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Movement of *Vicugna vicugna* to Sandy areas in response to competition for food resources and habitat disturbance

Movimiento de *Vicugna vicugna* hacia áreas arenosas en respuesta a la competencia por recursos alimenticios y la alteración del hábitat

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Abstract

The research on the population dynamics of vicuñas in three habitats within the regions of Puno and Moquegua aimed to: a) Quantify the population fluctuation of vicuñas and flora diversity in the Sandy, Wetlands, and Grasslands habitats. b) Estimate the population density of vicuñas and flora biomass in the Sandy, Wetlands, and Grasslands habitats. To conduct this investigation, linear transect methodology was employed, utilizing the Hayne estimator for each mentioned habitat and random quadrants. The results revealed a trend towards an increase in the number of individuals and family groups in the Sandy dune habitat, while lower values were recorded in the Wetlands and Grasslands habitats. However, it is worth noting that population density was higher in the Wetlands habitat, with a value of 0.699 indiv/ha, followed by the Sandy habitat with 0.275 indiv/ha, and the Grassland with 0.163 indiv/ha. Additionally, a higher number of females than males were observed,

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with groups of up to 34 male individuals forming herds. Furthermore, the Sandy habitat exhibited lower flora diversity and biomass (1653.89 kg), whereas greater flora diversity and biomass were recorded in the Wetlands (24773.76 kg), and the Grasslands calculated at 25524.48 kg. These findings provide valuable information regarding the population dynamics of vicuñas, flora diversity, and biomass in the analyzed habitats, crucial for their conservation and proper management in the regions of Puno and Moquegua.

Keywords: Grassland, Habitat, Sandy, Vicuña, Wetland.

Resumen

La investigación sobre la dinámica poblacional de vicuñas en tres hábitats dentro de las regiones de Puno y Moquegua tuvo como objetivo: a) Cuantificar la fluctuación poblacional de vicuñas y la diversidad de flora en el hábitat del Arenal, Humedales y Pastizales. b) Estimar la densidad poblacional de vicuñas y la biomasa de flora en el hábitat del Arenal, Humedales y Pastizales. Para llevar a cabo esta investigación, se empleó la metodología de transectos lineales, utilizando el estimador de Hayne para cada hábitat mencionado y cuadrantes aleatorios. Los resultados revelaron una tendencia al aumento en el número de individuos y grupos familiares en el hábitat de dunas arenosas, mientras que los valores más bajos se registraron en los hábitats de humedales y pastizales. Sin embargo, cabe destacar que la densidad poblacional fue mayor en el hábitat de humedales, con un valor de 0.699 indiv/ha, seguido del hábitat arenal con 0.275 indiv/ha, y el pastizal con 0.163 indiv/ha. Además, se observó un mayor número de hembras que machos, con grupos de hasta 34 individuos formando tropillas de machos. Asimismo, el hábitat de dunas arenosas mostró menor diversidad de flora y biomasa (1653.89 kg), mientras que en los humedales se registró mayor diversidad de flora y biomasa (24773.76 kg), y en los pastizales se calculó una biomasa de 25524.48 kg. Estos hallazgos proporcionan información valiosa sobre la dinámica poblacional de vicuñas, la diversidad de flora y la biomasa en los hábitats analizados, fundamental para su conservación y manejo adecuado en las regiones de Puno y Moquegua.

Palabras clave: Pastizal, Hábitat, Arenoso, Vicuña, Humedal.

INTRODUCTION

The vicuña (*Vicugna vicugna*) is a wild South American camelid that inhabits the highlands of Peru, Ecuador, Bolivia, Chile, and Argentina (Minam, 2013). In Peru, it is found at altitudes ranging from 3800 to 4800 meters above sea level in 16 departments (Zuñiga, 2007) and shares its habitat with other camelids that inhabit arid ecosystems of the high plateau (Arzamendia et al., 2006; Rojo et al., 2012), such as natural Grasslands (Quispe et al., 2022).

According to the national census of 2012, the vicuña population was recorded at 208899 heads, with the region of Puno being the second department with the largest population, with 38673 heads, while Moquegua had 1583 vicuñas (DGFFS, 2014). In 2018, as a result of vicuña management in the Cusco region, which included both captive and wild vicuñas, with a total of 58 captures (chacus), 6777 vicuñas were recorded, with 3229 in the wild and 3548 in captivity (Pacheco et al., 2020). Furthermore, in the Salinas and Aguada Blanca National Reserve (RNSAB), a population of 14111 vicuñas was estimated (Medina et al., 2018).

Vicuña family groups can be composed of one male and up to 16 females, but there are also troops of males without a leader (Zuñiga, 2007). In these cases, there are small troops with 2 to 5 individuals, medium-sized troops with 6 to 19 individuals, large troops with 20 to 40 individuals, and very large troops with over 40 individuals (Wawrzyk, 2013). On the other hand, solitary males are those that have completed their biological cycle and are expelled from their family groups by younger males (Vilá, 1999; Zuñiga, 2007).

The habitat chosen by vicuñas largely depends on vegetation availability, especially in terms of palatability and nutrient content, as well as the risk of predator presence (Rueda, 2006; Arzamendia et al., 2006). However, the expansion of mining activities has negatively impacted vicuña habitats, in addition to the degradation of Grasslands due to overgrazing by domestic livestock (Acebes et al., 2018).

It is essential to understand the botanical composition and quality of vicuña diets for proper management (Castellano et al., 2020), considering that the vicuña is a generalist herbivore (Gonzalez, 2020) that prefers Grasslands, grasses, and dicotyledonous herbs in both dry and wet areas, provided there is water availability (Benitez et al., 2006; Wawrzyk, 2013; Castellaro et al., 2020).

The high Andean zone boasts a rich variety of flora (Flores et al., 2005). The Wetlands, which experience persistent surface flooding throughout the year, are a crucial habitat in terms of food for the camelids. In these Wetlands, herbaceous species of the Asteraceae family can be found (Gonzáles, 2015). The vegetation composition in high-Andean habitats such as Grasslands, Wetlands (bofedales), and Sandy areas in Peru plays a fundamental role in the feeding ecology of vicuñas (*Vicugna vicugna*). Grasslands are dominated by species such as *Stipa ichu* and *Festuca orthophylla*, which represent key forage resources for vicuñas during most of the year (Maldonado, 2014; Polk et al., 2019).

