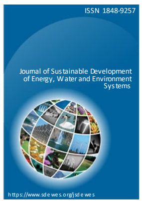
Journal of Sustainable Development of Energy, Water and Environment Systems

http://www.sdewes.org/jsdewes



Year 2024, Volume 12, Issue 2, 1120503

Original Research Article

Prediction of High Andean Grasslands Biomass in the Upper Zone of the National Sanctuary of Ampay, Peru, for Promoting Adequate Management of Natural Grasslands

Carolina Soto Carrión*[*1], Wilber Jiménez Mendoza[2], Iris Pérez-Almeida[3], Carlos Marín Rodriguez[4]

[1] Technological University of the Andes, Apurimac
email: csotoc@utea.edu.pe; caro7001@hotmail.com
[2] National University Micaela Bastides of Apurímac
email: wjimenez@unamba.edu.pe
[3] Ecotec University, Samborondon, Ecuador
email: iperez@ecotec.edu.ec
[4] Central University of Venezuela, Faculty of Agronomy, Maracay, Venezuela
email: carlmarinr@gmail.com

Cite as: Soto Carrión, C., Jiménez Mendoza, W., Perez-Almeida, I., Marin Rodriguez, C., Prediction of high Andean grasslands biomass in the upper zone of the National Sanctuary of Ampay-Peru for promoting an adequate management of natural grasslands, J.sustain. dev. energy water environ. syst., 12(2), 1120503, 2024, DOI: https://doi.org/10.13044/j.sdewes.d12.0503

ABSTRACT

Grasslands are characterised by native non-forest vegetation, occupying a large land area worldwide. The study was conducted in the Andean National Sanctuary of Ampay, Peru, at 3,500–4,500 masl. The purpose has been to evaluate the relationship between biomass, forage productive potential, degree of soil erosion, and presence of valuable species for grazing. The three-step (Parker) method was used for natural pastures and the linear intercept for vegetation. The herbaceous vegetation frequency results were obtained from thirteen zones distributed in three study sectors (Yanacocha, Uspacocha, and Faccha). The annual grazing carrying capacity was 1.2 animal units per hectare. The most productive sector with species desirable for livestock was Uspacocha, which had better soil conditions without overgrazing, while the least productive was Yanacocha. The predominant families in herbaceous plant associations were *Rosaceae, Poaceae,* and *Asteraceae;* the study area was in regular conservation condition with few eroded areas. Currently, the inhabitants of the communities surrounding the study area use many plant species for feeding, medicinal, fuel, fodder, and manufacturing purposes. It is necessary to promote self-sustainable development by strengthening production units.

KEYWORDS

Biomass, Carrying capacity, Desirable species, Grazing potential, Natural grasses, Vegetation cover.

INTRODUCTION

Grasslands are known to play a vital role in the global carbon cycle [1]. The paramo and puna grassland ecosystems are the most widespread in the world. They are important in protecting the natural environment and the socioeconomic development of rural populations [2]. Grassland ecosystems differ in the composition and appearance of plant and

[*] Corresponding author

animal species depending on location and climate, and they cover a large part of the planet's ice-free land surface [3].

These ecosystems are characterised by great spatial heterogeneity in structure, aboveground biomass production, forage quality for livestock, mosaics of vegetation types that show short-growing species with high nutritional quality for livestock, and tall grasses of lower quality [4] and other important services for the local community [5].

Grasslands provide a set of ecosystems sociocultural and biodiversity regulation services and provide forage to feed more than 80% of the national livestock, contributing substantially to food security [6]. High Andean grasslands are highly sensitive ecosystems to climate change and anthropogenic activity [7]. Grasslands are enormous in their extent, and native and non-native grasslands now cover approximately 50% of the global terrestrial environment.

The composition and structure of the plant formations are heterogeneous. However, the average level of similarity between vegetal formations suggests that it is more feasible to carry out improvement processes between spaces shared by grasslands of *Festuca* and *Calamagrostis* and with less success in plant formations of puna grass [8]. Human intervention in grassland ecosystems affects biodiversity, primary productivity, and ecosystem stability due to species' decline [9].

The use of natural pastures has occurred since colonial times. However, it has not been the most appropriate, causing in many areas of Peru an imbalance in the ecology itself so that today, vast areas with considerable reductions in their productive potential foraging, different degrees of erosion, desirable botanical species in extinction, greater presence of undesirable and invasive plants that compete with good forage, and so, can be observed. This situation impacts low biomass production and, consequently, the low productive yields of grazing livestock. Forage species are mainly divided into grasses and legumes. The floristic composition of grasslands and their distribution pattern varies depending on topography, soil type and climate [10]. The floristics of grasses are dominated in the upper stratum by grasses of the genera *Festuca*, *Calamagrostis* and *Stipa,* while in the lower stratum, grasses and short grasses predominate and, to a small extent, legumes [11]. The floristic diversity of grasslands is not homogeneously distributed worldwide, with strong differences in the number of species they contain [12]. Forage grasses are the main food source for herbivores, as they grow spontaneously on most grasslands. These adapt easily to climate variations and provide most of the dry matter and carbohydrates animals consume. They belong to the monocotyledons characterised by shallow roots in most species, cylindrical stems with nodes, alternate leaves with parallel veins, leaf bases usually wrapped around the stem, and their flowers usually are spikelets [13].

Legumes, plants belonging to the dicotyledonous group, are frequently used to increase the protein portion of the animals' ration. They constitute the most important group after grasses, mainly due to their forage value and the capacity to enrich the soil through atmospheric nitrogen fixation. Some of their characteristics are deep roots and nitrifying nodules, that is, small nodules that fix nitrogen through a symbiotic relationship with bacteria of the *Rhizobium* genus; the leaves are broad and usually composed of three or more leaflets, and the seeds almost always grow within a pod or legume [14]. Forages are the predominant feeding alternative within the different livestock production systems in the tropics; however, they often have limitations in quantity and quality [15].

The highest yields in dry matter are obtained during the rainy season, decreasing in the low rainfall season [16]. Similar results were reported [14], which corroborate that in periods of high rainfall, there is a greater supply of forage and higher dry matter yields [17]. Natural grasslands include all plant species that develop in a given area. In the case of the high Andean Puna, these can be made up of scrub forests, chaparral, or grasslands. The climax vegetation is in balance with the environment, as is the case of the "ichu" grass, also known as Peruvian feathergrass, which can be altered by the action of man (burning of pastures) or domestic animals (overgrazing) [18].

Grasslands are considered the largest managed ecosystem on the planet and are exposed to the combined effects of frequent human activities and ongoing global climate change [19]. Currently, the native grasslands of the high Andean zone of Peru are overgrazed due to the insufficiency of animal species and the number of animals per unit area in the native grassland. The consequences are a decrease in the native forage potential, soil erosion, decreased vegetation cover, low production, and decreased productivity of the primary products of economic activity.

Land use has substantial restrictions in this area due to its proximity to the Ampay National Sanctuary protected natural area, a buffer zone. The glacier is a water reservoir that allows the productive activities of the peasants to be prolonged in the buffer zone of the Ampay National Sanctuary and the valley of the Pachachaca River [20]. The rural populations near the Ampay National Sanctuary are grouped into Peasant Communities (P.C.) and Associations of Small Agricultural Producers (A.P.A.), which make up a total of nine groups [21].

In the Andean grasslands of the upper area of the Ampay National Sanctuary, overgrazing causes alterations in both the vegetation and the microclimate, so it is necessary to propose management strategies to preserve the ecosystems. The purpose of this research has been to evaluate the vegetation cover, botanical composition, carrying capacity, and soil erosion by applying rapid, reliable methods recommended to promote adequate management of natural grasses. The management is aimed at conserving them, using them appropriately, without activities that put at risk to the production of natural pastures, showing the benefits that these have for animals and man, as well as identifying the activities carried out by the residents of the areas surrounding the Ampay National Sanctuary.

Study area location and weather

Table 1 and **Figure 1** show that the Ampay glacier is part of the Vilcabamba mountain range. It is in the region of Apurimac, province of Abancay; its maximum altitude is 5,235 masl (metres above sea level), geographically located at the coordinates 72° 55’ to 72° 54’ from west latitude and 13° 33’ to 13° 34’ south longitude. The climate in Abancay is 16.7 °C annual mean temperature and 685 mm annual average rainfall [20]. The access to the Ampay glacier from Abancay city is by a paved road, travelling 51 km to Karcatera, where it is possible to find informative signs, and then following a 6-hour road to reach the base camp [20]. The areas of interest of this research were the grasslands of the communities surrounding the upper area of the National Sanctuary of the Ampay, from 3500 to 4500 masl. The Sanctuary area has 3,635.50 ha, whereas the high Andean zone has 100% grazing land with natural pastures mostly destined for feeding cattle or sheep.

Table 1. Access routes to the Sanctuary from the city of Abancay

Route name	Itinerary	Travel time one way [h]
Central	Abancay – Arcopunco – Visitor Center – Supaywayq'o-Ankasqocha Lagoon – Tuturpampa – Usphaqocha Lagoon – Foot of the Nevado Ampay Left	6
West	Abancay – Karkatera – Chakiqocha – Willkaqocha – Nevado Ampay	5

The inhabitants inside the Sanctuary carry out subsistence agricultural activities such as cultivating potatoes, corn and other native crops, as well as sheep and cattle farming in a controlled way. On a smaller scale, they extract medicinal and edible plants, among which we can mention the “limancho” (*Peperomia pellucida*) and “ullpu” (*Asplenium squamosum*), both used in their food [21].

