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Unmanned aerial systems and passive remote sensors to classify microecosystems of high Andean grasslands

Sistemas aéreos no tripulados y sensores remotos pasivos para clasificar microecosistemas de pastizales alto andinos

Sistemas aéreos não tripulados e sensoriamento remoto passivo para classificar microecossistemas de pastagens altas andinas

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Crop Production

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Abstract

Pastures are the fodder base for camelid and sheep production in the southern Peruvian Andes, where 80 % of alpacas and 15 % of sheep live, which requires better land management and grazing programs through the classification of microecosystems. The objective of this study was to classify the microecosystems based on the grasslands of the Kayra Agronomic Center in the Region of Cusco using unmanned aerial vehicles and remote sensors. To do this, traditional evaluation and estimation methods such as modified Parker and quadrat sampling, were combined with biomass classification and estimation methods supported by multispectral images. This was done using 5 m RapidEye satellite images, and multispectral orthophotographs acquired with a Micasense sensor transported by a Matrix 300 RTK Drone with 10 cm pixels. Processing was performed by Pix 4D version 4.7.5 photogrammetry software, and ENVI and ArcGIS 10.3 image processing software. An algorithm designed in the R programming language was used to estimate the biomass. The results show three life zones, three climatic zones, four ecosystems, and four plant communities with eleven dominant species. The condition of the grasslands evaluated was regular with a tendency to poor and a carrying capacity of 0.3 UV.ha^{-1}.year^{-1}; 0.83 UO.ha^{-1}.year^{-1} and 1.11 UA.ha^{-1}.year^{-1}. The use of remote sensors made it possible to classify grasslands quickly and efficiently.

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Resumen

Los pastos son la base forrajera de la producción de camélidos y ovinos en el sur de los Andes peruanos, donde habitan el 80 % de las alpacas y el 15 % de las ovejas, lo que exige una mejor gestión de las tierras y programas de pastoreo, mediante la clasificación de los microecosistemas. El objetivo del presente estudio fue clasificar los microecosistemas considerando como base los pastizales del Centro Agronómico Kayra de la Región Cusco, mediante vehículos aéreos no tripulados y sensores remotos. Para ello se combinó métodos de evaluación y estimación tradicionales, como el de Parker modificado y el cuadrante de muestreo con métodos de clasificación y estimación de biomasa apoyados con imágenes multiespectrales. Para ello se utilizó imágenes satelitales RapidEye de 5 m y ortofotografías multiespectrales adquiridas con un sensor Micasense transportado por un Dron Matrix 300 RTK con pixeles de 10 cm. El procesamiento se realizó en el software de fotogrametría Pix 4D versión 4.7.5 y software de procesamiento de imágenes ENVI y ArcGIS 10.3. Para estimar la biomasa se utilizó un algoritmo diseñado en el lenguaje de programación R. Los resultados mostraron tres zonas de vida, tres zonas climáticas, cuatro ecosistemas y cuatro comunidades vegetales con once especies dominantes. La condición de los pastizales evaluados fue de regular con tendencia a pobre y capacidad de carga de 0,3 $UV.ha^{-1}.año^{-1}$; 0,83 $UO.ha^{-1}.año^{-1}$ y 1,11 $UA.ha^{-1}.año^{-1}$. El uso de sensores remotos permitió clasificar los pastizales de forma rápida y eficiente.

Palaras Clave: capacidad de carga, ecosistema, NDVI.

Resumo

As pastagens são a base forrageira para a produção de camelídeos e ovinos no sul dos Andes peruanos, onde vivem 80 % das alpacas e 15 % das ovelhas, o que exige uma melhor gestão do território e programas de pastoreio, através da classificação dos microecossistemas. O objetivo deste estudo foi classificar os microecossistemas com base nas pastagens do Centro Agronómico Kayra na região de Cusco, utilizando veículos aéreos não tripulados e deteção remota. Para isso, métodos tradicionais de avaliação e estimativa foram combinados, como o método de Parker modificado e o quadrante amostral com métodos de classificação e estimativa de biomassa suportados por imagens multiespectrais. Para isso, foram utilizadas imagens de satélite RapidEye de 5 m, e ortofotografias multiespectrais adquiridas com sensor Micasense transportadas por um Drone Matrix 300 RTK com pixels de 10 cm. O processamento foi realizado utilizando o software de fotogrametria Pix 4D versão 4.7.5 e os softwares de processamento de imagem ENVI e ArcGIS 10.3. Para estimar a biomassa, foi utilizado um algoritmo projetado na linguagem de programação R. Os resultados mostram três zonas de vida, três zonas climáticas, quatro ecossistemas e quatro comunidades vegetais com onze espécies dominantes. A condição das pastagens avaliadas era regular com tendência a ruim e tem capacidade de suporte de 0,3 $UV.ha^{-1}.ano^{-1}$; 0,83 $UA.ha^{-1}.ano^{-1}$ e 1,11 $UA.ha^{-1}.ano^{-1}$. O uso do sensoriamento remoto permite que as pastagens sejam classificadas de forma rápida e eficiente.

