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Herbivory impact of *Odocoileus virginianus* and *Sylvilagus brasiliensis* on the paramo grasslands of the Antisana Hydrological Conservation Area.

Trabajo de integración curricular presentado como requisito para la obtención del título de Biólogo

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Dedication

A mis padres, por ser mi fuerza inquebrantable, mi refugio en los momentos difíciles y mi mayor ejemplo de amor y perseverancia. Gracias por creer en mí incluso cuando yo dudaba de mi capacidad. Sus sacrificios, apoyo incondicional y palabras de aliento han sido la base que me ha sostenido en esta etapa tan importante.

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Resumen

En este estudio se evalúo el impacto de la herbivoría del venado de cola blanca *(Odocoileus virginianus)* y el conejo andino *(Sylvilagus brasiliensis)* en el Área de Conservación Hídrica del Antisana mediante el diseño experimental de exclusiones donde se establecieron parcelas que impedía la presencia de estos herbívoros en cinco hábitats de este ecosistema. La metodología incluyó el uso de técnicas de muestreo no destructivas para medir la cobertura y composición de especies, y se aplicaron análisis estadísticos como ANOVA y análisis de clúster para identificar diferencias significativas. Los resultados revelaron que existen cambios importantes en la abundancia y la diversidad de especies vegetales entre los puntos de control y las áreas de exclusión. Las curvas de acumulación de especies mostraron una disminución en la riqueza de especies en áreas no excluidas, lo cual indica que la regeneración y reducción de especies es influenciada por la ausencia de herbívoros, mientras que el análisis de clúster y PCA indicaron cambios en la estructura vegetal, reflejando una mayor diferenciación entre hábitats en ausencia de herbívoros. Las plantas en zonas de exclusión se adaptan y exhiben una recuperación más efectiva, según la comparación de los centroides de los clústeres antes y después de un año de exclusión. Por último, la preservación de la biodiversidad en el páramo del Antisana depende de la eliminación de los herbívoros; esto establece una base sólida para las estrategias de manejo y conservación en este ecosistema de alta montaña. .

Palabras Clave:

Herbivoría, Diversidad vegetal, Exclusiones, Puntos de control, Venado de cola blanca, Conejo andino.

Abstract

In this study, the impact of herbivory by white-tailed deer *(Odocoileus virginianus)* and Andean rabbit *(Sylvilagus brasiliensis)* in the Antisana Hydrological Conservation Area was evaluated through the experimental design of exclusions where plots were established that prevented the presence of these herbivores in five habitats of this ecosystem. The methodology included the use of non-destructive sampling techniques to measure species cover and composition, and statistical analyses such as ANOVA and cluster analysis were applied to identify significant differences. The results revealed that there are important changes in the abundance and diversity of plant species between control points and exclusion areas. Species accumulation curves showed a decrease in species richness in non-excluded areas, indicating that species regeneration and reduction are influenced by the absence of herbivores, while cluster analysis and PCA indicated changes in vegetation structure, reflecting greater differentiation between habitats in the absence of herbivores. Plants in exclusion zones adapt and exhibit more effective recovery, according to the comparison of cluster centroids before and after one year of exclusion. Finally, the preservation of biodiversity in the Antisana páramo depends on the elimination of herbivores; this establishes a solid basis for management and conservation strategies in this high mountain ecosystem.

Keywords:
Herbivory, Plant diversity, Exclusions, Control points, White-tailed deer, Andean rabbit.

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Chapter 1

Introduction

1.1 Background

The Antisana paramo is a high mountain ecosystem located in the Andean region of Ecuador between the provinces of Napo and Pichincha, characterized by its unique biodiversity and its fundamental role in the regulation of water resources in the area [Aguirre et al., 2013].

In Ecuador, adequate preservation of the paramo is essential for the subsistence of thousands of people, either directly or indirectly. Many surrounding communities directly depend on this area for activities such as agriculture, livestock, and water collection, as it acts as a natural sponge that regulates the hydrological cycle. Indirectly, it is important to supply water to large cities as well as to generate energy. This highlights the significant relevance both from an ecological and economic point of view that this ecosystem has for the country [Irazábal Morales, 2016]. The availability of water to Quito depends largely on the preservation of the paramo ecosystems and the protected areas that surround them since these play a crucial role in its water supply [Beltrán et al., 2009].

In addition to their essential role in the regulation of the water cycle, which is a critical ecosystem service, paramos also provide several other crucial benefits. These include carbon storage, protection against soil erosion, and prevention of droughts and floods. Additionally, they serve as habitats for endemic species of plants, fungi, and animals, which have developed unique adaptations to thrive in this environment [Cuesta et al., 2014].

The Antisana paramo is located at altitudes ranging from approximately 3800 to over

4600 meters above sea level [Francou et al., 2004],[Minaya et al., 2016]. This elevation significantly impacts its climate, which is characterized by key weather conditions such as low temperatures, high ultraviolet (UV) radiation, and high relative humidity that promote fog formation. Due to its altitude, temperatures in the Antisana paramo are cold year-round. Nights can be especially cold, with temperatures ranging from 5 degrees to -10 degrees Celsius [Vargas et al., 2012].

In addition to normal climatic conditions, Antisana experiences considerable annual rainfall ranging from 900 to 1200 mm, mainly in the form of rain and snow. This precipitation plays a fundamental role in maintaining biodiversity and supplying water to nearby rivers and basins.

Coronel (2019) highlights that precipitation in the paramo ecosystem plays a crucial role in water regulation, an essential process to sustain life in the Andean region of Ecuador.

In this environment, one of the most notable species is the White-tailed deer *(Odocoileus virginianus ustus)*, a herbivorous mammal that has developed adaptations to survive in these conditions which include thick, long fur, flexible diet, ability to move on difficult terrain, among others. [Tellkamp et al., 2019]. White-tailed deer are artiodactyl mammals belonging to the family Cervidae. They are mainly found at altitudes ranging between 3,800 and 5,700 meters above sea level, although they can descend to lower altitudes during winter [Albuja Viteri, 2007].

The Antisana white-tailed deer are generally smaller than other lowland deer. They possess thick fur that allows them to withstand cold temperatures and a distinctive white tail used for communication within the group. For instance, in dangerous situations, they raise their tails to alert others, and when fleeing, the white tail serves as a guide through dense vegetation. These adaptive behaviors are complemented by their seasonal mobility, as they move in search of fresh food and shelter during extreme weather conditions, ensuring their survival in this challenging environment.

They generally live in family groups known as "herds." These herds comprise adult females and their young, while males are usually solitary or form temporary groups of young males when it is not mating season [García et al., 2016].

Figure 1.1: White-tailed deer (*Odocoileus virginianus*) in the Antisana paramo.

In the Antisana paramo, another characteristic species is the Andean rabbit (Sylvilagus brasiliensis), which plays an important role as a species adapted to life at high altitudes[García et al., 2016].

In the paramo, the Andean rabbit is a generalist herbivore that mainly consumes grasses, herbs, shrubs and herbaceous plants. It is important to note that the Andean rabbit's diet can vary depending on the seasonal availability of food and the particular composition of the flora in its environment [Moscarella et al., 2003].

By feeding on plants, they can carry seeds in their paws and snout, thus contributing to the regeneration of vegetation. Plant consumption by the Andean rabbit, as well as the White-tailed deer, can influence the composition of the paramo vegetation. This, in turn, has implications for the availability of food for other species and habitat structures.[Albuja Viteri, 2007].

Despite its small size, the Andean rabbit is an agile and fast animal. Their quick movements and leaps allow them to escape predators and move efficiently in their mountainous environment. It has natural predators, such as birds of prey such as the Black-chested Buzzard-Eagle *(Geranoaetus melanoleucus)*, mammals such as the Andean fox *(Lycalopex* *culpaeus)*, and the puma *(Puma concolor)*. [Minaya et al., 2016].

Figure 1.2: Andean rabbit (*Sylvilagus brasiliensis*) in the Antisana paramo.

The Antisana Ecological Reserve has a Hydrological Conservation Area (ACHA) by its Spanish acronym of approximately 84,5 square kilometers [Aguirre et al., 2013].

According to Tellkam et al. (2019), in ACHA there are six major habitats: Humid Herbaceous Vegetation, Dry Herbaceous Vegetation, Exposed Soil, Cushion plants, Shrubby páramos and Páramo grasslands. Each habitat has a representative flora (see Table 1.1).

(ACHA) differs significantly from other paramos in Ecuador due to its rich diversity of natural habitats. These habitats include a variety of ecosystems that support unique species and ecological processes, making it an essential area for biodiversity conservation and ecosystem services [Beltrán et al., 2009].

Typical landscapes of paramos are often characterized by the presence of cushion plants, whose predominance has significant implications for the hydrological cycle [Madriñán et al., 2013]. Specifically, in habitats where these plant species prevail, a favorable water balance is observed. Additionally, these plants help prevent erosion and create microhabitats that support the growth and persistence of other plant species [Rodríguez-Echeverría et al., 2021]. However, they are not the only dominant type of vegetation. Other key habitats are also observed, such as grass prairies, necessary for feeding the Andean rabbit and the white-tailed deer [Cleef, 1978]. Humid herbaceous vegetation is also observed where large wetlands are formed.

Table 1.1: Habitat Categories of vegetation in the Antisana Hydrological Conservation Area. Obtaining from: Tellkamp et al. (2019). Population Estimates and Habitat Selection of White-tailed Deer (*Odocoileus virginianus ustus*) in the Antisana Water Conservation Area, Ecuador.

Habitat Categories	**Descriptions**
Humid herbaceous vegetation	A mixture of small herbaceous plants with predominance of *Calamagrostis fibrovaginata, Geranium* sp., *Werneria nubicola, Valeriana rigida*, and occasional cushion plants; predominant habitat in Mangahurco.
Dry herbaceous vegetation	Similar to the previous one, but the composition is very similar; however, the NDVI is much brighter, indicating higher levels of photosynthesis, presumably due to greater humidity levels in the soil.
Exposed soil	Bare, exposed soil with sparse cushion plants; some of these areas now being recuperated as páramo grassland with *Calamagrostis intermedia.*
Cushion plants	A variety of cushion plants are covering large expanses of land within the reserve, usually on high ridges and humid valley bottoms, near streams; dominant species in this category are *Baccharis caespitosa, Plantago rigida, Valeriana aretioides, Xenophyllum humile, Axerella pedunculata* and, *Gentiana sedifolia*
Shrubby páramos	A mixture of *Calamagrostis intermedia*, various herbs, *Werneria nubicola* and *Valeriana rigida*, cushion plants and Shrubs, most commonly *Chuquiraga jussieui* and *Hypericum* spp.
Páramo grasslands	Grasslands heavily dominated by *Calamagrostis intermedia*; may have various herbs and small cushion plants growing among the bunchgrass.

1.2 Problem statement

Herbivory, an essential biological phenomenon, is the process by which animals feed on plants. In paramos ecosystems, herbivory plays a crucial role in the form and diversity of vegetation [Milchunas and Lauenroth, 1993]. This process not only shapes the plant community but also plays a vital role in nutrient cycling by facilitating the redistribution of essential elements for plant growth.

However, herbivory also impacts the water balance of these ecosystems since the consumption of plants by animals can alter the availability and distribution of water in the region. Thus, herbivory in the paramos is an interconnected and integral process that defines the fundamental characteristics of this ecosystem and its relationship with the key elements of the environment such as nutrient cycling, soil stability, and microclimate[McNaughton, 1984],[Augustine and McNaughton, 1998].

Deer and rabbits, prominent members of the mammalian class, are among the most common and abundant herbivores. These animals not only consume grasses, shrubs, and frailejones, but they also facilitate the spread of these and other plants through their feces, which act as a natural fertilizer[Rooney and Waller, 2003].

Depending on a number of factors, herbivory by deer and rabbits on paramos can have positive or negative effects. The interaction with other factors affecting this ecosystem, the selectivity of the plants they consume, and the intensity and frequency with which the animals feed are all factors. A moderate level of herbivory, for example, can encourage the regeneration of some plant species by decreasing competition for resources such as light and nutrients. However, overexploitation of important species can result from prolonged or intense herbivory.[Lundgren et al., 2020].

Herbivory by deer and rabbits in the paramos supports essential ecological processes, such as seed dispersal. By consuming fruits of key species like frailejones and defecating the seeds in new locations, these herbivores promote the colonization of new areas, maintaining ecosystem balance [Rooney and Waller, 2003].

On the other hand, the negative impact of herbivory is manifested in the ability of deer and rabbits to cause direct damage to plants. This phenomenon results in reduced biomass, alteration of morphology, decreased reproduction, and increased mortality of affected plants. These adverse effects impact the structure and composition of paramo vegetation and the provision of essential ecosystem services [Rooney and Waller, 2003].

If the impact that certain animals have on the vegetation of the paramo is not known, their effect on the ecosystem can be overestimated or underestimated, which can lead to the ecosystem being more vulnerable to sudden changes, compromising it.

1.3 Objectives

1.3.1 General Objective

Evaluate quantitatively the differential impact of herbivory by the White-tailed deer (*Odocoileus virginianus ustus*) and the Andean rabbit (*Sylvilagus brasiliensis andinus*) on the diversity and composition of plant communities in five representative habitats of the Antisana Hydrological Conservation Area through an experimental design of exclusions over one year.

1.3.2 Specific Objectives

- Validate the methodology by comparing the point intercept method with the grid method to determine their effectiveness and accuracy in assessing vegetation cover in the paramo ecosystem.
- Determine the differences in the diversity and abundance of plant species between deer exclusions and deer and rabbit exclusions in the different habitats of the paramo.
- Compare the impact of herbivory between exclusion areas and control sites, assessing vegetation characteristics such as species composition, coverage, and other ecological parameters in the paramo ecosystem.
- Compare the modifications in the vegetation structure between the exclusion areas in different habitats of the paramo to identify the effects of White-tailed deer and Andean rabbit herbivory on the physical composition and spatial arrangement of the plant communities.

Chapter 2

Theoretical Framework

2.1 Study site

The Antisana paramo, located in the Eastern Cordillera of Ecuador, about 50 km southeast of Quito, the capital of Ecuador, is one of the five most important paramos in the country. [Hall et al., 2017].

The Quijos River, a tributary of the Coca River, is formed from the basins located to the north, east, and south of the snow-capped and icy summit of Antisana, whose altitude reaches 5753 meters. The waters flowing from the glaciers and paramos of Antisana directly feed these basins, influencing the flow and water quality of the Quijos River. Similarly, the Antisana River, a tributary of the Napo River, originates in the basins located to the west and southwest of the volcano, where glacial melt and precipitation captured in the paramos also play a crucial role. Both rivers are not only part of the Amazon river system but also act as important water sources, indirectly contributing to the water supply of Quito through their connection to the regional hydrological network [Hastenrath, 1981].

The paramo vegetation and volcanic soil are essential for retaining and releasing water slowly; this contributes to reducing the impact of droughts and floods in low-lying areas [Buytaert et al., 2011].

In the Antisana paramo, a designated water conservation area known as the Antisana Hydrological Conservation Area (ACHA) is located. This area is set up to safeguard vital water resources originating from the volcano [Singh et al., 2023]. The ACHA covers a variety of ecosystems, such as exposed soil and paramo grasslands.

The vegetation acts as a natural sponge, absorbing water and slowly releasing it, ensuring a constant supply throughout the year [Tonneijck et al., 2010].

2.2 Ecology of paramo plants

The paramos of Ecuador are recognized for housing a rich plant diversity, which has adapted to extreme environmental conditions. In Antisana, there is a wide variety of plant species, including grasses, cushion plants, and bryophytes [Jimenez Ramirez, 2019].

Plant species in the paramo have developed several adaptations to survive extreme conditions, including tolerance to UV radiation, nutrient-poor soils, and sudden temperature fluctuations throughout the year. In addition to pubescent leaves, deep roots, and rosette growth minimize exposure to freezing wind, thus maintaining heat and humidity in the center of the plant [Grubb et al., 2020].

2.2.1 Plant-Herbivore interactions in the paramo

Interactions in paramos may be dynamic and complex and may have a significant influence on the structure and composition of vegetation. Over time, paramos plants have developed strategies to defend themselves against herbivory. In addition to herbivory, there are predation interactions and competition for limited resources, such as water and nutrients.[Renvoize, 2000].

These strategies include mechanical defense, which involves developing physical structures such as thorns and hard leaves, making it difficult for herbivores to access and eat the plants [CHANGE, 2012].

Another important strategy is chemical defense, whereby plants produce chemical compounds that will act as a deterrent. These deterrents include alkaloids, tannins, and cyanogenic glycosides that could be toxic or reduce flavor [Leon-Garcia and Lasso, 2019].

Herbivores can alter the structure of plant communities by favoring species that are less palatable or more resistant to herbivory. This can lead to the emergence of grass species and a decrease in shrub and rosette diversity. In areas where herbivores are abundant, ecological succession may be delayed; fast-growing plants will dominate while smaller species will be suppressed or eliminated. The presence of large and small herbivores affects soil fertility by compacting and reducing plant cover, thus affecting water absorption and nutrient accumulation. Excessive numbers of hervibores can cause long-term soil erosion and changes in the structure of plant communities [Renvoize, 2000]. In grasslands, these effects may be more pronounced, as the dominant herbaceous plants are adapted to herbivory and can regenerate quickly, which in turn may reduce species diversity. However, in other ecosystems, such as moors or forests, regeneration may be slower, and the loss of key species may have longer-lasting effects that are difficult to reverse due to the lower resilience of soil and vegetation[Cingolani et al., 2005].

2.3 Study methods in paramo

One widely used experimental method in ecology is the use of exclusions. This involves building barriers to prevent herbivores from interacting with plant communities. Researchers use this method to study the impact of herbivory on vegetation. For example, the use of exclusions for large and small herbivores has been effective in understanding and analyzing plant regeneration and ecosystem recovery in diverse natural areas [Tilman, 1989].

2.3.1 Experimental design with exclusions

Implementing exclusion studies is crucial in ecology to assess and understand how herbivory affects vegetation. By creating areas that herbivores do not have access to, researchers can isolate and analyze the specific impacts that these animals generate on plants. The designs of these experiments vary depending on the objectives of the study and the type of ecosystem in which they are applied.

There are 3 types of exclusion: total, partial, or temporary exclusions [Crawley, 1983].

Total exclusions

This type of exclusion requires the creation of high and dense fences or barriers that will prevent the access of all types of animals and organisms to the study area. These barriers are usually built with resistant elements such as barbed wire and metal mesh, and they even usually contain barriers below the ground to prevent animals from digging and entering them [Tilman, 1989].

Partial exclusions

This type of exclusion requires the creation of fences or barriers where a certain type of animal or organism is excluded, but access is allowed to others; for example, fences with barbed wire can exclude large animals, such as deer or grazing animals, while small animals, such as hares or insects, can easily enter. This type of exclusion allows the specific analysis of a certain type of animal in a given area [Barbour et al., 1980].

Temporary exclusions

In this type of exclusion, barriers or fences are used only for a certain period of time. Therefore, it is necessary to study the effects that animals can have on the ecosystem at different times of the year [Mueller-Dombois and Ellenberg, 1974].