Wetlands, known as bofedales, are critical ecosystems that provide year-round high-quality forage, especially during dry seasons. These habitats are primarily composed of species like *Distichia muscoides*, *Oxychloe andina*, and *Carex spp.*, which are preferentially consumed by vicuñas due to their high nutritional value (Maldonado, 2014; Squeo et al., 2006). Grassland

The vicuña produces one of the finest fibers in the world (Vilá et al., 2010), making it susceptible to poaching that threatens its populations (Acebes et al., 2018). Additionally, vicuñas are susceptible to Eimeriosis (Coccidiosis), a parasitic disease caused by *Eimeria* spp., which can lead to mortality (Dubey, 2018). Fortunately, thanks to conservation policies, local community involvement, and the efforts of scientists and naturalists, sustainable and community-based management has been implemented through chaku (Vilá et al., 2020), proving to be biologically sustainable (Vilá et al., 2010). However, the presence of minor fiber flaws (dandruff) in vicuña fiber has also been reported, causing economic losses for producers in the high Andean regions (Chacón, 2021). This issue appears to be related to nutritional deficiencies, primarily affecting individuals in growth and reproductive stages (Flores et al., 2021). These nutritional deficiencies may be due to competitive interactions between livestock and wildlife species (McLaren et al., 2018).

Various actors are involved in the utilization of vicuña fiber, including communities (66.7%), associations (17.5%), individuals (10%), committees (2.7%), companies (2.2%), cooperatives (0.7%), and universities (0.2%) (Minagri, 2019). Building on these background details, the present research aims to quantify the population fluctuation and density of vicuñas in the habitats of Sandy, Wetland and Grassland.

Research questions

- *What are the main factors driving the migration of vicuñas from Grasslands and Wetlands to Sandy areas?*
- *Which characteristics of the Sandy habitat and the plant species it contains allow vicuñas to utilize it as an alternative forage area?*
- *What ecological and adaptive impacts might this migration have on vicuñas and the Sandy area ecosystem?*
- *What implications does this phenomenon have for the conservation of vicuñas and the sustainable management of their habitats?*
- *How does human pressure influence the migration dynamics and adaptation of vicuñas?*

Specific objectives

a) Compare the social behavior patterns and population dynamics of vicuñas.
b) Analyze the territorial use and mobility patterns of vicuñas.
c) Propose conservation and restoration strategies to improve the living conditions of vicuñas in their habitats.

MATERIAL AND METHODS

Study area

The research was conducted during the months of January, February, March, and July 2022 in three types of habitats: Sandy, Wetland and Grassland, located in areas above 4000 meters above sea level, in the distrito of Pichacani, Puno region, and in the district of Carumas, Moquegua region, Peru. Sampling was carried out from 07:00 to 16:00 h. The study's transect length was 171.35 km (Fig. 1).

To determine the population density of vicuñas, linear transect surveys were conducted along the Interoceanic South Highway. We used a 4x4 vehicle traveling at speeds between 40 and 60 km/h. The transect started at the Loripongo Bridge (coordinates 19K0377684, UTM8200921), at an altitude of 4130 meters above sea level, and extended to the Tacna, Moquegua, and Puno junction (coordinates 19K0338993; UTM8135786), at an altitude of

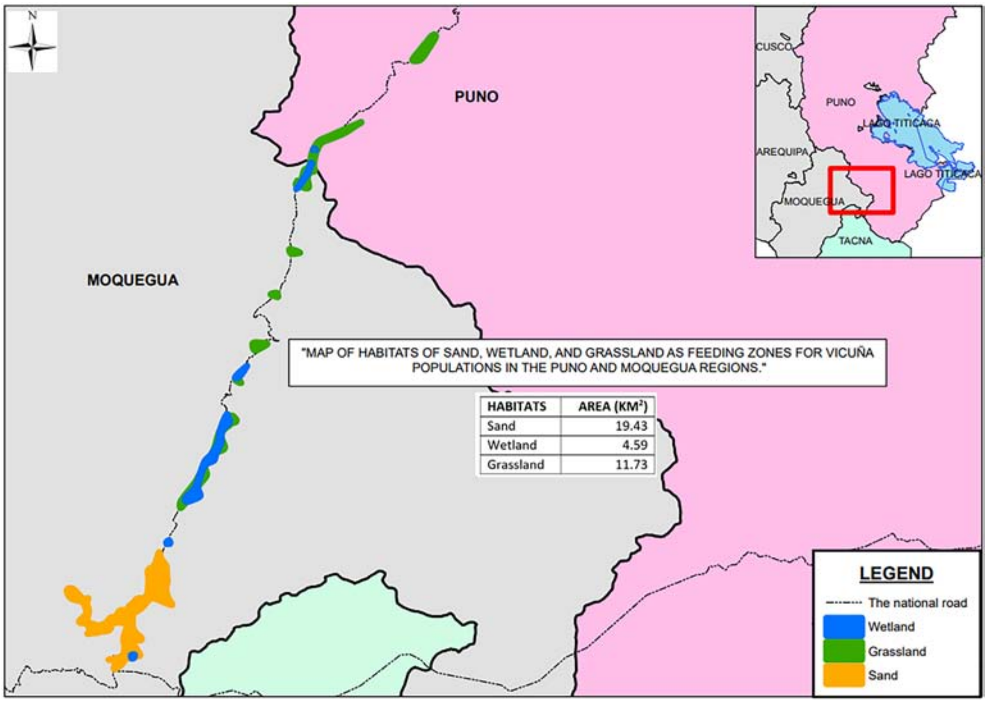

Fig. 1. Geographic Location of the Study Area for *Vicugna vicugna* Population Dynamics.

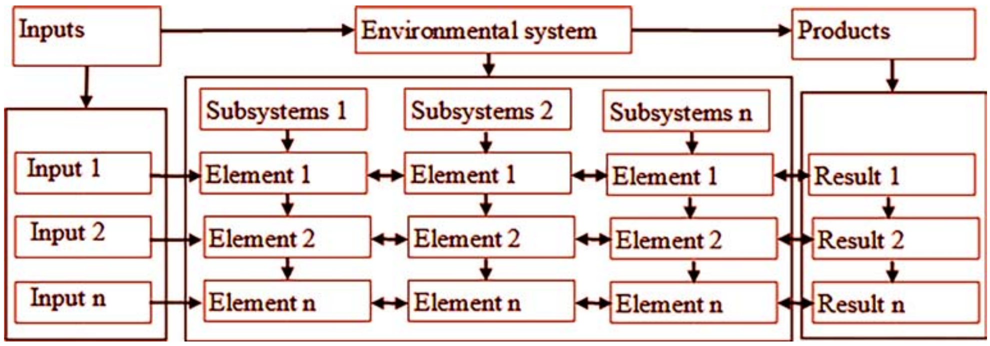

Fig. 2. Diagram of the ecosystem approach to the environmental system.