Palabras chave: capacidade de suporte, ecossitema, NDVI.

Introduction

Grasslands are economically, ecologically, and socially important because of the ecosystem services they provide to rural (puna grasslands) and urban populations (Zorogasúa *et al.,* 2012). These resources, which are essential for the development of the Andes, are increasingly threatened by the global processes of climate change, desertification, and degradation of grazing lands, with the consequent loss of biodiversity and productive capacity (Tomasi, 2013). This accelerated grassland deterioration and biodiversity loss process is strongly influenced by anthropogenic actions such as inadequate grazing, shifting cultivation, and land use change (Fuhlendorf *et al.*, 2012; Muñoz *et al*., 2018).

Peru is a tropical Andean-Amazonian country and due to the presence of the Andean Mountain Range, it has a special characteristic with several altitudinal levels and life zones with a diversity of plant communities favoring livestock production (Comer *et al*., 2012; Zaragoza *et al.*, 2022; Zarria and Flores, 2015).

"*The destructive or direct method consists of cutting the aerial part of the plant to take to a laboratory*" (Ramirez *et al*., 2006; Yaranga, 2020), a method by which the estimation of primary production and biomass availability requires more time and effort. However, the information generated through the direct method can be complemented and improved with indirect methods that show greater accuracy, such as remote sensing with remote sensors and microsensors on unmanned aerial vehicle platforms (Seo *et al.,* 2014). This new sensor technology makes it possible to conduct evaluations in large territories in a short time and in some cases with the use of drones in real time (Estrada and Ñaupari, 2021; Pizarro, 2017).

Nowadays, remote sensing has become a tool that provides up-to-date and accurate information to identify plant communities and estimate biomass production and animal carrying capacity per hectare (Lussem *et al.,* 2019; Yim *et al.,* 2009).

In the dry puna of southern Peru, plant communities have been identified and biomass production has been estimated with the support of remote sensing (Quispe, 2016). Likewise, the researchers reported that from orthophotographs with different spectra or bands (blue, green, red, red edge, and near-infrared) and the use of various vegetation indices, image classification processes have been improved, as well as the estimation of biomass production, given the quality of data provided by microsensors (Lussem *et al.,* 2019; Xu and Guo, 2015).

On the other hand, geographic information systems, with the help of photogrammetry software and software for satellite image processing such as ArcGIS or QGIS, allow supervised and unsupervised classifications to be made from multispectral images (Chen *et al.,* 2004; D'Oleire *et al.,* 2012).

The Ministry of the Environment of Peru (MINAM) has developed a set of tools for the analysis of the territory based on microecosystems, whose institution defines them "*.....as small territorial spaces that present homogeneous characteristics of flora, fauna, and geographical configuration*". The purpose of these tools is to homogenize variables and criteria for the analysis of natural resources, soil, water, and vegetation, with an emphasis on grasslands (MINAM, 2016).

Environmental researchers, entities in charge of natural resource management, academia (which requires new content for its teaching and learning processes), public policymakers, and decision-makers demand current, modern, and reliable tools for monitoring grasslands and their plant communities in high Andean-Amazonian mountain ecosystems. In addition, they must be simple to use and extremely reliable in their temporal, spatial, and radiometric scales for effective grassland monitoring (Chavez *et al.,* 2017).

On the other hand, the use of remote sensors in the classification of grasslands and the determination of ecosystems requires the production of tools that are accurate in land cover classification, especially for high mountain territories (Melville *et al.,* 2019).

