11-11-2023

Ecological Change and Livestock Governance in a Peruvian National Park

Kenneth R. Young
The University of Texas at Austin

Eyner Alata
Pontificia Universidad Catolica del Peru

Rodney Chimner
Michigan Technological University, rchimner@mtu.edu

Randall B. Boone
Colorado State University

Gillian Bowser
Colorado State University

See next page for additional authors

Recommended Citation

Young, K., Alata, E., Chimner, R., Boone, R., Bowser, G., Bourgeau-Chavez, L., Fuentealba, B., Gilbert, J., Ñaupari, J., Polk, M., Resh, S., Turin, C., & Zarria-Samanamud, M. (2023). Ecological Change and Livestock Governance in a Peruvian National Park. *Land, 12*(11). http://doi.org/10.3390/land12112051
Retrieved from: https://digitalcommons.mtu.edu/michigantech-p2/317

Follow this and additional works at: https://digitalcommons.mtu.edu/michigantech-p2
Part of the Forest Sciences Commons

Authors

Kenneth R. Young, Eyner Alata, Rodney Chimner, Randall B. Boone, Gillian Bowser, Laura Bourgeau-Chavez, Beatriz Fuentealba, Jessica Gilbert, Javier A. Ñaupari, Molly H. Polk, Sigrid Resh, Cecilia Turin, and Melody Zarria-Samanamud

land

MDPI

Article

Ecological Change and Livestock Governance in a Peruvian National Park

Kenneth R. Young [1,*], Eyner Alata [2], Rodney A. Chimner [3], Randall B. Boone [4], Gillian Bowser [4], Laura Bourgeau-Chavez [5], Beatriz Fuentealba [6], Jessica Gilbert [7,†], Javier A. Ñaupari [8], Molly H. Polk [1], Sigrid C. Resh [3], Cecilia Turin [9,‡] and Melody Zarria-Samanamud [4]

[1] Department of Geography and the Environment, University of Texas at Austin, Austin, TX 78712, USA; mollypolk@utexas.edu
[2] Departamento de Ciencias Sociales, Pontificia Universidad Católica del Perú, Lima 15088, Peru; eyner.alata@pucp.edu.pe
[3] College of Forest Resources and Environmental Science, Michigan Technological University, Houghton, MI 49931, USA; rchimner@mtu.edu (R.A.C.); scresh@mtu.edu (S.C.R.)
[4] Department of Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO 80523, USA; randall.boone@colostate.edu (R.B.B.); gillian.bowser@colostate.edu (G.B.); melody.zarria-samanamud@colostate.edu (M.Z.-S.)
[5] Michigan Tech Research Institute, Michigan Technological University, Ann Arbor, MI 49931, USA; lchavez@mtu.edu
[6] Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña, Huaraz 02002, Peru; bfuentealba@inaigem.gob.pe
[7] Department of Ecology and Conservation Biology, Texas A&M University, College Station, TX 77843, USA; jessica_gilbert@fws.gov
[8] Animal Production Department, Universidad Nacional Agraria La Molina, Lima 15024, Peru; jnaupariv@lamolina.edu.pe
[9] Instituto de Montaña, Lima 15088, Peru; cturin@lamolina.edu.pe
* Correspondence: kryoung@austin.utexas.edu
† Current address: U.S Fish and Wildlife Service Southeast Regional Office, 1875 Century Blvd NE, Atlanta, GA 30345, USA.
‡ Current address: Animal Production Department, Universidad Nacional Agraria La Molina, Lima 15024, Peru.

Abstract: While the grazing of livestock has occurred for millennia in the Andes, current sustainability debates center on concerns with co-managing climate change and pastoralism. These discussions have special resonance in places protected by the state for biodiversity, scenery, and sustainable and traditional land uses, such as those found in protected areas and biosphere reserves. For this article, we integrate data from a social-ecological research project on the land use systems that affect high-elevation ecosystems in Peru's Huascarán National Park, with special emphasis on the wetlands. We used land cover and land use data and insights from interactions with pastoralists to show that (1) wet meadows dominate the lower reaches of the park, while peatlands predominate above 4000 m elevation; (2) wet meadows are most useful for traditional grazing systems, while the peatlands are especially susceptible to trampling by livestock; and (3) there is limited ecological space at the highest elevations for the successful future upward relocation of either land use or potential habitats for species identified as of concern. We explore the implications of these findings for the adaptive strategies of biophysical and social processes in terms of livelihoods and biodiversity in and around a protected area. We conclude that there are many additional opportunities to be explored to inform the management of ecosystem services and provide improvements for the adaptive capacity of communities and park managers.

Keywords: biodiversity shifts; climate change; grazing systems; livestock; protected areas

check for updates

Citation: Young, K.R.; Alata, E.; Chimner, R.A.; Boone, R.B.; Bowser, G.; Bourgeau-Chavez, L.; Fuentealba, B.; Gilbert, J.; Ñaupari, J.A.; Polk, M.H.; et al. Ecological Change and Livestock Governance in a Peruvian National Park. *Land* **2023**, *12*, 2051. https://doi.org/10.3390/land12112051

Academic Editor: Rosalind Bryce

Received: 11 September 2023
Revised: 25 October 2023
Accepted: 7 November 2023
Published: 11 November 2023

1. Introduction

Natural protected areas provide critical ecosystem functions and services in an increasingly anthropogenic world. Protected areas were initially conceived as places to conserve iconic landscapes and wildlife; however, they currently serve to achieve a wide variety of conservation and socioeconomic purposes [1]. Protected areas are crucial for conserving biological systems that will otherwise be depleted or degraded; however, historically, protected areas have aroused criticism for following international guidelines that overlook local communities' interests, negatively impacting peoples' rights and livelihoods [2].

Climate change impacts ecosystems worldwide by altering mean temperature and precipitation conditions and climate variability. As such, it has special resonance for protected areas. Temperature extremes in northwestern South America are projected to become warmer and more frequent, with reduced and more variable precipitation associated with changes to the El Niño–Southern Oscillation [3,4]. Climate change also exerts additional pressure on ecosystems that are already facing degradation, fragmentation, and biodiversity loss [5]. Wetlands are highly threatened and biodiversity-rich ecosystems that need special attention regarding protected areas [6]. Overall, climate change represents a challenge and threat for protected areas that require conservation managers to adapt strategies for biodiversity conservation [7].

The high-elevation mountain regions in Peru contain several protected areas that are known for the presence of tropical glaciers, endemic species, migratory bird feeding grounds, and high diversity for certain taxonomic groups [8]. Here, we focus on Huascarán National Park (HNP), which includes much of the Cordillera Blanca, a mountain range known for containing many of the highest peaks in the tropics, and it is capped with numerous glaciers, vast high-elevation wetlands, and glacial lakes, all of which are affected by recent climate change [9]. The buffer zone of the park includes towns, settlements, and agriculture. Some local people living in the buffer zone have access rights for grazing inside HNP due to arrangements made as part of the park's establishment in the 1970s.

Wetlands offer a multitude of ecosystem functions and values, including enhanced water quality and storage, nutrient transformation and storage, habitat, grazing areas, and carbon storage [10]. Due to concerns about climate change, the conservation, restoration, and sustainable management of wetlands are receiving considerable attention. Wetlands contain a significant proportion of the Earth's total soil carbon, which can be released into the atmosphere if these areas are degraded or drained [11]. Peatlands, which are defined as wetlands with more than 40 cm of organic soil, globally hold the largest soil carbon stocks of any ecosystem type [12]. According to current estimates, peatlands store approximately one-third of the world's soil carbon in just 4% of the land area [13]. While other types of wetlands also store significant amounts of carbon, peatlands exceed them in terms of carbon storage [14,15].