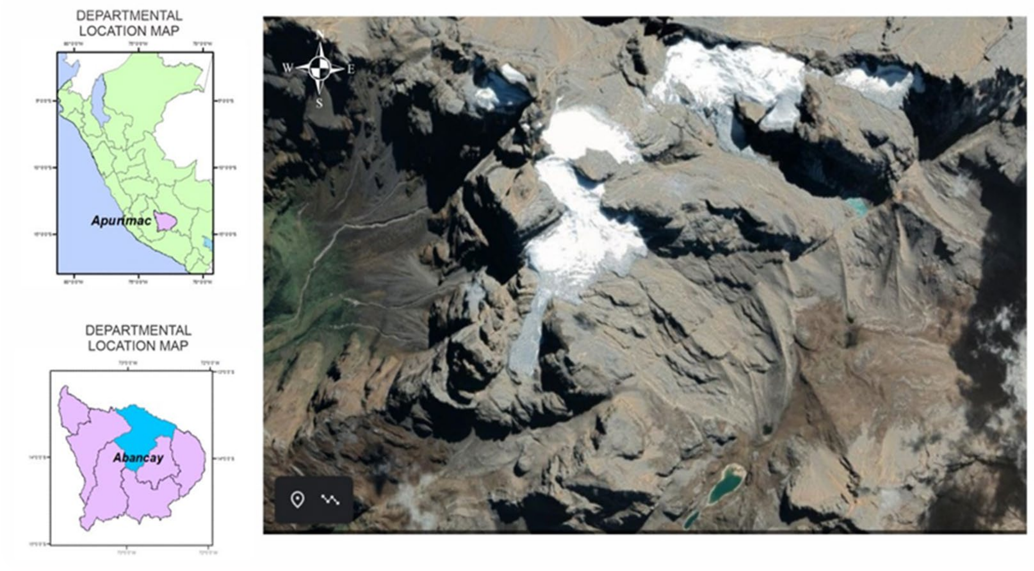


Figure 1. Geographical location of Ampay National Sanctuary [20]

Figure 2 and Table 2 represent the mean annual temperature and precipitation fluctuation from 1991−2017 based on the data observed in Abancay, obtained from the National Meteorological and Hydrological Service (SENAMHI). Two well-defined seasons are observed: a rainy period from October to April and a dry season between May and September. Temperatures decrease between 2300 to 3600 masl, and the average temperature varies between 11 °C and 16 °C. Then colder temperatures are seen that correspond to the puna, from 3800 to 4800 masl, where the temperature varies from 0 °C to 10 °C. Finally, temperatures below 0 °C are distinguished by snowfall in altitudes of 5000 masl, such as those recorded in the glacier. Precipitation in the high parts reaches up to 710 mm annually. The greatest rainfall occurs between January and March [22].

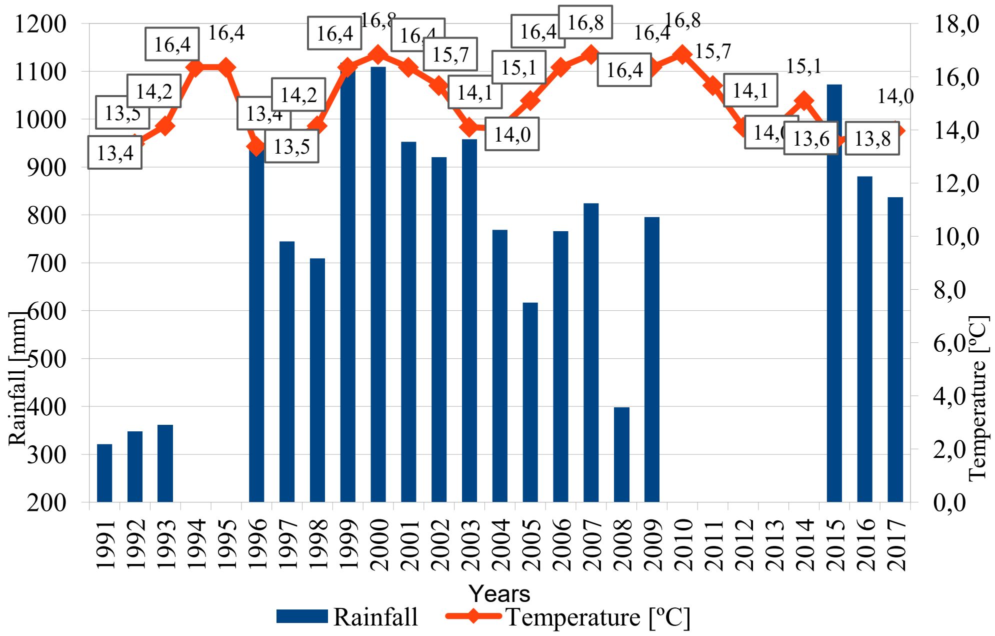


Figure 2. Graphical representation of the annual average temperature and rainfall in the period 1991–2017; no data are available for years 1994−1995 and 2010−2014

METHODS

The areas of interest were selected using vegetation cover maps prepared from field information. The study was conducted in grasslands with tall grasses, such as *Festuca dolichophylla,* and short grasses, such as *Calamagrostis heterophylla*. The grasslands are characterised by the presence of tall grasses with hard leaves, among which *Festuca, Stipa ichu,* and *Calamagrostis* stand out, accompanied by herbaceous vegetation with simple or poorly branched stems.

Floristic composition and data collection

Data collection was done according to the floristic characteristics of the study area, which can be regarded as a representation of native and non-native grasslands now covering approximately 50% of the global terrestrial environment [23]. The taxonomic ordering of the species was accomplished using the Phylogenetic Classification System of Angiosperms.

For the structure and floristic composition of the pastures, data collection was carried out by applying the method of transects by Parker, considering the differentiation of puna and grassland grasses formations [24], and recording the plant species, including mulch (organic matter that covers the soil), moss, bare soil, and rock. The Parker (or three-step) method was selected as dynamic and specific for grassland evaluations [25].

Three sectors were zoned Faccha, Uspacocha, and Yanacocha with transects in the study area, and taxonomic identifications were done.

Three-step transection method

The three-step evaluation method applied to evaluate vegetation is illustrated by a flow chart in **Figure 3**. Parker [25] described this method for natural meadow evaluations because it allowed the identification of the associations of native grasses with simple and safe procedures consisting of three different steps.

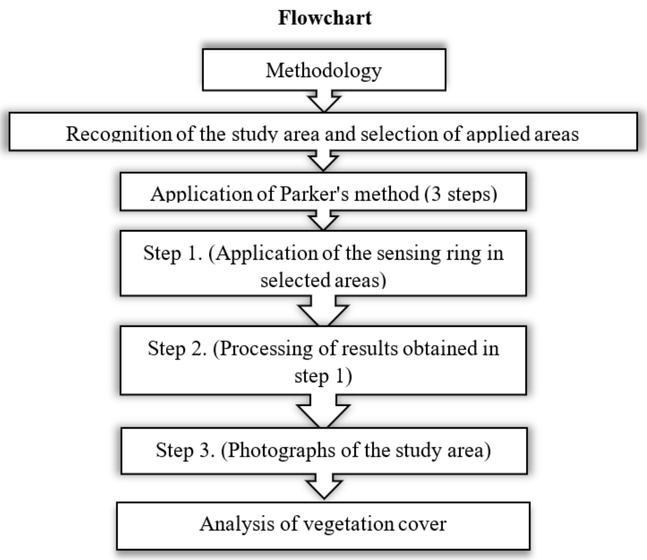


Figure 3. Three-step method flow chart

First Step. For rapid evaluations in areas with herbaceous vegetation and areas with dispersed vegetation, the method of lines with intercept points is appropriate to apply [26]**.** It is easy, simple and comparatively fast to obtain accurate estimates of the coverage and frequency in low-rise plant communities, where the plants have more or less compact foliage. Based on establishing a specific longitudinal line through which the length intercepted by each species is recorded, regardless of whether they are plants, individuals or accumulations of individuals, in a certain sense, the procedure can be considered as a height transect reduced to a minimum [26]. This method helped identify plant species and monitor grasslands through the evaluated transects, so we measured 13 homogeneous areas in the three evaluated sectors (A, B, C). It consisted of stretching a rope of 30 m in length, graduated every 30 cm. Fixed by stakes to the left side so that they are permanent, 100 observations are made in each line (transect) using a census ring of 22.5 mm diameter that is placed on the left side of the line; the transections must be done in the growing season of the plants. Each major subtype of vegetation has been studied separately; the distribution of the transection groups is carried out according to the usual grazing places. Each line has been considered an imaginary axis of a plot 30 m wide and 45 m long (it projects 7.5 m in length beyond each end of the line, for a total of 1350 m^2). Certain standards were considered for the assessment of pasture meadows. The transects have been carried out during pasture growth (November to March). It is not convenient to stretch in "bofedals" (prairie wetland areas) or areas with high slopes, but rather in homogeneous areas. Figure 4 shows the census ring that allowed differentiating pasture species as palatable and non-palatable; this ring allowed the first step of the applied method to be accomplished. Figure 5 shows the distribution of the transects that were assessed while maintaining the distances specified in the applied method using the census ring.

Figure 4. Census ring for pasture identification

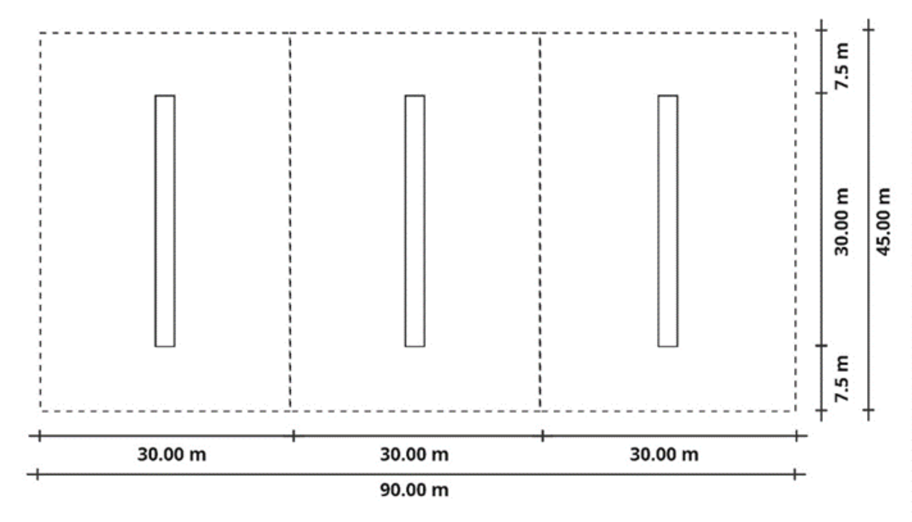


Figure 5. Parallel distribution of transects

When making the 100 observations, it is necessary to classify the species recorded as Most Valuable, Intermediate, or Less Valuable (the most important from the forage point of view are the first two). The annotations are registered in a table of 100 cells. Annual plants are not recorded; they are only used as indicators of pasture trends. The Basal Area Index of forage plants is obtained by adding the annotations corresponding to the Most Valuable and Intermediate species. The Coverage Index is the sum of the three categories of plants plus mulch and moss. Once the observations are finished, the species found in the imaginary plot must be recorded and registered in the place.

