Original Research Article

Composition, diversity, and value of ecological importance in Andean grassland ecosystems according to the altitudinal gradient in the Huacracocha micro-watershed, Peru

ABSTRACT

Aims: determine the composition and floristic diversity, the similarity between sites based on the distribution of species in the altitudinal gradient, and determine the value of ecological importance, in Andean grassland ecosystems.

Study design: Original research.

Place and Duration of Study: This study took place in the Huacracocha micro-watershed in the Central Highlands of Peru, during the rainy season (January - March 2022)

Methodology: The agrostological evaluation points were determined taking into account twelve sites of interest were determined, located from the lowest part of the micro-watershed (4091.8 masl) to the part with the highest vegetation cover (4512.27 masl), the agrostological reading process at each evaluation site was carried out using the radial transect method with the line and intercept point technique.

Results: We observed the presence of the presence of 78 vascular species, included in 51 genus and 21 families, was found. The dominance of certain species characterized the type of grassland vegetation, and at least 3 species determined the similarity between sites. The alpha diversity index was low, and the value of ecological importance ranged between 0.0062 and 0.2194.

Conclusion: It was concluded that the Andean grassland ecosystems are constituted by a complex community of grasslands based on numerous floristic families, genus, and species, likewise, the dominance of species among the shared sites characterizes the vegetation type, and the diversity index and the IVI determine the complex structural characteristics with great biodiversity.

***Key words**: Andean grassland, floristic composition, floristic diversity, ecological importance, site similarity*

1. INTRODUCTION

Andean grassland ecosystems maintain a peculiar floristic diversity made up of natural grass species that are differentiated according to the type of vegetation involved, such as: tussock grases, puna grass, wetlands, and others, etc. [1, 2]. These differences are characterized by soil variation, relief, altitude and microclimatic conditions. For such reasons, there are grassland species that are present in certain ranges of altitude or environmental conditions that are particularly appropriate for them [3]. Knowledge of the variation of floristic diversity is important because these interact with abiotic factors to condition the existence of diverse habitats favorable for fauna diversity, the provision of ecosystem services such as water regulation, soil erosion cover and control, carbon fixation and storage, shelter for fauna diversity, landscape beauty, and ecotourism [4,2], as well as the forage production service that constitutes the basis of livestock feeding for the vast majority of pastoral communities, being the only source of economic income that guarantees the survival and self-development of rural families. However, the tools to quantify the resilience of rangelands to disturbances, both in the short and long term, are still poorly developed [5].

In the framework of these considerations, the research was oriented to determine the floristic diversity of the Andean grassland and wetlands, based on the altitudinal gradient of a micro-watershed, taking into account that, the knowledge of the floristic composition helps to evaluate the plant diversity in a heterogeneous landscape, through the comparison of plant communities according to their species richness [6,7]; likewise, it allows establishing the inventory of life on Earth for the sustainable use of nature, protecting local knowledge and traditions, due to the fact that local or regional flora is always associated with some territory [8]. However, it is necessary to mention that the structure (stratification, density) of the vegetation responds to several abiotic factors such as: the incidence of solar radiation [9], the flow of precipitation within the community, the action of the wind and geographic isolation [10,4].

On the other hand, the importance value (IVI) is a parameter that measures the ecological value of each species applied to different plant communities. This parameter is obtained through the sum of three main parameters: dominance (cover or basal area), abundance, and frequency transformed into relative values [11]. In the case of grasslands, abundance is considered as an aspect of cover due to the difficulty of measuring density, in addition to the fact that the IVI can only be measured in two combinations [12].

With these criteria, it is affirmed that knowledge and evaluation of the structure and dynamics of grassland ecosystems are fundamental factors in determining the possibilities of utilization in production, conservation, or regulation, as well as in designing strategies that allow adequate management and conservation of their potential, thinking about the well-being of current and future populations [13]. In this framework, grassland ecosystems are the least studied in the topics of composition and floristic diversity compared to forests, even less when it comes to Andean grasslands and their territorial relationship [7], which highlights the scarcity of knowledge on these important issues for any territorial unit, indicating that there is still a lack of sufficient scientific basis to adequately design a sustainable management plan [6,8,2], so that conservation, restoration and improvement programs for grasslands in the Andean area can be implemented based on scientific information.

In Peru, there are few studies related to the subject in the last 10 years, such as [7] in Junín found 103 species in 52 genus and 22 families with H' between 2.75 and 3.41, [14] who in Moquegua found 210 vascular species 131 genus in 52 families, [15]found H' Diversity value between 1.511 to 2.822 and [16] in Junín found 43 species included in 15 families with H' ranging from 2.1891 to 2.4706, de [17] in Huaraz found 112 species in 29 families.

In this context, the study reflects the need to determine the composition and floristic diversity, the similarity between sites based on the distribution of species in the altitudinal gradient, and determine the value of ecological importance, in Andean grassland ecosystems of a micro-watershed of the central Andes of Peru, located between 4000 and 5600 meters above sea level, through agrostological evaluation in 12 sites determined.

2. MATERIAL AND METHODS

2.1 Study area

The research was conducted in the Huacracocha micro-watershed during the rainy season (January - March 2022), which is located on the eastern side of the Mantaro Valley and the city of Huancayo in the central region of Peru. The micro-watershed is characterized by the presence of Andean geasslands and wetland ecosystems located between 4000 and 5600 meters above sea level (Fig. 1), whose vegetation cover is exclusively natural grasses, which is why it constitutes the food base for Andean livestock, managed by pastoral families through the mixed breeding of cattle, sheep, and andean camelids. The vegetation cover is made up of a highly diversified floristic community with species that vary in structure and function, from cushion species (*Distichia muscoides, Plantago rígida, Aciachne pulvinata*) to tussock species (*Festuca rigiscens, Jarava ichu, Calamagrostis rígida*), as shown in Fig. 2.