The identification of objects and processes on the grassland surface for the study of high mountain plant communities requires knowledge of the reflectivity of soil, vegetation, and water, concerning the different wavelengths (Melville *et al.,* 2019; Zarria and Flores, 2015). Each wavelength that gives the reflectivity in percentage is known as a "spectral signature" and constitutes a mark of affiliation of the objects. Knowledge of this facilitates and makes it possible to distinguish between soil, water, and vegetation, and even between different types of soil and vegetation (Meneses *et al.,* 2015).

The objective of the present study was to classify the microecosystems based on the grasslands of the Kayra Agronomic Center using unmanned aerial vehicles and passive remote sensors.

Materials and methods

The fieldwork was carried out during the rainy season (February and March) and at the end of the dry season (October) of 2020 and 2021. During this time, samples were collected from three representative areas (the upper part of pastures, the middle part of forest plantations, and the lower part made up of agricultural and urban areas) of the Kayra Agronomic Center. This zone has a total area of 2,153.20 ha and is located in the Cusco Region of Peru (SL 13°33'29.43" WL 71°52'14.0", between 3,200 and 4,600 meters above sea level).

In the first stage of the study, using the Google Earth Pro platform, the recognition and identification of the sampling areas was performed and their geographical location was determined, duly georeferenced for the subsequent acquisition of RapidEye satellite images. Once the study areas were selected, flight plans were prepared with the following characteristics: height of 100 m, horizontal overlap of 75 %, vertical overlap of 70 %, speed of 8 $m.s^{-1}$, and time interval of 3 s for each photograph. For this process, a flight autonomy of 25 to 30 min of the Matrix 300 RTK Drone, suitable for the conditions of Cusco, was also considered.

In the sampling areas, 8 control points were placed, these control points were 80 cm x 80 cm plywood and painted red, blue, and white. The control point was placed at the start and end point of the transects, which was used to make geometric corrections.

In the second stage, the acquisition of 5 m RapidEye four-band (blue, green, red and NIR) multispectral images of the Planet Scope platform was performed (Estrada and Ñaupari, 2021).

Field sample collection was carried out using the modified Parker method with three 100 m transects (georeferenced with differential GPS, 2 cm approximation). These transects, in turn, served as control points and lines for the geographic correction of the RapidEye satellite images and the orthophotographs acquired with the drone.

In the transects, in addition to identifying the species and determining their frequency of occurrence, samples were taken to estimate biomass production in 0.5 m x 0.5 m quadrats. For this purpose, the aerial biomass was cut with pruning shears at a height of 2 cm from the soil and in 30 quadrats per selected zone (10 samples per transect) with a distance of 10 meters between samples.

The third stage of the study included the processing of samples to estimate the production of biomass in green matter (GM) and dry matter (DM), in the pasture processing room of the Laboratory of Animal Science and Climate Change of the Professional School of Zootechnics of the National University of Saint Anthony the Abbot in Cusco (UNSAAC), Cusco – Peru.

In the remote sensing cabinet of the same laboratory, the RapidEye images were processed using ENVI and ArcGIS software, with the corresponding geometric corrections. With the Pix 4D photogrammetry software, the photographs obtained by the drone were processed, and multispectral orthophotographs with different spectra (blue, red, green, NIR) and an orthophotography of normalized difference vegetation indices (NDVI) with 10 cm pixels and high resolution were generated.

Using as reference (ROIs) the orthophotographs of the drone, the supervised classification of the RapidEye images was carried out with the ArcToolbok's spatial command tool analysis of the ArcGIS, then maps of the variables required to obtain the ecosystems map were generated, these being: 1) slope map, 2) altitudinal zonation map, 3) plant community map, and 4) vegetation cover. Finally, the map of microecosystems of the Kayra Agronomic Center based on grasslands was obtained.

For the estimation of biomass production by plant community, the algorithm developed by *Estrada et al*. (2022) to classify and estimate biomass in high Andean plant communities was used. This algorithm uses the libraries "Caret", "Performance Analytics", "Corrplot", "RandomForest", "Rgdal", "Raster", "Sp" in the R programming language and requires as input information orthophotographs with the 5 spectra (blue, green, red; red edge and NIR), NDVI orthophotographs and the biomass production data in the green matter (GM, DM).