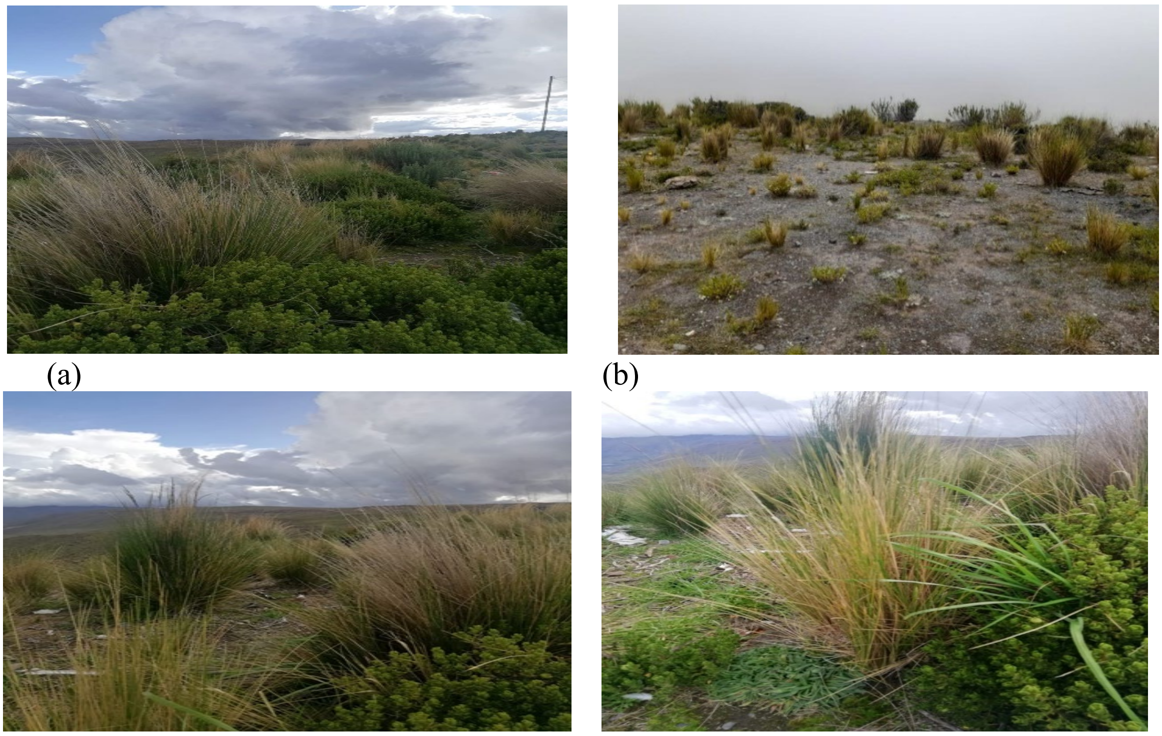
Within the imaginary plot, measurements are made of the leaf height of two or three of the Most Valuable forage species. Five individuals are measured on each side of the line, thus obtaining ten measurements, which allow the setting of an average and eliminating the error of appreciation that could occur when taking the height of a single individual. The height is measured to the apex of the leaf that reaches higher with an approximation of 0.5 cm.

Second Step. The data recorded in the field were summarised in a numerical form, corresponding to the number of touches made on the Most Valuable, Less Valuable, and Intermediate species of each of the transects of the group. The sum of the three categories of each transect was then weighted to 100 to estimate their composition percentages. The summary table recorded the data referring to the touches on the bare ground, erosion pavement, rock, mulch, and moss, as well as the Basal Area index of forage plants and the Coverage Index. Finally, the average was found.

The classification and appreciation of the group was made as follows:

I) Evaluation of the vegetation where the transections were made. Reaching the final classification of the vegetation necessitated assigning points to the Forage Plant Index, the average composition of desirable species, and the leaf height of the species; these values must be previously interpolated with the standard table values respectively, and they were placed at the bottom of the working form. The evaluation used adjectives ranging from Excellent to Bad.

II) Assessment of soil stability was made following the same sequence indicated above − first determining the Coverage Index score and soil erosion stage, then comparing with a scale of values specially made; the points were added, and in this way, the soil where transection was performed, was qualified.



(a) (b) (c) (d)

Figure 6. Natural grasses in sectors A, B, and C: grassland association (a), grassland with bare soil zone (b), high zone in sector B with natural grasses (c), and grasslands in sector C of Yanacocha (d)

Third Step. Herbaceous samples were collected for the preparation of the herbarium simultaneously with their evaluation, and soil samples were collected from different places and altitudes in the study area to analyse their quality. The samples were collected from three sectors: A, B, and C. Finally, numerous photographs of the study area were taken, understanding that the objective was to determine the vegetation and soil quality of the high Andean area selected for the study. Completing the three steps yields accurate information on a grassland area, which can be analysed yearly or as often as necessary.

In **Figure 6**, the grasslands of the study area have shown associations of plant species (6a), bare soil (6b), areas with plant abundance (6c), predominant areas of grasses of Yanacocha (6d), which has allowed them to be evaluated by sectors. The pastures in rainy seasons are used by animals such as cattle, sheep and horses, which will be used for sale or self-consumption by the residents of the communities surrounding the study area.

RESULTS

The current state of the pastures and soils of the upper zone of Ampay National Sanctuary showed 13 homogeneous zones in the three sectors (A, B, and C). The vegetation exhibited five zones in good condition, four in a regular state, three in excellent condition, and one in bad condition.

The soil evaluation (for which nine zones were defined) indicated two good zones, six regular zones, and one bad. The plant associations in the study area were represented by dominant species such as *Alchemilla pinnata, Stipa inconspicua, Festuca dolichophylla, and Festuca tectoria,* whose development occurred in soils with good organic matter. Samples with the dominance of *Festuca dolichophylla, Calamagrostis amoena*, and *Stipa inconspicua* were identified with considerable vigour conditions.

The Faccha, Uspacocha, and Yanacocha sectors in **Figure 7** define the dominance of species, critical zones, cultivation zones, and arboreal vegetation of the upper zone of the Ampay Sanctuary. The Faccha area presents critical areas where a meteorological phenomenon with characteristics of alluvium-type landslides has occurred for years. Yanacocha presents more pasture areas and major agricultural and livestock activity.

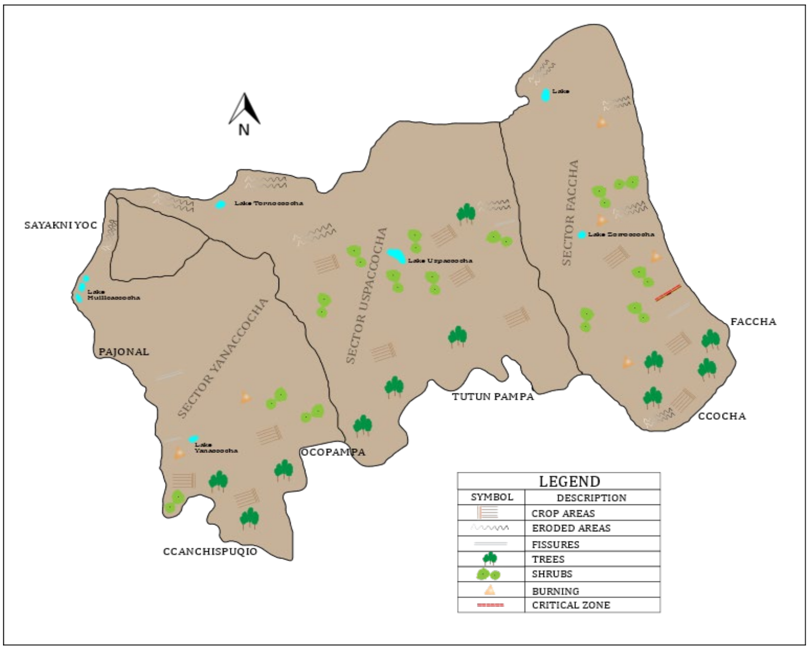
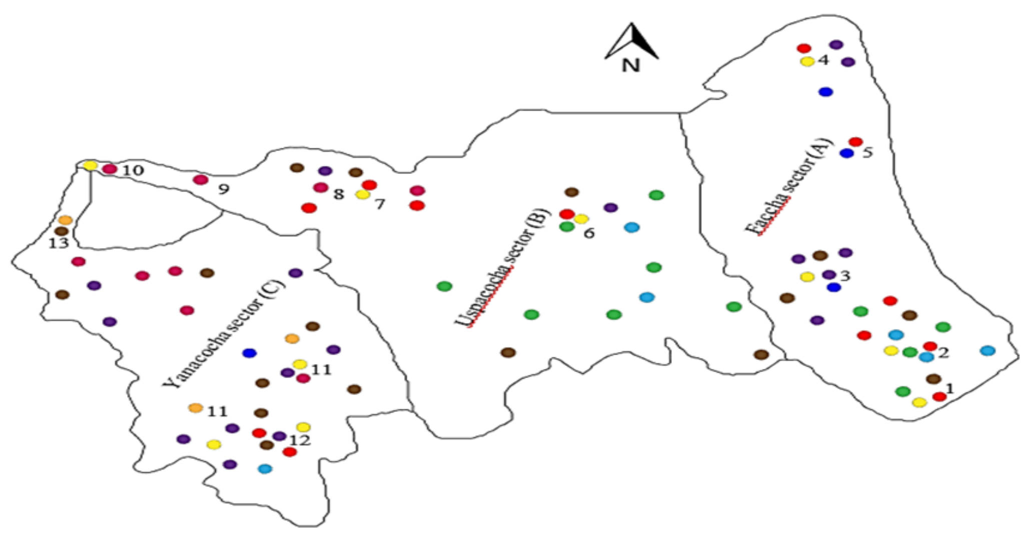


Figure 6. Map with the zoning of sectors Faccha, Uspacocha, and Yanacocha

Figure 8 shows the dominance of plant associations by sectors (A, B, C), with 13 homogeneous evaluation zones from 3500 masl to 4500 masl, showing associations between the *Calamagraostis, Festuca, and Poa* species.



