and actions today.

HNP is emblematic of global change impacts. Its boundaries include the longest extension of glaciers anywhere in the tropics. Glacier retreat is about 30% on average but on the ground, there are some places where the valley-head ice is already gone, meaning that the valley downslope is now "postglacial," with hydrology now regulated by precipitation and groundwater, and no longer supplemented by glacial runoff. In valleys under the highest peaks, the ice is predicted to last for at least another century. So, glacial retreat is adding additional heterogeneity as to how wetlands function, and implications for human land use also vary from valley to valley depending on the size and height of glaciers' upslope. We expect to find that this heterogeneity will be an important part of explanations for how and why wetlands change from place to place.

The use of a coupled agent-based model (DECUMA) and ecosystem model (L-Range model) is being used to help us understand the complexities of these coupled natural-human interactions (Boone and Galvin 2014; Boone et al. 2018). We are simulating how landscape features such as topography, wetland location and cover, primary production, and the location of water sources influence land-use decisions of agropastoral families. The coupled model is also being used to analyze scenarios of climate change and their impacts on the landscape, wetland sustainability, and households and communities' actions. Management scenarios such as changes in livestock population and rotation of grazing lands will be established using a participatory approach. The use of a coupled-modeling simulation approach will provide us information about the role of natural and human drivers on the ecosystem, decision-making processes, and explore the impact of short vs. long-term management options. Since wetlands are key ecosystems in this landscape, the model will provide insights of their role for land and livestock management, as well as information of how these ecosystems could be impacted due to climate change and management decisions.

FUTURE ISSUES

Mountain wetlands act as important sentinels of global changes, mediated by shifts in climate, associated ecological/hydrological alterations, and a suite of interactions with people. The global pandemic highlighted the intersections between large-scale landscape changes due to climate conditions coupled with changes in socioeconomic stability for local communities (loss of tourism due to COVID for example). Mountain wetlands are most directly affected by their hydroperiod, set by surface and groundwater hydrology, overlying biodiversity and ultimately by rainfall and runoff from glaciers in glaciated watersheds. Because of their importance for ecosystem services, they are often considered valuable by local people, who often utilize wetlands in their pastoralism systems, or by conservationists as keystone ecosystems with high endemism in protected areas such as national parks. Yet most of the ecosystem characteristics unique to the high elevation remain unknown, such as rates of endemism in high elevation birds, shifts in anuran composition in wetlands and the decline of wild pollinators such as Andean bombus species. The number of endemic species such as wild pollinators or birds is threatened by shifts in the wetlands systems coupled with the introduction of invasive pollinator species as a secondary stressor. The lack of knowledge of species diversity and overall endemism is profound especially as high elevation habitat patches shift along with local livelihoods - a perfect storm for the collapse of many ecosystem services appears to be brewing yet unseen in research inquiry.

The monitoring of glacial retreat, stream discharge, and depth to water table would all provide insights into controls on hydroperiod. The monitoring of the extent and spatial configuration of the wet meadows and peatlands can be done through mapping with remote sensing (Chimner at al. 2019). In particular, our additional use of active remote sensing data through satellite-borne radar can map both surface and subsurface features. Vegetation shifts of interest in those wetlands include the shift from dominance by graminoids at lower elevations to cushion plants nearer the peaks.

The human dimensions involved are multifaceted given that individual valleys in the park have different histories on land uses that are permitted, and especially in regards to the degree of control that park neighbors have (or do not have) in access rights that allow them to use park lands for livestock grazing and firewood collection. Some valleys have virtually no human impact, except for the passing of occasional hikers, while others are overgrazed with extensive trampling, an especially damaging impact on wetlands. The monitoring and evaluation of these anthropogenic influences is hence more complicated and may require nuances in mediating park-people interactions that may in some cases be antagonistic or may have histories of such antagonism.

Although COVID-19 was not a consideration when we developed our research plans for the park, now it is and will require us to think about wetlands, socioeconomic drivers such as tourism, livestock and biodiversity in an entirely new context. For instance, COVID-19 has sharply reduced tourism and much of the regional interchanges of highland agricultural products for consumer goods from the coastal cities of Peru. At HNP, the local communities have problems with their incomes since they do not have opportunities to provide guiding services, transport, hostels, and food, as well as to sell souvenirs. New approaches to food security, such as the localized production of honey, which has increased 100-fold in recent years, may also increase due to the pandemic, modifying the current land management. The local economy has been decreasing and presents an economic slowdown. The infrastructure for communications, drinking water, and public health is especially poor in smaller and more isolated settlements, perhaps meaning that subsistence farming and pastoralism is once again more important for the people living as neighbors to the park. We do not know what this will mean for park-people relations, and in particular for the ongoing dynamism of the mountain wetlands, but suggest that it be an important focus of monitoring for the next decade. ■

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