Using partial exclusions can have several advantages, one of the main ones being the ability to control the presence or absence of animals in the environment. This allows researchers to focus on establishing comparisons between areas that have been excluded and those that have not. Data collection is key to developing models that allow us to understand better how animals interact in that environment [Gotelli et al., 2004].

While this technique has its advantages, it also has disadvantages and limitations, such as the cost, which can be very high, especially in areas of difficult mobility, and the need for constant monitoring and maintenance to keep it running throughout the study. The habitat can also be altered by changing the plant microstructure, which can have an impact on ecological relationships and the behavior of other animals not participating in the study. In addition, these exclusions can alter the plant community, potentially helping the spread of invasive species or altering the competitiveness that species have with each other.[Barbour et al., 1980],[Mueller-Dombois and Ellenberg, 1974].

Furthermore, exclusion study is a methodology that can be used in diverse ecosystems such as humid forests where total exclusions are used most of the time, tropical forests, and paramos where partial exclusions are the best choice, which makes it a vital tool for the study of ecology.

2.3.2 Vegetation sampling and monitoring

In the paramo, studying vegetation is crucial, and sampling and monitoring are key to understanding the composition and structure of plant species in this environment [Mueller-Dombois and Ellenberg, 1974]. Using different techniques, researchers obtain precise and conclusive data that are the key to managing natural resources.

Among these studies, there is the quadrant sampling method, which consists of establishing plots of a varying sizes depending on the study area where all the species present will be recorded and counted. This will help us to have data on the density and composition of the environment.

An advantage of using this method is that it provides detailed data on vegetation, offering a comprehensive assessment of diversity. However, it is laborious and time-consuming to apply effectively, especially in areas that are difficult to access or span large regions. The methodology is particularly effective in habitats with dense and diverse vegetation, such as rainforests and tropical forests, where capturing the spatial variability of species is essential [Taylor et al., 1993].

Another method widely used in ecology is transect sampling, which consists of straight lines of land in the study area, where all the species that intersect the line are counted and recorded. This technique is efficient if the time it takes to carry it out is considered, and it is generally used to determine the spatial distribution patterns of the species [Levin, 1988], [Welles and Cohen, 1996]. A common disadvantage of this method is that if the transects are not well distributed, it may not consider all the species found in that ecosystem; therefore, the data taken will vary and will depend on the correct implementation of the same [Welles and Cohen, 1996].

A fast and effective technique is the point intercept method, which is widely used in studies on vegetation to estimate the coverage and relative abundance in an ecosystem. It consists of establishing fixed points along transects or exclusions and generally using a rod that will be vertical to the ground to count and record all the species that intercept it. These points can be evenly distributed, allowing these regular intervals to cover the entire area, or rods can be placed randomly in the ground, trying to cover the largest area to record the species [Levy and Madden, 1933]. The size of the plots used in this method can significantly influence the percentage of cover. Smaller plots may not capture the full variability of the ecosystem, while larger plots tend to offer a more accurate representation by including greater habitat heterogeneity. This is a non-destructive technique, which means that the environment will not be affected when it is implemented. A common important disadvantage of using it is the bias that can occur on the part of the observer since the data collection will be affected by the precision and experience of the researcher. In addition, it may not consider all species if the points are not well distributed. This bias is also a problem in other techniques, such as quadrat sampling. In addition, the line transect method, although robust, can be influenced by the observer's accuracy in identifying and recording species along the transect. [DW, 1953].

One of the most used and preferred techniques by researchers is grid sampling. This technique consists of a generally small frame divided into smaller parts, making a grid, and this is used to estimate the coverage of the species. The use of this technique is easy: the grid is placed on the ground, and within each grid, all the species and their percentage cover are recorded. Typically, the grid measures one square meter, and the internal grids are established according to the needs of the researcher [Greig-Smith, 1983], [Pielou, 1966].

This technique has many advantages, the main ones being precision, ease of repetition, and a clear visualization of the species. On the other hand, it is a technique that requires time and effort since it can be more cumbersome than other sampling techniques [Jenkins et al., 2003].

The point intercept method method and grid sampling are techniques used to estimate plant species cover and composition. Square point is a fast and less invasive technique ideal for large areas. It focuses on specific points along transects, providing data on species cover and frequency. On the other hand, grid sampling is more detailed and systematic. It is more laborious and time-consuming, making it less suitable for large or hard-to-access areas.

2.4 Previous studies and cases

2.4.1 Impact of herbivory on mountain ecosystems

The effects of herbivory in several mountain ecosystems, including paramos, have been studied. In Colombia, in the Chingaza paramo, which is characterized by the presence of humid vegetation, shrub thickets, grasslands, and frailejones, it has been shown that the elimination of herbivores increases the biomass and variety of native species [Ramsay, 1992].

All this is thanks to the reduction of grazing. Another study in Venezuela pointed out the preference of herbivores for woody plants, causing grasses to spread, so the exclusion of these animals served to recover woody species and led to a notable improvement in soil structure. The study was conducted in the Venezuelan paramos, characterized by a mix of grasslands and woody plants, including common species like frailejones and other shrubs adapted to the high-altitude conditions [Cingolani et al., 2003].

In the Alps, herbivory also has a significant impact on plant communities. A study conducted in the Gran Paradiso National Park in Italy for ten years determined that the reduction in grazing by deer and ibex increased the population of herbaceous species as well as the total biomass [Tyler et al., 2006].

In Argentina, a study suggests that the management of grazing species is crucial for the conservation of biodiversity. This study revealed that the exclusion of sheep and guanacos from the environment promoted the growth of native species [Cheli et al., 2016]. Some of the native plants that benefited from this exclusion include grass species such as *Stipa neaei* and *Poa ligularis*, as well as shrubby plants such as *Larrea divaricata* and *Atriplex lampa*.

2.4.2 Studies in the Antisana paramo

According to Buytaert (2011), the Antisana paramo, being one of the most representative of Ecuador, has been the subject of various studies, including the influence of herbivory and ecological dynamics, among others.

A study carried out for the conservation of the Andean paramos found that the exclusion of these animals, which included both domestic herbivores like cattle and sheep, as well as wild herbivores such as the White-tailed deer *(Odocoileus virginianus)* and the Andean rabbit *(Sylvilagus brasiliensis)*, led to an increase in biomass and species diversity, in addition to the regeneration of native species. Therefore, it was concluded that the proper management of herbivores, as well as the reduction of the presence of grazing, is essential for the conservation of the paramo, including the Antisana paramo [Cuesta et al., 2014].

Another study by Hofstede and Sevink (1996) evaluated the impact of livestock herbivory on vegetation structure. The results showed that the continued presence of domestic herbivores negatively affects vegetation cover, increasing erosion. This study indicates the need to implement management strategies to reduce grazing pressure and protect the ecological integrity of the paramos[Hofstede et al., 1996].

Chapter 3

Methodology

This study was based on the use of exclusions to isolate the herbivores present in the study area and sampling techniques for data collection. In addition, a validation of the different methodologies was carried out, and R-statistical software was used as a tool for data analysis.

3.1 Choice of study area

The area of the Antisana Hydrological Conservation zone is approximately 84,5 square kilometers. This area is composed of different habitats, including humid herbaceous vegetation, dry herbaceous vegetation, exposed soil, cushion plants, shrubby paramos, and paramo grasslands [Tellkamp et al., 2019].

The place for the implementation of the exclusions was based on various ecological and logistical parameters, as the altitude of the land reached 4100 meters above sea level, in addition to trying to cover all the different habitats present in the area. Therefore, two different types of partial exclusions were implemented: one for rabbits and deer, one exclusively for deer, and a control. These exclusions and the control were placed at an altitude between 4000 and 4100 meters above sea level. They were placed in the following habitats: humid herbaceous vegetation, dry herbaceous vegetation, exposed soil, cushion plants, and paramo grasslands.

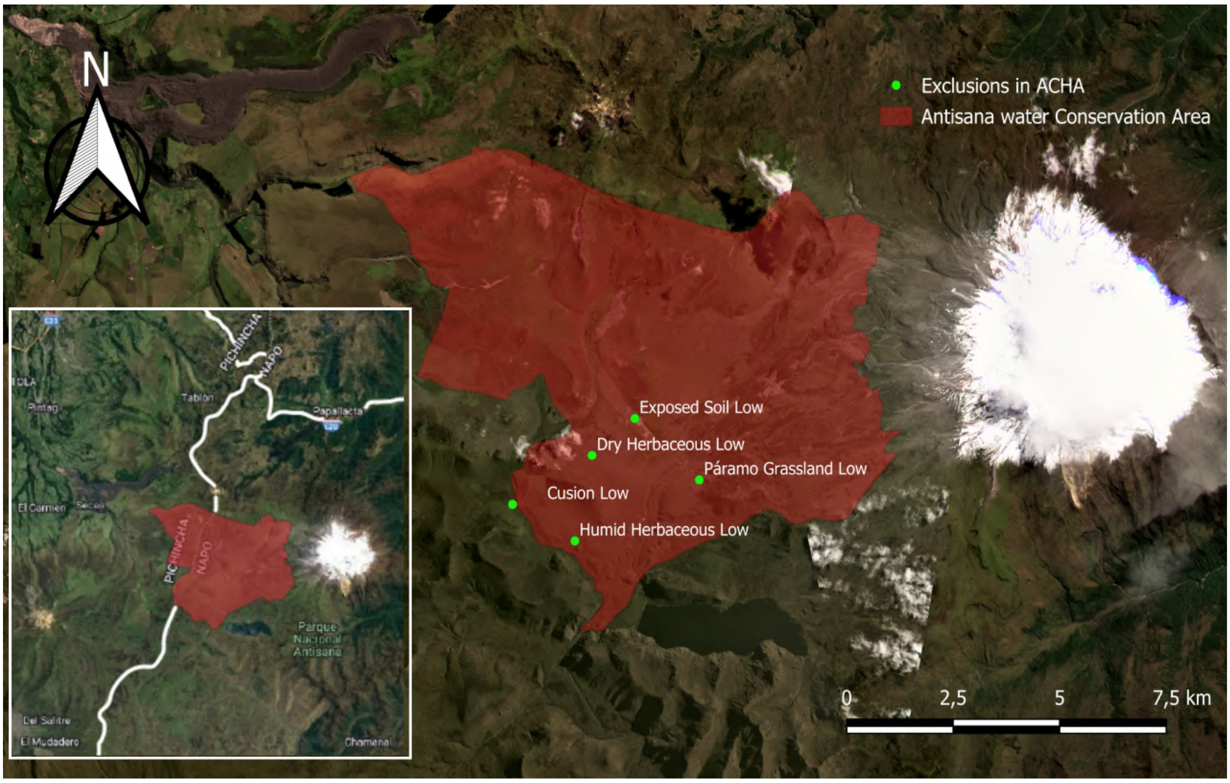


Figure 3.1: Locations where exclusions of rabbits and deer, deer, and control were placed in the different habitats of Antisana Hydrological Conservation Area in the Antisana paramo.

3.2 Building of exclusions and control sites

The two different types of partial exclusions were created with rectangular posts, barbed wire, and metal mesh, and the control was with half-inch PVC pipes. These exclusions and controls are delimited by approximately 100 meters from each other to ensure the representativeness of the samples and to minimize possible interferences between treatments.

The deer exclusion barrier is a rectangular construction with dimensions of 2 meters wide, 3 meters long, and 1.60 meters high. This barrier is surrounded by approximately ten lines of barbed wire, separated from each other from ground level to a height of 1.40 meters. This implementation aims to create a controlled environment to assess deer behavior and its impact on paramo vegetation.

Figure 3.2: Exclusions for deer in the paramo grasslands of Antisana Hydrological Conservation Area in the Antisana paramo.

In addition, joint exclusions for rabbits and deer have been implemented, consisting of a mesh buried in the ground at a depth varying from 30 centimeters to a height of 80 centimeters to one meter. This also maintains the characteristics of the rectangular structure and the dimensions mentioned above.

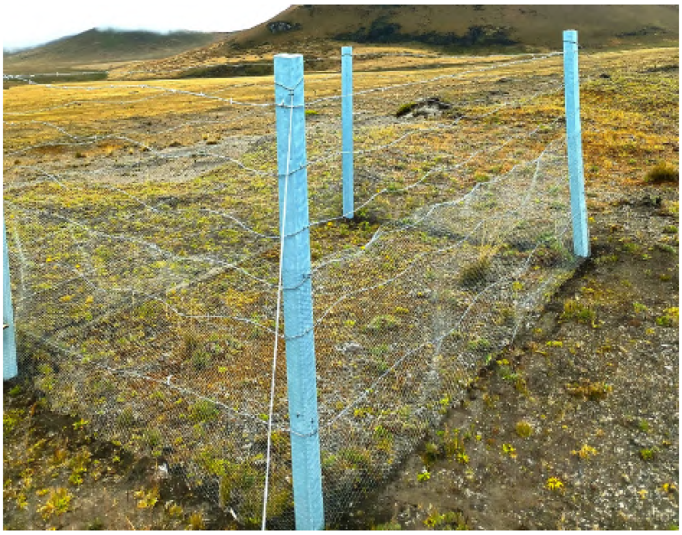


Figure 3.3: Exclusions for rabbits and deer in the exposed soil of Antisana Hydrological Conservation Area in the Antisana paramo.

Finally, the control has the same dimensions, length, and width as the exclusions, but it only has PVC pipes buried in the vertex to allow the animals to enter.

3.3 Data collection

Data were collected using two different methodologies: the grid method and the point intercept method. The grid method was used for general data collection, while the point intercept method was employed both for methodological validation and to measure the impact of herbivory.

3.3.1 Grid method for methodological validation

This method consists of using a square meter grid divided into smaller quadrants of 20 per 20 centimeters, having a total of 25 quadrants. For data collection, a voice recorder was used where the necessary parameters were recorded for faster data collection in the field, in addition to the GPS Status software to have the exact location of the exclusions. This method consists of placing the grid on the vegetation and recording all the parameters required for the study.

Among the parameters taken into account at the time of registration were the weather, UTM coordinates, date, to which exclusion it belongs, the quadrant, the name of the species, the coverage in square centimeters of each species, and to which sub-quadrant it belongs. Once all this information was collected, it was transferred to a database (see Table 3.1).

In this study, our exclusions have 6 square meters, where a square meter was chosen at random for data collection; the square meter selected was called a quadrant, which could be from 1 to 6, where all the plant species and their coverage in square centimeters present in each sub-quadrant of the grid were recorded. Then, a different square meter was chosen, which was called a microhabitat, taking into account the existence of a greater richness of plant species for its selection.

Table 3.1: Example of a database table using the grid method.

Weather	**UTM Coordinates**	**Date**	**Exclusions**	**Quadrant**	**Plant name**	**Cover (cm2)**	**Sub-quadrant**
Cloudy	17M 805680 9942372	20/5/2023	Cushion plants Control	5 Random	*Species 1*	60	A1
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
Cloudy	17M 805680 9942372	20/5/2023	Cushion plants Control	5 Random	*Species n*	50	A1

3.3.2 Point intercept method for methodological validation and herbivory impact

The point intercept method was used, which is a fast and effective method for counting and recording plant species. This method consists of recording all the species that touch the rod that is thrown perpendicularly to the ground. In this case, to speed up the data collection in the field, as in the grid method, a voice recorder was used for the record, and the GPS Status software was used for georeferencing, which helps us to have the exact coordinates of the exclusions for future data collection.

According to DW Goodall (1953), approximately 100 points are used in the transects or plots to have optimal data. In this study, 96 reference points were used and distributed as follows: from each vertex of the exclusion, 20 centimeters were separated lengthwise and widthwise. Once this was done, 12 points began to be counted along the exclusion and 8 points across, managing to cover the entire exclusion.

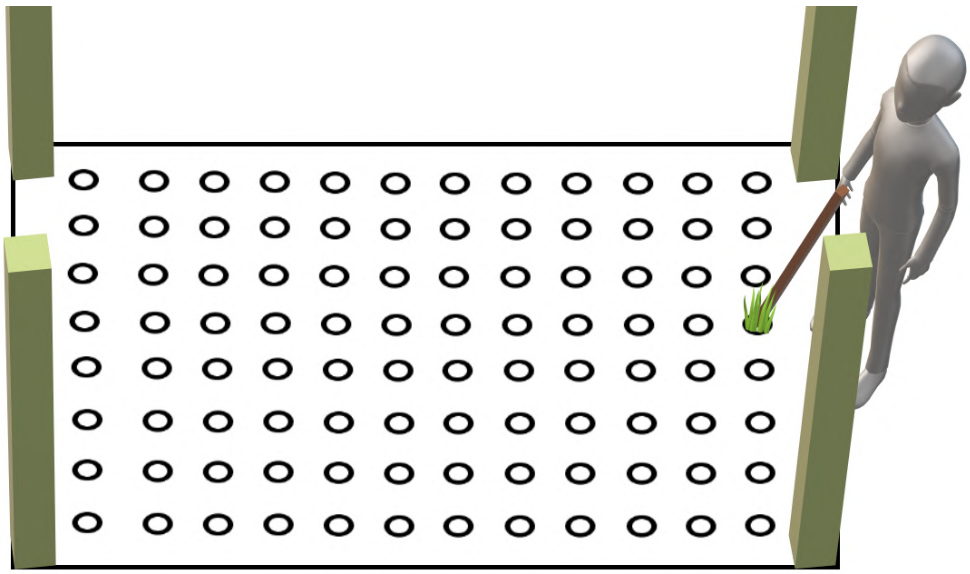


Figure 3.4: Graphic representation made in Adobe Illustrator of the data collection using the point intercept method.

Among the new parameters taken into account at the time of recording were the sampling point and the level of vegetation growth. Once all this information was collected, it was transferred to a database (see Table 3.2).

Table 3.2: Example of a database table using the point intercept method.

Weather	UTM Coordinates	Date	Habitat	Exclusion	Point	Ground level	Vegetation level one	Vegetation level two
Cloudy	17 M 805680 9942372	20/5/2023	Exposed soil	Deer	*1*	Species 1	Species 1	Species 1
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
Cloudy	17 M 805680 9942372	20/5/2023	Exposed soil	Deer	*96*	Species n	Species n	Species n

3.4 Methodology validation

To ensure that the grid and point intercept techniques used were the most appropriate, a validation of the methodology was carried out. Evaluating both their precision and efficiency, this procedure included a thorough comparison of the results obtained with both techniques. A comparison was made of the total contacts that each of the techniques recorded, as well as the percentage of cover of the plant species at the different sampling points.

It is important to note that the validation was carried out only with the control sites, which made it possible to ensure that natural variations in the ecosystem did not cause variations in abundance and plant cover.

This comparison made it possible to identify the technique that best adapted to the conditions of the paramo, thus guaranteeing the integrity of the data obtained during the study.

3.5 Statistical analysis for herbivory impact

Once the data was collected in the field, it was entered into a digital database for further cleaning. This process included verifying that the species names, sampling points, and exclusion coordinates matched the recordings taken in the field. In addition, it was ensured that the plant species were correctly classified within their corresponding vegetation level and that they did not contain any errors.

To begin the analysis, comparative bar graphs were generated to visualize the total number of contacts of the plant species throughout the study area, both at the first visit and at the follow-up one year later. These graphs include one that shows the total number of contacts in each habitat, others that show the number of contacts of each species in a specific habitat. In addition, graphs are shown that compare the total number of contacts at control and exclusions. After this, bar graphs were generated that represented the percentages of cover, comparing the original data with those obtained one year later. These graphs include an overview of the percentage of cover in each habitat of the study, as well as specific graphs for each species in a single habitat and at the corresponding exclusions and control.