Most wetlands are situated in low-lying areas worldwide, although they are also plentiful in numerous mountainous regions thanks to abundant groundwater, high precipitation resulting from orographic uplift, and cool temperatures [16]. Wetlands are abundant in the tropical Andes [17–20]. For instance, wetlands accounted for 18% of the mapped area in the Ecuadorian Andes [21], and 11% of the area in Huascarán National Park, Peru, was classified as wetlands [22]. Wet meadows and peatlands are the primary types of wetlands found in the park, and they can exist independently or together, forming wetland complexes [23]. Wet meadows are mineral soil wetlands with seasonally saturated soils [24,25], and they are typically dominated by herbaceous plants [16]. In the Andes, it can be challenging to visually distinguish peatlands from wet meadows. This is due to the similarity of the plant communities that grow on both types, which can either be cushion- or graminoid-dominated, and the fact that they can exist together in large complexes [22]. Mappings revealed that around 50% of the wetlands in Huascarán National Park, Peru, consist of wet meadows, with the other half being peatlands [22]. Nevertheless, a significant difference exists in the carbon stocks between the two types, with peatlands having an average amount of 1092 MgC ha^{-1}, whereas wet meadows store only an average amount of 30 MgC ha^{-1} [23]. Overall, wetlands in Huascarán National Park have a total of 24.4 teragrams of carbon, with peatlands containing 97% of the wetland carbon and wet meadows containing 3% of the wetland carbon [23].

In addition to storing vast amounts of carbon, wetlands in the Andes are critical pasture areas for local communities. In our collaborative research, we have emphasized the evaluations of wetlands as centers of grazing activity, especially in the context of protected alpine areas. We previously discussed the implications for conservation [26], and here, we evaluate the implications from a social-ecological perspective by including land uses in our observations and syntheses. High Andean wetlands can be conceptualized as social-environmental systems because their characteristics are only partially regulated by the biophysical processes of water and nutrient cycles, e.g., [27–29], and the dynamics of ecological succession, e.g., [30]. Rapid changes in weather patterns and glacier retreat further drive ecological shifts and hence complicate social-environmental responses [31,32]. Peru's Andean rangelands provide 46.5% and 23.8%, respectively, of the national demand for meat and milk [33]. Melting glaciers have transformed landscapes via lake outburst floods and modifications of climbing and trekking routes, and lower-elevation plant species have moved upward [34]. These problems are worsened by growing demands for natural resources that are associated with economic growth [35].

The natural resources of the Andes, including glaciers and the associated high-elevation landscapes, are relied upon by Andean agropastoralists [36], a type of land use that embodies a form of social organization based on the growing of crops and the raising of livestock as the primary economic activity. People have grazed native alpacas and llamas in the Andes for millennia, although livestock used today also includes cattle, horses, and sheep. Andean wetlands have long been recognized as having special importance for grazing systems, e.g., [37–39], as well as for rare and endemic high-elevation species such as the Andean bumblebee (*Bombus rubicundus*) and the giant hummingbird (*Patagona gigas*). Therefore, protecting such areas in Peru, as elsewhere, comprises an uneasy management mixture that tries to balance economic development and agropastoralist uses while also considering the need to protect high-elevation biodiversity and ecosystem services. For instance, many Andean wetlands have been managed since pre-Hispanic times via water management technology [40–42]. They often serve as sources of livestock forage during the dry season. In fact, Palacios [43] states that the size of the herd is set in relation to the amount of wetland available in drier parts of the Andes. Briske [44] edited a book titled *Rangeland Systems*, and the book helps delimit the biophysical and socioeconomic drivers of change that are likely to be important in affecting grazing systems, such as those that affect wetlands in the tropical Andes.

For this article, we integrate data concerning human cultural systems and high-elevation ecosystems in and near Huascarán National Park (Figure 1) to characterize the interactions of biophysical processes with human social dynamics. We built upon previous wetland ecology studies to merge those data with new information on the grazing systems that affect the national park. Our methods here are transdisciplinary, using syntheses of biodiversity and land cover information in relation to qualitative social research on perceptions and responses of the stakeholders involved. Specifically, we explore the implications of adaptive livelihood and biodiversity strategies in this protected area by evaluating the land uses associated with people who live in the park's buffer zone and providing insights into likely future trajectories. Specifically, we ask the following: (1) What are the governance practices associated with livestock grazing systems and how do those rules and practices relate to the zonation of the national park? (2) What are the implications for park integrity, biodiversity, and management, especially given the ongoing climate change?

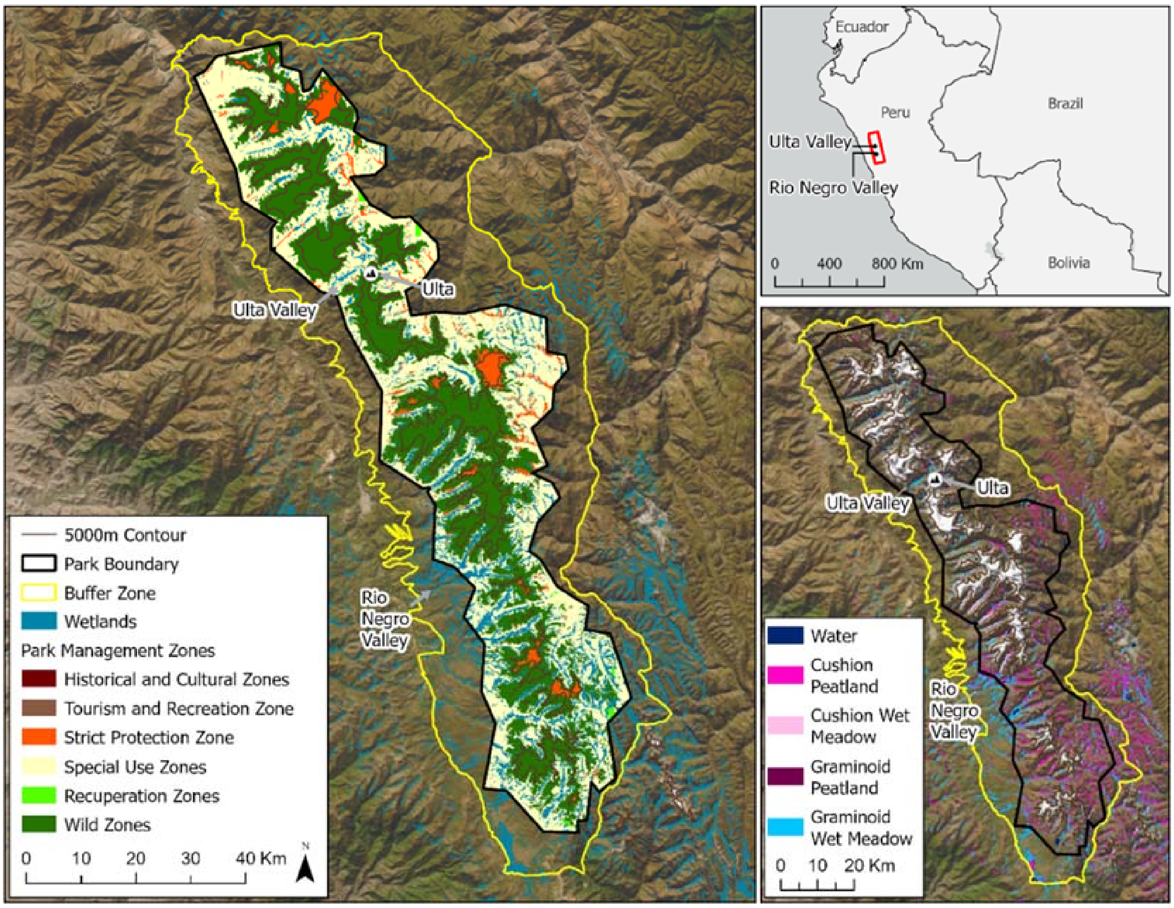

Figure 1. HNP and its buffer zone, major wetland types, and location in Peru. The buffer zone is delimited by the yellow lines and surrounds the park. The nucleus of the park is further subdivided into several zones based on land use and management goals and in relation to the types of wetland vegetation shown on the right side of the figure.