4586 meters above sea level. The perpendicular distance from the road varied depending on the habitat type but averaged about one kilometer.

An ecosystem approach, incorporating the environmental model, was utilized to conduct a comprehensive analysis of the specific environmental issue. This approach considered inputs, system, subsystems, products, outcomes, and functional elements, which serve as inputs enabling a logical framework for system functioning, subsequently yielding positive or negative outcomes for the species under analysis (Canales, 2010) (Fig. 2).

To record vicuña individuals, we conducted observations from the vehicle with the assistance of Bushnell binoculars, which facilitated the identification and counting of family groups. The type of habitat in which the vicuñas were found, whether feeding, resting, or moving, was also recorded.

To estimate vicuña density, the Hayne density estimator proposed by Burnham was applied (1979) (Eq-1):

$$D=\frac{10^4\,\Sigma\frac{1}{d_i}}{2L}$$

Where: D = estimated density, L = Transect length, d_i = observation distance.

In order to assess the flora diversity, random 1 m2 quadrants were used with 10 repetitions in each habitat (Sandy, Wetland, and Grassland), determined using the Shannon Index (Eq-2):

$$H=-\sum_{i=1}^{n} pi*\log(pi)$$

Where: H = Shannon index, pi = Number of species, and n = Total number of species.

The Kruskal-Wallis statistical test was used to assess differences among the three habitat types (Sandy, Grassland, and Wetland). Statistical analysis was conducted using the InfoStat v. 2020 statistical package, and the map creation was done using QGIS. Finally, Principal Component Analysis (PCA) was applied to determine the relationship between habitat, number of individuals, flora diversity, vicuña density, and biomass.

RESULTS

a) Compare the social behavior patterns and population dynamics of vicuñas

One novel and significant aspect highlighted as a result of this research is the tendency of the vicuña population to utilize the Sandy habitat for feeding, defecation (dung piles), and family group activities. In the Sandy habitat, the highest population variation is observed, with a count of up to 293 individuals, including males, females, and family groups, with 15 young individuals standing out. In contrast, in the Wetland habitat, up to 105 individuals were recorded, including 17 young ones. During February, 54 vicuñas were sighted in this habitat, with five young one's present, engaging in feeding activities within family groups, where the presence of young ones is also noted (Fig 3a).

Another critical habitat for the vicuña population is the Wetlands, where a greater diversity of wild plants accessible for these animals' feeding is found. However, due to human activity in the area, vicuñas tend to migrate to safer areas, such as the Sandy habitat (Fig. 3b).

The Grassland habitat is also an area where vicuñas feed. Furthermore, these Grasslands serve as areas of movement during local migrations towards the Sandy habitat. In the Grasslands, significant competition for access to food is observed with the rearing of alpacas, as the latter use the Grasslands as feeding areas (Fig. 3c).

What are the main factors driving the migration of vicuñas from Grasslands and Wetlands to Sandy areas?

Reduced rainfall in high Andean ecosystems has led to the drying up of Grasslands and Wetlands, limiting water availability and the regeneration of native plants consumed by vicuñas. This degradation drives the search for alternative means of survival. Competition with alpacas for food resources and habitat disturbance due to human activities. Increasing livestock activity, particularly alpaca farming, has intensified competition for the available grasses in the vicuñas' traditional habitats. Additionally, habitat disturbance (e.g., water usage for other purposes) has influenced the migratory behavior of vicuñas.

Fig. 3. Examples of vicuñas in their various environments: a) Sandy habitat, b) Wetland habitat, and c) Grassland habitat.

The Sandy habitat showed a greater abundance of vicuñas, comprising both males and females, compared to the Wetland and Grassland habitats. Across all three habitats, an increase in the number of individuals was observed in March relative to January, when population numbers were lower (Fig. 4).

In the Sandy habitat, the number of vicuñas per family group was higher in July, with an average of 7.55 individuals, while in January, February, and March, there were between 4 and 6 individuals per group. In the Wetland, there were between 3 and 5 individuals per family group in the months of January, February, and March, but no vicuñas were observed in JulyGrassland. Shows that in the Grassland habitat, family groups consisted of approximately 5 to 7 individuals during all sampling months, including July.

This contrasts with the Sandy habitat, where no individuals were observed in July, suggesting differential habitat use by vicuñas depending on seasonal conditions and resource availability (Fig. 5).

The composition of family groups showed significant differences (p=0.0070) in relation to habitat and observation months.

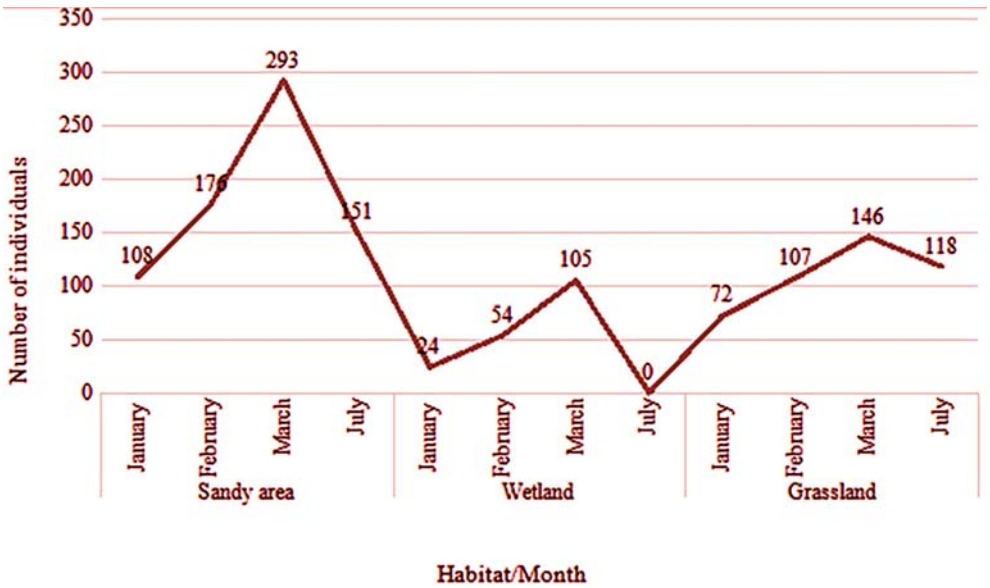

Fig. 4. Number of vicuñas sighted per month in three habitats (Sandy, Wetland and Grassland) along a delimited transect from the Loripongo Bridge (coordinates 19K0377684, UTM8200921, altitude of 4130 meters above sea level) to the Tacna, Moquegua, and Puno junction (coordinates 19K0338993; UTM8135786; altitude of 4586 meters above sea level) on a car journey at 40-60 km/h.