After creating the contact and percentage graphs, the species accumulation curve graphs are made. This is done with the help of the R-Statistical software vegan package and the specaccum function.

A graph is created to interpret the species accumulation in all habitats. A graph of the accumulation curve is created for each habitat. A graph is created representing all the exclusions and control, and finally, the graph is created for each control and exclusion.

3.5.1 Cluster analysis

A cluster analysis was performed, necessary to identify patterns and groupings in the exclusion and control of the study area. The most important columns of the data were selected, which are the name of the species, the exclusions to which they belong and the percentage of cover and were transformed into a wide format, then the NA were replaced by 0 since this does not influence the analysis, but it is necessary because the statistical software does not allow the necessary operations to be performed with empty data, after this the data were normalized. A Euclidean distance matrix of the data was calculated. The optimal number of clusters was determined by the accumulated variance method with the help of the elbow method. A principal component analysis (PCA) and multidimensional scaling (MDS) were performed.

The process carried out in the analysis is detailed in the attached flowchart, which has the necessary functions of the different libraries in R-Studio, including dplyr, tidyr, ggplot2, factoextra, and vegan.

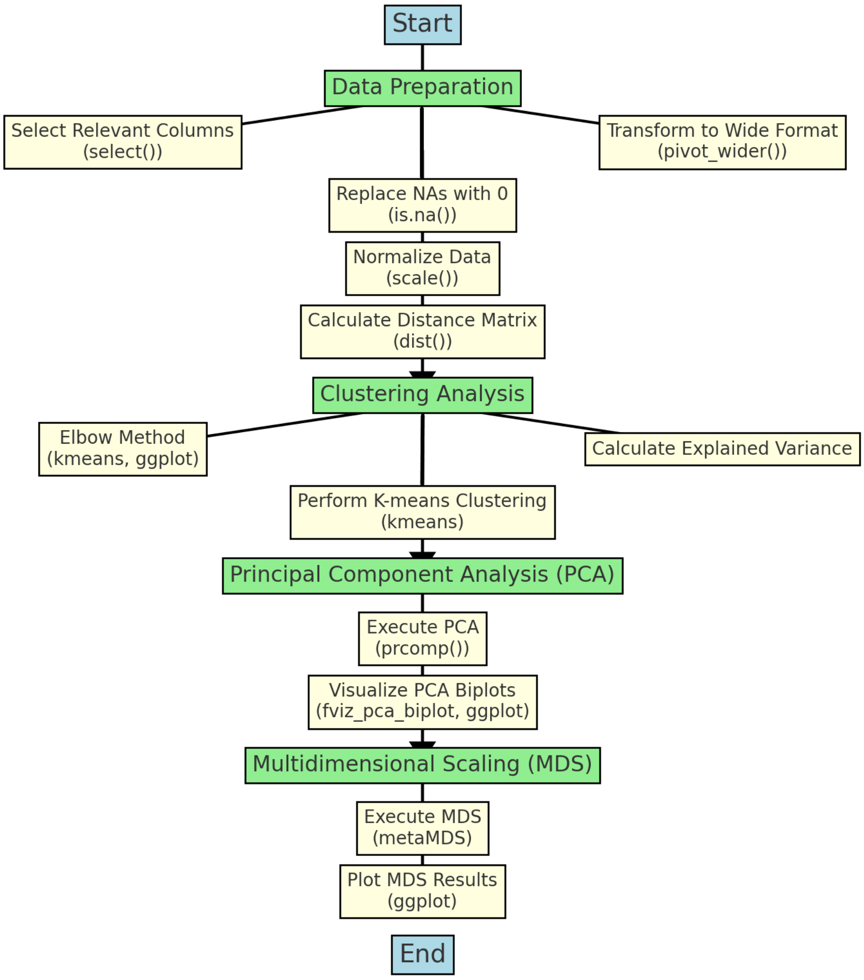


Figure 3.5: Flowchart of the clustering analysis performed in R-Studio, illustrating the use of statistical techniques to explore plant diversity and ecological interactions in different exclusions and control of the Antisana Hydrological Conservation Area.

In addition to the main analysis, comparative analyses of the homogeneity and separation of the groups formed were performed, and finally, a comparison of the centroids obtained by K-means.

As a final step in the statistical analysis, a repeated measures ANOVA was performed to assess significant differences in the percentage cover of plant species. This analysis allowed us to study how the clusters that were formed from the normalization of the data affect the variability within and between groups. This was done for both the original data and those taken after one year.

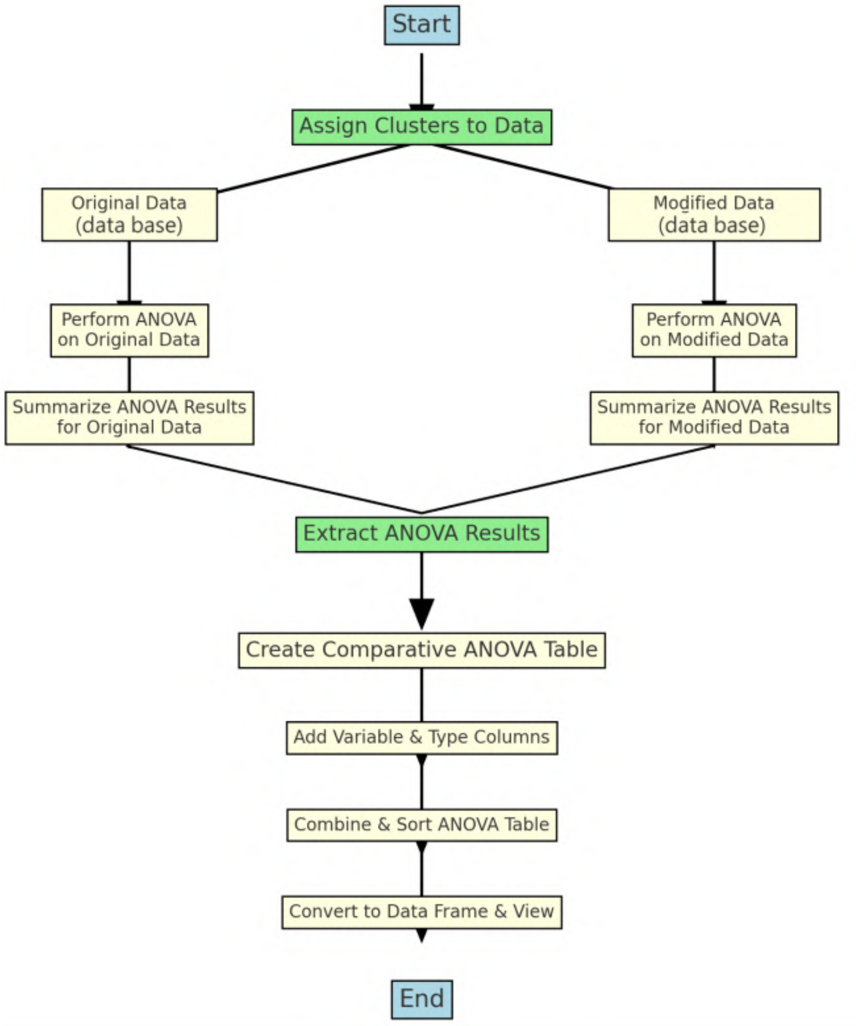


Figure 3.6: Flowchart of repeated measures analysis of variance (ANOVA) performed in RStudio illustrating the use of statistical techniques to explore plant diversity and ecological interactions in different exclusions and control of the Antisana Hydrological Conservation Area.

Chapter 4

Results

This section presents the findings of our study on vegetation in the ACHA, focusing on the impact of herbivory and the validation of the methodologies used. We will analyze in depth the cover and species composition in various habitats, as well as the differences found between the control and exclusion areas created to assess the impact of herbivory.

4.1 Methodological validation

4.1.1 Total numbers contacts

As a first step, the total number of plant species found using each method was recorded. The results were presented in a comparative graph showing the efficiency of each technique in representing species richness in the study area, which is a key component for assessing plant diversity.

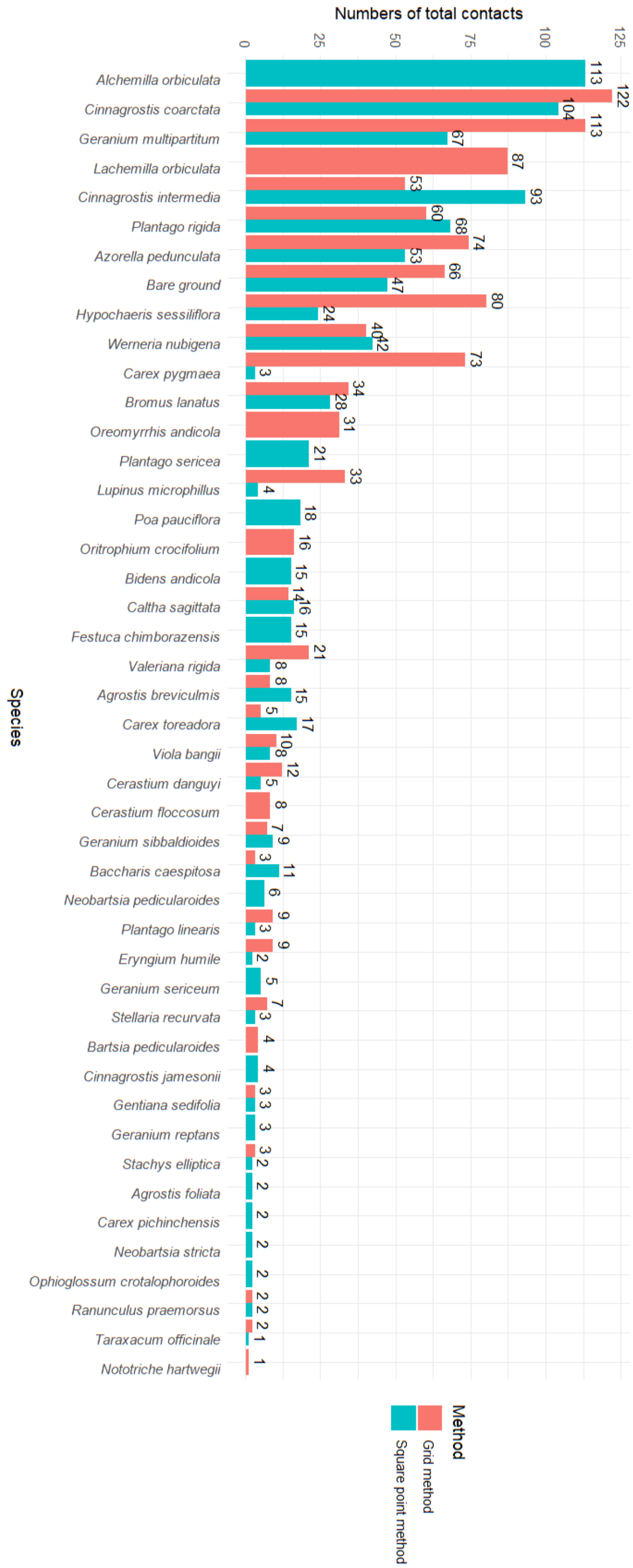


Figure 4.1: Total number of contacts of plant species using the point intercept method and grid method at the five different controls in the different habitats of the ACHA.

As can be seen in Table (4.1), the point intercept method detected a greater number of plant species compared to the grid method.

Table 4.1: Plant species detected exclusively by each method at the controls of the ACHA.

Point Intercept Method	Grid Method
Agrostis foliata	*Bartsia pedicularoides*
Alchemilla orbiculata	*Cerastium floccosum*
Bidens andicola	*Lachemilla orbiculata*
Carex pichinchensis	*Nototriche hartwegii*
Cinnagrostis jamesonii	*Oreomyrrhis andicola*
Festuca chimborazensis	*Oritrophium crocifolium*
Geranium reptans	
Geranium sericeum	
Neobartsia pedicularoides	
Neobartsia stricta	
Ophioglossum crotalophoroides	
Plantago sericea	
Poa pauciflora	

4.1.2 Percentage of plant species coverage

In the second step, the percentage coverage of each plant species at the control in the different habitats was calculated. This step is important because it will help us understand how vegetation is structured and distributed in space.

Each graph below represents the percentage of coverage of plant species in different habitats at their control. This helps us visually and quantitatively compare the effectiveness of each method and how the species are distributed in an environment, helping us with subsequent analyses.

In Figure 4.2, the species *Cinnagrostis intermedia* showed the highest coverage in both methods, with 96.88% coverage in the point intercept method and 84.48% in the grid method. Other species, such as *Werneria nubigena* and *Alchemilla orbiculata* also showed significant coverage, with 14.58% and 4.98%, respectively, in the point intercept method.

The point intercept method detected more species with high coverage compared to the grid method. For example, *Stellaria recurvata* showed 3.12% coverage, while in the grid method, it was 0.78%.

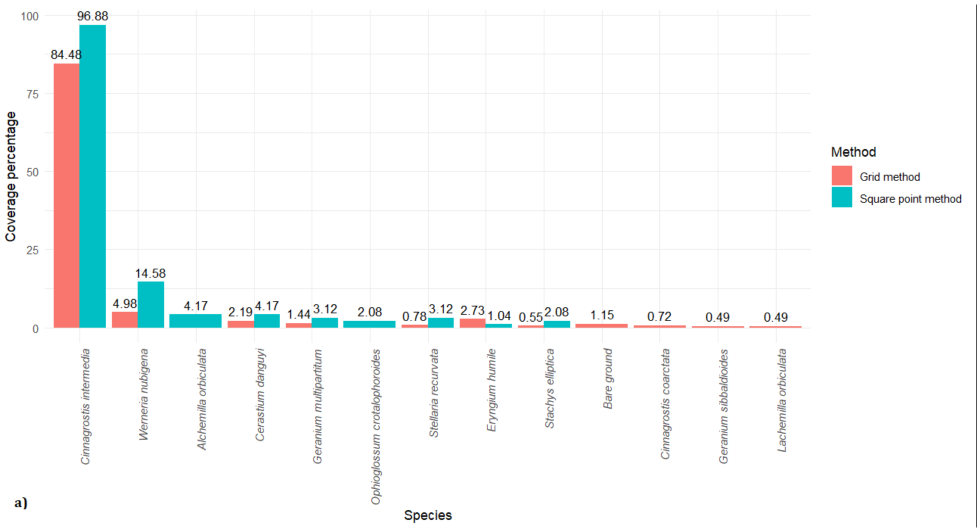


Figure 4.2: Percentage of coverage of plant species at the controls in different habitats of ACHA. a) Paramo grasslands

Bromus lanatus shows a high coverage in both methods, with a slight superiority in the point intercept method (29.17%) compared to the grid method (27.92%) (Figure 4.3). *Geranium multipartitum* also has a considerable presence in both methods, with a coverage of 34.38% for the point intercept method and 13.73% for the grid method. In addition, seven species appear that are detected only by the point intercept method and ten by the grid method.

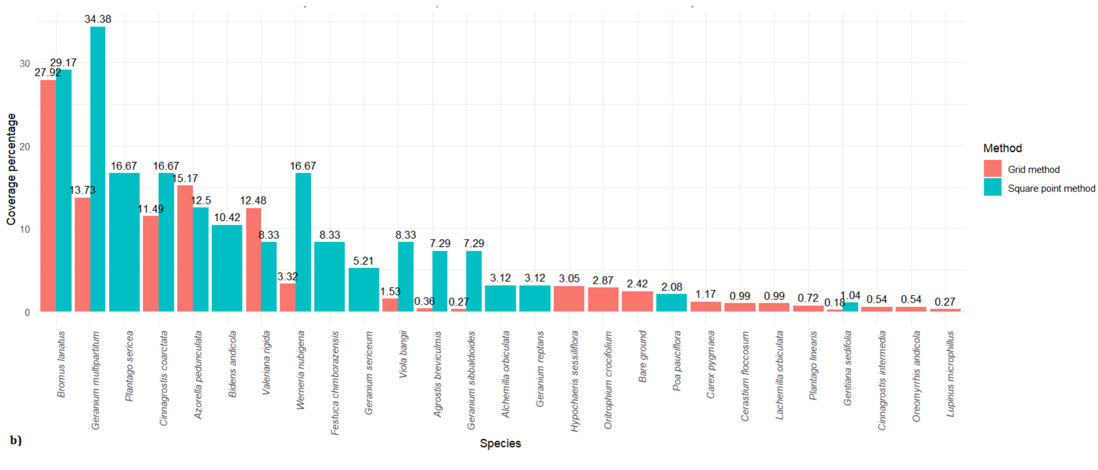


Figure 4.3: Percentage of coverage of plant species at the control point in different habitats of ACHA. b) Dry herbaceous vegetation

Alchemilla orbiculata stands out for having the highest coverage with the point intercept method (67.71%) compared to the grid method, where it is not represented. Other species, such as *Plantago rigida* and *Cinnagrostis coarctata*, also show considerable differences between both methods (Figure 4.4), which may be due to the structure and layout of the wet grassland, where the point intercept method seems to capture the dominant species better.

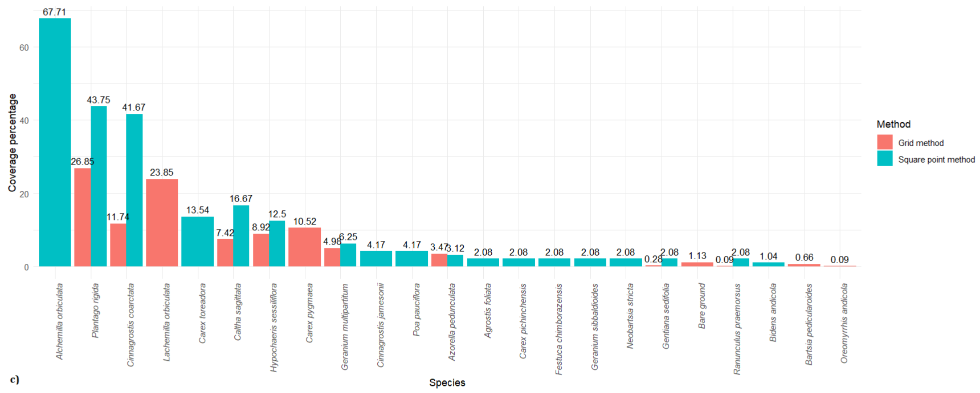


Figure 4.4: Percentage of coverage of plant species at the control in different habitats of ACHA. c) Humid herbaceous vegetation

It is evident that the surface presents the greatest difference between methods, with a significantly higher coverage in the grid method (64.48%) compared to the point intercept method (48.96%) (Figure 4.5). However, *Lupinus microphyllus* presents an interesting difference, with a higher coverage using the grid method (12.94%) compared to the square point method (4.17%). In addition, six species have a percentage only for the point intercept method and eight species for the grid method.