2. Study Area

Huascarán National Park (HNP), created in 1975, was declared a UNESCO Biosphere Reserve in 1977, and it was listed as a World Heritage Site in 1985. The park (340,000 ha) is surrounded by 43 agropastoralist communities that existed before the park's creation, with people who trace their occupation of high-elevation rangeland back several millennia. Some communities continue to have access rights to resources under specific agreements and arrangements with the park, although the communities themselves are situated outside park boundaries. The most common land use utilized is livestock grazing, with cattle and sheep being the most numerous livestock and there being limited numbers of horses and donkeys. There are also some small-scale efforts to raise llamas and alpacas as an alternative, but this is limited to a few communities.

The nucleus of the park is divided into five land use categories (Figure 1). Most of the park is zoned as a Special Use Zone (49% of the total park area, or 166,600 ha) occurring in the lower elevations (~<5000 m) in areas with agropastoral use prior to the establishment of HNP; this designates where agropastoral activities are currently permitted in the park. Most of the remainder is a Wild Zone (45.5% of the total park area, or 154,700 ha), which comprises steep mountainous terrain (~>5000 m) with less human intervention, mainly consisting of the occasional presence of hikers. Three other zones are much less common and include the Strict Protection Zone for high-priority conservation areas that are supposed to have very limited human activities and that protect the *Polylepis* woodlands; a Tourism Zone; and a Recuperation Zone where degraded land is recovering.

Livestock grazing within the park is divided into 64 sectors (each a different *quebrada*) managed by their own usage committee (*Comite de Usuarios de Pastos*, CUP), which may be family units, members of neighboring campesino communities, or members of neighboring settlements, depending on the sector. This system came into practice in 1980 (under *Resolución Ministerial* № 01200-80-AA-DGFF), and with it a set of agreements between the park and livestock grazers. The park has established a general system of rules to prevent overgrazing, pasture degradation, burning, hunting, etc., but personnel typically do not enforce grazing rules specific to each valley. No permanent housing for people is located inside the park.

3. Methods

Our social-ecological research consisted of both biophysical and social research, plus syntheses using the entire research group to make consensus representations of the likely interactions and feedback. The synthesis research reported here was premised on wetland research that was previously developed using a combination of multi-date, multi-sensor radar and optical imagery [45,46]. For Huascarán, we used a fusion of PALSAR (L-band ~23 cm wavelength), Radarsat, or other C-band data (e.g., Sentinel-1a, ERS-2; ~5.7 cm wavelength); Landsat or Sentinel-2 (optical, IR, and thermal); and SRTM DEM derivatives for the areas delineated by the park's boundaries. Wetlands are challenging to map with optical data alone, but seasonal SAR imagery permits discrimination based on differences in hydrology throughout the seasons. Topographic effects on SAR backscatter were alleviated via careful radiometric terrain correction (RTC) [46] with a suitable DEM. The Alaska satellite facility (ASF) software tool MapReady or AWS web tool OpenSARLab was used for the correction of C-band data. L-band data from PALSAR are available from ASF as already radiometrically terrain-corrected products. Our remote sensing work found that in HNP, grasslands comprise 17%, woodlands comprise 8%, and wetlands comprise 11% of the park area, with the remaining area consisting of rock and ice. We also found that wetlands increase in abundance with elevation, with wetlands occupying an area of just a few percent in lower park elevations and up to 50% at high elevations (see [23] for details). A simplified version of the wetland mapping is shown in Figure 1.

In conjunction with the fieldwork for wetland mapping, rapid biodiversity assessments were conducted using focal habitat and transect sampling along wetlands in both valleys, where aquatic invertebrates, terrestrial insects, and birds were sampled using a combination of aquatic sample collections and visual surveys (Figure 2). Lakes were appraised using pre-established transect points (Bowser and Ñaupari data collection sites) for invertebrate collections and amphibian and fish observations (Bowser, personal communication). Point counts of bird populations were conducted and documented in eBird and iNaturalist citizen science databases. These data were used to help inform our evaluations of likely species shifts and the appearance of species that are new to science, but the specific details will be published elsewhere.

Our newly reported empirical observations of land use for this article centered on two valleys in HNP—Rio Negro in the southern end of the park and Ulta Valley in the north–central section (Figure 1). Both valleys are on the western slope of the Cordillera Blanca range. Work in Rio Negro was focused on a high elevation grazing area within HNP in the Arhuaycancha sector, covering an area of 3802 ha from 3900 to 5000 m elevation. The most recent park-sponsored livestock census from 2017 reported 91 total registered users owning 369 cows and 2259 sheep. Management is performed generally by family units. During the dry season, livestock graze in high-elevation wet meadows, while in the wet season, animals graze in areas outside the park. The Ulta Valley covers an area of 4047 ha from ~3500 to 5100 m elevation. Grazing within the valley is primarily performed by families from the Centro Poblado of Huaypán who typically walk ~2 h to reach their livestock. The park census from 2018 reported approximately 154 pastoralists managing 472 cattle. We observed signs of degradation within this valley, which may be due in part to the effects of overgrazing.

Figure 2. A butterfly observed during sampling for invertebrates in HNP, Peru. Photograph by G. Bowser.

We used information from the park to examine data on stocking levels and agreements with the local communities that bring livestock into the park. We then used household case studies to understand the land use and tenure dynamics. We asked participants in the study valleys to draw land tenure maps that indicate their boundaries. At the same time, households and community leaders were asked to draw maps showing all the grazing spots they use, including their travel routes (daily and seasonal), and indicate all access arrangements (renting, borrowing, etc.). Participant observations were carried out with agropastoralists accompanying their herds and flocks; coauthor Eyner Alata carried out many of the observations and was able to conduct interviews in both Spanish and Quechua, as appropriate. Interviews were carried out between June–July and December 2017 and between March and June–July 2018, with 17 families in the Rio Negro Valley, specifically members from the *Comunidad Campesina Cordillera Blanca* near the population center of Canray Chico who graze cattle in Arhuaycancha, and 13 families from Huaypán, 4 of which had cattle in Ulta Valley. We also reviewed the Master Plan of HNP and the social-environmental goals according to management criteria and zonation. Conversations and interviews with four park personnel helped us compare park goals with agropastoralists' social-environmental goals.

The nucleus of the protected area is within the park boundaries, the buffer is the area adjacent to the park boundaries that have limited park management, and the transition zone is outside the buffer with no park management. The nucleus zone of the park is separated into four geographic sectors, including the Llanganuco and Carpa sectors on the western slope and the Ichic Potrero and Potaca sectors on the eastern slope. The Ulta Valley is in the Llanganuco sector, and the Rio Negro Valley is in the Carpa sector. We have some experience in the Ichic Potrero sector in the Tambillos Valley for a peatland restoration project [47].

Additional experiences suggest that there are likely other management approaches in other parts of the park and its buffer area; although the two study valleys are distinct enough for us to consider them grazing system archetypes, they may not represent all the diversity of management regimes that affect HNP.

4. Results

Our overall takeaway message from this study is that rapid climate change will directly impact the environmental system, with concomitant changes to the social system causing further detrimental feedback relative to the environmental system. We predict that agropastoralism as a land use type will respond to climate change via altered grazing management practices, e.g., [48]. The challenge will be to carry out agropastoralism in ways that do not lead to land degradation, while also considering ecosystem functions and the needs of endemic and high elevation species that require protected areas to survive. Our approach here is to take a social-ecological perspective, one that requires the synthesis of wetland ecology and park management studies, with new data on the land use systems involved.