Legend	
Symbol	Description
(yellow)	Agrostis brevicaulis
(green)	Carex sp
(purple)	Alchenilla pinnata
(orange)	Scyrpus rigidus
(red)	Calamagrostis heterophylla
(light blue)	Poa annua
(crimson)	Festuca dolycofylla
(brown)	Luzula peruviana
(blue)	Festuca tectoria

Table of the Homogeneous study area by sector			
Location	Homogeneous áreas	[m.a.s.l]	Sectors
01	Layme	3 350.00	Faccha
02	Marampata	3 500.00	Faccha
03	Zorraccocha	3 750.00	Faccha
04	Guerreana	4 200.00	Faccha
05	Mamaccoya	3 900.00	Faccha
06	Machaypunco	3 650.00	Uspaccocha
07	Tornoccocha	4 200.00	Uspaccocha
–08	Tornoccocha	4 250.00	Uspaccocha
09	Tornoccocha	4 300.00	Uspaccocha
10	Abra del Nevado	4 500.00	Uspaccocha
11	Yanaccocha	4 300.00	Yanaccocha
12	Chaquiccocha	4 100.00	Yanaccocha
13	Huillcaccocha	4 300.00	Yanaccocha

Figure 7. Species dominance associations in Sectors A, B, C.

Data analysis

The data related to frequency or abundance, vegetation scale, soil scale and coverage were tabulated by zone, sector, and herbaceous species. One variance analysis of two independent factors without interaction was performed for the abundance variable. Previously, the assumption of normality for the abundance variable was verified. The Shapiro-Wilks normality test revealed one value of $W = 0.856$ ($p = 0.0499$), indicating a good approximation of the data to a normal distribution. For the post hoc test of means, Fisher's improved least significant difference (LSD) was used [27].

Two main-component analyses of the total variance were conducted to establish relationships between herbaceous species, vegetation, soils, coverage, and abundance according to the zones and their sectors. In the first, the area was considered a classification criterion, a bi-plot was obtained by zone sector, and the variables vegetation, soil, cover, and abundance were graphed as vectors. The second was like the previous one, with the difference that herbaceous species were considered a classification criterion [28].

Vegetation and soil rating

Table 2 shows the vegetation cover and soil assessment carried out in the 13 homogeneous zones and the three sectors (A, B, C). The names of the assessed sites within each sector are indicated. The relationship between vegetation and soil condition determines the productivity of the grassland. Evidence of soil erosion was observed due to the presence of Nevado Ampay and slight natural landslides and rocky areas.

Table 2. Vegetation and soil condition in the upper area of the Ampay National Sanctuary

Sector	Denomination	Vegetation	Soil
A	Layme	Bad	Regular
	Marampata	Regular	Good
	Zorraccocha	Good	Regular
	Guerreana	Good	Good
	Mamaccoya	Regular	Regular
B	Machaypunco	Good	Bad
	Tornoccocha	Regular	Regular
	Abra del nevado	Excellent	Regular
	Tornoccocha	Excellent	Regular
	Tornoccocha	Excellent	Good
C	Chaquiccocha	Regular	Regular
	Yanaccocha	Good	Good
	Hilcaccocha	Good	Good

In **Table 3**, one hundred seventeen (117) transects were prepared, and 4,741 individuals were present. The most dominant species were identified by sectors, as shown in the table, indicating the plant species' dominance in Faccha, Yanacocha, and Uspacocha.

For the evaluation of vegetation and the soil, the vegetation in the place where the group of transects was made, adding points to the index of forage plants, the average composition of the most desirable species and the average of points awarded to the leaf height of the species, interpolated with the values of the standard table, evaluated with adjectives from excellent too bad. The assessment of soil stability used the area score, the coverage index, then the state of soil erosion, and compared with a specially prepared scale of values. The points were added, and the soil where each transect was made was classified.

Table 3. Species frequency and species dominance

Species	Sector A Faccha	Sector B Uspacocha	Sector C Yanacocha	Total number of individuals
Alchemilla pinnata	284	164	95	543
Stipa conspicua	101	59	26	186
Carex sp.	77	63	28	162
Fectuca tectoria	09	165	00	174
Festuca dolichophylla	198	245	00	443
Calamagrostis amoena	86	199	02	285
Pitptochaertium setifolium	36	07	41	84
Calamagrostis brevifolia	123	234	06	363
Poa annua	13	03	55	71
Paspalum bonplandianum	17	23	02	42
Gnaphalium purpureum	104	67	88	259
Agrostis brevicaulis	97	98	109	304
Luzula peruviana	88	15	78	181
Hipochoeris glabrata	59	36	72	167
Werneria caespitosa	26	35	34	95
Various	520	673	189	1382
	1838	2086	825	4741

In **Figure 9**, the plant species of the study area have been identified by families [30]. The figure shows the dominance of the families *Fabaceae*, *Poaceae, Asteraceae,* and *Rosaceae*, among others, allowing the identification of grassland species in the upper area of the Ampay Sanctuary.

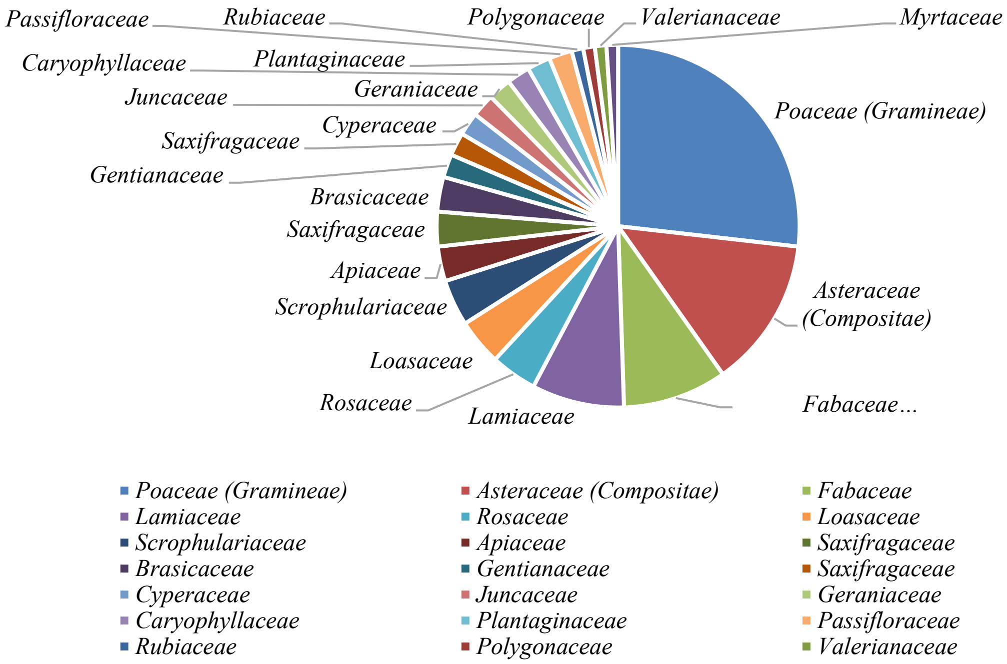


Figure 8. Predominantly observed plant families

According to **Table 4**, from 39 homogeneous zones in the three sectors, an average of 75.5% for vegetation cover between categories 4 and 5 is in regular conservation condition, with some evidence of laminar erosion in certain cases.

Table 4. Vegetation analysis

Sector	Denomination	Coverage [%]	Category
A	Faccha	79.60	5
B	Uspacocha	67.50	4
C	Yanacmocha	79.40	5
	Mean	75.5	4.8

In **Table 5**, the soils showed good, fair, and poor characteristics. These results show that in communities surrounding the Ampay National Sanctuary, the inhabitants' agricultural activities diminish the soil quality. In the three sectors of study A, B, and C, three evaluations of the vegetation were performed for each, determining that the characteristic of the vegetation was between good and regular.

Table 5. Vegetation condition and soil status

Sector	Place	Vegetation	Soil
A	1 (15 transects)	Good	Regular
	2 (15 transects)	Good	Good
	3 (15 transects)	Regular	Regular
B	4 (15 transects)	Regular	Bad
	5 (15 transects)	Good	Regular
	6 (15 transects)	Regular	Regular
C	7 (09 transects)	Good	Good
	8 (09 transects)	Good	Regular
	9 (09 transects)	Regular	Regular

In **Table 6**, the condition of the grasslands in the study area was good to fair, with an Annual Carrying Capacity (ACC) reaching up to 2.2 AU/(ha year), i.e., 2.2 animal units per hectare per year. Overgrazing was notorious, with cattle, sheep and horses being the consumers. In the upper part of the study area, there are opportunities for raising cattle, horses, and sheep. The cattle remain in the high parts between August and May, coming down in June and July to eat the corn husk. The surrounding communities have agricultural activity that is complemented by livestock farming.

Table 6. Condition of the vegetation by its loading capacity

Sector	ACC [AU/(ha year)]	Grassland condition
A	2.2	Good
B	1.7	Regular
C	2.0	Good

Palatability

To determine the grazing capacity, the support/bearability values of the sites were averaged according to the condition to find a value for each homogeneous zone of vegetation; with these values multiplied by the area of each homogeneous zone, livestock sustainability was estimated. On the other hand, palatability was classified based on the acceptability of the predominant livestock.

Figure 10 shows that of the total number of identified species, 57.80% have been more valuable species (palatable), 34.20% intermediate species (not very palatable), and 8% less valuable (not palatable) for livestock in the study area. Pastures not palatable to livestock are consumed very little but are part of the desirable herbaceous plant cover.

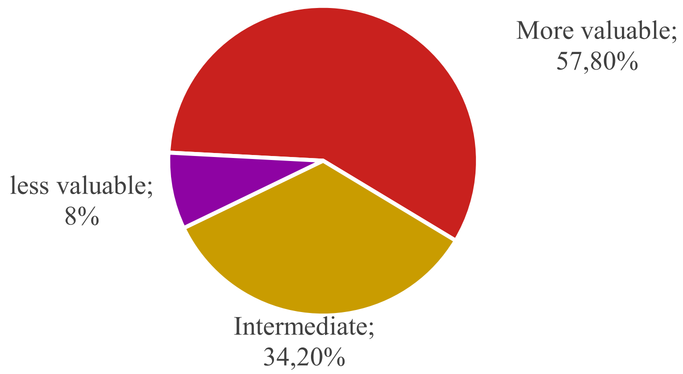


Figure 9. Palatability of the total species identified for livestock

Vegetation and soil condition in the Faccha, Uspacocha, and Yanacocha sectors

In **Figure 11**, the herbaceous plant associations of the zone's total area show a predominance of the families *Rosaceae, Poaceae,* and *Asteraceae*. It is known that some parts of this type of vegetation have medicinal uses, some as repellents and others as fuel. The data from soil evaluation indicate that the Yanacocha sector has better soil conditions than other sectors in the study area.