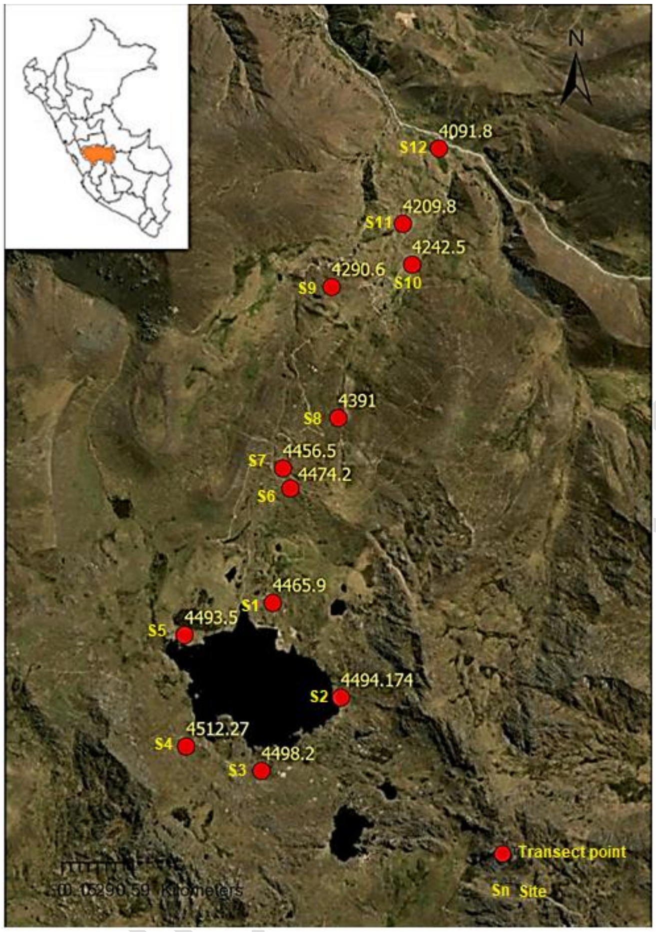

Fig. 1. Location map of the Huacracocha micro-watershed, showing the evaluation sites and corresponding altitudes.

Fig. 2. Headwaters of the Huacracocha micro-watershed

This scenario is the main source of water for human consumption and agricultural irrigation for the cities of Huancayo, Tambo and Chilca located on the southern side of the Mantaro Valley. In this environment, the average seasonal temperature varies from -8°C during the early morning to 16.2 °C during the day in the dry period (May to September) and from 4 °C to 12 °C during the rainy period (October to April) and the average daily seasonal rainfall is 0.56 mm and 2.88 mm, respectively, which accumulates an annual average of 1170 mm, according to data recorded by the Acopalca Meteorological Station of the Peruvian National Hydrology and Meteorology Service (Servicio Nacional de Hidrología y Meteorología del Perú).

2.2 Data collection

2.2.1 Determination of evaluation points

The agrostological evaluation points were determined taking into account the vegetation cover of interest in the landscape scenario, looking for representative areas in the altitudinal gradient. Twelve points of interest were determined, located from the lowest part of the micro-watershed (4091.8 masl) to the part with the highest vegetation cover (4512.27 masl), below the line of rocky areas with scarce cover (Fig 1). The altitude and magnetic north were determined using a Garmin 62CSX GPS.

2.2.2 Agrostological evaluation

Previously, samples of taxa were collected from all the determined points and taken to the laboratory of the "Andean Ecosystem" research group of the Universidad Nacional del Centro del Perú, for the corresponding identification. The agrostological reading process at each evaluation site was carried out using the radial transect method with the line and intercept point technique (Mostacedo and Fredericksen 2000). The implementation of the process consisted of, first, determining the radial centroid, second, locating the first linear transect of 30 linear meters in the direction of magnetic North, followed by the other two transects separated at approximate angles of 120° with equal distance. Secondly, we proceeded with the reading of each transect, recording data corresponding to, the species present, mulch, bare soil, rock and water, as appropriate at each intercept point. These points corresponded to each 1-meter (100 cm) linear mark determined by a 100-meter-long fabric winch.

2.2.3 Data analysis

The data obtained in the agrostological evaluation were organized in an Excel spreadsheet, in which data reduction and appropriate ordering was performed to submit them to the richness analysis (number of species) for each evaluation point, which was called a "site" [18,19], as well as the number of species according to genus and the number of genus according to families. The agrostological data were also arranged in a double-entry matrix (sites in rows and species in columns) to generate graphs of the abundance of species in the micro-watershed and of genus for each site.

A distance correlation analysis was used using the free software Rstudio vs 4.2.3, using the "vegan" library and the "vegdist" function, applying the "Euclidean" method for its higher performance in the analysis of ecological data; while the cluster analysis was performed using the "hclust" function and the "average" method to strengthen the analysis of similarity between sites according to the presence of species [20].

The Shannon Wiener diversity index (H'), was calculated for each evaluation site by applying equation 1 below [21]:

$$H' = - \sum pi \ln(pi) \quad (E\text{-}1)$$

Where: pi is the proportion of the number of individuals of species i with respect to the total number of individuals, and ln(pi) is the logarithm of pi.