HNP has the highest peaks in Peru and the largest area of tropical glaciers in the world. The cryosphere supplies water to drainages on both the Amazon and Pacific Ocean sides of the country. Climate change has caused some of the glaciers to completely disappear, while some glaciers will still be here in a century, leaving the downslope valleys in varying hydrological regimes of some, none, and recently lost hydrological connectivity to glaciers. We used these environmental gradients to guide our sampling of moist to seasonally dry climates, over 4000 m of topographic relief, and a shift from strict park protection to essentially open access. We illustrate these interactions in Figure 3, which is our summary interpretation of how biophysical gradients interact with the human dimensions of livestock grazing in HNP.

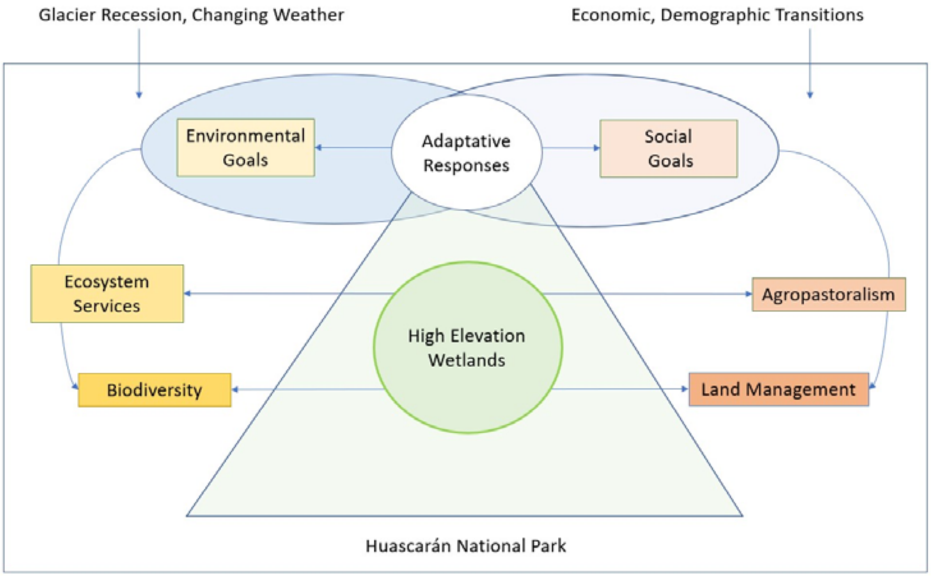

Figure 3. Integrating social and environmental goals for wetlands in Huascarán National Park, a protected area impacted by glacier recession, changing weather, and economic and demographic transitions.

Our wetland mapping (Figure 1) illustrates that the agropastoral Special Use Zone of the park already extends to most of the available land area for grazing. Our biodiversity sampling showed that the Wild Zone provides limited potential as future refugia for many native species, especially endemic birds such as the Andean Coot (*Fulica gigantea*), due to its low accessibility and high coverage of bare habitat: According to the park, over 94% of the Wild Zone are rock and cliff faces, unvegetated moraine areas, and glaciers. Species unknown to science were discovered in these areas, with two new harvestman spiders

(*Acrograhinotus* spp., D. Proud, personal communication); we expect that further identification will continue to reveal new taxonomic and distributional information. The ability of a species to shift its range in response to change or disturbance depends on its physiological constraints and tolerances, dispersal potential, and the degree of connectivity between habitat patches within the landscape. Previous research has found that mammalian wildlife in HNP avoids areas occupied by cattle and people, including high-priority habitat areas in the Strict Protection Zone (J. Gilbert, personal communication). Due to active avoidance, these species are likely to be most abundant in higher elevations of their range but have limited dispersal potential beyond park boundaries.

Regarding the grazing systems utilized, land use data suggest that the park–people interactions in our study area involve two general archetypes of land use: a seasonal rotational livestock system that actively brings in cattle to the wetlands and sheep to the hillslopes of the park during the dry season (see Figure 4 for an example) and a more passive management system that keeps cattle in the park year-round (see Figure 5 for examples). The former appears to be less environmentally damaging (and reportedly more productive economically), but the latter is still common because cattle owners who remove their livestock risk losing access rights in the future. For example, in Ulta Valley's free-range system, wetlands are grazed throughout the year with no chance for recovery or regeneration; labor demand is minimal, as the animals are not actively managed or watched over. Rio Negro Valley has a seasonal rotational grazing system, where wetlands have the chance to recover/regenerate for the next grazing season; labor is permanent and requires following livestock throughout both daily and seasonal shifts. Wetlands inside the park are mostly used by cattle only during the dry season, giving them a chance to recover during the rainy season. For this reason, the seasonal rotational system is less environmentally damaging. In contrast, the free-range system requires less investment of time and effort by agropastoralists.

Thus, based on interviews and other interactions with the managers and grazers of HNP, we conclude that two distinct livestock–rangeland management types exist across the different sectors and zones of the park. In addition, at higher elevations, livestock–rangeland management types may tend to change into styles that are frequently less managed with more free-range management due both to labor opportunity costs and risks due to extreme weather conditions.

Figure 4. Livestock, like these sheep and cattle, may be herded in relation to pasture suitability, seasonality, and access rights for the herders. The flat topography includes wet meadow vegetation. Photograph by E. Alata.

Figure 5. Peatlands (**top left**) and wet meadows (**top right**) are both common in HNP, but grazing is more damaging in peatlands (**bottom left** and **right**) compared to wet meadows (**top right**). Photographs by R. Chimner.

In addition to grazing practices, the access rights and tenure issues of agropastoralists as reported to us are also causing sustainability concerns because recent market shifts have impeded rangeland management, changed familial land divisions, and led to altered agropastoral management capacity. For example, a trend reported by our informants is that livestock owners may hire laborers to move and check on animals, or one family member may care for livestock belonging to extended family members. Pasture availability to those who are not members is limited to areas outside the park's boundaries (J. Gilbert, personal communication). We observed that the respective households, communities, and park management personnel all have different and at times opposing goals for livestock management.

Typical habitats and pasture use in the park are shown in Figure 5. Based on our observations, we note that conflicts and disputes involving the grazing systems affecting the park will tend to increase if park managers have incorrect interpretations of agropastoralist goals, making relationships with the nearby communities difficult: use of rangelands inside the park provide diversification options for agropastoralists, e.g., [48,49]. To better inform park and rangeland management, researchers and conservationists need further information on how the social-environmental system functions in HNP, giving insights that could be used to assess how climate change adaptation at the park and community levels will interact with environmental benefits.

Mountain peatlands are found predominantly in the highest parts of the park and are very susceptible to grazing impacts due to their thick and soft organic soils, which are easily trampled [50,51] (see Figure 5 for examples). Trampling can significantly reduce or reverse carbon storage and increase the emissions of the potent greenhouse gas methane by an order of magnitude [52]. These peatlands are also viewed as hazardous by some local people because livestock can perish in the soft peats; nevertheless, they are a global biodiversity concern given their unique habitat for specialized native species. Although they cover a relatively small area in HNP, the high-elevation wetlands and *Polylepis*-dominated woodlands provide essential habitats to over 780 species, many of which are considered threatened or near threatened by the IUCN Red List of Threatened Species [53–56]. Risks to peatlands associated with drier conditions under a changing climate further complicate management. Long-saturated organic biomass in low temperatures decomposes slowly through anaerobic pathways, which has allowed carbon to build to extraordinary levels [23]. Reduced inflow from glacial melt and less rainfall will promote drier conditions and aerobic decomposition, initially reducing emissions compared to baseline emissions but then speeding the emissions of greenhouse gases upon periodic rewetting [57].