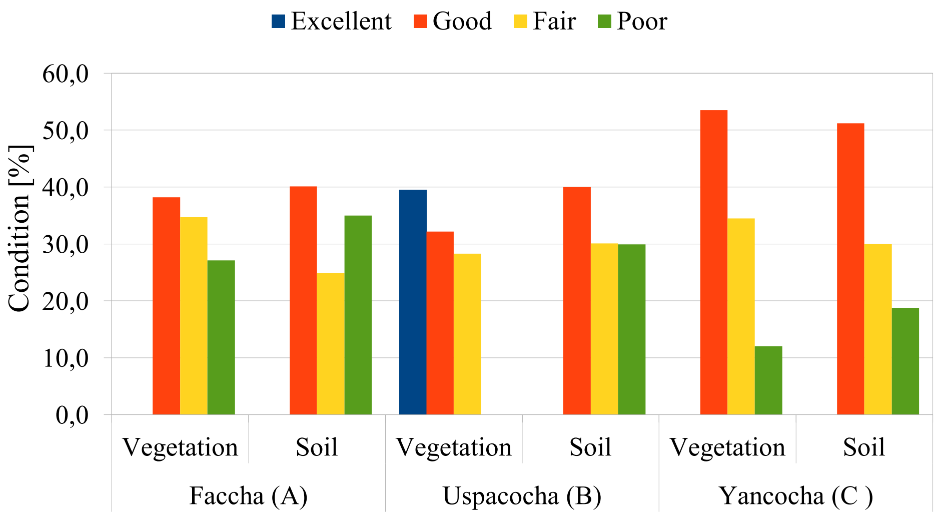


Figure 10. Vegetation and soil condition in the Faccha, Uspacocha, and Yanacocha sectors

Determination of biomass

The quadrant method was applied to determine biomass: nine homogeneous areas parallel to the evaluation area of the linear transects were delimited, and the 1 m^2 square was placed. Nine points close to the evaluated sectors were selected, the grass within the square was cut, and the height of all grasses was measured. All materials were cut at ground level with manual shearing scissors without separating the live material from the dead and subsequently cut into pieces to be dried [29]. The material was weighed as fresh green grass; a sample was placed in the oven at 60 °C for 48 hours in the University laboratory to determine dry matter percentage. The mass of dry matter (DM) was determined using the biomass formula that employs the term of Grams fresh mass × (Dry matter percentage/100) × Correction Factor.

The dry matter was very variable in the natural pastures evaluated, and the repetitions were also variable concerning the physiological state of the pastures; its evaluation was during the rainy season. In Table 7, the availability of dry matter of pastures in the rainy season presented an average of up to 1893.2 kg/ha in sector B of Uspacocha. In the rainy season, grasses in pastures were predominant in its production.

Table 7. Biomass determination − production of natural grasses

Sector	Fresh mass [g]	Dry matter [%]	Correction factor	Biomass [kg DM/ha]	Species in quadrants of 1 m^2
A (Facha 1)	250	16	6.4	1600.0	Desirable, undesirable
A (Facha 2)	245	15	6.0	1470.0	
A (Facha 3)	260	14	5.6	1456.0	
B (Uspacocha 1)	263	18	7.2	1893.2	Desirable, undesirable
B (Uspacocha 2)	259	17	6.8	1761.2	
B (Uspacocha 3)	260	17	6.8	1768.0	
C (Yanacocha 1)	259	16	6.4	1657.6	Desirable, undesirable
C (Yanacocha 2)	256	14	5.6	1433.6	
C (Yanacocha 3)	240	13	5.2	1248.0	

As shown in Table 8, the communities surrounding the Ampay Sanctuary use plant species from the study area for medicinal purposes, as fuel (firewood) and food. The plants provide an additional economic resource for the residents and are sold in the local markets. Many of these species are abundant during the rainy season.

Table 8. Different uses of plant species

Family	Scientific name	Common name	Use
Adiantaceae	*Asplenium squamosum*	Ullpu	Alimentary
Asteraceae	*Ageratina* sp.	Wamanchilka	Forage, medicinal
Asteraceae	*Ambrosia arborescens*	Marko, marku	Medicinal
Asteraceae	*Aristeguietia discolor*	Chillka	Medicinal
Asteraceae	*Baccharis tricuneata*	Tayanka	Fuel
Asteraceae	*Barnadesia berberoides*	Llaulli	Medicinal
Asteraceae	*Gynoxis caracensis*	Q'oto kiswar	Fuel
Asteraceae	*Perezia coerulescens*	Sutuma, valeria	Medicinal
Asteraceae	*Perezia multiflora*	Escorzonera	Medicinal
Asteraceae	*Senecio canescens*	Huira huira	Medicinal
Asteraceae	*Senecio* sp.	Tikllaywarmi	Medicinal
Asteraceae	*Smallanthus glabratus*	Qalasto llakon	Fuel, fodder
Asteraceae	*Xenophyllum dactylopphyllu*	Kuñuca	Medicinal
Betulaceae	*Alnus acuminata* sp.	Aliso, lambras	Manufactures
Bignoniaceae	*Tecoma punch. Vetulina*	Waranway	Manufactures
Clusiaceae	*Clusia multiflora*	Puko puko	Fuel
Ephedraceae	*Ephedra americana*	Pinko pinko	Medicinal
Fabaceae	*Otholobium pubescens*	Culen	Medicinal
Fabaceae	*Senna versicolor*	Mutuy	Medicinal
Grossulariaceae	*Escallonia myrtilloides*	T'asta	Fuel, manufacture
Grossulariaceae	*Escallonia resinosa*	Chachakomo	Manufactures
Lamiaceae	*Minthostachys silky*	Raphy muña	Medicinal
Lamiaceae	*Satureja brevicalyx*	K`uñaka muña	Medicinal
Lamiaceae	*Satureja* sp.	Pasha muña	Medicinal
Loasaceae	*Cajophora* sp.	Pucashinua	Medicinal
Podocarpaceae	*Podocarpus glomeratus*	Intimpa	Manufactures
Polygonaceae	*Muehlenbeckia volcanica*	Mullaka	Medicinal
Rhamnaceae	*Colletia spinosissima*	Chaccara	Fuel
Rosaceae	*Rubus robustus*	Siraq'a	Alimentary
Rosaceae	*Rubus roseus*	Siraq'a	Alimentary
Solanaceae	*Physalis* sp.	Awaymantu	Alimentary
Solanaceae	*Saracha punctata*	Chawchapay	Manufactures
Valerianaceae	*Valeriana coarctata*	Valeriana	Medicinal

DISCUSSION

Previous evaluations of pastures in the highland areas under study are very scarce, which has not allowed for greater comparisons, with no precedents in the area that could serve as a reference, so we hope that this research will serve as a background for future studies of Andean pastures and their management in this area. It is recommended that self-sustainable development be promoted by strengthening the production units of the communities surrounding the Sanctuary. The study was conducted during the rainy season (November−March) to identify the greatest amount of pasture production. However, this season presents difficulties in terms of travel due to climatic risks.

Globally, grasslands are degraded more than any other biome [31]. Their biomass composition and floristic composition are varied. Ampay National Sanctuary is a good example due to the diverse native species identified in the vegetative plots of the upper area.

Soils of the Andean floor or puna, between 3,800 to 4,500 masl, are dark horizon soils rich in organic matter with grass cover. As it extends towards the upper parts, stony and abrupt soils of rocks and crags are spotted. The soils and vegetation of this part withstand drastic climate changes, low temperatures at night and sunny weather during the day. Due to ecosystem fragility, the soil and vegetation cover dry out quickly during the summer; however, during the rainy months, the landscape looks like a green grass carpet with humid soil, with abundant fog and cloudiness.

In the upper parts of the study area, there was a variety of natural grasses, showing some genera of species such as *Calamagrostis* and *Festuca,* as well as *Werneria, Azorella*, and *Valeriana*, distributed irregularly. As the altitude decreased, between 3,500 and 4,000 masl, there was a predominance of subshrub species, such as *Baccharis buxifolia* (Tayanka)*, Berberis lutea* (Cheqche), and *Lupinus*, and in sheltered places *Podocarpus* (Intimpa), and *Escallonia mytilloides*. Below 3,500 masl, species such as *Eucalyptus globulus* (Eucalyptus), *Buddleja incana*, *B. coriacea* (Kolle), *Polylepis* sp. (Qewña), *Escalonia resinous* (Chachacomo). Furthermore, *Schinus molle* (Molle) was among the dominant species in the lower part.

Problems in natural grasslands are frequently caused by anthropic activities, added to the effects of climate change, that cause the loss of palatable species and decrease the availability of pastures for sheep and cattle, contributing to the scarcity of vegetation cover, increased erosion, soil compaction due to animal trampling, decreased water infiltration and retention due to lack of organic matter and microbial activity.

In addition, overgrazing produces an imbalance between the carrying capacity of a plant species association and the animal load to which it is subjected for a long period, and consequently, does not allow the prompt recovery of the pasture, also due to inappropriate management by the producer to maintain his livestock capital [32].

Throughout the evaluation, the condition of these pastures was linked to soil quality, topography, water availability and animal load, considering grazing and ease of use [33]. The soil evaluation indicated two good zones, six regular zones, and one bad.

The dry matter (DM) availability of the studied grassland is very dynamic and changes permanently depending on the time of year, growth rate and consumption of cattle and sheep. The results in the rainy season were higher than in the dry season. During the rainy season, the best environmental conditions favour the growth of plants, resulting in greater availability of DM for grazing animals [34].

The coverage of natural pastures corresponded to a 75.7% average per sampling unit of the three homogeneous studied zones. The most productive area with desirable species for livestock was Uspacocha, which had better soil conditions without overgrazing. The least productive area of natural pastures turned out to be Yanacocha. It had certain herbaceous plant associations in the study area, the predominant families being *Rosaceae, Poaceae, Asteraceae*. In the Faccha area, predominant associations of plant species were *Alchemilla acheafolia*, *Agrostis brevicaulis,* and *A. pinnata,* and in Uspacocha predominated *Scyrpus rigidus, Agrostis brevicaulis*, *Festuca dolichophylla,* and *Luzula peruviana*. Finally, in the Yanacocha area, *S. rigidus, L. peruviana and A. pinnata* were the dominant herbaceous associations.