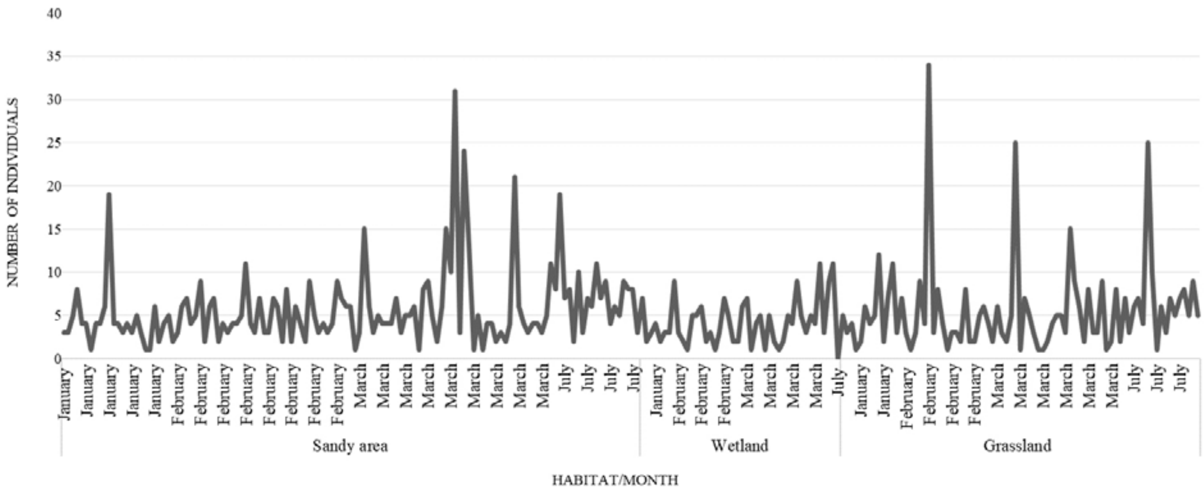

Fig. 5. Number of vicuñas per family group in three habitats of the Peruvian highlands (Sandy, Wetland and Grassland).

What characteristics of the Sandy habitat and the three plant species present allow vicuñas to use it as an alternative food source?

Vicuñas have a specialized diet and can consume specific plant species adapted to extreme high-altitude conditions. The three species identified in the Sandy area (*Nototriche meyenii*, *Nototriche rugosa*, and *Senecio melanandrus*) are likely to possess high nutritional value and are readily accessible for grazing. Vegetation in Sandy habitats is generally composed of xerophytic species, adapted to arid environments, with phenological traits that allow them to maintain green foliage under stressful conditions, thus ensuring a continuous forage supply.SandySandy Additionally, in Sandy habitats, the absence of direct competitors such as alpacas and other domestic herbivores allows vicuñas to access resources more efficiently.

b) Analyze the territorial use and mobility patterns of vicuñas

What ecological and adaptive impacts might this migration have on vicuñas and the Sandy area ecosystem?

For vicuñas.— The development of physiological and behavioral adaptations to arid conditions, such as changes in dietary preferences and mobility patterns, as well as potential health issues related to a different diet or nutritional deficiencies. For the Sandy area ecosystem. - Alterations in soil dynamics, such as compaction or erosion caused by vicuñas' trampling, potential pressure on the three plant species (*Nototriche meyenii*, *Nototriche rugosa*, and *Senecio melanandrus*) affecting their regeneration and associated biodiversity, and the creation of new ecological niches that might attract other species.

Table 1. Number of male and female vicuñas in three habitats (Sandy, Wetland and Grassland), assessed in January, February, March, and July 2022.

Habitats	Month	Family group	Functional group	Group of males	Male	Female	Offspring	Number of individ.
Sandy area	January	25	22	3	45	63	0	108
	February	36	31	5	41	128	7	176
	March	46	40	6	122	156	15	293
	July	20	19	1	38	113	0	151
Wetland	January	7	6	1	8	16	0	24
	February	14	12	2	16	33	5	54
	March	22	19	3	25	63	17	105
	July	0	0	0	0	0	0	0
Grassland	January	14	12	2	16	56	0	72
	February	20	15	5	57	47	3	107
	March	28	22	6	57	82	7	146
	July	17	16	1	41	77	0	118

In the Sandy habitat, the highest number of males and females was recorded in March. It is important to note that each family group is composed of one male, but this study also observed solitary males and troops consisting of 19 to 31 males. In the Wetland, the highest number of male and female records occurred in March, and there were no records in July. Solitary males were also counted. Meanwhile, in the Grassland, in the month of February, 57 males and 47 females were recorded (Table 1).

Dominant males control their family groups by defending their territory from individuals who do not belong to the group. The family group expels male offspring when they are between 6 and 9 months old, as well as females at 10 to 11 months of age (Wheeler, 2006).

It has been observed that there is greater vegetal biomass available for vicuña populations in the Grassland and Wetland habitats. From these areas, a constant migration of vicuña family groups to the Sandy habitat has been recorded. One of the main causes of this migration is habitat disturbance due to human activities such as livestock farming, mining, and the construction of irrigation systems and dams for water storage. These activities have affected the feeding behavior of vicuña populations that migrate to the Sandy habitat, where they have access to six species of plants that grow and thrive in this environment. However, there is a sustainability risk for these vicuña populations that carry out their feeding and familial activities in this habitat due to the increase in population.