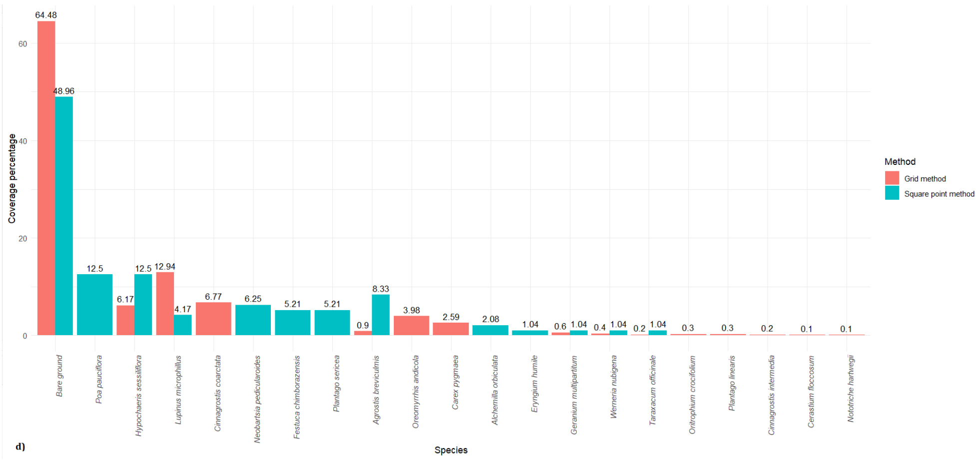


Figure 4.5: Percentage of coverage of plant species at the control point in different habitats of ACHA. d) Exposed soil

Observe that *Alchemilla orbiculata* shows a higher coverage when using the point intercept method (40.62%) compared to the grid method, where no percentage is found (Figure 4.6). Other species, such as *Azorella pedunculata*, also show a significant difference between the methods, with a coverage of 39.58% in the point intercept method and 34.57% in the grid method. The most notable difference is for *Cinnagrostis coarctata*, which shows a higher coverage in the point intercept method (50%) compared to the grid method (10.58%).

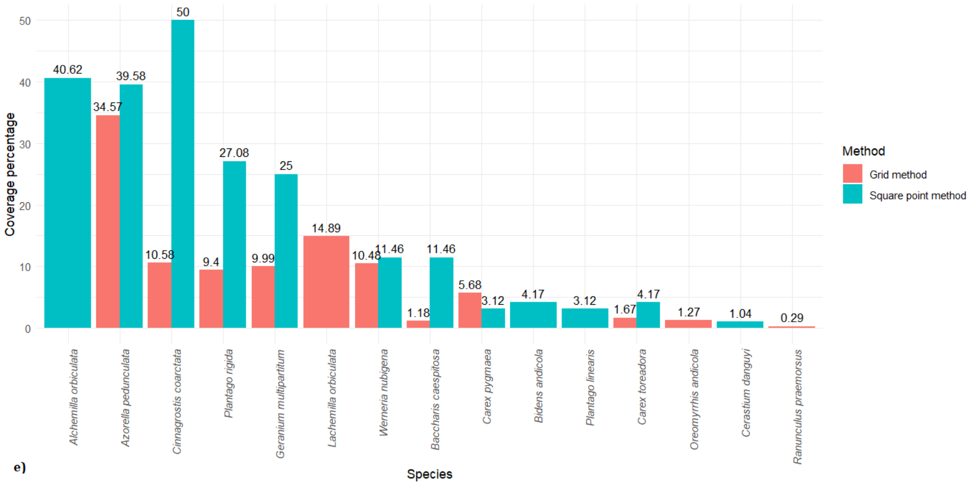


Figure 4.6: Percentage of coverage of plant species at the control point in different habitats of ACHA. e) Cushion plants

4.2 Hervibory impact

4.2.1 Total numbers of contacts

The bar graph presented shows the total number of contacts of plant species using the point intercept method, comparing data taken in March 2023 and October 2024.

Alchemilla orbiculata stands out as the most predominant species in both periods, showing a slight increase in the number of contacts, going from 294 in 2023 to 305 in 2024. On the other hand, species such as *Azorella pedunculata* show a more marked increase, which could be related to a favorable change in habitat conditions.

Species such as *Ophioglossum crotalophoroides* and *Senecio chionogeton*, which had been recorded in 2023, no longer appear in 2024.

The other species show a slight increase or a minimal decrease.

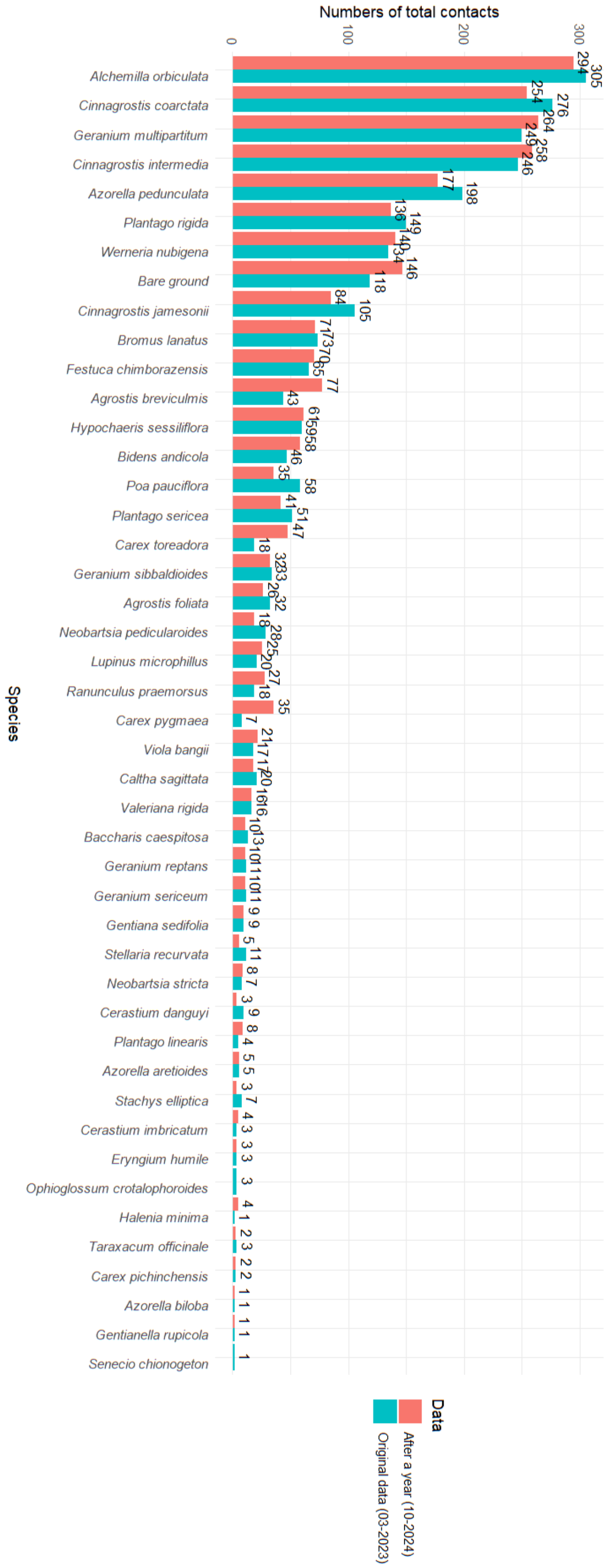


Figure 4.7: Total number of contacts of plant species using the point intercept method of the original data and one year later in the ACHA.

4.2.2 Total numbers of contacts in habitats

This graph represents the total number of contacts between plant species that have occurred in the different types of habitats in the ACHA.

In the cushion plant habitat, the number of contacts decreased from 630 in the original data to 582 after one year. In the humid herbaceous vegetation, an increase is recorded, going from 569 to 619 contacts between March 2023 and October 2024. For the dry herbaceous vegetation, contacts remain stable, with 555 and 556.

In the paramo grassland, the number of contacts remains practically the same, with 387 in the original data and 386 after one year. Finally, in the exposed soil, a slight increase in contacts is observed, going from 346 in March 2023 to 376 in October 2024.

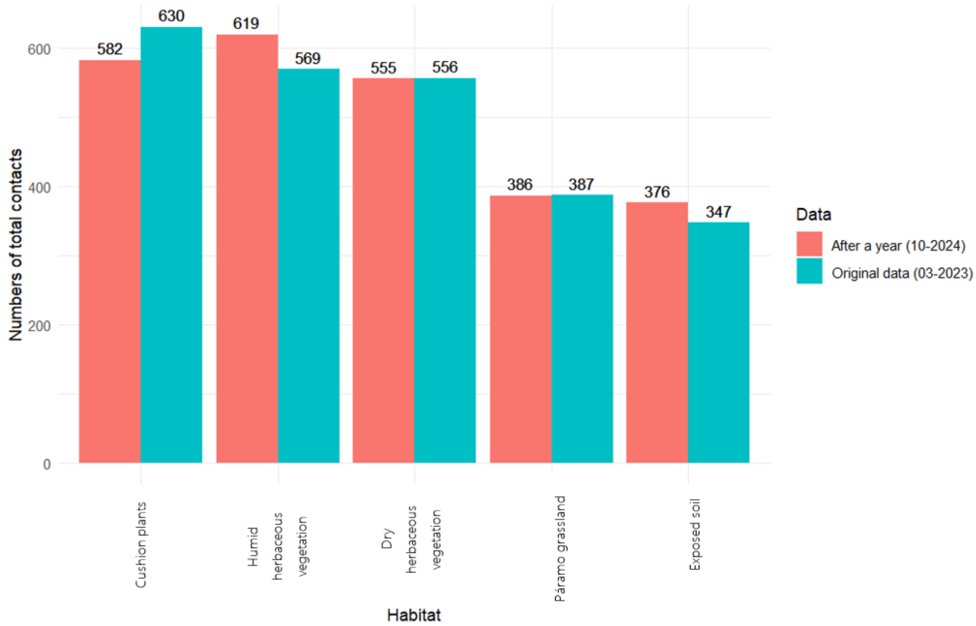


Figure 4.8: Total number of plant species contacts in the different habitats of ACHA using the square point method of the original data and one year later.

4.2.3 Total numbers of contacts in each habitat

For this case, five comparative bar graphs are presented, each one representative of a habitat.

In the paramo grassland habitat in the (Figure 4.9), the species that stands out the most for its total number of contacts is *Cinnagrostis intermedia*, with an increase from 246 contacts in March 2023 to 258 in October 2024. This reflects that this species remains the most representative in this habitat.

Werneria nubigena and *Geranium multipartitum* also show considerable numbers of contacts, with *Werneria nubigena* going from 43 contacts in 2023 to 48 in 2024, while *Geranium multipartitum* from 36 to 39 contacts between both periods.

Cerastium danguyi, *Stellaria recurvata* and *Stachys elliptica* show a decrease in the number of contacts. While *Ophioglossum crotalophoroides* disappears after one year.

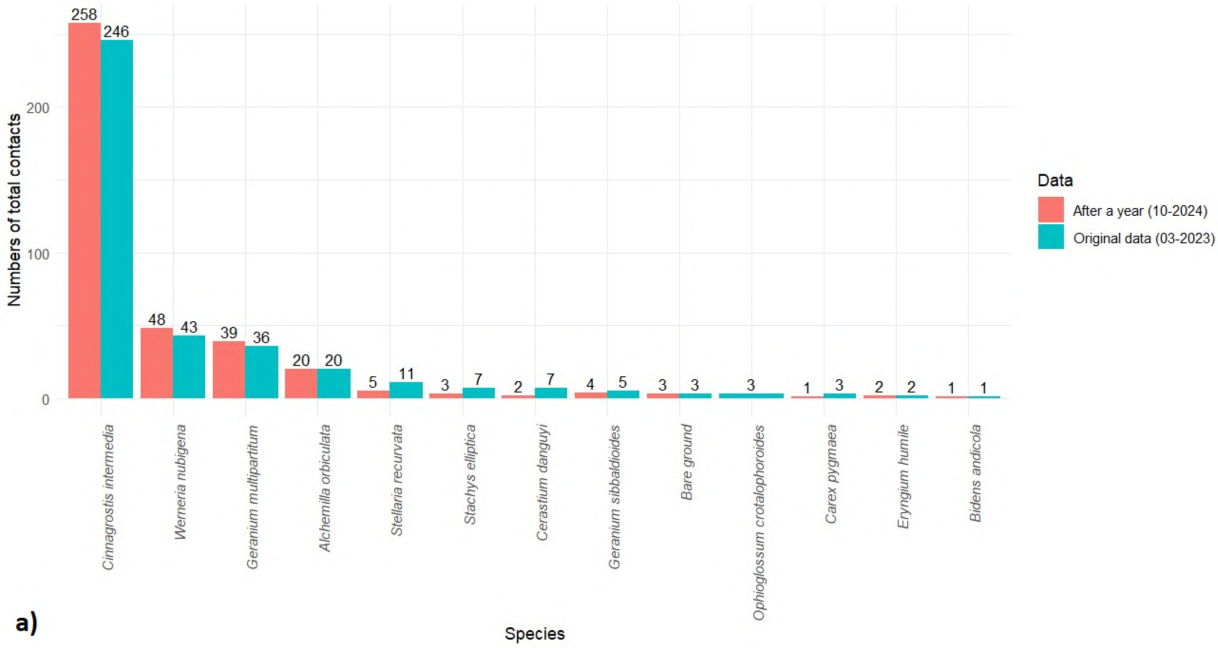


Figure 4.9: Total contact numbers of plant species in different habitats of ACHA. a) Paramo grasslands

In the dry herbaceous vegetation habitat in the (Figure 4.10), the most numerous species is *Geranium multipartitum*, which slightly decreases the number of contacts, going from 110 in October 2024 to 93 in the original data from March 2023. *Cinnagrostis coarctata* also shows a decrease, going from 84 contacts in 2023 to 69 in 2024. *Werneria nubigena* shows a small increase from 62 to 60 contacts between both periods, while *Bromus lanatus* maintains a downward trend, going from 59 to 54 contacts. *Bidens andicola* shows a greater increase, going from 22 to 38 in one year. While *Senecio chionogeton* disappears throughout the period.

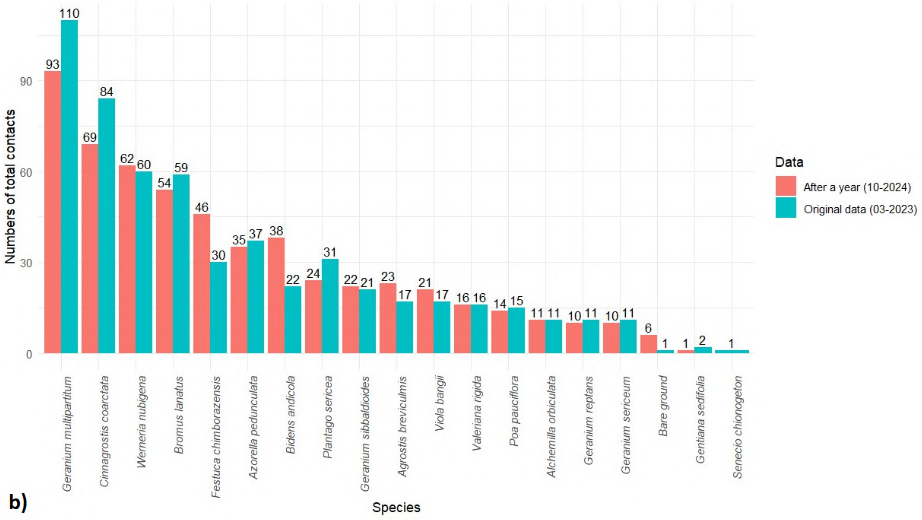


Figure 4.10: Total contact numbers of plant species in different habitats of ACHA. b) Dry herbaceous vegetation

In the humid herbaceous vegetation habitat (Figure 4.11), *Alchemilla orbiculata* remains the species with the highest number of contacts, decreasing slightly from 140 in March 2023 to 132 in October 2024. *Cinnagrostis jamesonii* shows a notable decrease, from 105 to 84 contacts. Other species, such as *Geranium multipartitum* and *Carex toreadora*, show increases. *Carex pygmaea* is a species that appears in the data after one year with 13 contacts.

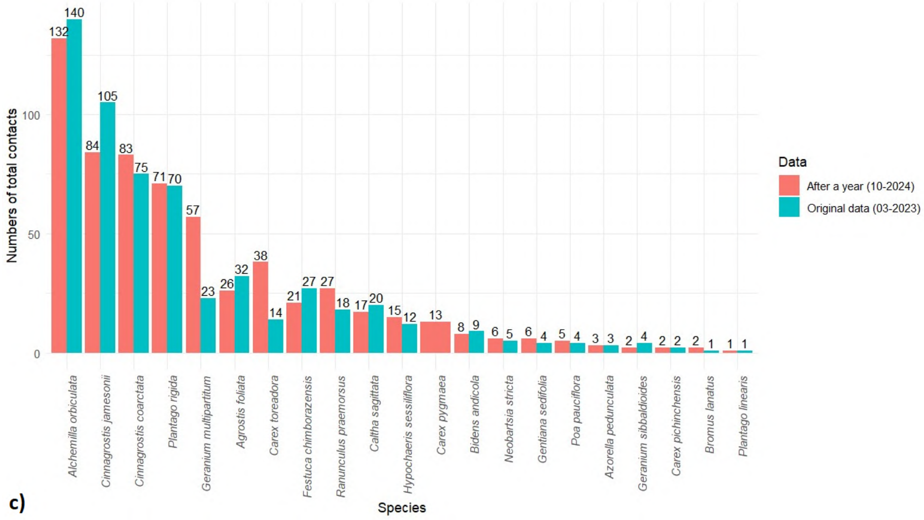


Figure 4.11: Total contact numbers of plant species in different habitats of ACHA. c) Humid herbaceous vegetation

In the exposed soil habitat (Figure 4.12), bare ground is the most representative, showing an increase in contacts from 114 in March 2023 to 137 in October 2024. *Hypochaeris sessiliflora* remains relatively stable, with a small decrease from 47 contacts to 46 in the same period. *Agrostis breviculmis* also shows an increase, going from 25 to 54 contacts. On the other hand, *Poa pauciflora* and *Neobartsia pedicularoides* show a notable decrease in the number of contacts. *Carex pygmaea* shows a noteworthy increase, going from 1 to 18 contacts. *Carex toreadora* appears with one contact in the data taken in October after one year.