The value of ecological importance was calculated from the abundance matrix, on which the abundance and relative frequency were generated for the participating species at each site, using equations 2, 3, and 4 below:

$$Ar = (Ni/Nt) * 100 \quad (E\text{-}2)$$
$$Fr = (a/A) * 100 \quad (E\text{-}3)$$
$$IVI = Ar + Fr \quad (E\text{-}4)$$

Where: Ar is the relative abundance, Ni is the abundance of species i, Nt is the total abundance of all individuals; Fr is the relative frequency, a is the number of occurrences of a species, and A is the total occurrences of all species. The IVI is the sum of the two referred attributes.

3. RESULTS AND DISCUSSION

3.1 Richness of the Andean grassland ecosystem

Among the 12 sites evaluated, 77 vascular species included in 51 genus and 21 families were found, of which site 11, located at 4209.8 masl, showed the highest number of genus (24) and species (27), followed by site 5, at 4493.5 masl, which showed 18 genus and 25 species; these sites were apparently grazed with a higher animal load. Likewise, the sites with lower richness were site 1, located at 4465.9 masl, with 11 genus and 15 species; and site 12, at 4091.8 masl with 12 genus and 13 species, both sites correspond to spaces flooded at least during the rainy season (Table 1, Fig. 1).

Table 1.Distribution of the number of genera, species, and abundance of individuals in each evaluation site.

Descriptor	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Genus	11	15	14	15	18	14	14	12	16	13	24	12
Species	15	17	16	18	25	21	16	15	17	15	27	13
Abundance	20	59	77	70	79	79	80	64	60	74	73	70

The abundance of individuals according to species showed the curve that characterizes the dominance of species, in this sense, it was the genus Calamagrostis that reached the highest abundance with 208 individuals (relative abundance of 0.2476) based on the main participation of *Calamagrostis curvula* and *C. rigida*; in second place, the participation of the genus Festuca was observed with 119 individuals (relative abundance of 0.1476) of the species *Festuca rigescens*, then the genus Plantago with 114 individuals (relative abundance of 0.1357) with the main participation of the species *Plantago rigida* and *P. tubolosa*. 1476) of the species *Festuca rigescens*, then the genus Plantago with 114 individuals (relative abundance of 0.1357) with the main participation of the species *Plantago rigida* and *P. tubolosa*, also the participation of the species *Carex ecuadorica* was important, with 59 individuals, from this a block of genus participate with 10 to 37 individuals in descending order: Azorella, Hypochaeris, Werneria, Lachemilla, Aciachne, Poa, Cotula and Gentiana; the others oscillate with participation of 1 to 10 individuals, configuring the characteristic of rare species (Fig. 3).

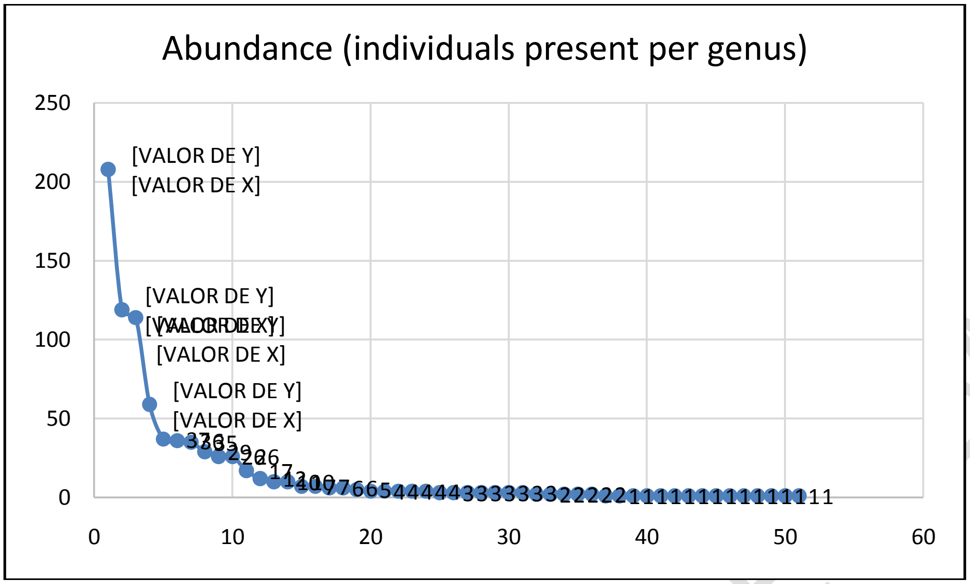

Fig. 3. Abundance of individuals according to genera observed in the Hucracocha micro-watershed.