The output products of the algorithm are different land cover or classification maps, with the estimation of biomass production per pixel. From this, the biomass production per ecosystem was estimated and finally, the animal carrying capacity for the identified grassland microecosystems was calculated. This procedure took into account the production of biomass per pixel and the animal requirement based on dry matter, considering that an animal requires 10 % of its weight in GM and 3 % of its weight in DM.

Results and discussion

Identification of natural grass species

In the plant communities studied, 11 species of grasses were identified, the dominant ones being: *Stipa ichu, Festuca dollicophill,* and *Festuca ortophylla.* The low number of species was due to the grassland and forest fires that occurred during the years 2020 and 2021. However, it was observed that grasslands, still in the process of degradation, maintained their capacity for grazing animals that consume tall grasses (table 1).

Identification of grassland-based ecosystems with the assistance of passive remote sensors

Applying Holdrigde's life zone classification methodology (1978), the Kayra Agronomic Center has three life zones: Subtropical Montane Moist Forest (bh_MS), Subtropical Low Montane Dry Forest (bs_MBS), and the Wet Sub-Andean Subtropical Paramo zone (pmsh_SaS) (figure 1a).

Table 1. Floristic composition of grasslands.

Family	Gender	Species	Key	Local Name
Asteraceae	*Hypochaeris*	*Hypochaeris taraxacoides*	Hyta	Pill amarillo
Cyperaceae	*Carex*	*Carex* sp.	Carsp	Ccaran ccaran
Fabaceae	*Trifolium*	*Trifolium amabille*	Triam	Layo
Poaceae	*Paspalum*	*Paspallum pigmaeum*	Papy	Sara sara
Poaceae	*Festuca*	*Festuca dollicophylla*	Fedo	Chillihua, coya
Poaceae	*Festuca*	*Fescue orthophylla*	Feor	Iru ichu
Poaceae	*Poa*	*Poa* sp.	Posp	Llachu, chili
Poaceae	*Stipa*	*Stipa ichu*	Stich	Ichu
Geraniaceae	*Geranium*	*Geranium sessiflorum*	Gese	Ojotillo
Rosaceae	*Alchemilla*	*Alchemilla pinnata*	Alpi	Sillu sillu
Asteraceae	*Baccharis*	*Baccharis* sp.	Basp	Mullaca