Based on participant observations and conversations, we found that grazing may not be equally distributed across the landscape of HNP, with much of the uplands being covered by tussock grasses (locally called ichu; *Calamagrostis*, *Festuca*, *Stipa* species) and shrubs that are less palatable to cattle and sheep, especially if the vegetation is not burned, which is an activity forbidden inside the park. Because wetlands are wet for most of the year and covered by lush, palatable plant growth, we expect that most of the grazing will occur in wetlands. Low-elevation wetlands in and near HNP are mostly wet meadows, while high-elevation wetlands are peatlands that have much greater carbon storage and softer substrates.

With an increase in elevation, livestock–rangeland management types may result in less carefully managed and more free-range animals at higher elevations due to longer travel distances to monitor livestock, increased labor demands, and a lack of alternative pastures in lower elevation areas.

Our biodiversity observations also suggest that in the future, there might be shifts in distributions as invasive species and lower-elevation species move into the ecological spaces currently used by cold-adapted species, such as the Andean bumblebee, while agropastoralism and development in lower elevations may encourage some lower elevation species to shift upwards into higher elevation refugia [58,59]. Montane specialist species (for example, some birds, particularly *Polylepis* habitat specialists), cold-adapted species (e.g., reptiles, amphibians, insects), and dispersal-limited species are at higher risk of mountaintop extinctions with respect to future changes.

5. Discussion

Climate change in HNP will likely continue to alter agropastoralist grazing practices. Unpredictable water supplies and scarcity due to changing seasonal patterns (longer dry season and shorter rainy season) may directly affect rangeland production. Some valleys have large head valley glaciers, while others are now “postglacial” in the sense that the cirques are ice-free. In response, people told us that they have been modifying their use of rangelands and stocking rates (see also [60,61]). More grazing is also likely to occur at higher elevations if warmer conditions prevail, although we also note that our observations suggest that social factors may act to limit how far up valley pastoralists may be willing to shift their flocks and herds. Furthermore, our cartographic assessments show that there is limited ability to move grazing upwards as wetlands are only found below 5000 m due to rocky substrates, and these wetlands transform into peatlands that are more sensitive to grazing (and less desirable) compared to lower elevation (3000–4000 m) wet meadows. We conclude that the park's wetlands will be much more susceptible to grazing impacts with an increase in elevation, including large changes in biodiversity, soil carbon, and impacts on greenhouse gasses (CO_2 and CH_4) [28,29,47,52], and these changes will magnify as grazing intensity increases.

Based on these observations, we hypothesize that areas that are currently most degraded are a result of a combination of social access and tenure issues, with grazing management type overlapping with ecosystem type (e.g., wet meadows and peatlands). In other words, we expect that wet meadows, and especially peatlands within areas of intense use and conflict, will be the hotspots of degradation, with cascading impacts on biodiversity; there is also a special concern for the rare and endemic species found in high elevations. We lastly conjecture that climate change adaptation will have to be well planned if biodiversity and important ecosystem functions are to be maintained in HNP and similar protected areas as there are limited areas for upward shifts.

In our study area, the residents of Huaraz, the main city on the western side of HNP's buffer zone, recognize the ecological and economic value of wetlands and have indicated a willingness to pay for the benefits they provide to society [62]. Important future research topics would include land tenure, economic policies, labor constraints, and reduced livelihood opportunities, all of which are challenges to Andean agropastoralists [63]. As a result, social-ecological feedback and interactions explain landscape dynamism but must be examined via transdisciplinary approaches.

The next steps in research could include simulation models combined with empirical measures, community knowledge, and other data determined via literature searches and sampling to address integrated and jointly developed questions. For example, in HNP, we have used citizen science datasets for biodiversity and the documentation of taxonomic groups tagged with wetland datapoints and geo-referenced them together. These included sample points for aquatic invertebrates and sweep surveys for terrestrial invertebrates [64,65]; and non-destructive techniques, such as camera traps and iNaturalist. We have collected some community knowledge expressed through stories, interviews, and on-the-ground mapping, coupled with tools to measure ecological change that can build on the traditional knowledge of the community [66]. Ecological oral histories record knowledge of dynamic landscapes based on observations and interpretations of social-environmental systems [67,68]. Finally, we are in the process of building on experiences in constructing local scenarios for other agropastoral communities [69] to develop and adapt simulation models [70,71]. As technology improves, communities can use data and science to increase awareness and change perceptions, e.g., [72]. This local connection is a key aspect of the dissemination and outreach concerning climate scenarios and for creating decision support tools for the local community and for the protected area itself.

Broadening the focus from our specific study sites leads us to generalize that the tropical Andes are in ecological flux due to rapid land cover changes, which are caused by both biophysical and socioeconomic drivers. These landscapes are shaped in part by the legacies of past human land use with respect to ancient pastoralism and farming [73] and by millions of downstream users who are dependent upon glacier-fed streams for water and energy production [74]. Grazing has occurred for millennia in the Andes, but traditional systems in Peru underwent drastic changes due to the colonial introduction of cattle, sheep, and other livestock; and changes in land tenure arrangements, including the establishment of large haciendas during the colonial period and Agrarian Reform expropriation and redistribution in the late 1960s, followed by the creation of protected areas in the 1970s [75,76].

Beyond applications to the park–people system documented here, the findings are also relevant to the design, management, and governance of grazing systems elsewhere in the world. Our study touched on many of the topics covered in Briske's [44] edited volume on rangeland systems, which include ecological shifts, ecohydrology, nonequilibrium conditions, and the challenges and opportunities of taking a social-ecological approach to adaptive management. Globally, there are frequently differences in ecosystem impacts found in either permanent or rotational grazing regimes, depending on factors such as climate, soil characteristics, and vegetation composition. As an example, shorter bouts of grazing can be an effective strategy in semi-arid rangelands [77], and some forage species are more resilient to continuous grazing, while others benefit from rotational rest periods [78]. Rotational grazing can be associated with greater soil organic carbon, giving some climate change mitigation opportunities [79]. Rotational grazing at moderate intensity can help maintain or improve plant cover, productivity, and biodiversity; enhance soil structure and fertility; and increase carbon and nitrogen storage [80]. Implementing mutually beneficial land management strategies for conservation and livelihood sustenance, such as rotational grazing, is advisable to keep higher levels of biodiversity and the functionality of ecosystems, increase the productivity of grazing lands [80,81], and reduce disinvestment in pastoralism [81]. Moreover, the implementation of rangeland management practices should consider the effects of traditional pastoral practices before banning grazing, mainly in landscapes with a long history of coadaptation with ruminant animals [82]. These observations call attention to the need for monitoring the effects of grazing practices and adjusting them to meet specific goals and minimize negative impacts.

Author Contributions: Conceptualization, K.R.Y., R.A.C., G.B., B.F., J.G., J.A.Ñ., M.H.P., C.T. and M.Z.-S.; Methodology, E.A., R.A.C., R.B.B., G.B., L.B.-C., B.F., J.G., C.T. and M.Z.-S.; Software, L.B.-C.; Validation, M.H.P.; Formal analysis, K.R.Y., R.A.C., L.B.-C., J.G. and M.Z.-S.; Investigation, K.R.Y., E.A., R.A.C., R.B.B., G.B., B.F., J.G., J.A.Ñ., M.H.P., S.C.R., C.T. and M.Z.-S.; Writing–original draft, K.R.Y. and R.A.C.; Writing–review & editing, K.R.Y., R.B.B., G.B., L.B.-C., B.F., J.G., J.A.Ñ., M.H.P., S.C.R., C.T. and M.Z.-S.; Project administration, G.B.; Funding acquisition, G.B.. All authors have read and agreed to the published version of the manuscript.

Funding: Funding was from the U.S. National Science Foundation, DEB-1617429.

Data Availability Statement: Supporting data will be made available upon reasonable request, except for those where privacy concerns exist.