Regarding factors such as livestock grazing and mining activities, their description has been expanded in the manuscript. While they were initially mentioned only as potential influences on the mobility and habitat preferences of vicuñas, additional information has now been included to describe their actual presence in the study area. Specifically, it is noted that extensive livestock grazing—mainly involving sheep, alpacas, and llamas—occurs in the surrounding areas, along with mining operations. These factors represent potential pressures on the ecosystem and may affect the spatial behavior and habitat selection of vicuña populations.

The distribution of plant species associated with the habitats of *Vicugna vicugna* populations in the regions of Puno and Moquegua, Peru. The listed species belong to a variety of botanical families, with a notable dominance of Asteraceae and Poaceae. These species are distributed across three main habitat types: Sandy areas, high-Andean Wetlands (bofedales), and Grasslands.

Several species, such as *Gnaphalium sp.*, *Astragalus sp.*, *Festuca orthophylla*, and *Jarava ichu*, occur in more than one habitat type, suggesting ecological adaptability and potential importance in the diet or habitat use of vicuñas. Wetland habitats host a diverse range of specialized species, including *Distichia muscoides*, *Isoetes lechleri*, and *Carex sp.*, while Sandy habitats are characterized by species like *Senecio melanandrus*, *Draba obovata*, and *Arenaria sp* (Table 2).

Notably, three species found in the Sandy habitat — *Notothriche meyenii*, *Notothriche rugosa*, and *Senecio melanandrus* — are considered potential food resources for vicuña populations, highlighting the ecological significance of these areas in supporting foraging activity.

The species *Nototriche sp.* is an important plant in the Sandy habitat, serving as food for the vicuña population and growing throughout the year. Vicuñas consume the flowers, leaves, and stems (Fig. 6).

Fig. 6. Plant species *Nototriche* sp. found in the Sandy habitat and serves as food for vicuña populations.

The estimated density of vicuñas according to habitat is presented in Table 3. Previous research indicates that the density of vicuñas in shrub-steppe areas was 4.9 individuals per square kilometer (Rojo et al., 2012), while in this study, it was 0.163 individuals per hectare in the Grassland, possibly due to differences in habitat type. On the other hand, Medina et al. (2018) reported an estimated population density of 0.038 individuals per hectare in an area of 612.28 km^2. Furthermore, according to the Shannon index, the habitat with the lowest species diversity was recorded in Sandy, with an index of 0.47. This habitat registered four families of wild plants, namely Malvaceae, Caryophyllaceae, Asteraceae, and Brassicaceae, hosting six species: *Nototriche meyenii*, *Arenaria sp., Senecio pygmophyllus, Nototriche rugosa, Draba obovata,* and *Senecio melanandrus,* with a total biomass of 85.12 kg/ha. In contrast, the Grassland, with an index of 0.55, recorded eight families of wild plants, such as Poaceae, Rosaceae, Asteraceae, Juncaceae, Fabaceae, Verbenaceae, and Caryophyllaceae, encompassing 37 species including *Tetraglochin cristatum*, *Festuca orthophylla*, *Gnaphalium sp.*, *Pseudognaphalium sp., Nototriche rugosa, Hypochaeris sp.*, *Paranephelius sp.*, among others. Finally, in the wetland, with an index of 0.78, the habitat exhibited the highest species diversity of flora, comprising 11 families including Poaceae, Rosaceae, Asteraceae, Gentianaceae, Juncaceae, Orobanchaceae, Isotaceae, Fabaceae, Ranunculaceae, Apiaceae, and Caryophyllaceae, where 42 species were identified, such as *Alchemilla pinnata, Alchimilla diplophylla, Distichia muscoides, Gentiana sedifolia, Liliaeopsis macloviana, Ranunculus sp., Poa sp*., among others.

The biomass estimation was higher in the Grassland habitat, with 25,524.48 kg in an area of 11.73 km^2, while in the Wetland, it was calculated at 24,773.76 kg in an area of 4.59 km^2. Finally, in the Sandy habitat, the biomass was lower, at 1,653.89 kg in an area of 19.43 km^2.

This pattern reflects a clear variation in biomass distribution among the different habitats. Although the Grassland and Wetland areas differ significantly in size, they both contribute similarly high levels of total biomass, indicating that these habitats are more productive and support greater vegetation density. In contrast, the Sandy habitat, despite covering the largest area, contributes the least to total biomass, suggesting poor vegetation cover or low forage productivity in that environment. This contrast highlights not only differences in ecological productivity but also the potential implications for herbivore habitat use, as animals must balance the availability of forage with other ecological factors such as safety, ease of movement, or habitat structure. The data suggest that forage availability is unevenly distributed across the landscape, which could influence patterns of habitat preference, spatial use, and animal behavior.

Table 2. List of plant species found in the habitats of *Vicugna vicugna* populations in the regions of Puno and Moquegua, Peru.

N°	Family	Species	Sandy habitat	Wetland habitat	Grassland habitat
1	Apiaceae	*Lilaeopsis maclobiana*		X	
2	Asteraceae	*Belloa sp.*			X
3	Asteraceae	*Gnaphalium sp.*		X	X
4	Asteraceae	*Hypochaeris sp.*		X	
5	Asteraceae	*Paranephelius sp.*			X
6	Asteraceae	*Senecio melanandrus*	X		
7	Asteraceae	*Senecio pygmophyllus*	X		
8	Asteraceae	*Tagetes filifolia*		X	
9	Asteraceae	*Werneria rigida*		X	
10	Brassicaceae	*Draba obovata*	X		
11	Caryophyllaceae	*Arenaria sp*	X		
12	Caryophyllaceae	*Cardionema ramosissimum*			X
13	Caryophyllaceae	*Cerastium sp.*		X	
14	Fabaceae	*Astragalus arequipensis*			X
15	Fabaceae	*Astragalus garbancillo*			X
16	Fabaceae	*Astragalus sp.*		X	X
17	Gentianaceae	*Gentiana sedifolia*		X	
18	Gentianaceae	*Gentiana sp.*		X	
19	Gentianaceae	*Gentianella sp.*		X	
20	Isoetaceae	*Isoetes lechleri*		X	
21	Juncaceae	*Distichia compacta*			X
22	Juncaceae	*Distichia muscoides*		X	
23	Juncaceae	*Juncus sp*		X	
24	Malvaceae	*Nototrhiche meyenii*	X		
25	Malvaceae	*Nototrhiche rugosa*	X		X
26	Orobanchaceae	*Castilleja pumilla*		X	
27	Poaceae	*Carex sp*		X	X
28	Poaceae	*Cinnagrostis rigescens*		X	
29	Poaceae	*Festuca fedrigii*		X	
30	Poaceae	*Festuca orthophylla*		X	X
31	Poaceae	*Jarava ichu*		X	X
32	Poaceae	*Muhlenbergia fastigiata*			X
33	Poaceae	*Poa sp*		X	
34	Ranunculaceae	*Ranunculus sp*		X	
35	Rosaceae	*Alchemilla diplophylla*		X	
36	Rosaceae	*Alchemilla pinnata*		X	X
37	Rosaceae	*Tetraglochin cristata*			X

Table 3. Vicuña density (individuals per hectare) in three habitats (Sandy, Wetland and Grassland).