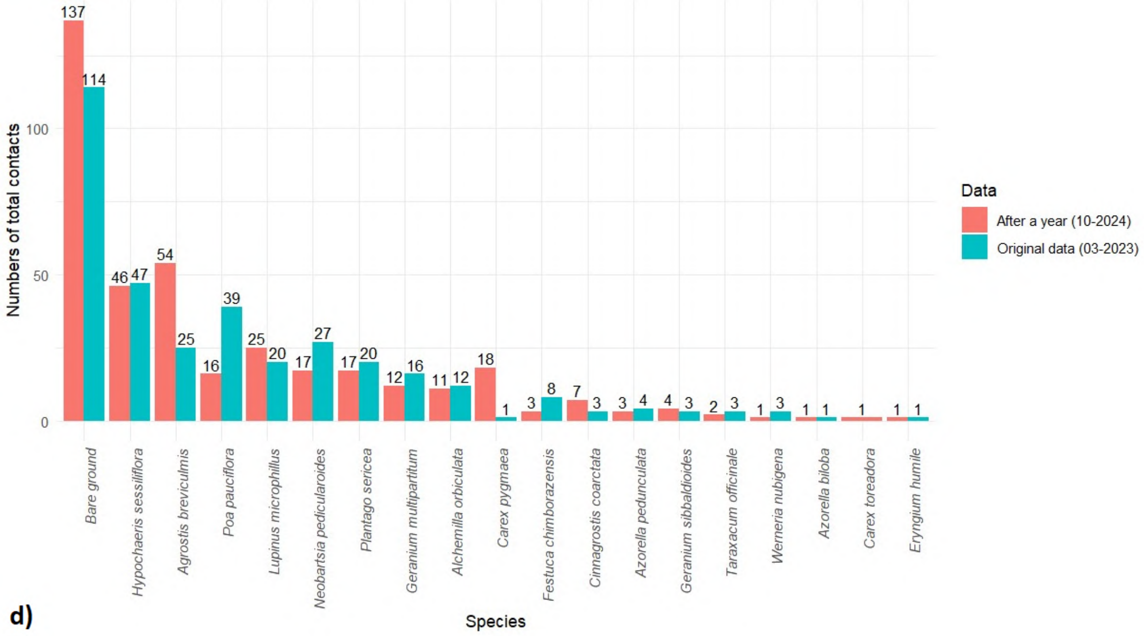


Figure 4.12: Total contact numbers of plant species in different habitats of ACHA. d) Exposed soil

In the cushion plant habitat (Figure 4.13), *Azorella pedunculata* shows a decrease in the number of contacts, going from 154 in the original data from March 2023 to 136 in October 2024. *Alchemilla orbiculate* remains practically stable in both periods. *Cinnagrostis coarctata* also shows a decrease, from 114 in 2023 to 95 in 2024.

Plantago rigida remains with a slight variation, going from 79 contacts in 2023 to 65 in 2024. *Agrostis breviculmis* disappears after one year.

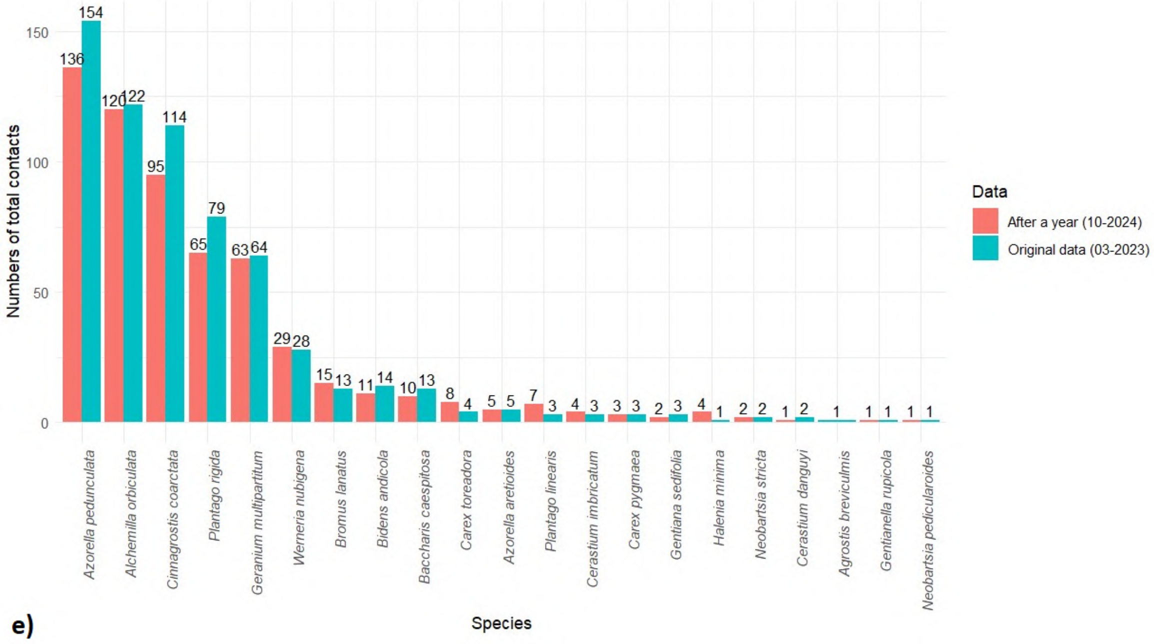


Figure 4.13: Total contact numbers of plant species in different habitats of ACHA. e) Cushion plants

4.2.4 Total numbers of contacts in each exclusion and controls.

This section presents the graphs with the most representative variations in the total number of contacts of each species in the different exclusions and control. Although at the beginning of the study in 2023, there were 36 exclusions and 18 control, the data presented below were taken from only 10 exclusions and 5 control. The results shown below correspond to where the greatest variation has been observed or where the data have proven to be more representative.

In the paramo grassland habitat in the exclusion of rabbits and deer (Figure 4.14), the species with the highest number of contacts is *Cinnagrostis intermedia*, which shows an increase from 66 contacts in March 2023 to 78 in October 2024. *Geranium multipartitum* records a decrease in the number of contacts, going from 26 to 18 in the same period. In contrast, *Carex pygmaea* has only one contact recorded in the original data and none in the last period.

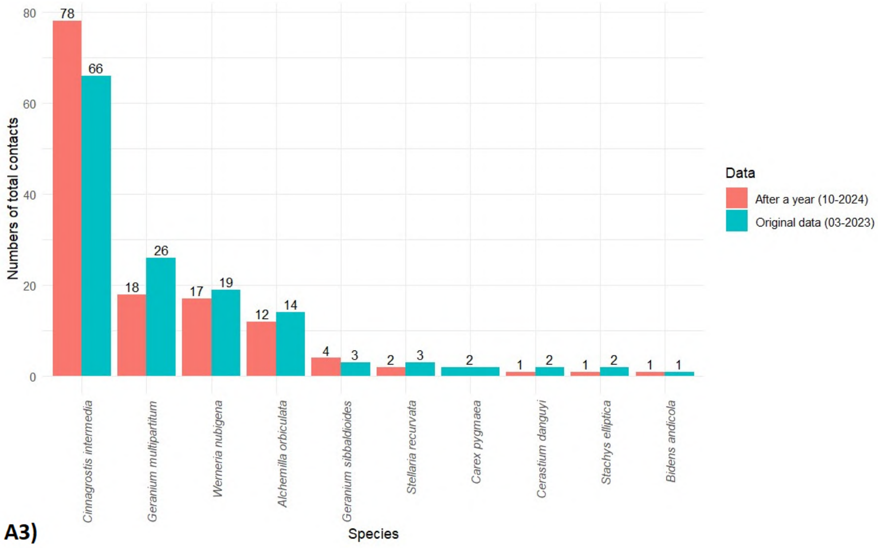


Figure 4.14: Total contact numbers of plant species in different exclusions and controls of ACHA. A3) Paramo grasslands exclusion of rabbits and deer.

In the graph for dry herbaceous vegetation habitat at the control (Figure 4.15), *Geranium multipartitum* is the species with the highest number of contacts, decreasing from 33 in the original data from March 2023 to 25 in October 2024. *Werneria nubigena*, *Bidens andicola*, *Festuca chimborazensis* and *Agrostis breviculmis* show a significant increase in the data taken after one year. *Plantago sericea* and *Cinnagrostis coarctata* show a decrease in contacts. In addition, bare ground appears in the data taken in 2024.

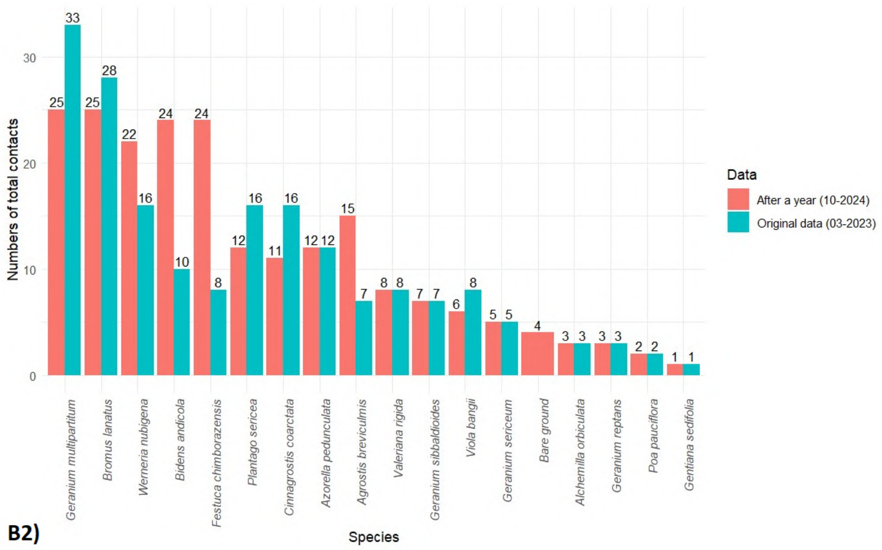


Figure 4.15: Total contact numbers of plant species in different exclusions and controls of ACHA. B2) Dry herbaceous vegetation control site

In the graph for exposed soil habitat in deer exclusion (Figure 4.16), bare ground is the category with the highest number of contacts, showing an increase from 18 in March 2023 to 31 in October 2024. *Agrostis breviculmis* also shows a considerable increase, from 13 to 27 contacts. *Poa pauciflora*, *Lupinus microphyllus*, *Geranium multipartitum*, *Neobartsia pedicularioides* and *Plantago sericea* show a decrease in the number of contacts after one year, while *Festuca chimborazensis* disappears and *Geranium sibbaldioides* appears within one year.

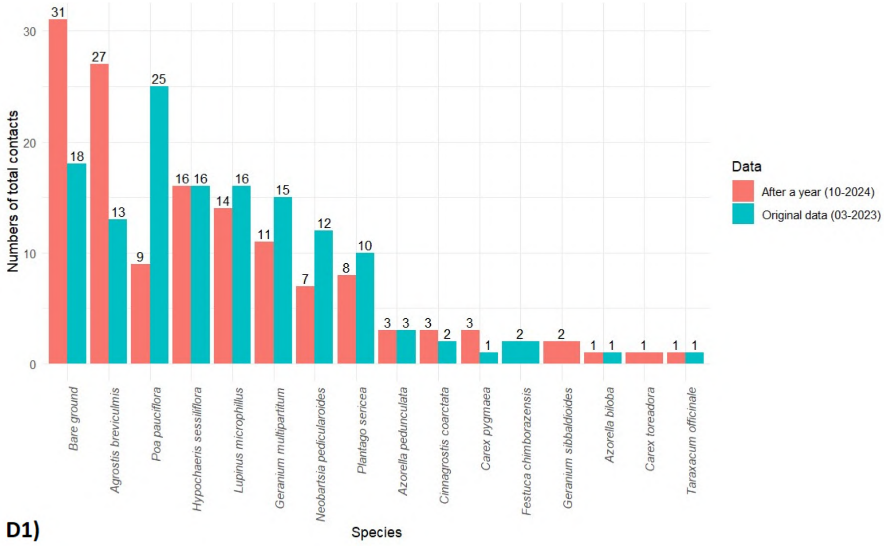


Figure 4.16: Total contact numbers of plant species in different exclusions and controls of ACHA. D1) Exposed soil exclusion of deer

4.2.5 Coverage percentage

Percentage in habitats

The following graph shows how the percentage of cover in different habitats has changed in the ACHA between March 2023 and October 2024.

In (Figure 4.17), it can be observed that in the cushion plant habitat, the percentage of cover decreased, going from 25.31% in the original data to 23.11% after one year. In the humid herbaceous vegetation, the percentage of cover increased from 22.86% in 2023 to 24.58% in 2024. The dry herbaceous vegetation shows a minimal variation, as does the paramo grassland. Finally, the exposed soil habitat showed a level of increase in cover, from 13.94% in March 2023 to 14.93% in October 2024.

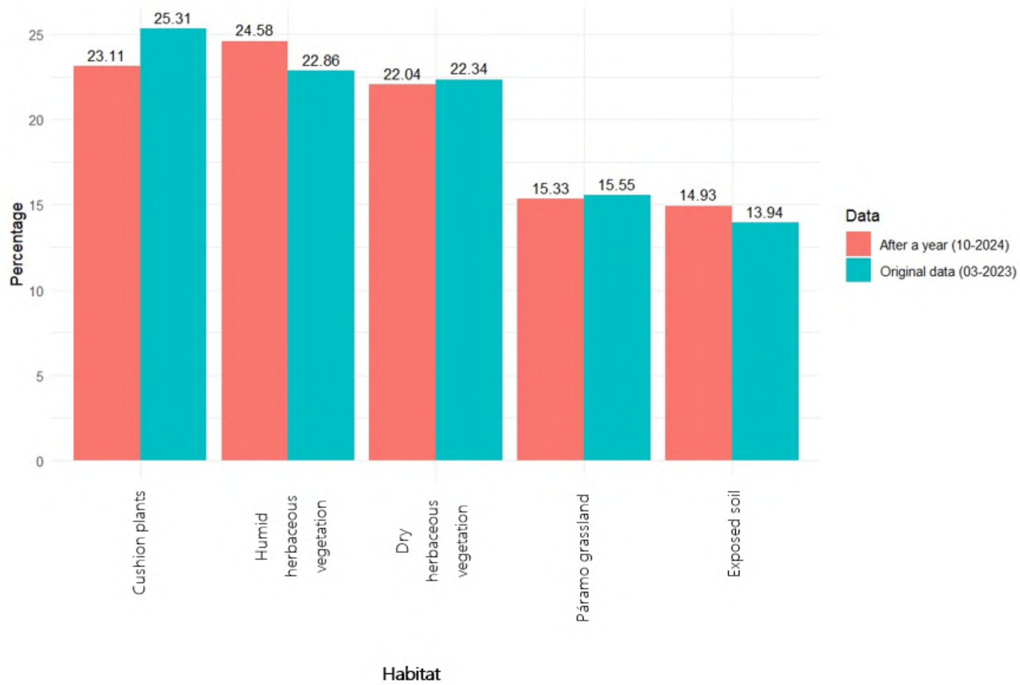


Figure 4.17: Percentage of total vegetation cover in the different habitats of the ACHA, comparing the data obtained in March 2023 and October 2024

Percentage in exclusions and control points

The figures show the percentage of coverage of the different plant species at the other control sites and exclusions. This allows us to visualize how the implementation of exclusions influences the vegetation cover in the various habitats studied.

In (Figure 4.18), humid herbaceous vegetation at the control, cushion plants deer, cushion plant control, cushion plants rabbits and deer, humid herbaceous vegetation deer, and dry herbaceous vegetation rabbits and deer show a decrease in their percentages of cover over a year. while humid herbaceous vegetation control, humid herbaceous vegetation rabbits and deer, and humid herbaceous vegetation deer show a significant increase in the percentage of cover. In the other exclusions and control, a minimal variation is observed.

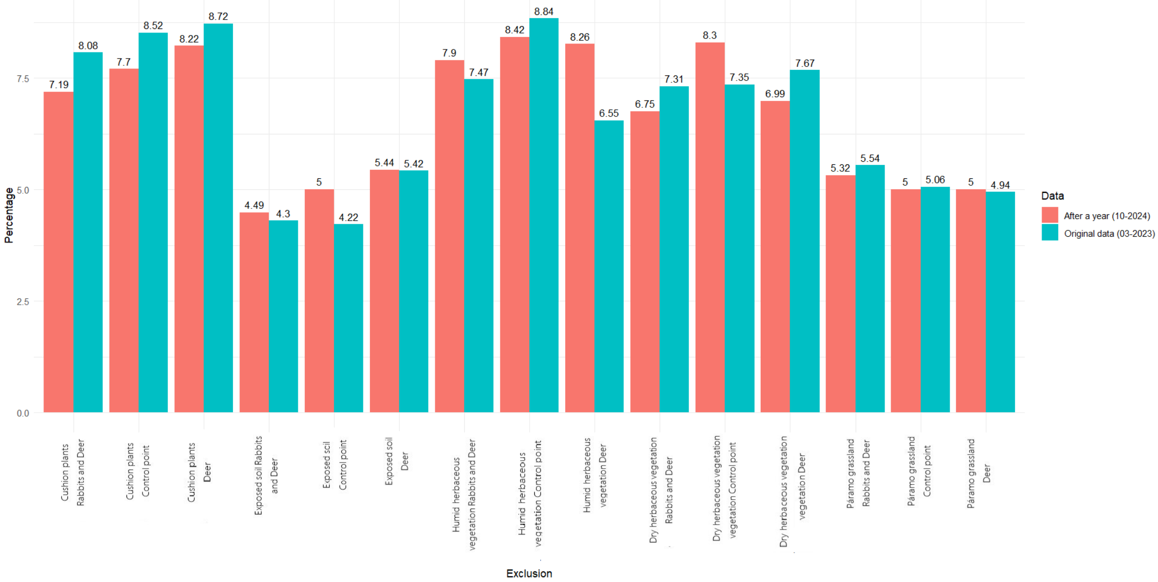


Figure 4.18: Total percentage of plant species coverage in different exclusions of ACHA.

4.2.6 Species accumulation curves

The graph presented is a curve comparing the data obtained in 2023 and 2024 for the accumulation of plant species richness in the different habitats in the paramo.

In (Figure 4.19), it can be observed that species richness tends to increase in all habitats over time, with slight differences between both periods. In habitats such as cushion plants and exposed soil, the accumulation curves are similar between both periods. In contrast, in habitats of humid herbaceous vegetation, dry herbaceous vegetation, and paramo grassland, species richness after one year shows a slight decrease compared to the original data.

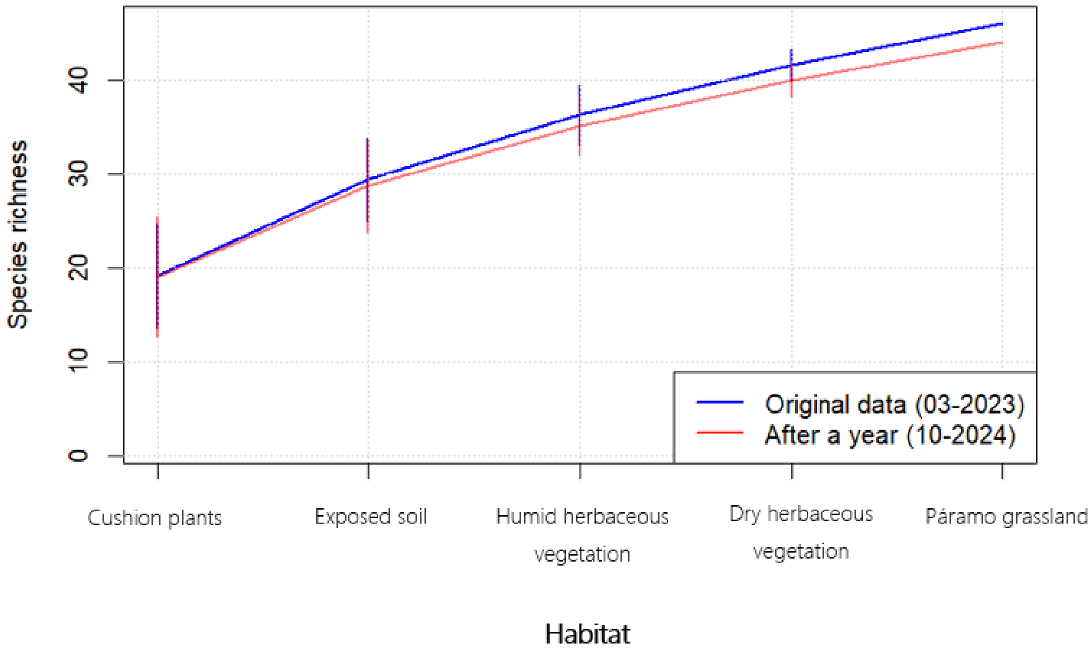


Figure 4.19: Curve of accumulation of plant species richness in the different habitats of ACHA.