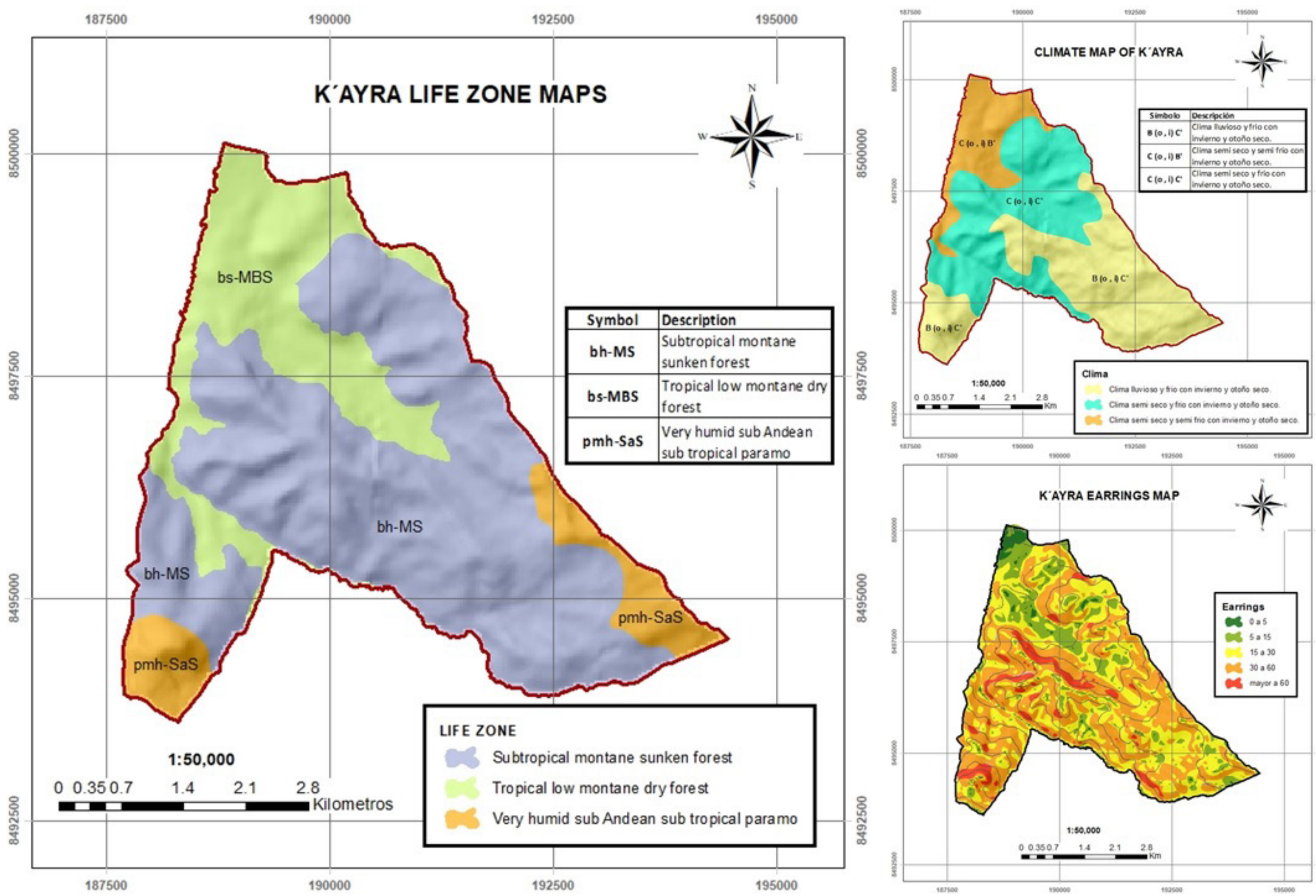

Figure 1. (a) Map of Kayra life zones (b) Climate and (c) slopes.

The study identified three climatic zones: Semi-dry climate, dry autumn, dry winter, semi-warm C(o,i)B’; Semi-dry climate, semi-dry, dry autumn, winter, cold C(o,i)C’ and rainy, dry autumn, winter, cold B(o,i)C’ (figure 1b).

According to the methodology for classifying microecosystems at the Kayra Agronomic Center, four ecosystems were determined: Ecosystems of hillside pastures with moderate slope in mountainous areas, with moderate precipitation and with capacity animal grazing (figure 2b); ecosystems of relict forests and plantations in low-slope massifs with moderate precipitation with the presence of grass species for animal grazing (figure 2d); agricultural ecosystems in flat and plateau areas, with moderate precipitation and intensive land use (figure 2c).