The floristic richness of Andean grassland ecosystems is highly variable in small spaces, due to the heterogeneity of relief and altitude, which in turn condition the variation of soils and microclimate [7,6,2], for these reasons the variation in richness among sites (Table 1) depended on among other factors: by grazing effect [3], microclimate characteristic and soil type [22]; however, the effect of non-destructive grazing avoided the monopoly of access to incoming solar radiation in the area, by some taller or dominant species such as the presence in the study area of *Festuca rigescens* or *Calamagrostis rigida*, whose morphological structure of wide coverage becomes a limiting factor to the photosynthetic activity and reproduction of the most vulnerable species or of lower growth as is the case of *Poa candamoana, Lachemilla pinnata* both of great forage interest [23,24,25], thus in sites 11 and 5 the presence of a greater number of species was visible [8,10]. The lower richness in genus and species observed at site 01 was due to the quality of the surface and eroded soil of the site, which determined the presence of rustic species such as *Plantago rigida* and *Aciachne pulvinata*, which are also indicative of advanced degradation of the grassland; while site 12 corresponds to a flooded area with wetland characteristics, evidenced by the dominance of semiaquatic species such as *Plantago tubulosa* and *Calamagrostis curvula*[1], generally wetlands have little floristic diversity because the cushion species tend to occupy notable spaces due to their horizontal and very compact development [26]. The proximity of species and genus richness between C2 - S4 and S6 corresponds to the characteristic of shallow soil with a depth less than 25 cm [27] of low agronomic quality [28] in environmental conditions typical of the Anadine mountain range [30], on which *Festuca rigescens* thrives in combination with other medium-sized species such as *Calamagrostis vicunarum*[24,2]. Respect to the studies conducted in Peruvian conditions, the richness found among genus and families with the most abundant species are very similar, due to the similar altitude range in Andean Mountain range conditions [7]; however, the variation in the number of species is a function of the amplitude of the space evaluated [1] and the inclusion of shrubs [14]. On the other hand, the genus Calamagrostis (Fig. 3) showed a greater presence based on the amplitude of distribution along the altitudinal gradient, due to its high tolerance to soil type, moisture saturation, morphological characteristics adapted to survive in extreme conditions of temperature and dry periods, these characteristics are shared with the genus

Festuca which was the second most important [30]; meanwhile, the genus Plantago coexists in two environments, first the species *P. rígida* coexists with species adapted to dry or low humidity soils and the species *P. tubulosa* shares with semiaquatic species adapted to wetland conditions; likewise, the species *Carex ecuadorica* showed preference to dry or moderately saturated shallow soils [17,20].

3.2 Similarity between sites based on species presence.

In the analysis of ecological similarity among the 12 evaluation sites, there were 5 similar groups (Fig. 4), in which sites 1 and 3 were similar based on the participation of the species *Carex ecuadorica, Calamagrostis curvula* and *Aciachne pulvinata*, sites 6 and 7 by the participation of *Plantago rígida, Calamagrostis curvula* and *Plantago tubulosa*; sites 5 and 10 by the common presence of *Festuca rigescens, Carex ecuadorica* and *C. vicunarum*; sites 4 and 11 by the common presence of *C. vicunarum, F. rigescens* and *P. tubulosa*; sites 2 and 4 with the common presence of *F. rigescens, P. tubulosa* and *Acaulimalva crenata* species.

Table 2. **Common natural grass species that characterize the similarity between sites.**

Similar sites	Common species		
S3 - S1	Caec,	Cacu	Acpu
S7 - S6	Plari	Cacu	Platu
S10 - S5	Feri	Caec	Cavi
S11 - S4	Cavi	Feri	Platu
S2 - S4	Feri	Caec	Acacre
S2 - S1	Caec,	Acpu	Plari
S3 - S2	Cacu	Caec	Wenu
S8 - S4	Feri	Platu	Caec
S11 - S8	Feri	Platu	Come
S12 - S8	Platu	Feri	Come

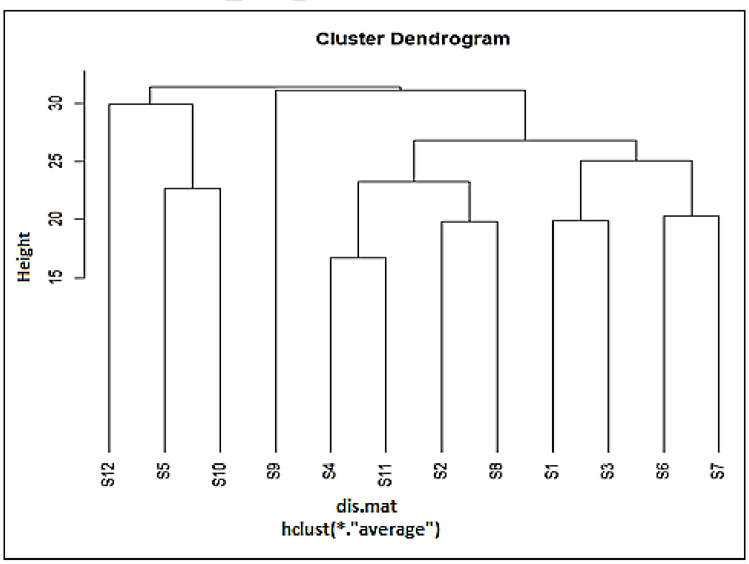

Fig. 4.Cluster showing the similarity between sites based on the common presence of certain natural grass species.

The distance correlation table showed, in addition to those mentioned above, the similarity between sites 1 and 2 due to the common presence of the species *C. ecuadorica, A. pulvinata* and *P. rígida*; sites 2 and 3 due to the presence of *C. curvula, C. ecuadorica* and *Werneria nubigena*; sites 4 and 8 due to the presence of *F. rigescens, P. tubulosa* and *C. ecuadorica*; sites 8 and 11 for the common presence of *F. rigescens, P. tubulosa* and *Cotula mexicana*, and finally the similarity of sites 8 and 12 for the common participation of the species *P. tubulosa, F. rigescens* and *C. mexicana* (Table 4 in appendix), which indicates that the correlation analysis was more tolerant than the cluster analysis.

Of the most common species, *Festuca rigescens* and *Carex ecuadorica* showed common presence in 06 pairs of similar sites, which means their wide altitudinal distribution, then the species *Plantago tubulosa* in 04 pairs of similar sites, *Aciachne pulvinata* in 03, *Calamagrostis curvula* and *Cotula mexicana* in 02 and *Calamagrostis vicunarum, Plantago rigida, Acaulimalva crenata* and *Werneria nubigena* only in 01 pair of similar sites.