4.2.7 Species accumulation curves in exclusions and control sites

Below is a graph of the species richness accumulation curve at the different exclusions and control sites in the paramo. The vertical lines indicate the confidence interval for the variability of the observations.

In (Figure 4.20) shows that species richness remains stable or shows a slight decrease over time for most of the exclosures and control sites. Overall, the accumulation curves for the exclosures and control show a similar trend, with a smaller increase in species richness in the 2024 data compared to the original 2023 data.

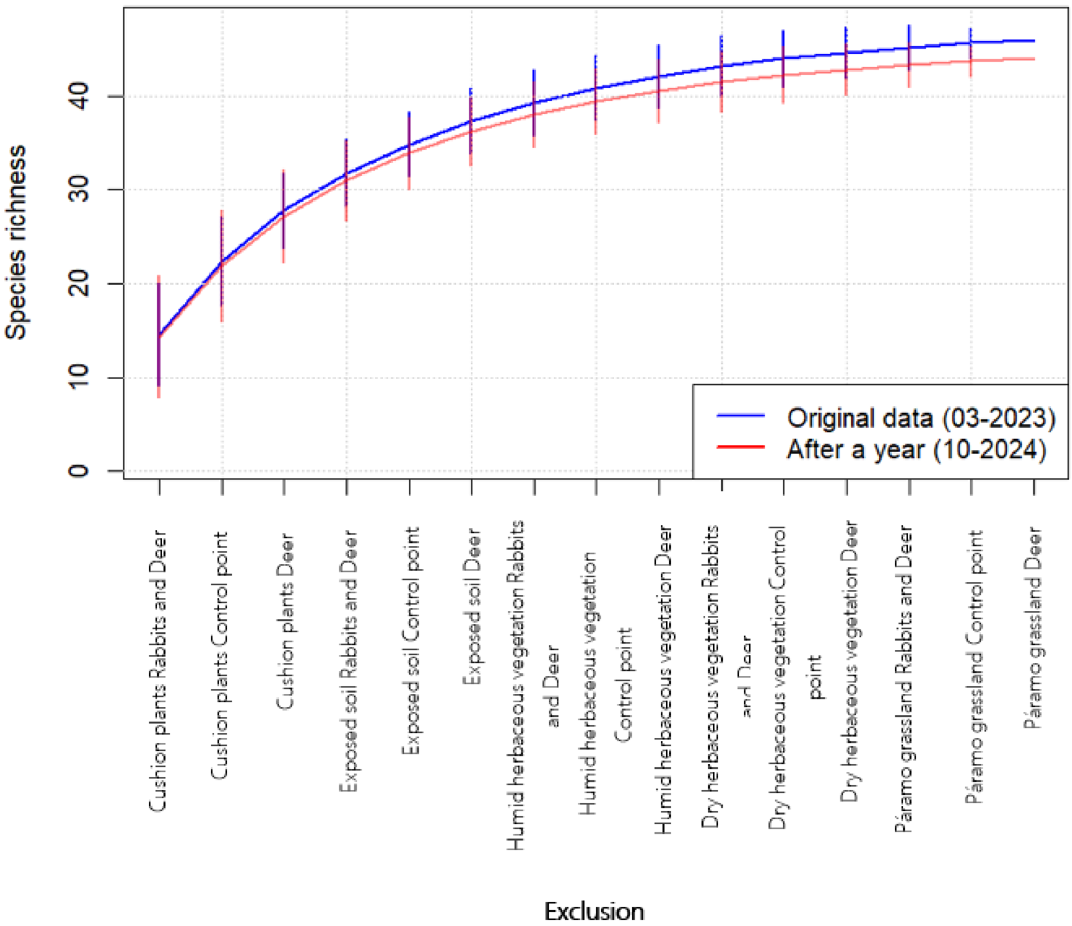


Figure 4.20: Curve of accumulation of plant species richness in different exclusions and controls of ACHA.

4.2.8 Clustering analysis

To evaluate the distribution and diversity of species in the different habitats and controls, a clustering analysis was carried out where the percentage data of coverage of plant species were available.

Euclidean distance matrix

The Euclidean distance matrix represents the distance between different data points in a multidimensional space. In this case, each point is represented by a plant species, and the Euclidean distance between these points will indicate how far apart or close they are, depending on their total numbers of contacts and percentage of coverage in the different exclusions and control sites.

The axes represent the points, in this case, the plant species. The color scale that is observed indicates the distance between these points, where a value close to 0 (light blue) indicates that the species are very close to each other, and a higher value (deep red) suggests that these points are very far apart.

In (Figure 4.21) species such as *Alchemilla orbiculata*, *Azorella pedunculata*, *Cinnagrostis coarctata*, and *Werneria nubigena* show larger distances from many other species, on the contrary, species such as *Halenia minima*, *Gentianella rupicola*, and *Ophioglossum crotalophoroides* are very close to each other, as shown by the blue areas in the matrix.

The matrix's diagonal, which represents the comparison of each species with itself, is deep blue since the Euclidean distance of a species from itself is zero.

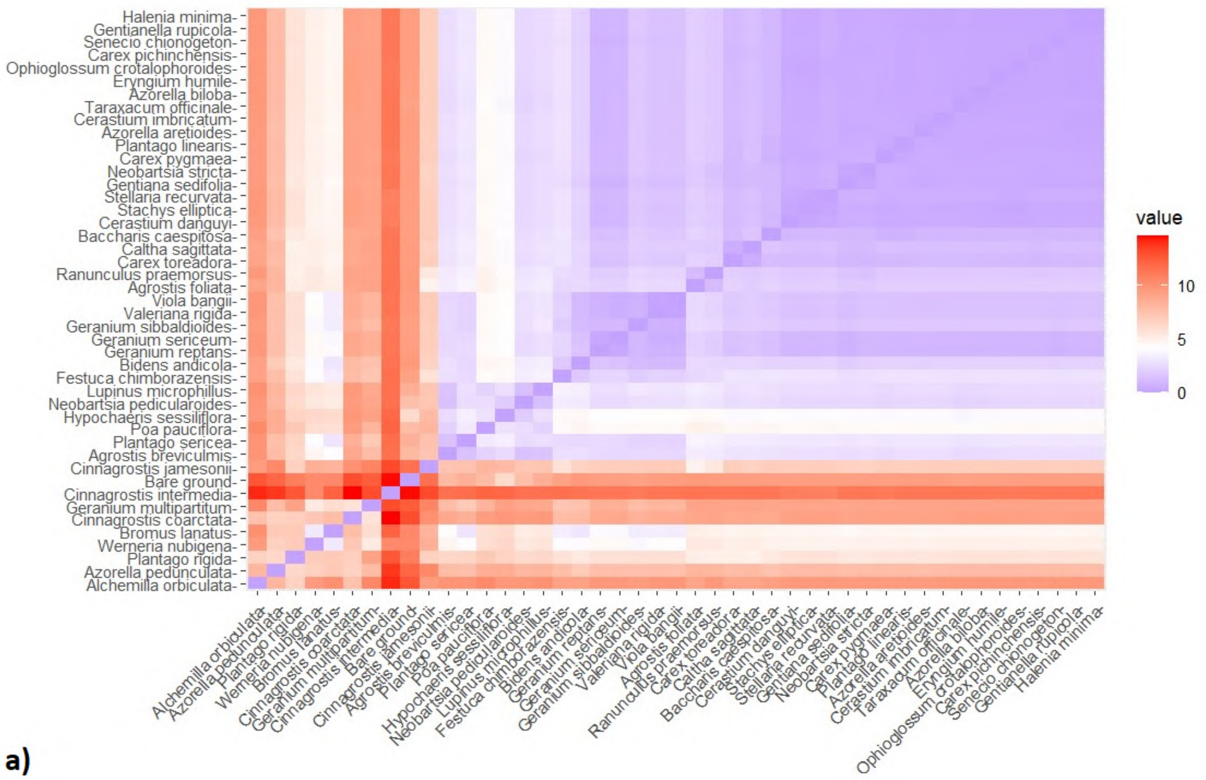


Figure 4.21: Euclidean distance matrix for the percentage cover of plant species at the different exclusions and controls of ACHA. a) Original data (03-2023)

In (Figure 4.22) species such as *Azorella pedunculata*, *Cinnagrostis coarctata* and *Alchemilla orbiculata* continue to show a high separation from other species. On the other hand, species such as *Halenia minima*, *Gentianella rupicola*, and *Eryngium humile* continue to show greater proximity to each other. A notable difference is that species such as *Bromus lanatus*, *Cinnagrostis intermedia*, and bare ground show a greater separation between themselves and the rest of the species compared to the previous year.

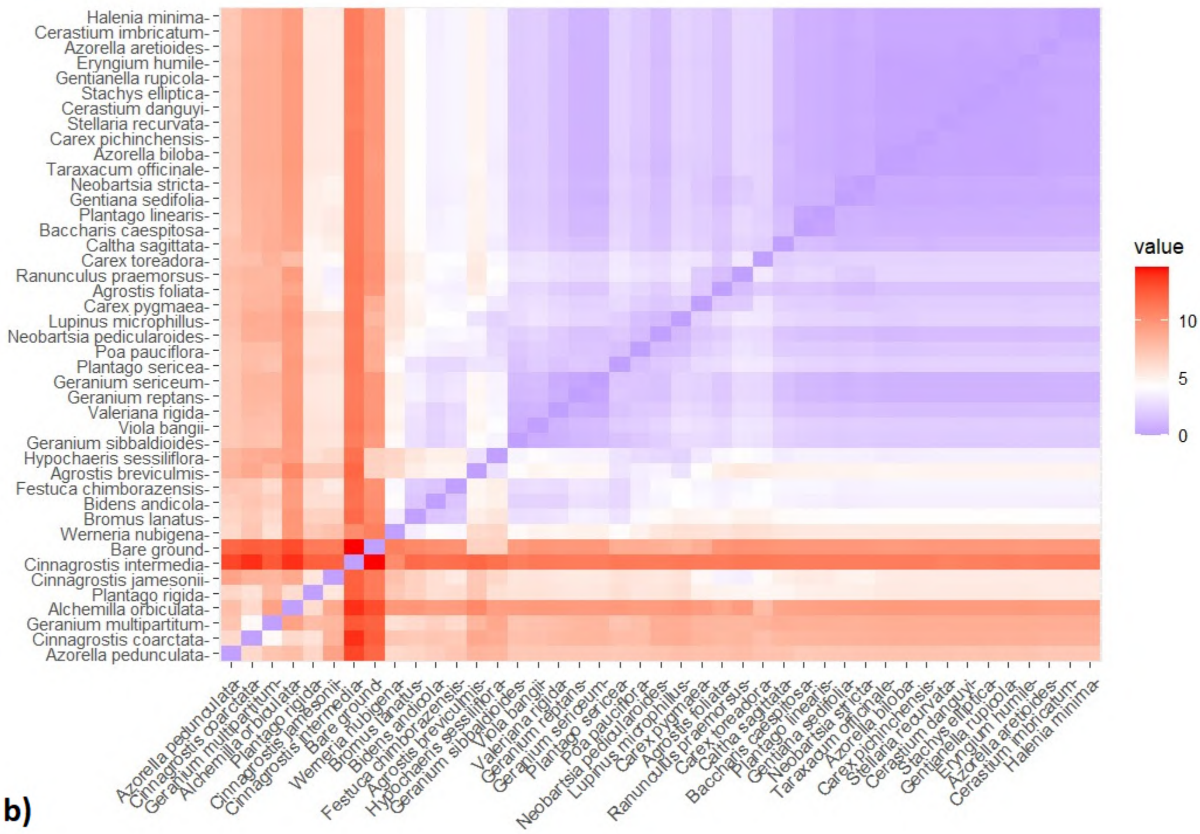


Figure 4.22: Euclidean distance matrix for the percentage cover of plant species at the different exclusions and controls of ACHA. b) Data after a year (10-2024)

Number of clusters by the Elbow Method and Cumulative Explained Variance

The Elbow method is implemented to choose the optimal number of clusters, and the Cumulative Explained Variance complements it.

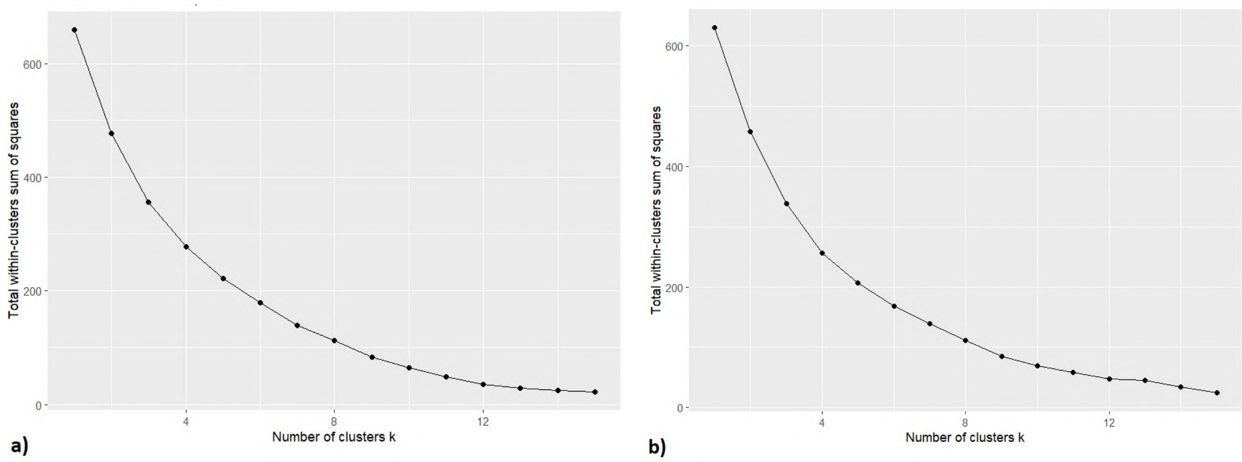


Figure 4.23: Elbow method to determine the optimal number of clusters. a) Original data (03-2023), b) Data after a year (10-2024)

Cumulative Explained Variance is an important tool for determining the optimal number of clusters that complements the Elbow Method.

In (Figure 4.24), both graphs, the explained variance increases as the number of clusters increases, reaching greater stabilization after k=4. However, there is a significant deceleration in the increase of the explained variation from this point onwards.

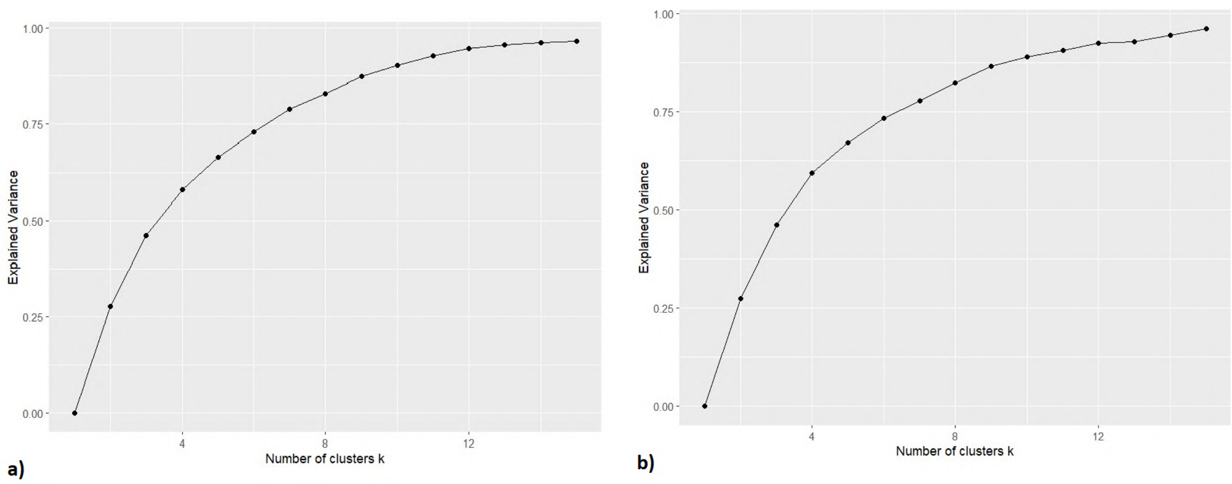
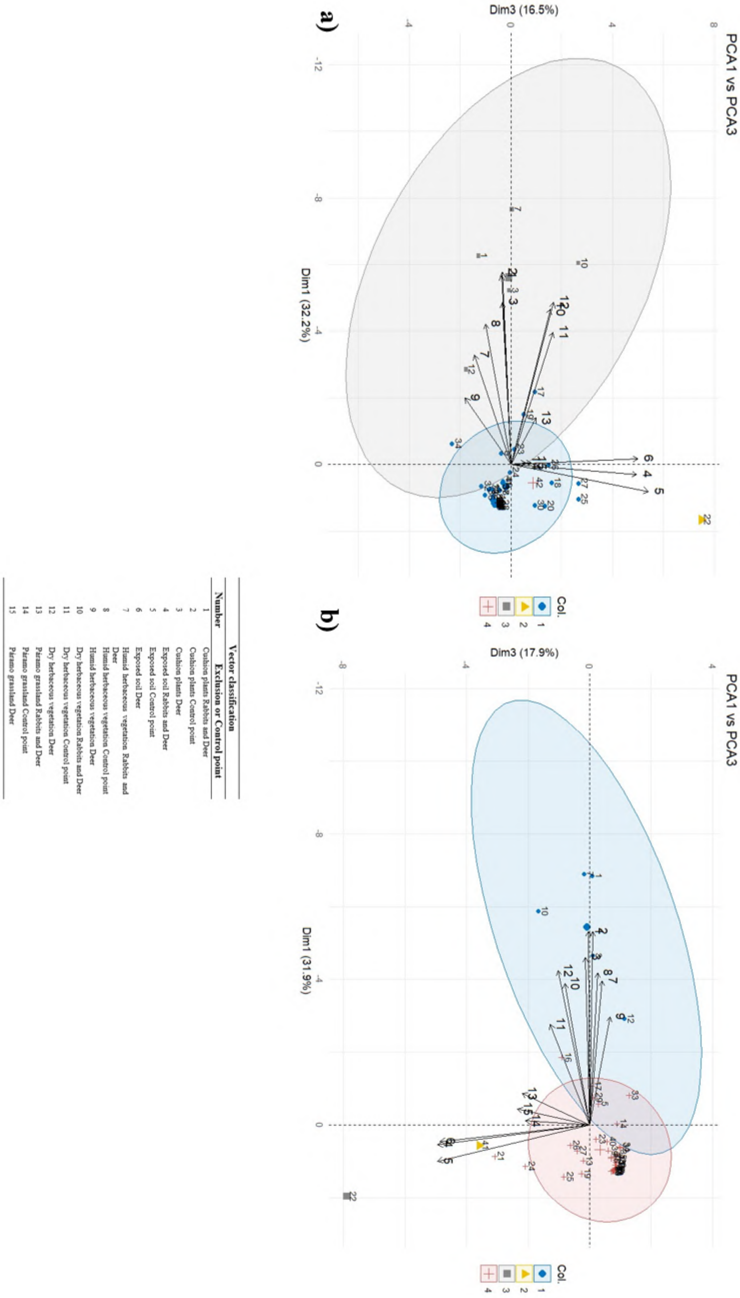


Figure 4.24: Cumulative Explained Variance to determine the optimal number of clusters. a) Original data (03-2023), b) Data after a year (10-2024)

A principal Component Analysis (PCA) makes these clusters visible, allowing us to distinguish the similarities and differences between the species in each cluster in different exclusions and control sites.