Acknowledgments: We are grateful to the many people who helped with the fieldwork, including the community members who participated in showing us their livelihoods and the HNP park personnel who helped in many ways. Figure 1 was made with assistance from Dorthea Vander Bilt.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Watson, J.E.; Dudley, N.; Segan, D.B.; Hockings, M. The performance and potential of protected areas. *Nature* **2014**, *515*, 67–73. [CrossRef] [PubMed]
2. Brockington, D.; Wilkie, D. Protected areas and poverty. *Philos. Trans. R. Soc. B Biol. Sci.* **2015**, *370*, 20140271. [CrossRef] [PubMed]
3. Chou, S.; Lyra, A.; Mourão, C.; Dereczynski, C.; Pilotto, I.; Gomes, J.; Bustamante, J.; Tavares, P.; Silva, A.; Rodrigues, D.; et al. Assessment of Climate Change over South America under RCP 4.5 and 8.5 Downscaling Scenarios. *Am. J. Clim. Change* **2014**, *3*, 512–527. [CrossRef]
4. Castellanos, E.; Lemos, M.F.; Astigarraga, L.; Chacón, N.; Cuvi, N.; Huggel, C.; Miranda, L.; Vale, M.M.; Ometto, J.P.; Peri, P.L.; et al. Central and South America. In *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2022; pp. 1689–1816. [CrossRef]
5. Malhi, Y.; Franklin, J.; Seddon, N.; Solan, M.; Turner, M.G.; Field, C.B.; Knowlton, N. Climate change and ecosystems: Threats, opportunities and solutions. *Philos. Trans. R. Soc. B* **2020**, *375*, 20190104. [CrossRef] [PubMed]
6. UNEP. Scientific Blueprint to Tackle the Climate, Biodiversity and Pollution Emergencies. *Nairobi.* 2021. Available online: https://www.unep.org/resources/making-peace-nature (accessed on 5 November 2023).
7. Ranius, T.; Widenfalk, L.A.; Seedre, M.; Lindman, L.; Felton, A.; Hämäläinen, A.; Filyushkina, A.; Öckinger, E. Protected area designation and management in a world of climate change: A review of recommendations. *Ambio* **2023**, *52*, 68–80. [CrossRef] [PubMed]
8. Pennington, R.T.; Lavin, M.; Särkinen, T.; Lewis, G.P.; Klitgaard, B.B.; Hughes, C.E. Contrasting plant diversification histories within the Andean biodiversity hotspot. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 13783–13787. [CrossRef]

9. Mark, B. Tracing tropical Andean glaciers over space and time: Some lessons and transdisciplinary implications. *Glob. Planet. Change* **2008**, *60*, 101–114. [CrossRef]
10. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
11. Strack, M.; Davidson, S.J.; Hirano, T.; Dunn, C. The Potential of Peatlands as NatureBased Climate Solutions. *Curr. Clim. Change Rep.* **2022**, *8*, 71–82. [CrossRef]
12. Page, S.E.; Baird, A.J. Peatlands and global change: Response and resilience. *Annu. Rev. Environ. Resour.* **2016**, *41*, 35–57. [CrossRef]
13. UNEP. *Global Peatlands Assessment—The State of the World's Peatlands: Evidence for Action toward the Conservation, Restoration, and Sustainable Management of Peatlands. Main Report. Global Peatlands Initiative*; United Nations Environment Programme: Nairobi, Kenya, 2022.
14. Nahlik, A.M.; Fennessy, M.S. Carbon storage in US wetlands. *Nat. Commun.* **2016**, *7*, 13835. [CrossRef]
15. Kolka, R.; Trettin, C.; Tang, W.; Krauss, K.; Bansal, S.; Drexler, J.K.; Wickland, R.; Chimner, D.; Hogan, E.J.; Pindilli, B.; et al. Chapter 13: Terrestrial wetlands. In *Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report*; Cavallaro, N., Shrestha, G., Birdsey, R., Mayes, M.A., Najjar, R.G., Reed, S.C., Romero-Lankao, P., Zhu, Z., Eds.; U.S. Global Change Research Program: Washington, DC, USA, 2018; pp. 507–567.
16. Cooper, D.J.; Chimner, R.A.; Merritt, D.M. *Western Mountain Wetlands*; University of California Press: Berkeley, CA, USA, 2012; pp. 313–328.
17. Earle, L.R.; Warner, B.; Aravena, R. Rapid development of an unusual peat-accumulating ecosystem in the Chilean altiplano. *Quat. Res.* **2003**, *59*, 2–11. [CrossRef]
18. Cooper, D.J.; Wolf, E.C.; Colson, C.; Vering, W.; Granda, A.; Meyer, M. Alpine Peatlands of the Andes, Cajamarca, Peru. *Arct. Antarct. Alp. Res.* **2010**, *42*, 19–33. [CrossRef]
19. Maldonado Foncen, M.S. An introduction to the bofedales of the Peruvian High Andes. *Mires Peat* **2014**, *15*, 5.
20. Salvador, F.; Monerris, J.; Rochefort, L. Peatlands of the Peruvian puna ecoregion: Types, characteristics and disturbance. *Mires Peat* **2014**, *15*, 1–17.
21. Hribljan, J.A.; Suarez, E.; Bourgeau-Chavez, L.; Endres, S.; Lilleskov, E.A.; Chimbolema, S.; Wayson, C.; Serocki, E.; Chimner, R.A. Multidate, multisensor remote sensing reveals high density of carbon-rich mountain peatlands in the páramo of Ecuador. *Glob. Change Biol.* **2017**, *23*, 5412–5425. [CrossRef] [PubMed]
22. Chimner, R.A.; Bourgeau-Chavez, L.L.; Grelik, S.; Hribljan, J.A.; Maria Planas Clarke, A.; Polk, M.H.; Lilleskov, E.A.; Fuentealba, B. Mapping extent and types of wetlands in the Cordillera Blanca, Peru. *Wetlands* **2019**, *39*, 1057–1067. [CrossRef]
23. Chimner, R.A.; Resh, S.C.; Hribljan, J.A.; Battaglia, M.; Bourgeau-Chavez, L.; Bowser, G.; Lilleskov, E.A. Mountain Wetland Soil Carbon Stocks of Huascarán National Park, Peru. *Front. Plant Sci.* **2023**, *14*, 1048609. [CrossRef]
24. Wolf, E.C.; Cooper, D.J. Fens of the Sierra Nevada, California, USA: Patterns of distribution and vegetation. *Mires Peat* **2015**, *15*, 1–22.
25. Schook, D.M.; Borkenhagen, A.K.; McDaniel, P.A.; Wagner, J.I.; Cooper, D.J. Soils and hydrologic processes drive wet meadow formation and approaches to restoration, Western USA. *Wetlands* **2020**, *40*, 637–653. [CrossRef]
26. Chimner, R.A.; Boone, R.; Bowser, G.; Bourgeau-Chavez, L.; Fuentealba, B.; Gilbert, J.; Ñaupari, J.A.; Polk, M.H.; Resh, S.; Turin, C.; et al. Andes, Bofedales, and the Communities of Huascarán National Park, Peru. *Wetl. Sci. Pract.* **2020**, *37*, 246–254.
27. Carey, M.; Baraer, M.; Mark, B.G.; French, A.; Bury, J.; Young, K.R.; McKenzie, J.M. Toward hydro-social modeling: Merging human variables and the social sciences with climate-glacier runoff models (Santa River, Peru). *J. Hydrol.* **2014**, *518*, 60–70. [CrossRef]
28. Enriquez, A.S.; Chimner, R.A.; Cremona, M.V. Long term grazing negatively affects nitrogen dynamics in Northern Patagonian wet meadows. *J. Arid Environ.* **2014**, *109*, 1–5. [CrossRef]
29. Enriquez, A.S.; Chimner, R.A.; Diehl, P.; Cremona, M.V.; Bonvissuto, G.L. Grazing intensity and precipitation levels influence C reservoirs in Northern Patagonia wet and mesic meadows. *Wetl. Ecol. Manag.* **2015**, *23*, 439–451. [CrossRef]
30. Young, K.R.; Ponette-González, A.; Polk, M.H.; Lipton, J.K. Snowlines and treelines in the tropical Andes. *Ann. Am. Assoc. Geogr.* **2017**, *107*, 429–440. [CrossRef]
31. Young, K.R.; Lipton, J.K. Adaptive governance and climate change in the tropical highlands of western South America. *Clim. Change* **2006**, *78*, 63–102. [CrossRef]
32. Anderson, E.P.; Marengo, J.; Villalba, R.; Halloy, S.; Young, B.; Cordero, D.; Gast, F.; Jaimes, E.; Ruiz, D.; Herzog, S.K.; et al. Consequences of climate change for ecosystems and ecosystem services in the tropical Andes. In *Climate Change and Biodiversity in the Tropical Andes*; Herzog, S.K., Martínez, R., Jørgensen, P.M., Tiessen, H., Eds.; Inter-American Institute for Global Change Research (IAI) and Scientific Committee on Problems of the Environment (SCOPE): Montevideo, Uruguay, 2011; 348p.
33. Flores, E. Cambio climático: Pastizales Altoandinos y seguridad alimentaria. *Rev. Glaciares Ecosist. Montaña* **2016**, *1*, 13. [CrossRef]
34. IPCC. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*; Po, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegri, A., Nicolai, M., Okem, A., et al., Eds.; IPCC: Geneva, Switzerland, 2019.
35. Mark, B.; French, A.; Bury, J.; Carey, M.; Young, K.; Wigmore, O.; Polk, M.H.; McKenzie, J.; Lautz, L.; Crumley, R.; et al. Glacier loss and hydro-social risks in the Peruvian Andes. *Glob. Planet. Change* **2017**, *159*, 61–76. [CrossRef]
36. Postigo, J.C. Perception and resilience of Andean populations facing climate change. *J. Ethnobiol.* **2014**, *34*, 383–400. [CrossRef]