The herbaceous vegetation of the upper zone was dominated by *Alchemilla pinnata, Carex* sp., and *Festuca dolichophylla,* considered desirable species for livestock, so pasture status was rated as regular.

The process of degradation of pastures was notably accentuated as the years went by due to the poor management of pastures and the influence of the rather hostile climate. Since the atmospheric state of the area, in recent years, has marked a notorious change in pre-existing physical conditions, it has become a fundamental factor in understanding the forms of adaptation and change at the level of productive practices [35]. However, the likelihood that the effects of climate change will gradually become more acute must also be considered. Failure to take the necessary corrective measures in the short term will lead to a drastic change in fodder vegetation, which will be very difficult to recover in the long term [36].

All vegetative formations have shown the genus *Calamagrostis* as the most abundant and with the greatest importance value, given its great capacity to associate with other species, the form of semi-erect growth and the abundance of tillers in each plant [37]. In the case of the central Andes of Peru, at altitudes higher than 3800 masl, it maintains its heterogeneity of richness in each vegetative formation [38].

In the evaluated vegetative communities, of the total transects evaluated, 11 families were found, the *Poaceae* being the most abundant, followed by the families *Asteraceae* and *Rosaceae* [39]. The communities surrounding the study area use much of the herbaceous vegetation for feeding, medicinal, fuel, fodder, and manufacturing purposes. This situation will positively affect the producers' economy and must be conserved and propagated in the high Andean zone to support the existing animal load.

The carrying capacity is subject to the forage production of the rainy season since, during the periods of the dry season, the availability of forage is considerably reduced, so grazing management should be directed to the restriction of the grazing time in the pastures in the critical forage periods, especially the maximum use of the available pasture in the areas that are rotated in the rainy season due to its relationship with the availability and nutritional quality in the subsequent grazing cycles, which is facilitated with the use of divided grazing [40].

More studies are needed to assess the socioeconomic impact of climate change on agricultural producers. Ours comprises a comprehensive inventory, but we are not policymakers. Efforts are also needed to identify the vulnerability of communities with agricultural land, land tenure, lack of public service coverage, and other factors.

For livestock, it is crucial to develop studies that address the spatial distribution and variation in productivity of high Andean ecosystems and their effect on the sustainability of livestock production. Also, to estimate the impact of climate change on pasture biomass production and its effect on milk and meat production. There is not much information on the impact of climate change on livestock species in the area [41]. It is necessary to reinforce biodiversity and ecosystem service monitoring systems.

Closing these gaps should aim to generate relevant information to strengthen the capacity of residents, guide the scaling up of adaptation strategies, and develop policies, plans, or actions to reduce the vulnerability of the most affected systems [41].

According to the latest research, high biological diversity in vegetation, crops, and livestock constitutes an economic advantage that should be exploited by expanding specific markets, such as trout, sheep meat, beef and milk, and alpaca meat and fibre. Peru has an important comparative advantage internationally regarding alpaca and vicuña populations and second place in llamas. For this advantage to become a factor in the development and fight against poverty in the sector of small producers that possess this valuable resource, effective actions are required to overcome technological, social, and economic limiting factors. The security bases in agricultural production in the Andes have been spatial management and ecological complementarity [42]. As one of the possible answers, there is an immediate need to recognise the importance of the traditional knowledge of the populations that have lived for centuries in the Andes and that, based on their experience, have developed complex systems for the use of resources (with greater resilience) as well as a worldview that respects the environment.

Precipitation and temperature are factors influencing the composition of grassland plant associations as well as biomass. Functional traits and biomass among various plant community types versus environmental factors demonstrate that precipitation drives floristic composition and diversity in temperate grasslands [43].

Grasslands are considered to have the potential to play a key role in greenhouse gas mitigation, particularly in terms of global carbon storage and enhanced carbon sequestration [44]. In the case of the upper zone of the Ampay Sanctuary, the pastures are showing an increase in the growth of livestock activities in the area, and it is necessary to implement mitigation actions for the recovery of bare soil due to the use of animals to increase the productivity of the pastures. Grazing is a key influencing factor that causes the dominant species in the community to change and alters the composition of the plant community [45]. In the case of the study, grazing by cattle, sheep, and horses is a direct contributor to grassland decline. Grasslands are an important part of the global ecosystem and cover 37% of the Earth's land surface. For various reasons, mainly related to overgrazing and the resulting problems of soil erosion and weed invasion, many of the world's natural grasslands are in poor condition and show signs of degradation [44]. The agricultural activities of the surrounding communities degrade the pastures and increase the use of soil for agriculture, endangering the conservation of the pastures. Grazing, burning of grasslands, and agriculture, along with rainfall and temperature, could affect the diversity of grassland vegetation, so it is necessary to promote self-sustainable development among the communities surrounding the Sanctuary.

CONCLUSIONS

The composition and structure of vegetative formations are heterogeneous. The natural pasture cover corresponded to the 75.7% average per sampling unit of the three homogeneous studied zones. The most productive sector with desirable species for livestock was Uspacocha, with better soil conditions without overgrazing. The least productive area of natural pastures was the Yanacocha sector.

Certain herbaceous plant associations were found in the study area, with *Rosaceae, Poaceae,* and *Asteraceae* being the predominant families. In the Faccha sector, the predominant plant associations were *Alchemilla acheafolia, Alchemilla pinnata*, and *Agrostis brevicaulis;* in Uspacocha predominated *Scyrpus rigidus, Agrostis brevicaulis, Festuca dolichophylla,* and *Luzula peruviana*. In the Yanacocha area, herbaceous associations of *Scyrpus rigidus*, *Luzula peruviana, Alchemilla pinnata,* and *Werneria caespitosa* dominated.

The soil quality was evaluated as good areas to bad. The study area showed regular conservation conditions with eroded areas in some cases.

The grazing animal carrying capacity estimate was 1.2 AU/(ha year), currently with overgrazing. Continuous annual studies are suggested to preserve the biodiversity of native grasses.

Currently, the inhabitants of the communities surrounding the study area use many plant species for feeding, medicinal, fuel, fodder, and manufacturing purposes.

ACKNOWLEDGMENT

Thanks are extended to the Technological University of the Andes and the Institute of Development and Environment for their support in completing the research.

NOMENCLATURE

Abbreviations

ACC	Annual Carrying Capacity
CF	Correction Factor
DM	Dry Matter
LSD	Least Significant Difference
PCA	Principal Components Analysis

REFERENCES

1. L. Zeng, B. D. Wardlow, D. Xiang, S. Hu, and D. Li, “A review of vegetation phenological metrics extraction using time-series, multispectral satellite data”. Remote Sens Environ, vol. 237, p. 111511, Feb. 2020, https://doi.org/10.1016/j.rse.2019.111511.
2. W. Zhou et al., “Dynamic of grassland vegetation degradation and its quantitative assessment in the northwest China”. Acta Oecologica, vol. 55, pp. 86–96, Feb. 2014, https://doi.org/10.1016/j.actao.2013.12.006.

3. R. T. Conant, C. E. P. Cerri, B. B. Osborne, and K. Paustian, "Grassland management impacts on soil carbon stocks: a new synthesis". Ecological Applications, vol. 27, no. 2, pp. 662–668, Mar. 2017, https://doi.org/10.1002/eap.1473.
4. M. P. Veldhuis, H. F. Fakkert, M. P. Berg, and H. Olff, "Grassland structural heterogeneity in a savanna is driven more by productivity differences than by consumption differences between lawn and bunch grasses". Oecologia, vol. 182, no. 3, pp. 841–853, Nov. 2016, https://doi.org/10.1007/s00442-016-3698-y.
5. T. Plieninger and L. Huntsinger, "Complex Rangeland Systems: Integrated Social-Ecological Approaches to Silvopastoralism". Rangel Ecol Manag, vol. 71, no. 5, pp. 519–525, Sep. 2018, https://doi.org/10.1016/j.rama.2018.05.002.
6. E. R. Flores, "Cambio Climático: "Climate Change: High Andean Grasslands and Food Security," Journal of Glaciers and Mountain Ecosystems, no. 1, Dec. 2016, https://doi.org/10.36580/rgem.i1.73-80.
7. C. S. Pizarro, "Degradation and vulnerability to climate change in high Andean grasslands". La Molina National Agrarian Univ., Lima, Peru, 2017.
8. R. Yaranga, M. Custodio, F. Chanamé, and R. Pantoja, "Floristic diversity in grasslands according to plant formation in the Shullcas river sub-basin, Junin, Peru". Scientia Agropecuaria, vol. 9, no. 4, pp. 511–517, Dec. 2018, https://doi.org/10.17268/sci.agropecu.2018.04.06.
9. Y. Hautier, D. Tilman, F. Isbell, E. W. Seabloom, E. T. Borer, and P. B. Reich, "Anthropogenic environmental changes affect ecosystem stability via biodiversity". Science (1979), vol. 348, no. 6232, pp. 336–340, Apr. 2015, https://doi.org/10.1126/science.aaa1788.
10. Tapia Núñez Mario E., Flores Ochoa, Jorge A. "Pastures and grasslands of the Southern Andes of Peru". National Institute for Agricultural Research and Promotion, [Accessed: 03.04.2024], https://pdf.usaid.gov/pdf_docs/PNAAR371.pdf.
11. A. Florez and E. Malpartida, "Management of Native Grasslands and Pastures in the Andean Region of Peru", vol. II. Lima, Peru: Agrarian Bank. Book Fund., 2005.
12. M. Wiesmair, A. Otte, and R. Waldhardt, "Relationships between plant diversity, vegetation cover, and site conditions: implications for grassland conservation in the Greater Caucasus". Biodivers Conserv, vol. 26, no. 2, pp. 273–291, Feb. 2017, https://doi.org/10.1007/s10531-016-1240-5.
13. E. M. Cardona, L. A. Rios, and J. D. Peña, "Availability of Pasture and Forage Varieties as Potential Lignocellulosic Materials for the Production of Bioethanol in Colombia," Technological information, vol. 23, no. 6, pp. 87–96, 2012, https://doi.org/10.4067/S0718-07642012000600010.
14. L. P. A. Portillo, D. H. Meneses-Buitrago, S. P. Morales-Montero, M. M. Cadena-Guerrero, and R. E. Castro, "Evaluation and selection of forage grass and legume species in Nariño, Colombia". Pastures and Forages, vol. 42, no. 2, 2019.
15. Méndez, D.F et al., "Seasonal forage production of Lolium multiflorum Lam cultivars". in different places. Published within the Argentine Journal of Animal Production, v 39 Supplement 1, Argentina, 2019, [Accessed: 03.04.2024], http://hdl.handle.net/20.500.12123/6837.
16. G. Zambrano B., J. E. Apráez G., and J. F. Navia E., "Relationship of soil properties with bromatological variables of Pastures, in a dairy system of Nariño," Revista de Ciencias Agrícolas, vol. 31, no. 2, pp. 106–121, Dec. 2014, https://doi.org/10.22267/rcia.143102.35.
17. J. D. J. Vargas- Martínez, A. Sierra-Alarcón, J. Benavidez-Cruz, Y. Avellaneda-Avellaneda, and C. Ariza-Nieto. "Establishment and production of ryegrass and clovers in two regions of the Colombian high tropics," Mesoamerican Agronomy, vol. 29, no. 1, p. 177, Jan. 2018, https://doi.org/10.15517/ma.v29i1.28077.
18. O. Tovar and L. Ocanoa, "Guide for the identification of high Andean natural pastures of greatest livestock importance". Huaraz, Peru, 2002.