The similarity between evaluated sites based on the presence of natural grass species over different altitudes evidenced the heterogeneity of the plant community in the evaluated area (Table 2), showing different vegetation associations based on some species that interact with each other, amid the local or regional, climatic, topographic, and edaphic gradient [31], determining that the physiognomic and floristic types respond differently to the elevation gradient [32]. The first observed similarity (Fig. 4) characterizes the puna grass vegetation type, by the medium size of the species *Carex ecuadorica* and *Calamagrostis curvula*, and the cushiony morphology of *Aciachne pulvinata* (Mamani *et al*. 2013; Yaranga *et al*. 2018) the second association characterizes humid or temporarily flooded sites by the presence of *Plantago tubulosa*[17,1]; while the third similarity, characterizes a type of grassland vegetation by the presence of *Festuca rigescens* and *Carex ecuadorica* that develop on deep and fertile soils. These same conditions are replicated in the fifth association. Additional similarities resulting from distance correlation confirm that sites S1 to S3 located at higher altitudes correspond to puna grass vegetation, and sites S5 to S12 located on medium and low altitude gradients correspond to wetland vegetation, always in the presence of F. rigescens, which confirms the conclusion of [32] that, floristic types are positively associated with more than one physiognomic type of vegetation.

3.3 Diversity index H'

The Shannon Wiener diversity index ranged from 1.99 to 2.87, which according to the classification range (0.1 to 2.9) is at the low diversity level (Fig. 5). In addition, no relationship was observed between the H' index and species richness at each evaluation site.

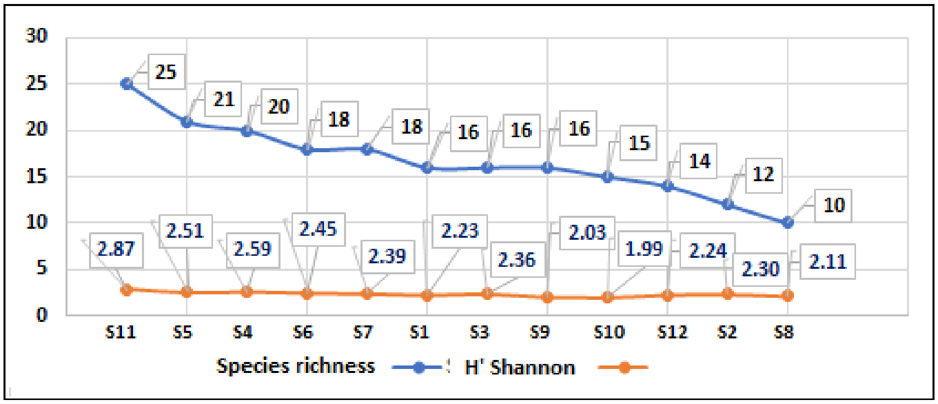

Fig. 5: Shannon Wiener diversity index (H') of the 12 agrostological evaluation sites, in relation to species abundance.

The Shannon Wiener diversity index is the most widely used to measure local diversity, preferably for the proposal of resource management and ecological conservation measures [33], due to the predominant feedback characteristic between plant and soil, which is considered one of the main drivers of species coexistence in highly dynamic and low diversity communities, as is the case of the present study [5,34]. The diversity index H' measures entropy, understood as the degree of uncertainty in the identity of the species to which a randomly selected individual belongs; therefore, grassland communities where all species have heterogeneous abundance with the presence of only 2 or 3 dominant species have high entropy, which translates into a low diversity index, contrary to plant communities that would have species with similar abundance to have high diversity [33]. This approach is confirmed by not obtaining any relationship between the relationship of richness and the diversity index H'. With respect to studies conducted in Peru the H' index resulted similar [15,16].

3.4 Ecological importance value of species

The highest value of importance in the ecosystem (Fig. 6) corresponds to the species *Festuca rigescens* with an ecological index of 0.2190 that characterizes the vegetation type wetland, together with the participation of *Carex ecuadorica* with 0. 1171, followed by a group of 05 species with values ranging from 0.0806 to 0.1055 such as: *Plantago tubulosa, P. rigida, Calamagrostis curvula, C. vicunarum, C. tarmensis*, followed by 11 other species before the significant break of lower values, such as: *Lachemilla pinnata, C. rigida, Acaulimalva crenata, Cotula mexicana, Aciachne pulvinata, Hypochaeris taraxacoides, Werneria nubigena, Hypochaeris sessiliflora, Poa candamoana, Distichia muscoides* and *Gentiana incurva*, with values ranging from 0. 0324 to 0.0734, and the importance values of the remaining 58 species were summed in a single block called rare species, with values ranging from 0.0062 to 0.0033.