37. Palacios, F. Pastizales de regadío para alpacas. In *Pastores de Puna. Uywamichiq Punarunakuna*; Flores Ochoa, J., Ed.; Instituto de Estudios Peruanos: Lima, Peru, 1977; pp. 155–191.
38. Yager, K.; Valdivia, C.; Slayback, D.; Jimenez, E.; Meneses, R.I.; Palabral, A.; Bracho, M.; Romero, D.; Hubbard, A.; Pacheco, P.; et al. Socio-ecological dimensions of Andean pastoral landscape change: Bridging traditional ecological knowledge and satellite image analysis in Sajama National Park, Bolivia. *Reg. Environ. Change* **2019**, *19*, 1353–1369. [CrossRef]
39. Monge-Salazar, M.J.; Tovar, C.; Cuadros-Adriazola, J.; Baiker, J.R.; Montesinos-Tubée, D.B.; Bonnesoeur, V.; Antiporta, J.; Román-Dañobeytia, F.; Fuentealba, B.; Ochoa-Tocachi, B.F.; et al. Ecohydrology and ecosystem services of a natural and an artificial bofedal wetland in the central Andes. *Sci. Total Environ.* **2022**, *838*, 155968. [CrossRef] [PubMed]
40. Morlon, P.; Cobo, B.; Orlove, B.; Palacios Rios, F.; Felipe-Morales, C.; Reynel, C.; Rozas, W. Capítulo 4. Infraestructuras agrícolas: ¿Vestigios del pasado o técnicas para el futuro? In *Comprender la Agricultura Campesina en los Andes Centrales: Perú-Bolivia*; Morlon, P., Ed.; Institut Français d'études Andines: Lima, Peru, 1996. [CrossRef]
41. Lane, K. Engineering the Puna: The Hydraulics of Agro-Pastoral Communities in a Northcentral Peruvian Valley. Ph.D. Thesis, University of Cambridge, Cambridgem, UK, 2006.
42. Lane, K. Water Technology in the Andes. In *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*; Selin, H., Ed.; Springer: Dordrecht, The Netherlands, 2014.
43. Palacios, F. Tecnología del Pastoreo. In *La Tecnología en el Mundo Andino. Runakunap Kawsayninkupaq Rurasqankunaqa*; Lechaman, H., Soleli, A.M., Tomo, I., Eds.; Universidad Nacional Autónoma de México: Autónoma de México, México, 1981; pp. 217–232.
44. Briske, D.D. *Rangeland Systems: Processes, Management and Challenges*; Springer Nature: Berlin/Heidelberg, Germany, 2017; p. 661.
45. Bourgeau-Chavez, L.L.; Endres, S.L.; Graham, J.A.; Hribljan, J.A.; Chimner, R.A.; Lillieskov, E.A.; Battaglia, M.J. 2018. Mapping Peatlands in Boreal and Tropical Ecoregions. In *Comprehensive Remote Sensing*; Liang, S., Ed.; Elsevier: Oxford, UK, 2018; Volume 6, pp. 24–44.
46. Ulander, L.M.H. Radiometric slope correction of synthetic-aperture radar images. *IEEE Trans. Geosci. Remote Sens.* **1996**, *34*, 1115–1122. [CrossRef]
47. Planas-Clarke, A.M.; Chimner, R.A.; Hribljan, J.A.; Lilleskov, E.A.; Fuentealba, B. The effect of water table levels and short-term ditch restoration on mountain peatland carbon cycling in the Cordillera Blanca, Peru. *Wetl. Ecol. Manag.* **2020**, *28*, 51–69. [CrossRef]
48. Yager, K.; Prieto, M.; Meneses, R.I. Reframing pastoral practices of bofedal management to increase the resilience of Andean water towers. *Mt. Res. Dev.* **2021**, *41*, A1–A9. [CrossRef]
49. Valdivia, C. Diversification as a risk management strategy in an Andean Agropastoral community. *Am. J. Agric. Econ.* **1996**, *78*, 1329–1334. [CrossRef]
50. Chimner, R.A.; Cooper, D.J.; Lemly, J.M. Mountain fen distribution, types and restoration priorities, San Juan Mountains, Colorado, USA. *Wetlands* **2010**, *30*, 763–771. [CrossRef]
51. Chimner, R.A.; Bonvissuto, G.L.; Cremona, M.V.; Gaitan, J.J.; Lopez, C.R. Ecohydrological conditions of wetlands along a precipitation gradient in Patagonia, Argentina. *Ecol. Austral.* **2011**, *21*, 329–337.
52. Sánchez, M.E.; Chimner, R.A.; Hribljan, J.A.; Lilleskov, E.A.; Suárez, E. Carbon dioxide and methane fluxes in grazed and ungrazed mountain peatlands in the Ecuadorian Andes. *Mires Peat* **2017**, *19*, 1–18. [CrossRef]
53. Fjeldså, J. The Avifauna of the Polylepis Woodlands of the Andean Highlands: The Efficiency of Basing Conservation Priorities on Patterns of Endemism. *Bird Conserv. Int.* **1993**, *3*, 37–55. [CrossRef]
54. Yensen, E.; Tarifa, T. Mammals of Bolivian Polylepis woodlands: Guild structure and diversity patterns in the world's highest woodlands. *Ecotropica* **2002**, *8*, 145–162.
55. Lloyd, H.; Marsden, S.J. Bird community variation across Polylepis woodland fragments and matrix habitats: Implications for biodiversity conservation within a high Andean landscape. *Biodivers. Conserv.* **2008**, *17*, 2645–2660. [CrossRef]
56. Gareca, E.E.; Hermy, M.; Fjeldså, J.; Honnay, O. Polylepis woodland remnants as biodiversity islands in the Bolivian High Andes. *Biodivers. Conserv.* **2010**, *19*, 3327–3346. [CrossRef]
57. Abdalla, M.; Hastings, A.; Truu, J.; Espenberg, M.; Mander, Ü.; Smith, P. Emissions of methane from northern peatlands: A review of management impacts and implications for future management options. *Ecol. Evol.* **2016**, *6*, 7080–7102. [CrossRef] [PubMed]
58. Dobrowski, S.Z. A climatic basis for microrefugia: The influence of terrain on climate. *Glob. Change Biol.* **2011**, *17*, 1022–1035. [CrossRef]
59. Michalak, J.L.; Stralberg, D.; Cartwright, J.M.; Lawler, J.J. Combining physical and species-based approaches improves refugia identification. *Front. Ecol. Environ.* **2020**, *18*, 254–260. [CrossRef]
60. Turin, C.; Valdivia, C. Off-farm work in the Peruvian Altiplano: Seasonal and Geographic Considerations for Agricultural and Development Policies. In *Seasonality, Rural Livelihoods and Development*; Deveraux, S., Sabates-Wheeler, R., Longhurst, R., Chambers, R., Eds.; Routledge: London, UK, 2012; Ch09; pp. 145–160. [CrossRef]
61. Turin, C. Perceptions of Rangeland Degradation and Its Causes in the Peruvian Altiplano Dry *Puna*. Ph.D. Thesis, University of Missouri-Columbia, Columbia, MO, USA, 2019. Available online: https://mospace.umsystem.edu/xmlui/handle/10355/71841 (accessed on 9 November 2023).
62. Alarcon, J.A.; Flores, E.; Barrantes, C. Determination of the availability of payment for conservation and improvement activities of wetlands ecosystem of the Huaraz City, Peru. *J. Environ. Pollut. Manag.* **2018**, *1*, 105.