Habitat	Family group	N° of individ.	∑ 1/di (m)	Transect Length (m)	Density (Indiv/ha)	Shannon index (Flora diversity)	Total biomass (kg/ha)	Area (km²)	Total biomass (kg)
Sandy	31.75	182.00	1.571	28,578.00	0.275	0.47	85.12	19.43	1,653.89
Wetland	10.75	45.75	0.728	5,211.80	0.71	0.78	5,397.3	4.59	24,773.76
Grassland	20.00	119.25	0.718	22,035.51	0.16	0.55	2,176.0	11.73	25,524.48

Note: The total biomass sum (kg) refers to the product of Total biomass (kg/ha) and Area (km²)

According to the Principal Component Analysis (PCA), on the first axis (PC1), which accounts for 89.0% of the total variation, there is a greater diversity of flora in the Wetland, with 11 families and 42 species, as well as a higher biomass. Additionally, despite being the smallest linear transect area studied, a higher density of vicuña population was recorded.

For the second axis (PC2), representing 22.2% of the variation, it is observed that in the Sandy habitat there is a greater number of vicuña individuals and a larger studied area compared to the other habitats. However, only four families with six species were recorded in this area, making it the habitat with the lowest flora diversity.

Finally, in the Grassland, eight families with 37 species were identified, making it the largest habitat in the evaluation and contributing to its higher biomass. However, this habitat had a lower number of vicuña individuals and a lower diversity of flora compared to the Wetland and Sandy (Fig. 7).

c) Propose conservation and restoration strategies to improve the living conditions of vicuñas in their habitats

The systemic environmental model is a crucial tool that allows for a comprehensive analysis of a specific environmental issue. It is based on inputs necessary for the system's functioning and explores the subsystems along with the elements within each. This holistic approach ultimately leads to positive or negative outcomes for the species under analysis (Canales, 2010).

What implications does this phenomenon have for the conservation of vicuñas and the sustainable management of their habitats?

Conservation of vicuñas.— There is an urgent need to develop strategies to minimize competition with alpacas in their original habitats, conduct constant monitoring of populations and health in the Sandy areas, and ensure the species' long-term viability.

Sustainable management. - Implement livestock management systems to reduce pressure on Wetlands and Grasslands, restore high Andean ecosystems through revegetation and water resource management, and protect Sandy areas as critical new habitats for vicuñas in the context of climate change.

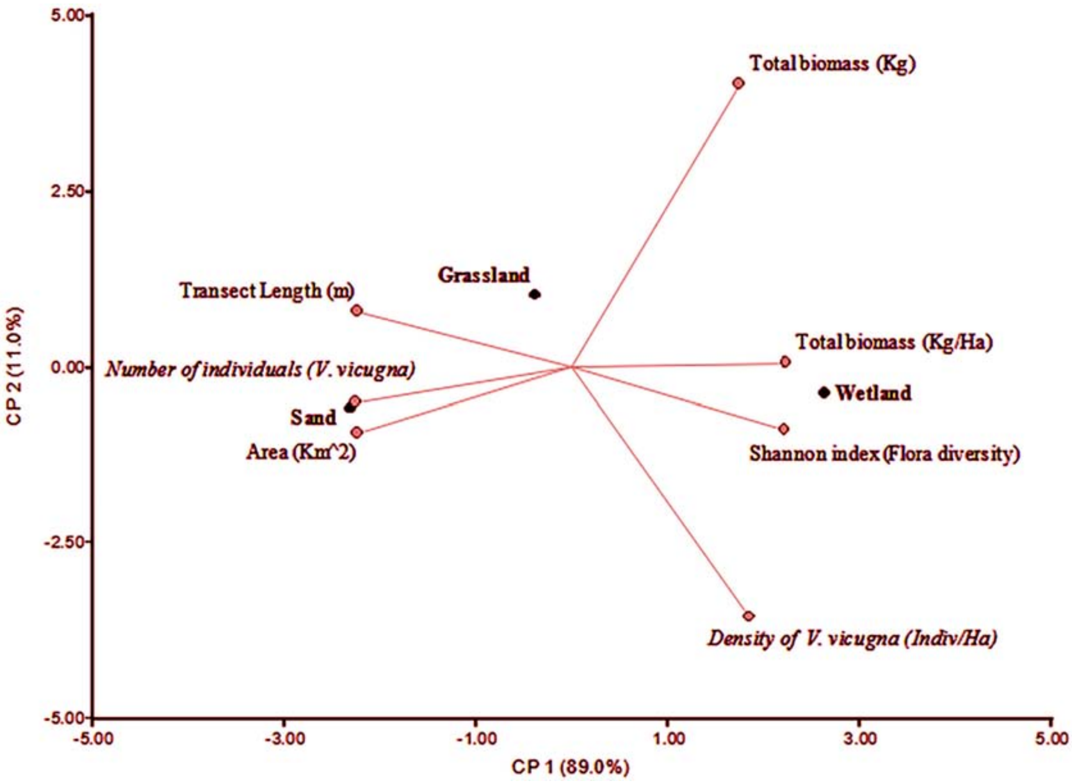

Fig. 7. Principal Component Analysis (PCA) of flora diversity, density, and vicuña numbers in three habitats (Sandy, Wetland, and Grassland).

How does human pressure (alpaca farming) influence the migration and adaptation dynamics of vicuñas?

Habitat modification.— Overexploitation of Grasslands by alpacas has significantly reduced the resources available for vicuñas, forcing them to migrate.