The principal component analysis (PCA) graph shows the results of the exclusions and controls. It can be observed how the exclusions and controls are grouped according to the variability explained by the first two main dimensions (Dim1 and Dim3). These components represent 32.2% and 16.5% of the variation in the first graph (a), and 31.9% and 17.9% in the second graph (b).



Vector classification	
Number	Exclusion or Control point
1	Cushion plants Rabbits and Deer
2	Cushion plants Control point
3	Cushion plants Deer
4	Exposed soil Rabbits and Deer
5	Exposed soil Control point
6	Exposed soil Deer
7	Humid herbaceous vegetation Rabbits and Deer
8	Humid herbaceous vegetation Control point
9	Humid herbaceous vegetation Deer
10	Dry herbaceous vegetation Rabbits and Deer
11	Dry herbaceous vegetation Control point
12	Dry herbaceous vegetation Deer
13	Páramo grassland Rabbits and Deer
14	Páramo grassland Control point
15	Páramo grassland Deer

Figure 4.25: Number of clusters visualized through Principal Component Analysis (PCA). a) Original data (03-2023), b) Data after a year (10-2024).

Multidimensional Scaling Analysis (MDS)

The table presented shows the summary of the data found after performing the Multidimensional Scaling Analysis (MDS). This analysis was performed by applying the previously calculated Euclidean distances, which allows us to visualize the similarity or dissimilarity that exists between the plant species in reduced dimensions, specifically in 2.

Table 4.2: Summary of results of Multidimensional Scaling Analysis (MDS).

Results	Original data (03-2023)	After a year (10-2024)
Distance	euclidean	euclidean
Dimensions	2	2
Stress	0.07212603	0.07344119
Stress type	1, weak ties	1, weak ties
Best solution repeated	2 times in 20 tries	1 time in 20 tries
Scaling	centring, PC rotation	centring, PC rotation

Homogeneity and Separation

Comparing cluster homogeneity and separation is necessary in the analysis, helping to assess how well-defined clusters are in the data.

Table 4.3: Comparison of Cluster Validation Indices for Original Data (03-2023) and After one year (10-2024) in the Antisana Hydrological Conservation Area.

Validation Index	Original Data (4 clusters)	After a year (4 clusters)
Connectivity	14.6183	13.9849
Dunn	0.4735	0.5086
Silhouette	0.5995	0.5714

Comparison of centroids

The differences between the centroids of the clusters must be analyzed to understand how the plant species responded to the treatments over time. The centroids show the average value of the variables, which are the exclusions for each cluster.

For clusters 1 and 4, no significant differences are seen between the centroids of the different exclusions and control sites. In contrast, clusters 2 and 3 change significantly in almost all exclusions and controls over one year.

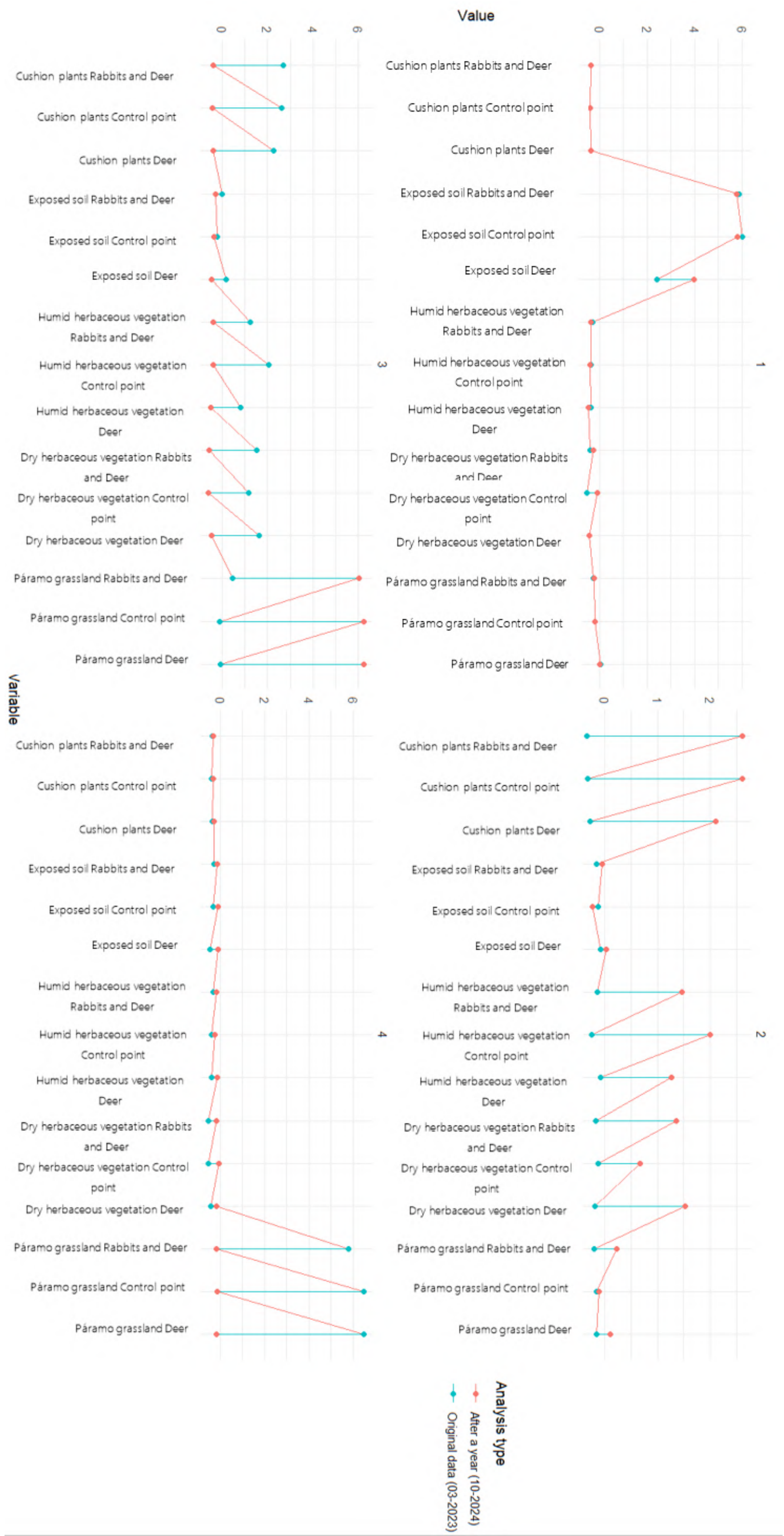


Figure 4.26: Comparison of Cluster Centroids Original data (03-2023) vs Data after a year (10-2024).

4.2.9 Repeated measures analysis of variance (ANOVA)

Repeated measures analysis of variance (ANOVA) provides information on how variables, in this case, species, are distributed across different exclusions and controls in various clusters and how these have varied over time.

Exclusions such as cushion plants rabbits and deer and paramo grassland deer show very high F values, indicating a high variability explained between clusters, with F values of 136.55 and 276.48, respectively, in the 2024 data. On the other hand, in other exclusions, such as exposed soil deer, lower variability is observed, with a lower F value of 8.32 in 2024, indicating a smaller difference in vegetation cover.

Table 4.4: ANOVA results on plant cover in herbivore exclusions and control points for Original Data (03-2023) and After one Year (10-2024) in the ACHA.

Variable	Type	Df..Cluster.	Df..Residuals.	Sum.Sq..Cluster.	Sum.Sq..Residuals.	Mean.Sq..Cluster.	Mean.Sq..Residuals.	F.value	Pr..F.
Cushion plants	After a year	3	39	38.349154	3.6508459	12.7830514	0.09361143	136.5543796	1.000586e-20
Rabbits and Deer	Original data	3	41	40.981909	3.0180915	13.6606362	0.07361199	185.5762437	7.001573e-24
Cushion plants	After a year	3	39	38.458745	3.5412547	12.8195818	0.09080140	141.1826415	5.530096e-21
Control point	Original data	3	41	39.059392	4.9406078	13.0197974	0.12050263	108.0457535	1.672153e-19
Cushion plants	After a year	3	39	25.185187	16.8148132	8.3950623	0.43114906	19.4713687	7.066061e-08
Deer	Original data	3	41	28.991516	15.0084839	9.6638387	0.36606058	26.3995611	1.134549e-09
Exposed soil	After a year	3	39	34.421259	7.5787408	11.4737531	0.19432669	59.0436301	1.457366e-14
Rabbits and Deer	Original data	3	41	35.6c89493	8.3105066	11.8964978	0.20269528	58.6915376	6.832990e-15
Exposed soil	After a year	3	39	34.786983	7.2130167	11.5956611	0.18494915	62.6964831	5.582998e-15
Control point	Original data	3	41	37.097210	6.9027900	12.3657367	0.16836073	73.4478678	1.549484e-16
Exposed soil	After a year	3	39	16.402076	25.5979244	5.4673585	0.65635704	8.3298544	2.107844e-04
Deer	Original data	3	41	6.330590	37.6694098	2.1101967	0.91876609	2.2967725	9.186189e-02
Humid herbaceous vegetation	After a year	3	39	12.267622	29.7323777	4.0892074	0.76236866	5.3638189	3.441985e-03
Rabbits and Deer	Original data	3	41	8.501814	35.4981855	2.8339382	0.86580940	3.2731663	3.054790e-02
Humid herbaceous vegetation	After a year	3	39	22.725997	19.2740027	7.5753324	0.49420520	15.3283139	9.652492e-07
Control point	Original data	3	41	23.868181	20.1318191	7.9560603	0.49101998	16.2031295	4.270143e-07
Humid herbaceous vegetation	After a year	3	39	9.184629	32.8153706	3.0615431	0.84141976	3.6385444	2.087543e-02
Deer	Original data	3	41	3.753964	40.2460357	1.2513214	0.98161063	1.2747635	2.957204e-01
Dry herbaceous vegetation	After a year	3	39	10.594811	31.4051892	3.5316036	0.80526126	4.3856619	9.405345e-03
Rabbits and Deer	Original data	3	41	13.174369	30.8256313	4.3914562	0.75184467	5.8409089	2.033250e-03
Dry herbaceous vegetation	After a year	3	39	2.769029	39.2309705	0.9230098	1.00592232	0.9175756	4.413382e-01
Control point	Original data	3	41	7.946162	36.0538376	2.6487208	0.87936189	3.0120941	4.087472e-02
Dry herbaceous vegetation	After a year	3	39	13.338506	28.6614937	4.4461688	0.73491009	6.0499492	1.745055e-03
Deer	Original data	3	41	15.192128	28.8078722	5.0640426	0.70263103	7.2072573	5.401059e-04
Páramo grassland	After a year	3	39	38.213195	3.7868055	12.7377315	0.09709758	131.1848550	2.037861e-20
Rabbits and Deer	Original data	3	41	36.235546	7.7644542	12.0785153	0.18937693	63.7802877	1.708573e-15
Páramo grassland	After a year	3	39	39.867453	2.1325465	13.2891512	0.05468068	243.0319295	2.851636e-25
Control point	Original data	3	41	42.829864	1.1701356	14.2766215	0.02853989	500.2339073	2.622008e-32
Páramo grassland	After a year	3	39	40.113896	1.8861043	13.3712986	0.04836165	276.4855878	2.608399e-26
Deer	Original data	3	41	43.031808	0.9681923	14.3439359	0.02361445	607.4220593	5.407278e-34

Chapter 5

Discussion

5.1 Methodological validation

Total numbers contacts

The results obtained reflect a clear difference between the point intercept method and the grid method in terms of the number of contacts recorded for the different species. The point intercept method, by providing clearer estimates, seems to be more suitable for detecting species with low density or less dominant in the paramo ecosystem. This is consistent with previous studies suggesting that this method is particularly effective in areas of high diversity and complex plant structure, where spatial heterogeneity is greater [DW, 1953]. On the other hand, the grid method, although less precise in some cases where vegetation is very abundant, is still useful in areas where vegetation is more homogeneous, as has been observed in long-term research in other montane ecosystems [Greig-Smith, 1983].

The fact that the point intercept method records more contacts for most species indicates its sensitivity to capture variations in vegetation cover. This is crucial in studies such as the present one, where vegetation composition and structure are influenced by factors such as rabbit and deer herbivory. In addition, the ability of the point intercept method to capture smaller or less abundant species has important implications for future studies, as it allows a more complete view of the plant biodiversity present in the paramo.

However, the grid method should not be discarded, especially in large-scale studies or long-term monitoring. The differences observed in species detection between both methods (13 for point intercept and 6 for grid) underline the need to select the appropriate method depending on the specific objectives of the study and the spatial structure of the ecosystem investigated. In this sense, future research could benefit from a combination of both methods to obtain a more comprehensive view of the state of vegetation in the paramo and other mountain ecosystems.

Percentage of plant species coverage

The point intercept method proved to be more efficient in habitats with vertical or dispersed plant species, providing detailed estimates of plant cover, especially in areas with high species density, such as paramo grassland. This ability to capture greater diversity is due to its sensitivity to record less abundant or smaller species such as *Alchemilla orbiculata* and *Geranium multipartitum*, which makes it especially suitable in complex ecosystems.

In contrast, the grid method proved to be more suitable in open and homogeneous habitats, where the spatial distribution of species is more uniform, such as humid herbaceous vegetation and cushion plants. However, a significant limitation of this method is its tendency to underrepresent those species with great height or irregular spatial distribution as in the case of paramo grassland where *Cinnagrostis intermedia* has a high percentage but species such as *Werneria nubigena*, *Stellaria recurvata* and *Stachys elliptica* have very low percentages.

The graphs presented in Annex 1 illustrate the differences in species cover at the different monitoring points in the Antisana paramo. A consistent trend can be observed in all graphs, in which the point intercept method presents a higher percentage of cover compared to the grid method. This pattern indicates that the square point method has a greater capacity to detect and represent species cover accurately, which could explain why, in most cases, species show higher percentages of cover when this method is used.

After a detailed analysis of the sampling methods used, the square point method best fits the objectives of this study. Its ability to accurately capture the diversity and cover of plant species without omitting those of lower abundance makes it the most suitable tool for monitoring vegetation in the paramo ecosystem.

5.2 Herbivory impact

Total numbers of contacts

A notable increase in the total number of contacts of some species can be observed between the data taken in March 2023 and those collected a year later, in October 2024. Specifically, species such as *Agrostis breviculmis* and *Carex pygmea* show an increase in contacts, which may be due to an expansion of their coverage. This increase could be related to a better adaptation to the specific conditions of the paramo in the exclusion zones, possibly due to factors such as changes in the availability of light or nutrients associated with the reduction of competition with other dominant species [Brown et al., 2022]. In this context, competition could be occurring with species such as *Cinnagrostis coarctata*, *Alchemilla orbiculata* or *Azorella pedunculata* which, according to the results, have maintained a high number of contacts but have shown a decrease compared to other species. The reduction in more competitive or larger species could have allowed smaller species, such as *Agrostis breviculmis*, to occupy new niches in the available space.

On the other hand, species such as *Cinnagrostis jamesonii* and *Poa pauciflora* show a decrease in the number of contacts, which could be related to their competitiveness or changes in the environmental conditions of certain habitats, such as dry herbaceous vegetation or the exposed soil of the paramo. These changes could be connected to variations in the availability of water or nutrients since previous studies have shown that species in these habitats are sensitive to decreased soil moisture and variations in temperature [Hwang et al., 2020]. In addition, competition with other better-adapted species, such as *Alchemilla orbiculata*, could be limiting their ability to maintain their presence in these areas, as has also been observed in other mountain ecosystems [Roy et al., 2020]. However, most species show small changes in the number of contacts, suggesting stability in vegetation composition across most of the study area.

Total numbers of contacts in habitats

In the cushion plant habitat, a decrease in the number of contacts was observed after one year. In the absence of herbivory, some faster-growing species, such as grasses and other herbaceous plants, may have increased, displacing less competitive species. This has been seen in previous studies indicating that herbivore exclusion can lead to a change in species composition due to the lack of selective pressure from herbivores [Zamora et al., 2017]. Suggesting that competition for resources such as light and nutrients is intensified in the absence of disturbance.

On the other hand, in the humid herbaceous vegetation and exposed soil habitats, an increase in the number of contacts was recorded, indicating a possible recovery of vegetation in these areas. The absence of herbivores allows the regeneration of plants sensitive to herbivory, such as fast-growing herbs. The growth of these species may be more evident in exposed soils, where soil stabilization plays a crucial role in the recovery of vegetation cover [Jaroszynska, 2019].

In the habitats of paramo grassland and dry herbaceous vegetation, the number of contacts has remained relatively stable between both periods. In studies of mountainous areas, it has been observed that certain plant species show little response to the exclusion of herbivores due to a high capacity to adapt to environmental conditions, which may be the case in these habitats [Mörsdorf et al., 2021].

Total numbers of contacts in each habitat

When looking at the results in each habitat, certain species show changes in the number of contacts, which could be related to herbivore exclusions and the characteristics of each habitat. For example, in the case of *Cinnagrostis intermedia*, its number of contacts increased in the paramo grassland, which may suggest a possible competitive advantage in the absence of herbivores. Previous studies have indicated that this species has a high capacity for recovery in areas with low herbivore pressure [Rejmánek and Van Katwyk, 2005], which could explain its increase. The opposite occurs with *Ophioglossum crotalophoroides*, which disappears after one year in this habitat.

In the dry herbaceous vegetation habitat, there are several decreases in species such as *Geranium multipartitum*, *Bromus lanatus*, *Cinnagrostis coarctata* and *Plantago sericea*, which could be related to their adaptation to changes such as grazing, which suggests that, in the absence of herbivory, these species lose competitiveness against others that dominate in areas without herbivore pressure. In contrast, species such as *Festuca chimborazensis* show an increase in their number of contacts, which may be related to their ability to compete for resources in open environments without herbivore competition, as has been reported in studies on grasses in mountain ecosystems [Speed et al., 2019].

Furthermore, in some habitats such as humid herbaceous vegetation, the appearance of new species is observed after a year of exclusion, as is the case of *Carex pygmea*, which could indicate that certain species previously limited by herbivory manage to establish themselves when conditions are more favorable. This phenomenon of post-exclusion colonization has been documented in other studies of ecological restoration, where the absence of herbivores promotes the appearance of opportunistic species [Chambers et al., 2016].