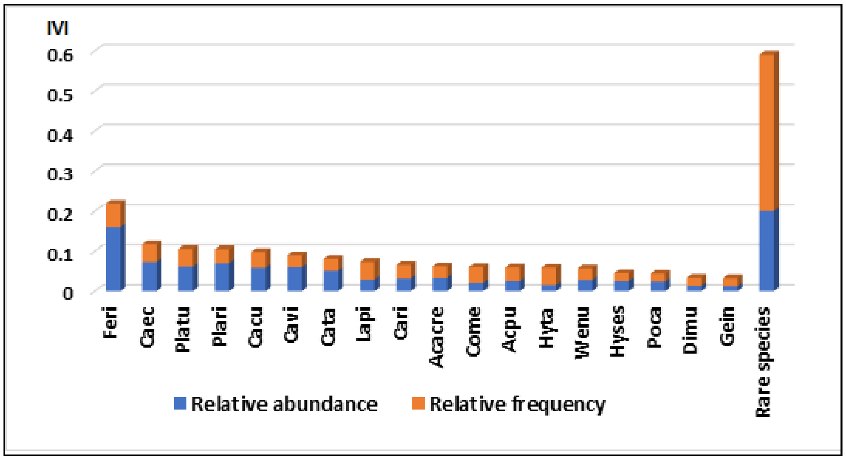

Fig. 6: Ecological importance value of the first 19 most abundant species. The 56 less dominant species were accumulated as rare species.

The ecological importance of the species has a very important meaning in the management of sustainable development, since the greater the floristic diversity in the ecosystem, the more resilient it will be. From this point of view, the ecological importance of native species is fundamental for the sustainability of the ecosystem [12,13]. According to Fig. 6, the value of ecological importance of the 6 most important species is supported by abundance rather than frequency of participation in the evaluated sites, which demonstrates the complex spatial distribution in the ecosystem beyond the altitudinal gradient [13], however, in the following species, the IVI rationale is reversed; that is, the frequency of participation in the 12 evaluated sites gains greater preponderance, which tells us that the species have participation in most of the sites but with lower abundance as rare species [35]. This behavior occurs due to the heterogeneity of the ecosystem with high biodiversity in which, a few species are dominant that characterize the vegetation type [35,12,36] in spite of the participation of many species.

4. CONCLUSION

Andean grassland ecosystems are constituted by a complex community of grasslands based on numerous floristic families, genus, and species, whose dominance among shared sites characterizes the vegetation type. Some low or cushion species showed a preference for site conditions (flooding, soils, grazing regime), while larger species such as *Festuca rigescens* showed no preference for altitudinal gradient or grazing regime, except for the condition of deep soils; this scenario configured the Huacracocha micro-watershed to have the characteristic of tussock grasses, with very few spaces of puna grass. The low Shannon Wiener diversity index based on entropy and the IVI confirm that only a few species are dominant, leaving the great majority in the condition of rare species, which become of special interest to generate ecosystem conservation plans aimed at maintaining their specific richness and sustainability.

REFERENCES

1. Yaranga R. High Andean Wetland of Peru: Floristic diversity, aerial net primary productivity, ecological condition and carrying capacity. Agricultural Science 2020;1(2): 213-221. https://doi.org/10.17268/agriculturalscience.2020.02.08
2. Cabrera-Amaya DM. Richness, floristic composition and structure of wild vegetation in the rural area of the basins of the Yomasa and Fucha creeks, Bogota, Colombia. Journal of the Colombian Academy of Exact, Physical and Natural Sciences, 2021;45(176), 761-776
3. Kaufmann I, Fieldman S and Sacido M. Effects of grazing on floristic richness, biomass and cover of a safflower pastureland, Argentina. Polytechnic Journal (Print Online), 2019;15(29): 95-107. DOI: 10.33571/rpolitec.v15n29a8.
4. Benítez B, M Vera, C Vogt, CP Sühsner, & ... Floristic diversity in pastures of the Reserve for San Rafael National Park, Paraguay. Scientificjournals.un., 2021. https://scientific.journals.un.index.php/stevia/article/view/2
5. Bellocchi G. & C Picon-Cochard. Effects of Climate Change on Grassland Biodiversity and Productivity. Agronomy, 2021;11(6), 1047;
6. Sardi A, AM Towers & G Broker. Floristic diversity in a rural landscape of the Cali Farallones piedmont, Colombia. Forest Colombia, sky.org.co,2018; http://www.sky.org.co/sky.php?script=sci_arttext&pid=S0120-07392018000200142
7. Yaranga R, Custodio M, Chaname F, & Floristic diversity of pastures according to vegetation formation in the Shullcas River subbasin, Junín, Peru. Scientia ..., 2018;9(4):511-5 DOI: 10.17268/agriculturalscience.2018.04.06

[PubMed] 8. Davydov, DA, & Gomlya, LM. Floristic diversity of steppe territories near Poltava town (Ukraine). Biosystems Diversity, 2020;28(1), 81-91, ISSN 2520-2529, Oles Honchar Dnipropetrovsk National University, https://doi.org/10.15421/012012

9. Ullah H, Mulk KS, Mariusz J, Ullah SZ, Ali I, Ahmad Z and Badshah H. Scientific Reports, 2022;12(1): 20973. https://doi.org/10.1038/s41598-022-21097-4
10. Baeza S, Paruel J & Ayala W. Radiation use efficiency and primary productivity in forage resources of eastern Uruguay. Agroscience Uruguay, 2011; 15(2), 48–59. http://www.sky.edu.uy/sky.php?script=sci_arttext&pid=S2301-15482011000200006&lng=pt&tlng=en
11. Ministry of Environment MINAM. Wild flora assessment guide. Deputy Ministry of Strategic Development of Natural Resources, 2010; Lima, pp:
12. Mustard F. and T Fredericksen. Handbook of basic methods of sampling and analysis in plant ecology. Sustainable forest management project (BOLFOR), Santa Cruz Bolivia, 2000; pp : 87
13. Petermann J. & O Buzhdygan. Grassland biodiversity. *Current Biology*, 2021; 31(19): r1195-r1201. https://doi.org/10.1016/j.cub.2021.06.060
14. Montesinos-Tubee DB, Sýkora KV, Quipuscoa-Silvestre V and, Cleef AM. Species composition and phytosociology of xerophytic plant communities after extreme rainfall in South Peru, *Phytocoenologia*2021;45 (3), 203-250.