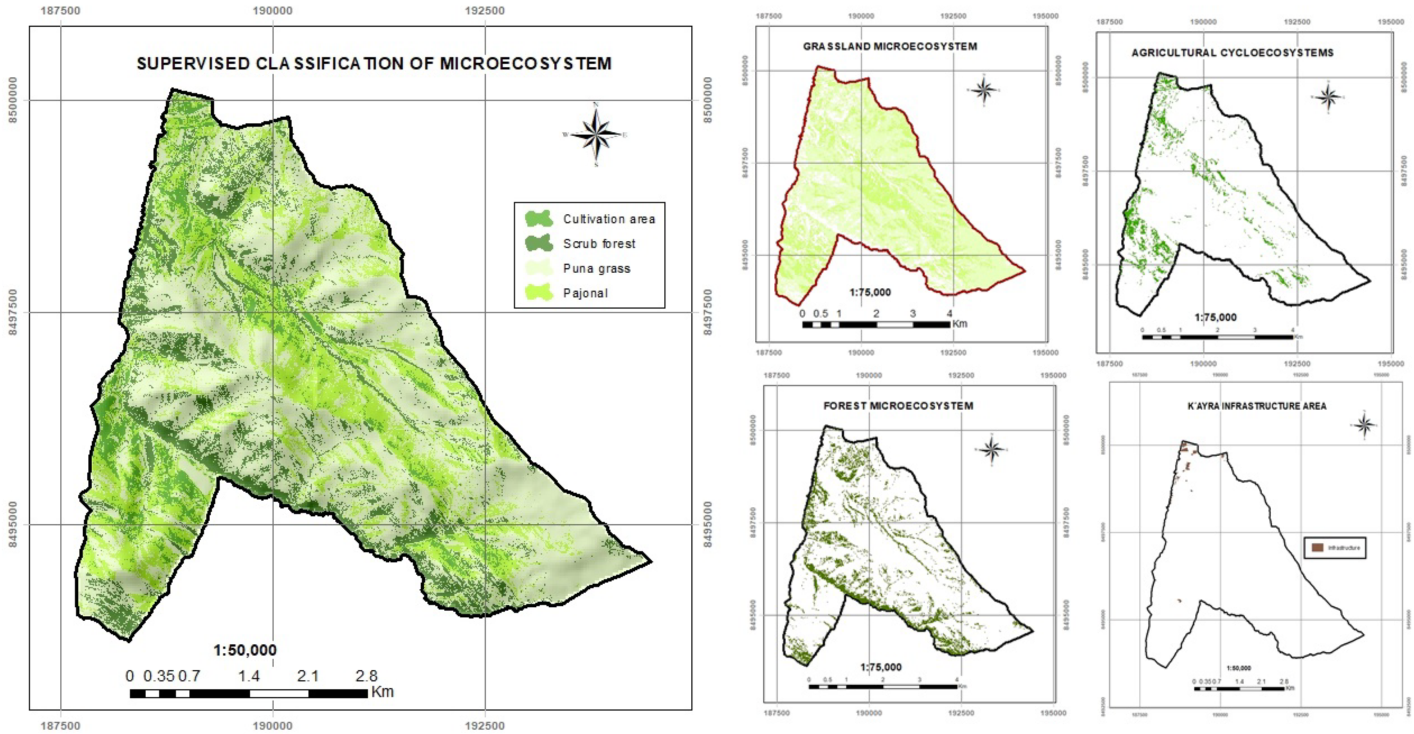

Figure 2. (a) Map of micro-ecosystems of the Kayra Agronomic Centre, (b) Grasslands, (c) Agriculture, (d) Forests, (e) Infrastructure.

The classification methodology implemented made it possible to determine the existence of 1,165 ha of grassland with potential for grazing animals [cattle (UV), sheep (UO) and alpacas (UA)] and 621 ha of forest ecosystem (natural and plantations in massifs) whose main potential is the production of wood for fuel or other uses and with possibilities for cattle and sheep grazing (table 2).

The Kayra Agronomic Center has an agricultural ecosystem, with Andean crops and a predominance of corn (*Zea mays* L.). This ecosystem also provides food for livestock in the form of stubble. Finally, the constructed area or infrastructure area was recorded (table 2).

Table 2. Ecosystems area of the Kayra Agronomic Center.

Microecosystem	Hectares
Grassland	1.165,00
Forest	621,00
Agricultural	327,30
Constructed	39,80
Total	2.153,20

Forest: natural and plantations in massif.

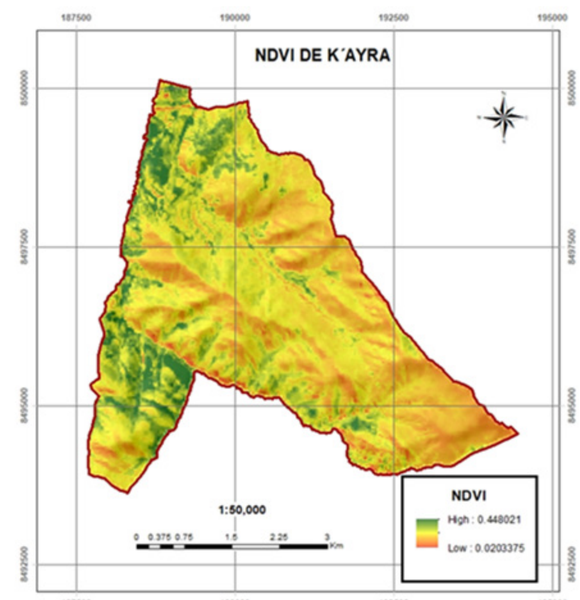

Figure 3. Normalized Difference Vegetation Index map (NDVI).