19. D. Wang, L. Wang, J. Liu, H. Zhu, and Z. Zhong, "Grassland ecology in China: perspectives and challenges". Front Agric Sci Eng, vol. 5, no. 1, p. 24, 2018, https://doi.org/10.15302/J-FASE-2018205.
20. C. Soto Carrión et al., "Multi-Temporal Analysis of the Glacier Retreat Using Landsat Satellite Images in the Nevado of the Ampay National Sanctuary, Peru". Journal of Sustainable Development of Energy, Water and Environment Systems, vol. 10, no. 1, pp. 1–15, Mar. 2022, https://doi.org/10.13044/j.sdewes.d8.0380.
21. N. S. of N. A. P. by the state SERNANP, "Diagnosis Master Plan of Ampay National Sanctuary 2015-2019". pp. 31–31, 2016.
22. R. Hostnig and C. Palomino., "The Ampay National Sanctuary: Refuge of intimacy in Apurímac, Peru". Apurimac, p. 153, 1997.
23. B. J. Wilsey, The Biology of Grasslands, vol. 1. Oxford University Press, 2018, https://doi.org/10.1093/oso/9780198744511.001.0001.
24. E. Barrantes and CA; Flores, "Estimating the willingness to pay for the conservation of high Andean grasslands". 12th ed., vol. 1–2. Aplica. Ecological, 2013.
25. K. W. Parker, "Application of Ecology in the Determination of Range Condition and Trend". Journal of Range Management, vol. 7, no. 1, p. 14, Jan. 1954, https://doi.org/10.2307/3894620.
26. R. H. Canfield, "Application of the line interception method in sampling range vegetation". J For, no. 39, pp. 399–394, 1941.
27. A. García Pérez, "Advanced applied statistics with R, Brooks". España, ISBN 8436278577, 9788436278576, 2022.
28. J. A. Di Rienzo, F. Casanoves, M. G. Balzarini, L. Gonzalez, M. Tablada, and C. W. Robledo, InfoStat. Argentina: National University of Cordoba, Argentina, 2011.
29. R. J. Crespo, J. A. Castaño, and J. A. Capurro, "Secado de Forraje con el Horno Microondas: Efecto Sobre el Analisis de Calidad". Agricultura Técnica, vol. 67, no. 2, Jun. 2007, https://doi.org/10.4067/S0365-28072007000200013.
30. A. Cronquist, "An Integrated System of Classification of Flowering Plants". USA.
31. D. D. Harmon, E. B. Rayburn, and T. C. Griggs, "Grassland Ecology and Ecosystem Management for Sustainable Livestock Performance". Agronomy, vol. 13, no. 5, p. 1380, May 2023, https://doi.org/10.3390/agronomy13051380.
32. P. I. Villalta-Rojas, J. G. Zapana-Pari, J. C. Zapana-Landaeta, F. Escobar-Mamani, and J. Araoz, "Evaluation of pastures and animal carrying capacity in the 'Carolina' farm of the National University of the Altiplano - Puno Peru.", Revista de Ciencias Altoandinas - Journal of High Andean Research, vol. 18, no. 3, Sep. 2016, https://doi.org/10.18271/ria.2016.219.
33. G. Castellaro G., T. Ullrich R., B. Wackwitz, and A. Raggi S., "Botanical composition of the diet of alpacas (Lama pacos L.) and llamas (Lama glama L.) in two seasons of the year, in highland meadows of a sector of the Province of Parinacota, Chile," Technical Agriculture, vol. 64, no. 4, Oct. 2004, https://doi.org/10.4067/S0365-28072004000400004.
34. E. D. Boyda and Butler Jack; Xu Lan, "Estimating Herbaceous Biomass of Grassland Vegetation Using the Reference Unit Method" , [Accessed: 03.04.2024], https://www.fs.usda.gov/research/treesearch/50251.
35. C. Riera and SG. Pereira, "Between climate risk and productive transformations: irrigated agriculture as a form of adaptation in Río Segundo, Córdoba, Argentina". Geogr. Res. Toro. Inst. Geogr., vol. 82, pp. 52–65, 2013.
36. G. H. Fischer, M. Shahm, and Veltuisen. Van, "Climate change and agricultural vulnerability", [Accessed: 03.04.2024], http://www.iiasa.ac.at/Research/LUC/JBReport.pdf.16-01-2006.
37. A. J. Peña Quiñones, B. Arce Barazorda, M. A. Ayarza Moreno, and C. E. Lascano Aguilar, "Simulation of water requirements of pastures in a scenario of climate changes

generated with singular spectral analysis". in fac. Agricultural. Science, vol. 1, La salle university, 2010, pp. 1–8.
38. L. R. Fiallos and R. Velázquez. Herrera, "Diversity of flora in the Ecuadorian paramo grassland ecosystem Flora diversity in the Ecuadorian paramo ecosystem". in Cuban Journal of Agricultural Science, vol. 49, 2015, pp. 399–405.
39. A. C. Estrada Zuñiga and J. G. Zapana Pari, "Carrying capacity of humid puna grasses in a context of climate change," Altoandinas Research Magazine - Journal of High Andean Research, vol. 20, no. 3, pp. 361–379, Jul. 2018, https://doi.org/10.18271/ria.2018.399.
40. S. J. D. Choquehuanca and R. E. Pelinco, "Vegetation Capacity and Parameters in alpaca habitat meadows in the Puno region: Campaign 2018.2022", [Accessed: 03.04.2024], https://orcid.org/0000-0003-3267-5611.
41. Valenzuela G. et al., "Andean Mountain Initiative (AMI, 2023). Vulnerability and Adaptation to Climate Change in High Mountain Areas of the Andean Region. A regional study organised by the Consortium for Sustainable Development of the Andean Ecoregion and the United Nations Environment Programme (UNEP). Prepared by DEUMAN". 2023.
42. M. Tapia, "Diagnosis of mountain ecosystems in Peru". FAO-MINAM, Peru, 2013, [Accessed: 03.04.2024], https://www.fao.org/fileadmin/templates/mountain_partnership/doc/TCP_Andes/DiagnosticoPeruVersion_2_de_sept-_1-55.pdf.
43. X. Bai, W. Zhao, J. Wang, and C. S. S. Ferreira, "Precipitation drives the floristic composition and diversity of temperate grasslands in China". Glob Ecol Conserv, vol. 32, p. e01933, Dec. 2021, https://doi.org/10.1016/j.gecco.2021.e01933.
44. F. P. O'Mara, "The role of grasslands in food security and climate change". Ann Bot, vol. 110, no. 6, pp. 1263–1270, Nov. 2012, https://doi.org/10.1093/aob/mcs209
45. C. Zhang et al., "Grassland Community Composition Response to Grazing Intensity Under Different Grazing Regimes". Rangel Ecol Manag, vol. 71, no. 2, pp. 196–204, Mar. 2018, https://doi.org/10.1016/j.rama.2017.09.007.

APPENDIX

Table A1 presents the results of species identification during the study and classification into families and species.

Table A1. List of plant species by family

Family	Species	Family	Species
Asteraceae	*Baccharis buxifolia*	*Apiaceae*	*Azorella biloba*
(Compositae)	*Baccharis cassinaefolia*		*Conium maculata*
	Baccharis incarum		*Daucus montanus*
	Baccharis caespitosa	*Brassicaceae*	*Brassica campestris*
	Bidens andicola		*Lepidium chichicara*
	Bidens pilosa		*Roripa nasturtium*
	Gnaphalium americana	*Caryophyllaceae*	*Cardionema ramosissinum*
	Gnaphalium spicatum		*Paronchis andina*
	Gnaphalium chonoticus	*Cyperaceae*	*Carex* sp.
	Liabum uniflorum		*Scirpus rigida*
	Hypochoeris glabrata	*Geraniaceae*	*Geranium filipes*
	Werneria caespitosa		*Geranium cicutarius*
	Taraxacum officinale		
Fabaceae	*Astragaluz garbancillo*	*Juncaceae*	*Luzula peruviana*
	Apurimacia incarum		*Distichia muscoides*
	Ñupinus corilacensis	*Lamiaceae*	*Stachys herrerae*
	Lupinus micropyllus		*Stachys peruviana*
	Lupinus dicercophorus		*Salvia sarmentosa*
	(endemic)		*Salvia oppositiflora*

	Medicago hispida *Trifolium amabile* *Trifolium* sp. *Vicia graminea*
Poaceae (Gramineae)	*Aciachne pulvinata* Benth *Agrostis perennas* *Agrostis brevicaulis* *Andropogon sacharoides* *Aristida ascencionis* L. *Bouteoua simplex* *Bromus lanatus* *Bromus pitensis* *Calamagrostis anotniana* *Calamagrostis amoena* *Calamagrostis brevifolia* *Calamagrostis heterophylla* *Calamagrostis* sp. *Calamagrostis echinatus* *Calamagrostis vicunarum* *Calamagrostis rigescens* *Dissanthelium peruvianum* *Festuca dolichopylla* *Festuca tectoria* *Hordeum muticum* *Pennicetum clandestinum* *Poa annua* *Poa gilgiana* *Poa gymnantha* *Stipa* sp. *Stipa incospicua* *Muhlembergia peruviana*

	Mintostachys setosa *Mintostachys glabrescens* *Hedeoma mandoniana* *Lepechinia meyeni*
Loasaceae	*Loaza* sp. *Cajophora horrida* *Nasa limata* (endemic) *Nasa vargasii*
Myrtaceae	*Eugenia pycnantha*
Passifloraceae	*Passiflora gracilens* *Passiflora pinnatistipula*
Plantaginaceae	*Plantago hirtella* *Plantago monticola*
Peopleandean-aceae	*Gentianella bellidifolia* *Gentianella prostrata*
Polygonaceae	*Muehlembeckia volcanica*
Rosaceae	*Alcehmilla pinnata* *Fragaria* sp. *Margyricarpus pinnatus* *Alchemilla erodiifolia*
Rubiaceae	*Galium* sp.
Saxifragaceae	*Escalonia resinosa* *Escalonia myrtilloides* L. *Saxifraga magellanica*
Scrophulariaceae	*Calceolaria myriophylla* *Calceolaria englenaria* *Castilleja fissiofolia* *Veronica persica*
Valerianaceae	*Valeriana officinalis*

Faccha Sector (A)

Frequency of herbaceous vegetation. From 15 transects, 610 individuals were determined in five homogeneous zones. The results are shown in **Table A2**.