63. Coppock, L.; Fernandez-Gimenez, M.; Hiernaux, P.; Huber-Sannwald, E.; Schloeder, C.; Valdivia, C.; Turin, C.; Turner, M.; Jacobs, M.; Arredondo, J. Rangelands in Developing Nations: Conceptual advances and societal implications. In *Rangeland Systems. Processes, Management and Challenges*; Briske, D., Ed.; Springer: Berlin/Heidelberg, Germany, 2017; ISBN 978-3-319-46709-2. Available online: http://www.springer.com/us/book/9783319467078 (accessed on 9 November 2023).
64. Roy, H.E.; Baxter, E.; Saunders, A.; Pocock, M.J.O. Focal plant observations as a standardised method for pollinator monitoring: Opportunities and limitations for mass participation Citizen Science. *PLoS ONE* **2016**, *11*, e0150794.
65. Ward, D.F.; Lariviere, M.C. Terrestrial invertebrate surveys and rapid biodiversity assessment in New Zealand: Lessons from Australia. *N. Z. J. Ecol.* **2004**, *28*, 151–159.
66. Polk, M.H. They Are Drying Out: Social-Ecological Consequences of Glacier Recession on Mountain Peatlands in Huascarán National Park, Peru. Doctoral Dissertation, The University of Texas at Austin, Austin, TX, USA, 2016.
67. Robertson, H.A.; McGee, T.K. Applying local knowledge: The contribution of oral history to wetland rehabilitation at Kanyapella Basin, Australia. *J. Environ. Manag.* **2003**, *69*, 275–287. [CrossRef]
68. Hanson, A.M. Shoes in the seaweed and bottles on the beach. In *A Political Ecology of Women, Water and Global Environmental Change*; Buechler, S., Hanson, A.-M., Eds.; Routledge: New York, NY, USA, 2016; pp. 165–184.
69. Boone, R.B.; Galvin, K.A.; BurnSilver, S.B.; Thornton, P.K.; Ojima, D.S.; Jawson, J.R. Using coupled simulation models to link pastoral decision making and ecosystem services. *Ecol. Soc.* **2011**, *16*, 6. [CrossRef]
70. Boone, R.B.; Conant, R.T.; Sircely, J.; Thornton, P.K.; Herrero, M. Climate change impacts on selected global rangeland ecosystem services. *Glob. Change Biol.* **2018**, *24*, 1382–1393. [CrossRef]
71. Sircely, J.; Boone, R.B.; Conant, R. Simulating rangeland ecosystem and vegetation dynamics with G-Range: Model description and evaluation at site and global scales. *Rangel. Ecol. Manag.* **2019**, *72*, 846–857. [CrossRef]
72. Chambers, R. Participatory mapping and geographic information systems: Whose map? Who is empowered and who disempowered? Who gains and who loses? *Electron. J. Inf. Syst. Dev. Ctries.* **2006**, *25*, 1–11. [CrossRef]
73. Young, K.R. Andean land use and biodiversity: Humanized landscapes in a time of change. *Ann. Mo. Bot. Gard.* **2009**, *96*, 492–507. [CrossRef]
74. Bury, J.; Mark, B.G.; Carey, M.; Young, K.R.; McKenzie, J.; Baraer, M.; French, A.; Polk, M.H. New geographies of water and climate change in Peru: Coupled natural and social transformations in the Santa River watershed. *Ann. Assoc. Am. Geogr.* **2013**, *103*, 363–374. [CrossRef]
75. López-i-Gelats, F.; Contreras Paco, J.L.; Huilcas Huayra, R.; Siguas Robles, O.D.; Quispe Peña, E.C.; Bartolomé Filella, J. Adaptation strategies of Andean pastoralist households to both climate and non-climate changes. *Hum. Ecol.* **2015**, *43*, 267–282. [CrossRef]
76. Rolando, J.L.; Turin, C.; Ramírez, D.A.; Mares, V.; Monerris, J.; Quiroz, R. Key ecosystem services and ecological intensification of agriculture in the tropical High-Andean Puna as affected by land-use and climate changes. *Agric. Ecosyst. Environ.* **2017**, *236*, 221–223. [CrossRef]
77. Hulvey, K.B.; Mellon, C.D.; Kleinhesselink, A.R. Rotational grazing can mitigate ecosystem service trade-offs between livestock production and water quality in semi-arid rangelands. *J. Appl. Ecol.* **2021**, *58*, 2113–2123. [CrossRef]
78. Pavlů, V.; Hejcman, M.; Pavlů, L.; Gaisler, J. Effect of rotational and continuous grazing on vegetation of an upland grassland in the Jizerské Hory Mts., Czech Republic. *Folia Geobot.* **2003**, *38*, 21–34. [CrossRef]
79. Byrnes, R.C.; Eastburn, D.J.; Tate, K.W.; Roche, L.M. A global meta-analysis of grazing impacts on soil health indicators. *J. Environ. Qual.* **2018**, *47*, 758–765. [CrossRef]
80. Dong, S.; Zhang, Y.; Shen, H.; Li, S.; Xu, Y. Grazing Management and Pastoral Production. In *Grasslands on the Third Pole of the World: Structure, Function, Process, and Resilience of Social-Ecological Systems*; Springer International Publishing: Cham, Switzerland, 2023; pp. 199–230.
81. Ingty, T. Pastoralism in the highest peaks: Role of the traditional grazing systems in maintaining biodiversity and ecosystem function in the alpine Himalaya. *PLoS ONE* **2021**, *16*, e0245221. [CrossRef] [PubMed]
82. Mu, J.; Zeng, Y.; Wu, Q.; Niklas, K.J.; Niu, K. Traditional grazing regimes promote biodiversity and increase nectar production in Tibetan alpine meadows. *Agric. Ecosyst. Environ.* **2016**, *233*, 336–342. [CrossRef]