Human-vicuña conflict.— The expansion of livestock farming creates territorial conflicts between vicuñas and alpaca herders, potentially restricting the vicuñas' access to certain habitats.

Forced adaptation.— Vicuñas are compelled to seek alternative food sources in marginal habitats, which may pose risks to their health and population stability

The environmental systemic model for the population dynamics of *Vicugna vicugna* considers various necessary inputs. Firstly, the presence of rainfall is crucial, as it allows habitats to have vegetation essential for the feeding of vicuñas. Additionally, rural communities play a significant role, as they utilize vicuña fiber through a process called Chacu of vicuñas (vicuña enclosure), which can have positive or negative effects on vicuña family groups. Likewise, mining companies in the area disturb the daily activities of vicuñas and affect the dynamic functioning of habitat plant biodiversity by using water for their mining activities. Therefore, it is crucial for the government to promote conservation policies for these habitats.

Within the environmental system, three subsystems have been identified: Grassland, Wetland, and Sandy, which are habitats where vicuña populations are found. For example, the Grassland habitat includes elements such as plant biodiversity that serves as food for vicuña populations, human and industrial disturbance activities, and conservation and management policies by the government. Similarly, the Wetland subsystem includes elements such as alpaca farming by rural communities, which competes with vicuñas for food, and water resources affected by human activities and climate change, resulting in decreased vegetation cover. Therefore, it is necessary to manage these habitats appropriately, not only for alpacas but also for vicuña populations and even for mining activities with environmental and social responsibility (Fig. 8).

The statistical analysis has revealed significant differences in the vicuña population among habitats (p=0.0076), with a higher population in the Sandy habitat, confirming the hypothesis proposed. This is due to a strong migration pressure from the Wetland and Grassland habitats towards the sand dunes, which is attributed to the activities related to the breeding of South

DISCUSSION

Vicuña family groups are typically composed of one male and can include up to 16 females. However, there are also groups of males that reach sexual maturity and are expelled, without a clear dominant leader (Zuñiga, 2007). These male groups are categorized as small, medium, large, and very large troops (Wawrzyk, 2013). In this study, we observed small groups consisting of three to five individuals, medium-sized groups with six to 15 individuals, and large groups with 17 to 35 individuals, including both males

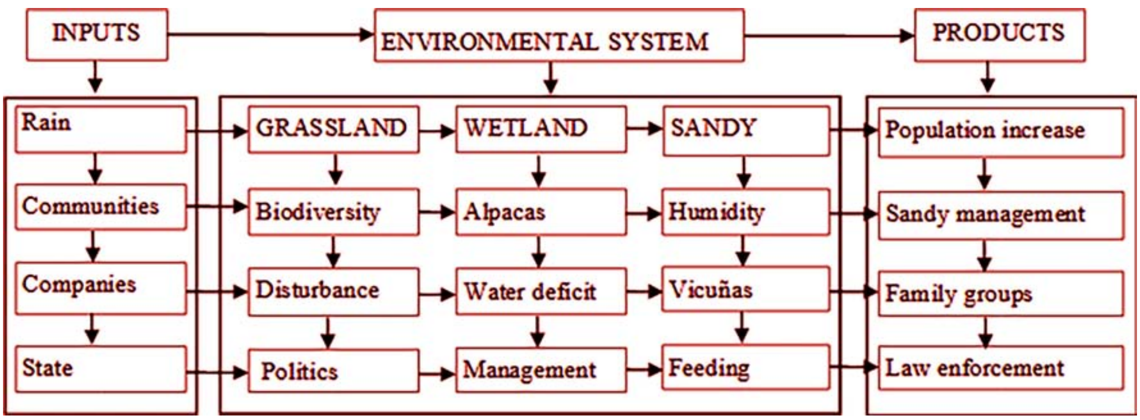

Fig. 8. Model of the environmental approach to Grassland, Wetland, and dune habitats crucial for the survival of the *Vicugna vicugna.*

and solitary males, in all three habitats. Solitary males are those that have completed their biological cycle and have been expelled from their family groups by younger males, and they are also considered non-reproductive adult males (Vilá, 1999; Zuñiga, 2007).

The composition of vicuña family groups varied across the three habitats, with an average ranging from 4 to 7 individuals. These results align with findings from Benitez et al. (2006), who reported an average of 5.6 to 8.0 individuals in family groups, typically consisting of one male, 3 to 4 females, and 2 to 3 offspring (Vilá, 1999). However, the chaku activity significantly reduced the average group size, decreasing from 4.67 to 3.60 individuals. Furthermore, only 27% of males managed to retain at least one female from their previous family group. As for adult females, after the chaku, only 55% managed to reunite with at least one member of their original family structure, and a mere 23% were able to preserve their own offspring. These results highlight that the chaku event caused a significant disruption in family groups, resulting in a high percentage of mothers losing their offspring subsequently (Quispe et al., 2022). During the study period, no vicuña roundups (chacu) were carried out in the areas we assessed

Additionally, vicuña populations form family groups and solitary male groups (Wawrzuk, 2013). Vicuñas are not aggressive towards other camelids, but they do not coexist with sheep or cattle (Arzamendia and Vilá, 2003). For these reasons, there is migration of vicuña populations to the Sandy habitat.

In other habitats, up to 14111 individuals have been recorded in an area of 366.936 hectares (Medina et al., 2018). In contrast, within the scope of the present research, up to 347 individuals were counted in an area of 58.59 hectares. On the other hand, Renaudeau et al. (2000) reports the presence of 521 vicuñas in an area of 150 kilometers in the Laguna Blanca Reserve (Argentina), where vegetation is sparse and dominated by *Fabiana densa*, *Baccharis bolivianensis*, and *Adesmia horridiuscula*, with areas with a considerable presence of *Stipa sp*.

In the Peruvian highlands, the predominant vegetation consists of herbaceous species from the Asteraceae family (Gonzáles, 2015). As for the Grasslands, they are considered reservoirs of species of importance for biological conservation .

Considering that vicuñas develop foraging strategies throughout the year to locate and select plants with high nutritional value, especially during the summer (Castellaro et al., 2020), it can be inferred that the lower presence of vicuñas in the Grassland, despite having 37 species, could be attributed to this reason. On the other hand, a higher concentration of vicuñas is observed in the Sandy, suggesting that certain species such as *Notothriche meyenii, Arenaria sp, Senecio pygmophyllus, Notothriche rugosa, Draba obovata,* and *Senecio melanandrus*, may possess high nutritional value, explaining their preference for this habitat.