Table A2. Frequency of herbaceous species at Sector Faccha Zone A1

Herbaceous species	Frequency [%]
Festuca dolichophylla L.	15.8
Alchemilla pinnata L.	14.6
Poa annua	14.2
Carex sp.	13.8
Calamagrostis heterophylla	12.5
Agrostis brevicaulis	10.6
Andropogon saccharoides	10.0
Festuca tectoria	08.5
General Mean	16.1
Mean square*	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Frequency of the most valuable vegetation. Using 15 transects, 543 most valuable individuals were determined in five homogeneous zones at 3350−4200 masl − **Table A3**.

Table A3. Frequency of the most valuable herbaceous species at Sector Faccha Zone A2

Herbaceous species	Frequency [%]
Carex sp.	38.9
Alchemilla pinnata	30.9
Calamagrostis heterophylla	17.3
Werneria caespitosa	07.9
Festuca dolichophylla	
General Mean	16.1
Mean square*	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Frequency of intermediate herbaceous species in the Faccha sector. From15 transects in 5 homogeneous areas, 640 individuals were determined as the most frequent − **Table A4**.

Table A4. Frequency of intermediate herbaceous species at Sector Faccha Zone A3

Herbaceous species	Frequency [%]
Pennisetum clandestinum	38.4
Scyrpus rigidus	11.5
Agrostis brevicaulis	10.7
Luzula peruviana	10.2
Hypochoeris glabrata	10.1
Werneria caespitosa	19.1
General Mean	16.1
Mean square*	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Uspacocha Sector (B)

Frequency of herbaceous species in the Uspacocha sector. From 15 transects performed, 876 individuals were determined; the frequency of species is shown in **Table A5**.

Table A5. Frequency of herbaceous species at Sector Uspacocha Zone B1

Herbaceous species	Frequency [%]
Festuca dolichophylla	16.8
Alchemilla pinnata	12.6
Poa annua	09.2
Carex sp.	12.6
Calamagrostis heterophylla	06.5
Werneria caespitosa	20.1
Others	22.2
General Mean	16.1
Mean square*	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Frequency of the most valuable species in the Uspacocha sector. From 15 transects in 5 homogeneous zones, 876 individuals were the most abundant species − **Table A6**.

Table A6. Frequency of the most valuable herbaceous species at Sector Uspacocha Zone B2

Herbaceous species	Frequency [%]
Festuca dolichophylla	22.6
Carex sp.	17.0
Alchemilla pinnata	16.8
Poa annua	12.4
Others	31.2
General Mean	16.1
Mean square*	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Frequency of intermediate species in the Uspacocha sector. From 15 transects, 175 individuals in 5 homogeneous zones, the dominant species were as shown in **Table A7**.

Table A7. Frequency of intermediate herbaceous species at Sector Upacocha Zone B3

Herbaceous species	Frequency [%]
Scyrpus rigidus	29.3
Luzula peruviana	17.8
Hypericum caespitosum	14.9
Gnaphalñium apicatu	09.2
Hipochoeris glabrata	09.2
Others	19.6
General Mean	16.1
Mean square*	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Yanacocha Sector (C)

Frequency of herbaceous vegetation in the Yanacocha sector. From 9 transects, 539 individuals were evaluated in the homogeneous zone of Huillcacocha at 4300 masl – **Table A8**.

Table A8. Frequency of herbaceous species at Sector Yanacocha Zone C1

Herbaceous species	Frequency [%]
Alchemilla pinnata	17.4
Festuca dolichophylla	16.2
Calamagrostis heterophylla	15.5
Scirpus rigidus	13.2
Alchemilla achellaefolia	7.1
Luzula peruviana	6.9
Other	23.7
General Mean	16.1
Mean square*	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Frequency of the most valuable species in the Yanacocha sector. From 9 transects, 288 individuals were identified as the most dominant − **Table A9**.

Table A9. Frequency of the most valuable herbaceous species at Sector Yanacocha Zone C2

Herbaceous species	Frequency [%]
Alchemilla pinnata	32.6
Festuca dolichophylla	*26.4*
Alchemilla achellaefolia	13.2
Poa yearly	10.1
Tectoria fescue	10.0
Festuca tectoria	*7.0*
General Mean	16.1
Mean square	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Frequency of intermediate herbaceous species in the Yanacocha sector. From 9 transects, 194 individuals in 3 homogeneous zones were evaluated; species abundance − **Table A10**.

Table A10. Frequency of intermediate herbaceous species at Sector Yanacocha Zone C3

Herbaceous species	Frequency [%]
Scirpus rigidus	36.6
Luzula peruviana	19.1
Agrostis brevicaris	11.3
Scirpus rigidus	11.3
Calamagrostis brevifolia	11.7
Carex sp.	10.0
General Mean	16.1
Mean square	0.0012*
Fisher − Least significant difference (LSD)	15.0
*P-value	<0.06

Multivariate analyses

Two Principal Components Analyses (PCA) were performed to establish the relationships among herbaceous species with vegetation, soil, cover and frequency or abundance. The first considered Zone as a classification method, whereas biplot by Zone-Sector and vegetation, soil, cover, and abundance were taken as vectors − **Figure A1**. The second PCA considered herbaceous species as a classification method − **Figure A2**.

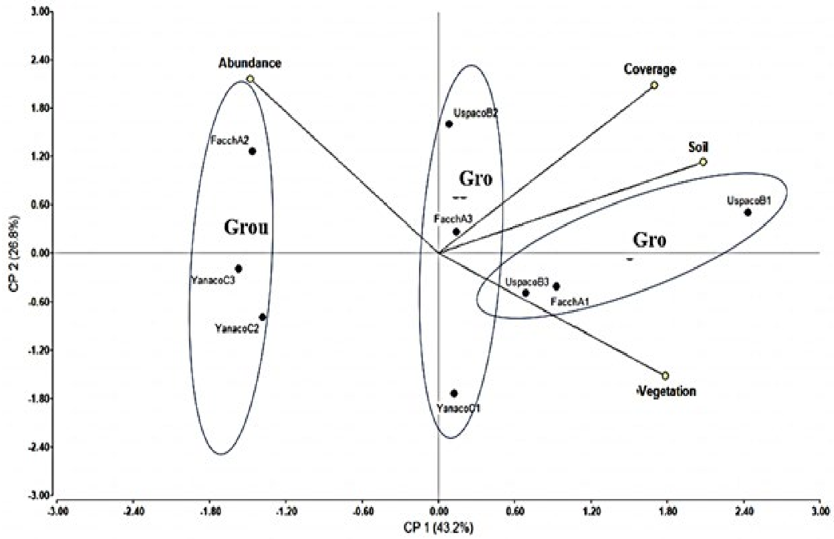


Figure A1. Principal components analysis of vegetation (scale), soil (scale), coverage [%] and abundance [%] by Zone-Sector

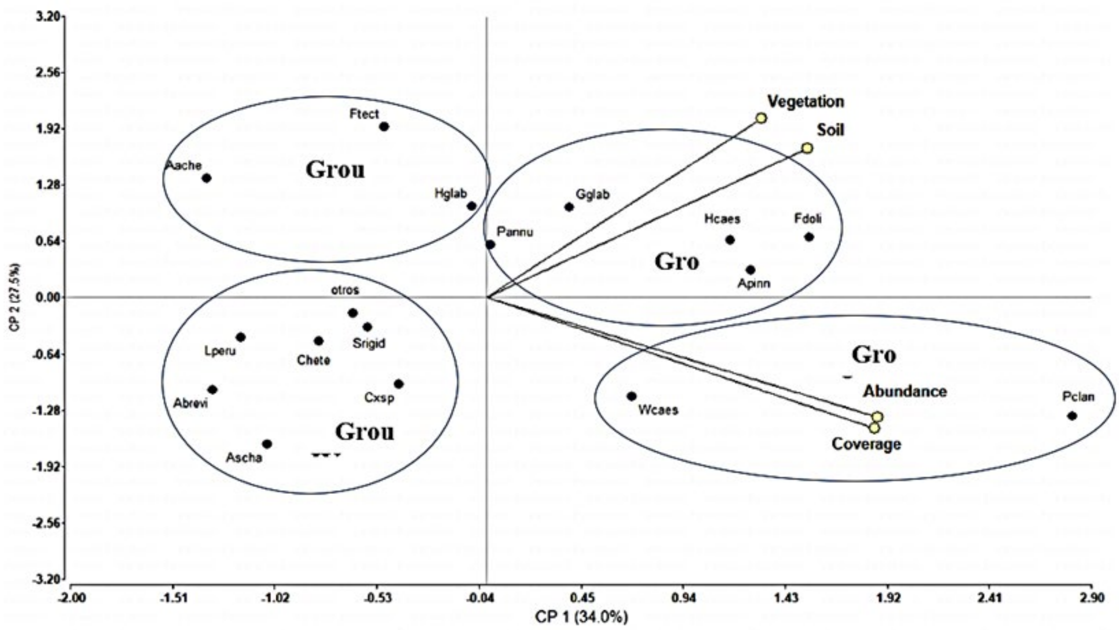


Figure A2. Principal components analysis of vegetation (scale), soil (scale), coverage [%] and abundance [%] by herbaceous species

Paper submitted: 13.11.2023
Paper revised: 03.04.2024
Paper accepted: 05.04.2024