15 Catorci A, Velasquez J, Maltesta L, and Tardella F. How environment and grazing influence floristic composition of dry Puna in the southern Peruvian Andes. Phytocoenologia 201;44(1-2): DOI: 10.1127/0340-269X/2014/0044-0577

16 Fernán Cosme Chanamé-Zapata; María Custodio-Villanueva; Raúl Marino Yaranga-Cano; Rafael Antonio Pantoja-EsquivelChamame et al. Diversity of the riparian

vegetation of high Andean wetlands of the Junín region, Peru. Ambiente & Agua. 2019;. 14(3): e2271. https://doi.org/10.4136/ambi-agua.2271
17 Polk MH, Young KR, Cano A, León B & Peat. Vegetation of Andean wetlands (bofedales) in Huascarán National Park, Peru. Mires and Peat, Volume 2019; 24(1): 1–26. DOI: 10.19189/MaP.2018.SNPG.387
18 Magurran, A. E. Measuring biological diversity. *Current Biology*, 2021;*31*(19), R1174-R1177.
19 Henderson PA. Species Richness, Diversity, and Packing. *Southwood's Ecological Methods*, 2021; 384-429, Oxford University Press, https://doi.org/10.1093/oso/9780198862277.003.0013
20 Oksanen J, F Guillaume, M Friendly, R Kindt, P Legendre, D McGlinn, P Minchin, R O'Hara, GL Simpson, P Solymos, M Henry, R Stevens, E Szoecs, and H Wagner. Community Ecology Package. Ordination methods, diversity analysis and other functions for community and vegetation ecologists. 2020; repository CRAN. https://cran.r-project.org, https://github.com/vegandevs/vegan
21 Ferriol, M., & H Merle. Los componentes alfa, beta y gamma de la biodiversidad. Aplicación al estudio de comunidades vegetales. *Grupo Intergubernamental De Expertos Sobre El Cambio Climático*, 2013; *26*(6), 236. https://doi.org/10.1073/pnas.262413599
22 Tiscornia G, M Juarena and W Baethgen. Drivers, Process, and Consequences of Native Grassland Degradation: Insights from a Literature Review and a Survey in Río de la Plata Grasslands. *Agronomy.*2019; (9) 239; doi:10.3390/agronomy9050239
23 Guo Tong . Grazing Exclusion Effects on the Relationship between Species Richness and Vegetation Cover in Mongolian Grasslands. *Polish Journal of Ecology*, 2020; *68*(3), ISSN 1505-2249, Museum and Institute of Zoology at the Polish Academy of Sciences, https://doi.org/10.3161/15052249pje2020.68.3.003
24 Zhao Y & Y Tian. *Effect of grazing on photosynthetic carbon allocation in a temperate grassland*., Copernicus GmbH, 2020;https://doi.org/10.5194/egusphere-egu2020-6814
25 Bonavent C, K Olsen, R Ejrnæs, C Fløjgaard, MD Hansen, S Normand, JC Svenning & HH Bruun. *Grazing by semi-feral cattle and horses supports plant species richness and uniqueness in grasslands*., Authorea, Inc., 2022; https://doi.org/10.22541/au.166723085.56550911/v1
26 Grasel D, ELH Giehl, F Wittmann & J Jarenkow. Patrones de diversidad y composición de plantas en humedales a lo largo de un paisaje subtropical: comparaciones entre estanques, riberas de arroyos y riberas de ríos. Wetlandss 2021; 41, 90 . https://doi.org/10.1007/s13157-021-01487-6
27 Lynch JP. Edaphic stress interactions: Important yet poorly understood drivers of plant production in future climates. Field Crops Research, 2022; 283, 108547.
28 Magurran, Anne e. Measuring biological diversity. Blackwell Publiching Company, 2005; pp: 70. https://doi.org/10.1016/j.fcr.2022.108547
29 Mosquera VB, JA Delgado, JR Alwang, LE López, YC Ayala, JD Andrade & R D'Adamo. Conservation agriculture increases yields and economic returns of potato, forage, and grain systems of the Andes. *Agronomy Journal*, 2019; *111*(6), 2747-2753. https://doi.org/10.2134/agronj2019.04.0280.
30 Tovar O. Las gramíneas (Poaceae) del Perú. RUIZIA, 1993; tomo 13, Madrid, pp: 481
31 Navarro G, F Luebert & JA Molina.*South American terrestrial biomes as geocomplexes: a geobotanical landscape approach. Vegetation Classification and Survey.2023; 4: 75-114. https://doi.org/10.3897/VCS.96710.*, Pensoft Publishers, https://doi.org/10.3897/vcs.96710.figure4
32 Giorgis M, A Cincolani and D Gurvich. Changes in floristic composition and physiognomy are decoupled along elevation gradients in central Argentina, *Applied Vegetation Science*, 2017; 20(4), 558-571. https://doi.org/10.1111/avsc.12324

33 Moreno C, F Barrgan, E Pineda y N Pavon. Reanálisis de la diversidad alfa: alternativas para interpretar y comparar información sobre comunidades ecológicas. Revista Mexicana de Biodiversidad, 2011; 82: 1249-1261.
34 Kuťáková E, L Mészárošová, P Baldrian, Z Münzbergová & T Herben. *Author response for "Plant–soil feedbacks in a diverse grassland: Soil remembers, but not too much"*., Wiley. 2023;https://doi.org/10.1111/1365-2745.14104/v3/response1
35 Rodrigo-Comino 2019
36 Henderson PA. Species Richness, Diversity, and Packing. *Southwood's Ecological Methods*, 2021; 384-429, Oxford University Press, https://doi.org/10.1093/oso/9780198862277.003.0013

APPENDIX

Table 3. Floristic richness of the Huacracocha micro-watershed, expressed in species according to genus and family.