The classification of grasslands by ecosystems is a methodology that allows for analyzing grasslands in a holistic way (Zarria and Flores, 2015) and determining their carrying capacity (Estrada *et al.,* 2022). The study carried out at the Kayra Agronomic Center made it possible to identify three large ecosystems that can become management units as proposed by Zorogasúa *et al.* (2012) and corroborated by Pizarro (2017) in the study of degradation and vulnerability to climate change in high Andean grasslands.

Identified grassland plant communities

Three plant communities were identified as hillside grassland, shrublands with shrub species, and forests with tree species and grasses, as well as a crop area (figure 3).

The study identified 840 ha of the hillside grassland plant community with an NDVI ranging from 0.020 to 0.20; the second plant community was that of scrub grassland with 325 ha and NDVI from 0.20 to 0.30; as well as a grassland forest plant community with an area of 621 ha and an NDVI from 0.30 to 0.40. The NDVI classification showed that agricultural crops for the sampling period had a range from 0.40 to 0.44 and higher, and 39.80 ha of cultivars (figure 3).

NDVI from 0.020 to 0.44 indicates low NDVI and grasslands that are reaching senescence or have been disturbed by fires. Estrada and Ñaupari (2021), established that the NDVI for hillside grasslands in the dry season ranges from 0.10 to 0.70 and it can be elucidated that the NDVI range found for the grasslands of the Kayra Agronomic Center is lower, despite being located in a humid zone. These results are also lower than those found by Paredes (2019) for the grasslands of the central grasslands of Peru, with the assistance of the Modis Terra sensor (table 3).

Table 3. Plant Community area and NDVI.

Plant community	Area (ha)	NDVI
Hillside grassland	840.00	0.02 – 0.20
Shrub grassland	325.00	0.20 – 0.30
Grassland forest	621.00	0.30 – 0.40
Agricultural crops	39.80	0.40 – 0.44

NDVI: Normalized difference vegetation index

Animal carrying capacity per community, plant ecosystem, and study area

Condition and animal carrying capacity were estimated from grazing areas used at the time of assessment. Each of the three grazing zones was composed of the ecosystems of hillside grassland, natural forest and plantations in massifs, agricultural ecosystem, and constructed landscape.

The study determined that the condition of the pasture (table 4) in the Kayra Agronomic Center, considering cattle, sheep, and alpacas, is regular, showing that the Perolpuquio area has poor grasslands and the Fierroccata and Chequicocha areas have regular condition. The poor condition of the Perolpuquio area was mainly due to the fires that occurred in 2020 and 2021.

Table 4. Condition and animal carrying capacity per study area.

Study area	Pasture Condition			Animal Carrying Capacity		
	Cattle	Sheep	Alpaca	Cattle (UV.year^{-1})	Sheep (UO.year^{-1})	Alpaca (AU.year^{-1})
Perolpuquio	Poor	Poor	Poor	0.13	0.5	0.33
Fierroccta	Regular	Regular	Regular	0.38	1	1.5
Chequilccocha	Regular	Regular	Regular	0.38	1	1.5
KAC	Regular	Regular	Regular	0.30	0.83	1.11

KAC: Kayra Agronomic Center

The condition of the pasture in the Kayra Agronomic Center for the study period was 0.30 UV.year^{-1}, 0.83 UO.year^{-1} and 1.11 UA.year^{-1}, while for the Perolpuquio area, the carrying capacity for cattle was 0.13 UV.year^{-1}; 0.50 UO.year^{-1} and 0.33 UA.year$^{-1.}$ In the areas of Fierroccata and Chequiccocha it was 0.38 UV.year$^{-1,}$ 1.11 UO.year$^{-1,}$ and 0.33 UA.year^{-1} for cattle.

It was determined that the grasslands of the Kayra Agronomic Center have a carrying capacity with a tendency from regular to low or poor (table 4). Considering the ecosystem and climate map, it can be noted that these grasslands are below the parameters established by MINAM (2016) and show the effects of disturbances such as grassland burning, fires, and overgrazing (Chavez *et al*., 2017; Pizarro, 2017; Zorogasúa *et al.,* 2012).

Conclusions

The use of satellite images and high-resolution orthophotographs from the Kayra Agronomic Center, taken with unmanned aerial vehicles, made it possible to qualify ecosystems and develop land cover maps with high precision.

The study has identified four microecosystems that can be used as a basis for soil management at the Kayra Agronomic Center.

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