Although Sandy areas present the lowest biomass availability, vicuñas (*Vicugna vicugna*) show a marked preference for these habitats even during the rainy season, when energy demand is higher due to the calving period. This apparent ecological paradox can be explained by the need for greater visibility to detect predators and ease of movement in open spaces—key factors for the protection of offspring (Karandikar et al., 2023; Monk et al., 2024). Moreover, although forage quantity is low, the quality and digestibility of certain plant species may be sufficient to meet nutritional requirements (Castellaro et al., 2020).

Recent studies also highlight that these areas can provide more favorable thermal conditions during critical hours of the day, as well as suitable space for social interactions within the reproductive group (Mosca-Torres et al., 2015). On the other hand, Arzamendia and Vilá (2015) show that habitat use by vicuñas is driven by complex strategies that integrate competition with other ungulates and resource availability. Similarly, Mata et al. (2024) emphasize the importance of open landscapes in maintaining the ecological connectivity of the species.

Vicuñas exhibit selective foraging behavior in Wetlands, low, and medium vegetation strata. They generally avoid consuming plants with higher nutritional value, thus considered generalists. They are sensitive to changes in the nutritional content of grasses (Borgnia et al., 2010), preferring the best pastures and remaining in areas with available water (Wawrzuk, 2013) and in habitats where the most nutritious foods are present, providing the highest average energy intake rate (Mosca and Puig, 2012). Additionally, the accumulated energy allows them to display aggressive behaviors towards predators (Pritchard et al., 2020).

Southamerican camelids and mining activity. The vicuña population in specific areas varies depending on the availability and nutritional quality of their food (Arzamendia et al., 2006; Rueda, 2006). Mining activities (Acebes et al., 2018; Beltrán et al., 2020), as well as overgrazing by domestic livestock, have a negative impact on the vicuña's habitat (Acebes et al., 2018). Therefore, a sustainable alternative for the feeding and coexistence of vicuña family groups is the Sandy habitat, where South American camelids do not compete for food or space with vicuña populations.

Conservation and management measures are proposed, such as habitat restoration and minimizing human disturbances in the Sandy habitat, to increase the diversity of food plants for the vicuña population. Additionally, education and awareness strategies are crucial for promoting environmental education and raising awareness among local communities about the importance of conserving vicuña habitats.

Activities such as alpaca farming, the construction of irrigation systems, dams, and reservoirs, as well as mining, are degrading these ecosystems and forcing vicuñas to migrate to the Sandy habitat. This new environment, although less disturbed by human activities, has low plant diversity, limiting the food options for the vicuñas. Migration to the Sandy habitat could have multiple impacts on the health and behavior of the vicuñas. The reduction in the diversity of their diet could affect their nutrition and overall health. Additionally, changes in their social and reproductive behavior could arise due to the new environmental conditions and the scarcity of resources. It is essential to understand how these factors influence the population dynamics of the vicuñas to develop effective conservation strategies.

Studies by Quispe et al. (2021) have shown that alpacas exhibit greater selectivity in grazing, preferring low herbaceous plants and humid areas, whereas llamas demonstrate a higher tolerance for drier and more fibrous grasses. These differences lead to a differentiated spatial use of the high Andean ecosystem. Additionally, Hoogesteger and Verzijl (2013) indicate that high Andean communities practice traditional grazing management based on seasonal rotation, where wetlands (*bofedales*) are reserved for the dry season, while higher areas are used during the rainy season. This management pattern affects forage availability and influences the distribution of wild camelids. Furthermore, Arzamendia and Vilá (2015) and McLaren et al. (2018) highlight that the presence and grazing pressure of domestic camelids can influence habitat use patterns by vicuñas, causing them to move to less competitive areas. Finally, Sandoval-Calderón et al. (2024) show that a reduction in livestock pressure in the puna, resulting from economic or social changes, can facilitate the recolonization and expansion of vicuñas in the best grasslands. Therefore, these elements should be considered key variables in understanding the mobility and habitat preferences of vicuñas in high Andean systems

CONCLUSION

In the Sandy habitat, lower flora diversity was recorded, along with lower estimated biomass (1,653.89 kg) over an area of 19.43 km^2. Conversely, higher flora diversity (0.78 indiv/ha) and biomass were observed in the Wetland (24,773.76 kg) over an area of 4.59 km^2. In the Grassland, a biomass of 25,524.48 kg was calculated over an area of 11.73 km^2, despite being the largest habitat in the assessment. In this habitat, the population of vicuñas is particularly disturbed by human activities.

The migration of vicuñas to Sandy areas is driven by climate change and anthropogenic pressures, including drought in high Andean Wetlands and Grasslands, competition with livestock (notably alpacas), and water resource extraction. These factors are displacing vicuñas from their traditional habitats. Although SSandy areas offer an alternative refuge, their capacity to sustain vicuña populations is limited.The plant species in Sandy area is critical for vicuña survival but risk overexplotation, potentially disrupting ecosystem regeneration. This migration demonstrates vicuñas' adaptability but poses long-term health risks due to dietary changes and harsh conditions. Additionally, the presence of vicuñas in Sandy areas may affect soil structure and plant biodiversity, risking ecosystem degradation without proper management.

Urgent action is needed to address human pressures, including livestock expansion and poor water management, which amplify climate impacts on Andean ecosystems. Conservation strategies must include ecological restoration of Wetlands and Grasslands, equitable natural resource access, sustainable livestock practices, and protection of Sandy areas as emerging habitats for wildlife.

AUTHOR CONTRIBUTIONS

All authors contributed to the conceptualization of the study and its design. Angel Canales Gutiérrez in methodology, statistics and final drafting of the manuscript, Marisol Sheyla Chambi-Alarcón in data collection and data processing and initial drafting of the manuscript, Danitza Fiorella Cáceres-García data collection, ordering and processing, Nataly Irene Mestas-Gutierrez in data collection, revision and adequacy of the report, processing, Katia Pillco-Mamani data collection, design and elaboration of graphs, Gelvi Canales-Manchuria Map elaboration and calculation of hectares for each habitat.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL APPROVAL

Not applicable.

CONSENT FOR PUBLICATION

All authors give consent for manuscript to be published in its current form.

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