Family	Genus	Specie
Apiaceae	Azorella	*Azorella diapensioides*
		Azorella crenata
Apiaceae	Eringeum	*Eringeum humile*
Apiaceae	Oreomyrrhis	*Oreomyrrhis andicola*
Asteraceae	Hypochaeris	*Hypochaeris taraxacoides*
		Hypochaeris sessiliflora
		Hypochoeris echegarayi
Asteraceae	Werneria	*Werneria nubigena*
		Werneria pygmaea
		Werneria candamoana
		Werneria lamprophylla
Asteraceae	Cotula	*Cotula mexicana*
Asteraceae	Paranephelius	*Paranephelius ovatus*
		Paranephelius bullatus
Asteraceae	Lucilia	*Lucilia conoidea*
Asteraceae	Baccharis	*Baccharis caespitosa*
Asteraceae	Bidens	*Bidens andicola*
Asteraceae	Gnaphalium	*Gnaphalium supinum*
Asteraceae	Taraxacum	*Taraxacum sessiliflora*
		Taraxacum officinale
Asteraceae	Novenia	*Novenia acaulis*
Asteraceae	Aphanactis	*Aphanactis villosa*
Asteraceae	Erigeron	*Erigeron pygmaeus*
Asteraceae	Senecio	*Senecio rhyzomatosus*
Cariophyllaceae	Cerastium	*Cerastium uniflorum*
Cariophyllaceae	Arenaria	*Arenaria crasipes*
Cyperaceae	Carex	*Carex ecuadorica*
Cyperaceae	Cyperus	*Cyperus sculentus*

Cyperaceae	Scirpus	*Scirpus rigidus*
Euphorbiaceae	Euphorbia	*Euphorbia huanchahana*
Fabaceae	Trifolium	*Trifolium amabili*
		Trifolium repens
Fabaceae	Astragalus	*Astragalus peruvianus*
Fabaceae	Vicia	*Vicia andicola*
Gentianaceae	Gentiana	*Gentiana incurva*
		Gentiana prostrata
Gentianaceae	Halenia	*Halenia umbellata*
Geraniaceae	Geranium	*Geranium sessiliflorum*
Icmadophilaceae	Tamnolia	*Tamnolia vermicularis*
Juncaceae	Distichia	*Distichia muscoide*
Juncaceae	Luzula	*Luzula racemosa*
Malvaceae	Acaulimalva	*Acaulimalva crenata*
Onagraceae	Oenothera	*Oenothera multicaulis*
Orchidaceae	Myrosmodes	*Myrosmodes paludosum*
Oxalidaceae	Oxalis	*Oxalis debilis corymbosa*
Plantaginaceae	Plantago	*Plantago rigida*
		Plantago tubulosa
		Plantago australis
Poaceae	Calamagrostis	*Calamagrostis curvula*
		Calamagrostis rigida
		Calamagrostis tarmensis
		Calamagrostis vicunarum
		Calamagrostis sp
		Calamagrostis heterophylla
Poaceae	Festuca	*Festuca rigescens*
		Festuca humilior
		Festuca dolychophylla
Poaceae	Aciachne	*Aciachne pulvinada*
Poaceae	Poa	*Poa candamoana*
		Poa perligulata
Poaceae	Nassella	*Nassela mucronata*
		Nasella brachyphylla
Poaceae	Muhlenbergia	*Muhlenbergia andina*
Poaceae	Bromus	*Bromus pitensis*
Poaceae	Jarava	*Jarava ichu*
Polygonaceae	Muehlenbeckia	*Muehlenbeckia vulcanica*
Polygonaceae	Rumex	*Rumex acetocella*
Pontederiaceae	Eichhornia	*Eichhornia diversifolia*
		Eichhornia sp

Ranunculaceae	Oreithales	*Oreithales integrifolia*
Ranunculaceae	Ranunculus	*Ranunculus praemorsus*
Rosaceae	Lachemilla	*Lachemilla procumbens*
		Lachemilla pinnata
		Lachemilla diplophylla
Violaceae	Viola	*Viola pygmaea*

Table 4. Correlation matrix according to the Euclidean distance method.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S2	**22.02**										
S3	**19.90**	**22.43**									
S4	30.94	25.77	29.48								
S5	29.27	29.46	31.19	26.12							
S6	21.73	26.25	26.00	23.30	27.77						
S7	27.15	23.71	25.55	31.18	36.50	**20.32**					
S8	23.96	**19.82**	26.15	**22.29**	24.39	21.73	28.97				
S9	33.94	28.55	33.05	30.08	30.55	33.70	35.28	24.66			
S10	37.72	36.28	39.59	27.31	**22.72**	34.10	43.20	28.90	31.16		
S11	30.59	25.94	31.94	**16.70**	28.51	24.33	32.48	**19.13**	29.83	28.76	
S12	35.14	31.91	34.34	26.27	28.11	28.51	36.66	**22.25**	33.78	31.72	28.69

NOTE: The figures in red were identified by the dendrogram and those in bold were also identified by the distance correlation matrix.