Total numbers of contacts in each exclusion and control sites

The results obtained show variations in the number of contacts of some species in different exclusions and control sites.

In the case of *Cinnagrostis intermedia* in the exclusion of deer and rabbits in the paramo grassland habitat, an increase in the number of contacts suggests that the species could be responding favorably to the absence of animals. This coincides with previous studies in Andean ecosystems where the reduction of herbivores has allowed the expansion of certain dominant grasses [Rejmánek and Van Katwyk, 2005]. The decrease of species such as *Geranium multipartitum*, *Werneria nubigena*, *Alchemilla orbiculata* and *Carex pygmaea*, on the other hand, indicates that these could be facing competition in the absence of herbivory, possibly due to the growth of different species.

At control sites such as the dry herbaceous vegetation habitat, species such as *Bidens andicola*, *Agrostis breviculmis* and *Festuca chimborazensis* are observed. Their increase in the number of contacts suggests that these species are not as affected by the presence of herbivores. This could be due to the fact that they are species adapted to herbivore pressure [Speed et al., 2019].

In the case of *Agrostis breviculmis* in the exposed soil habitat in the exclusion of deer, the increase in contacts indicates a possible rapid recovery in areas where herbivore pressure has been reduced. This grass seems to benefit from exclusion where fast-growing species tend to dominate in the absence of herbivore disturbances [Eck et al., 2024]. However, an increase in bare ground is also observed, which is reflected and consistent with the decrease in other species such as *Poa pauciflora*, and *Neobartsia pedicularoides*, showing that these species are affected without the presence of herbivores.

In general, the variations observed among species suggest that herbivore exclusion does not affect all species uniformly. Some species seem to clearly benefit from the absence of herbivores, while others may be experiencing more intense competition in the absence of herbivory.

5.2.1 Coverage percentage

Percentage in habitats

The reduction in the habitat cover of cushion plants, greater than 2%, suggests a loss in their dominance compared to other habitats. This may be due to various environmental and biological factors that negatively affect this type of vegetation, such as changes in climatic conditions. Herbivory can alter the structure of plants, especially in those that form cushions, as it is due to their high vulnerability to predation and limitations in their regeneration capacity [Singh et al., 2023].

In contrast, the increase in the cover of humid herbaceous vegetation by around 2% reflects a possible expansion of this habitat. It is likely that the greater availability of water favors growth and promotes the competitiveness of the species present in these areas. This is guided by previous research indicating that herbaceous vegetation in humid regions has a greater capacity to take advantage of soil moisture, allowing its expansion [Beltrán et al., 2009].

On the other hand, the slight increase in exposed soil cover of 1% suggests that changes or loss of vegetation are occurring in certain areas. This may be due to competition between species or biotic factors, such as herbivorous activity, which prevent the recovery of vegetation. [Llambí and Rada, 2019].

Percentage in exclusions

The results obtained show how the presence of exclusions in certain habitats of the paramo has had a direct impact on vegetation cover. In the case of humid herbaceous vegetation, the data indicate an increase in cover in the exclusion of deer and also for that of rabbits and deer, which reinforces the idea that the exclusion of these herbivores has allowed the species of this habitat to increase without the stress caused by herbivory. This has been documented in other studies, where the exclusion of large herbivores promotes the recovery and expansion of plant species [Jenkins et al., 2003].

Some areas, such as dry herbaceous vegetation, have shown variation in the exclusion of deer and rabbits and the exclusion of deer, suggesting that, in certain habitats, herbivory is not the main limiting factor for vegetation cover. Factors such as competition for resources, adaptation to extreme environmental conditions, or the lack of herbivores in these specific areas may play a more determining role [Suárez Avellaneda].

5.2.2 Species accumulation curves

The species accumulation graph by habitat shows a general decrease in species richness after one year compared to the original data. This trend is evident in all habitats where herbivore exclusion seems to have affected species diversity conservation. Although the difference in species richness is not drastic compared to the previous year, the small decrease observed could be due to environmental factors such as reduced soil moisture or increased erosion, which negatively affect species regeneration in these specific habitats.

These results highlight the importance of exclusions in decreasing the effects of herbivory in certain habitats but also suggest that in the long term, factors such as climate change and soil degradation could have a more widespread impact on species richness in the paramo, especially in more vulnerable habitats such as cushion plants and exposed soil [Tonneijck et al., 2010].

5.2.3 Species accumulation curves in exclusions

The species accumulation graph at exclusions and control sites shows a small decrease in species richness after one year. This trend may be related to the recovery of species after the absence of herbivores or the effect that exclusions may have, where the most resistant species have been maintained while others have disappeared. Although the decrease is not drastic, it indicates that changes in herbivory, although positive in some cases, do not always generate an immediate increase in biodiversity.

In other studies on exclusions in montane ecosystems, positive effects on species diversity may take more than a year to manifest. This is largely because slower-growing species require more time to establish themselves and occupy the spaces freed by the absence of herbivores, and an early recovery phase may be observed[Brown et al., 2022].

5.2.4 Clustering analysis

Euclidean distance matrix

In the observed Euclidean distance matrices, it can be seen that most plant species have close distances between them, which could reflect a high similarity in the distribution of these species within their respective habitats. In the case of the original data taken in March 2023, differences in distances stand out, especially between *Cinnagrostis intermedia* and other species such as *Alchemilla orbiculata*, *Cinnagrostis coarctata*, and *Azorella pedunculata*. These differences suggest that *Cinnagrostis intermedia*, a dominant species in the grassland ecosystem of the paramo, has managed to establish itself more solidly, surpassing other species in number of contacts and coverage. This may be related to its ability to adapt to habitat conditions and better resist competition with other species and conditions such as wind or cold [Cingolani et al., 2005].

In the case of data taken after one year in October 2024, the most notable distance is between *Cinnagrostis intermedia* and the exposed soil, which may be due to the ability of this species to dominate areas with more compact soils or closed vegetation, while the exposed soil is dominated by other species more adapted to erosion and extreme conditions[Jia et al., 2018].

Number of clusters by the Elbow Method and Cumulative Explained Variance

A clear decrease in the sum of distances within clusters (WSS) is observed, indicating that increasing the number of clusters reduces variability. However, from a point around 3 or 4 clusters, the reduction in WSS stabilizes, suggesting that adding more clusters does not provide significant benefits. Therefore, 4 clusters seem to be the optimal number since, from that point on, the groups are well-defined, and adding more does not improve the interpretation of the data.

The analysis of the cumulative explained variance shows that the first clusters capture most of the variability, suggesting that the species within these groups share characteristics that distinguish them from the rest. This is indicative that the first clusters represent the dominant ecological patterns in the ACHA. From the fourth cluster onwards, the curve stabilizes, suggesting that adding more clusters does not provide significant value in explaining the variability of the data. This point indicates that the use of four clusters is optimal, as it allows capturing a large part of the ecological structure. In addition, selecting between 4 and 5 clusters ensures that key dynamics between species and their response to environmental factors or herbivore exclusions are captured.

Cluster plots show how exclusions influence species grouping, revealing differences in homogeneity among groups.

It is notable how closely cushion plants, dry herbaceous vegetation, and wet herbaceous vegetation are grouped together in the principal component analyses (PCA). This indicates that these plant communities respond similarly to environmental factors and herbivory pressure. This similarity is likely due to these species sharing functional adaptations that allow them to survive and thrive under environmental stress and herbivory conditions.

Multidimensional Scaling Analysis (MDS)

The calculated stress values correspond to 0.07212603 and 0.07344119 for the original data and the data after one year, respectively. These values are below the accepted value of 0.1 [Clarke and Warwick, 2001] for a good fit, so our analysis reproduces the relationships between the distances very accurately.

In the MDS analysis, a type 1 stress value was used, which eases the closest relationships between points in the multidimensional space. This suggests that species clustered in this representation have closer ecological relationships.

The optimal configuration was replicated in several iterations, which provides confidence in the robustness of the results obtained. This consistency, combined with the use of a PCA rotation to optimize orientation in the two-dimensional space, ensures that the relationships between species are well represented.

The analysis suggests that species that appear close in the two-dimensional space share ecological characteristics, either due to their adaptations to herbivory or their ability to compete under similar conditions. On the other hand, more distant species reflect ecological differences to exclusion factors, which could be related to their resistance to herbivory or other biotic interactions.

Homogeneity and Separation

Connectivity helps to understand how points are connected within clusters. In this case, the data taken after one year has a slightly smaller value than the original data, suggesting that points are better grouped in the data taken after one year.

On the other hand, the Dunn index measures the internal compaction and external separation of the clusters. A higher value is sought to indicate that the clusters are well-compacted and separated. The data taken after one year show a higher value compared to the original data, suggesting better compaction and separation of the clusters.

The Silhouette index gives a measure of how well the data is grouped within clusters compared to other clusters. A value close to 1 indicates good clustering. The original data have a slightly higher Silhouette value, suggesting that species are better grouped.

The results suggest that after one year, there are significant changes in biodiversity and community structure in the Antisana paramo. These changes may be due to factors such as herbivore intervention, changes in climate, or competition between species.

Comparison of centroids

In clusters 2 and 3, centroid values increase and decrease, respectively. An increase in the centroid value indicates that the species associated with that variable are increasing their presence or influence in the exclusions, which could be related to greater colonization success or adaptation in the absence of herbivores.

The decrease in the centroid of cluster 3 suggests a reduction in the abundance of the species related to that variable. This decrease could be related to ecological or competitive factors that limit the growth of these species, such as competition between species or changes in environmental conditions. It highlights that not all species respond uniformly to the elimination of herbivores.

Finally, clusters 1 and 4 show slight variations in their centroids, indicating that the changes in the species associated with those clusters are more stable over time. This suggests that the species in these groups are well adapted to the conditions of the control points or exclusions and are not experiencing significant fluctuations in their distribution or abundance.

5.2.5 Repeated measures analysis of variance (ANOVA)

In the case of the exclusion of Cushion plants, Rabbits, and Deer, the original data, as well as the data taken after one year, show high F values and low P values, which suggests that there are significant differences between the clusters. For the exclusion of Exposed soil Deer, in the case of the original data, the difference is not substantial ($p > 0.05$), but in the case of the data taken one year later, it is. This tells us that after one year, the differences in this habitat have become more significant. For the Dry herbaceous vegetation Control point, the value of the original data showed significant differences between the clusters ($p < 0.05$), but the data taken one year later did not ($p > 0.05$). This indicates that the difference between clusters has decreased over time, suggesting a homogenization in this habitat.

Chapter 6

Conclusions

This study has shown that the exclusion of herbivores, such as the white-tailed deer *(Odocoileus virginianus)* and the andean rabbit *(Sylvilagus brasiliensis)*, generates significant changes in the composition and coverage of plant species after one year. Through an experimental design with exclusions, a reduction in contacts of certain species associated with herbivory was observed, while others showed a recovery in their coverage. These results confirm the impact of herbivory on the diversity and plant structure of the paramo, highlighting the importance of evaluating the management of this type of interactions in mountain ecosystems.

Species richness accumulation curves and analysis of variance confirmed significant changes in species cover within the exclusions. Variable responses were observed depending on the taxonomic group and habitat type: herbaceous species showed a significant increase in humid vegetation and cushion vegetation habitats after one year of exclusion, while some grass species experienced a decrease in their relative cover in dry vegetation habitats. These results suggest that the ecosystem responds differentially to herbivore exclusion, allowing the regeneration of some key species while others could decline, affecting the ecological dynamics of the paramo.

Finally, the comparison between the different exclusions and the control sites showed that the white-tailed deer and the andean rabbit significantly impact the composition and structure of the plant communities of the paramo. The results reveal that these herbivores influence differently depending on the type of exclusion and habitat, which highlights the importance of evaluating their individual roles in the ecosystem. Although a direct comparison of impact magnitudes was not established, the selective exclusion of both herbivores proved effective in identifying patterns of change in plant diversity and cover.

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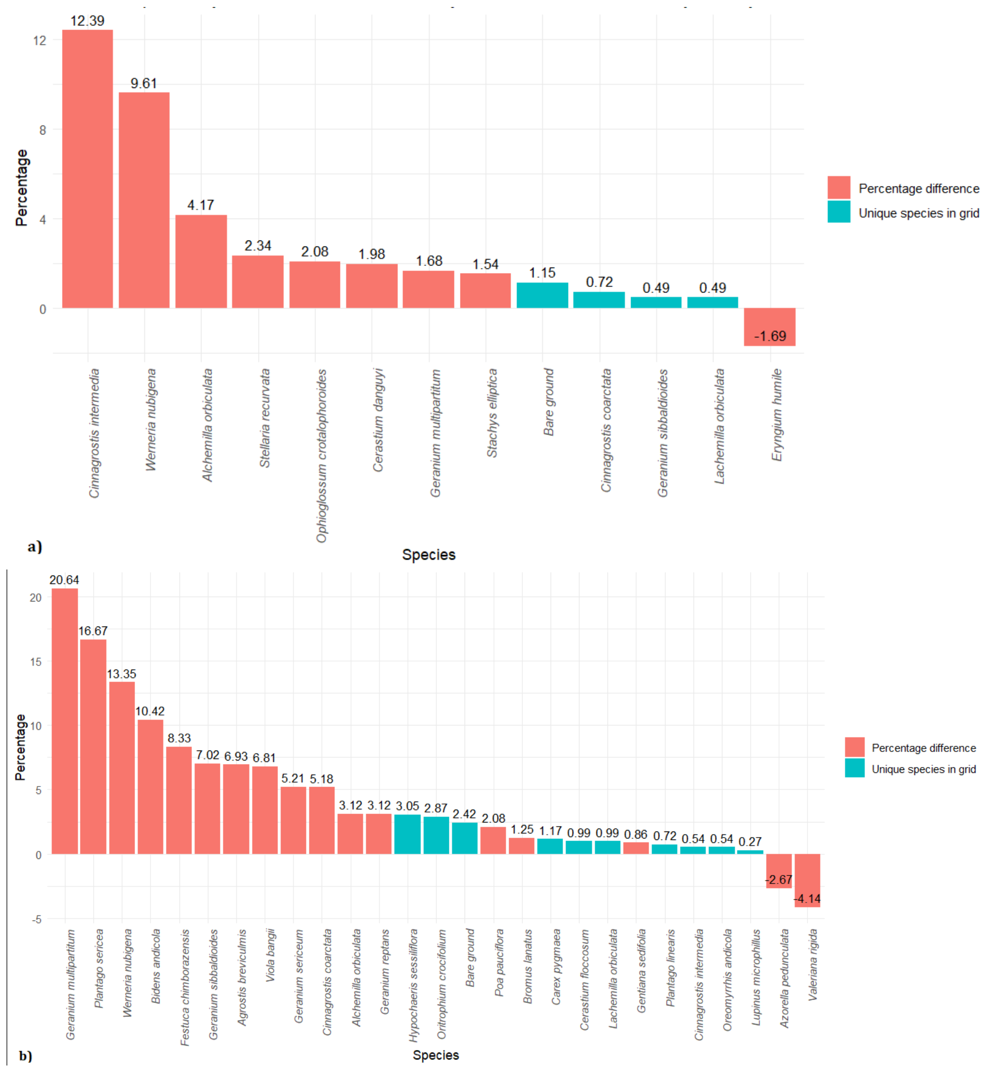
Appendices

Difference in percentage of coverage of plant species at the control point in different habitats of Antisana Hydrological Conservation Area.



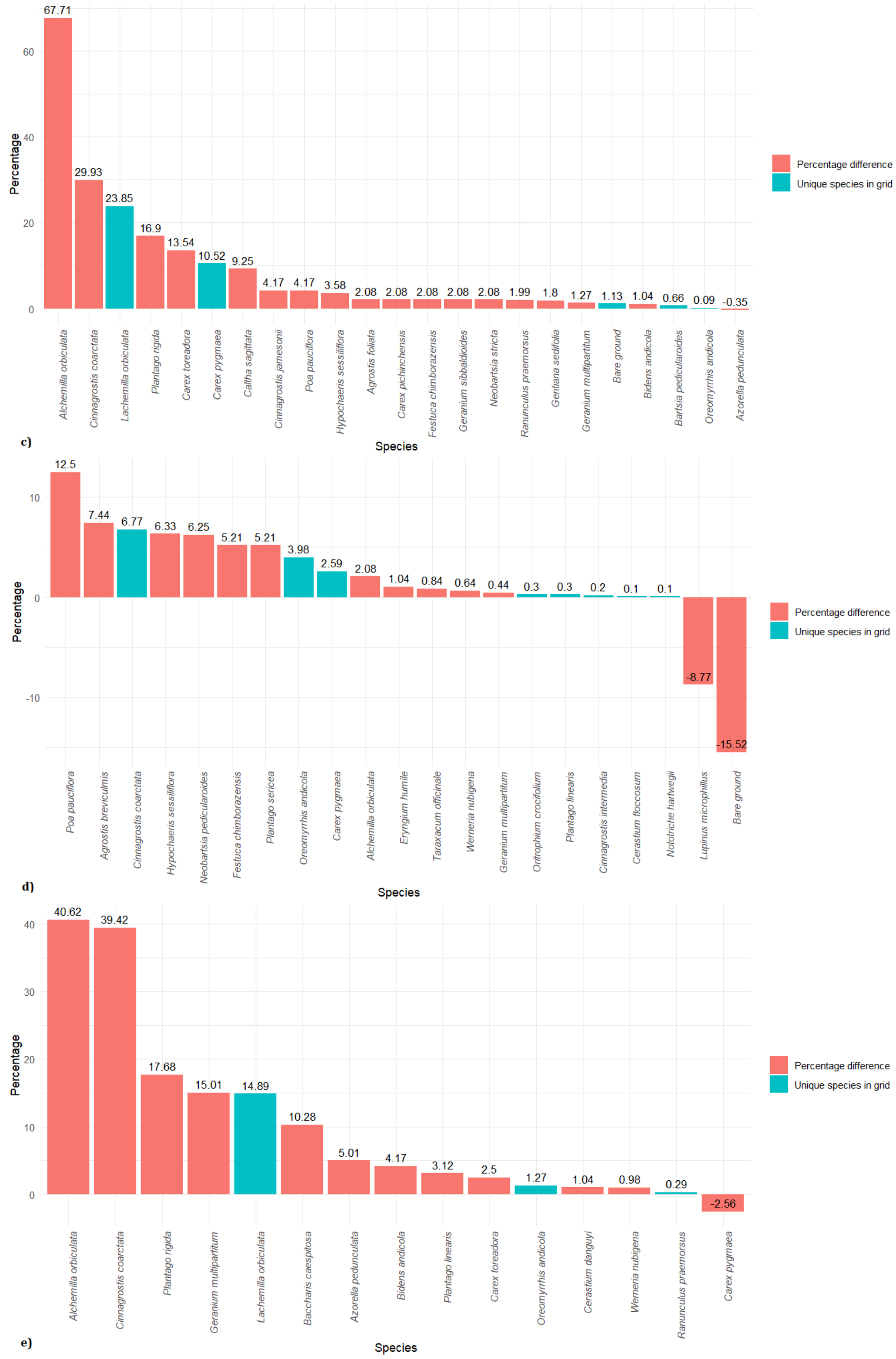
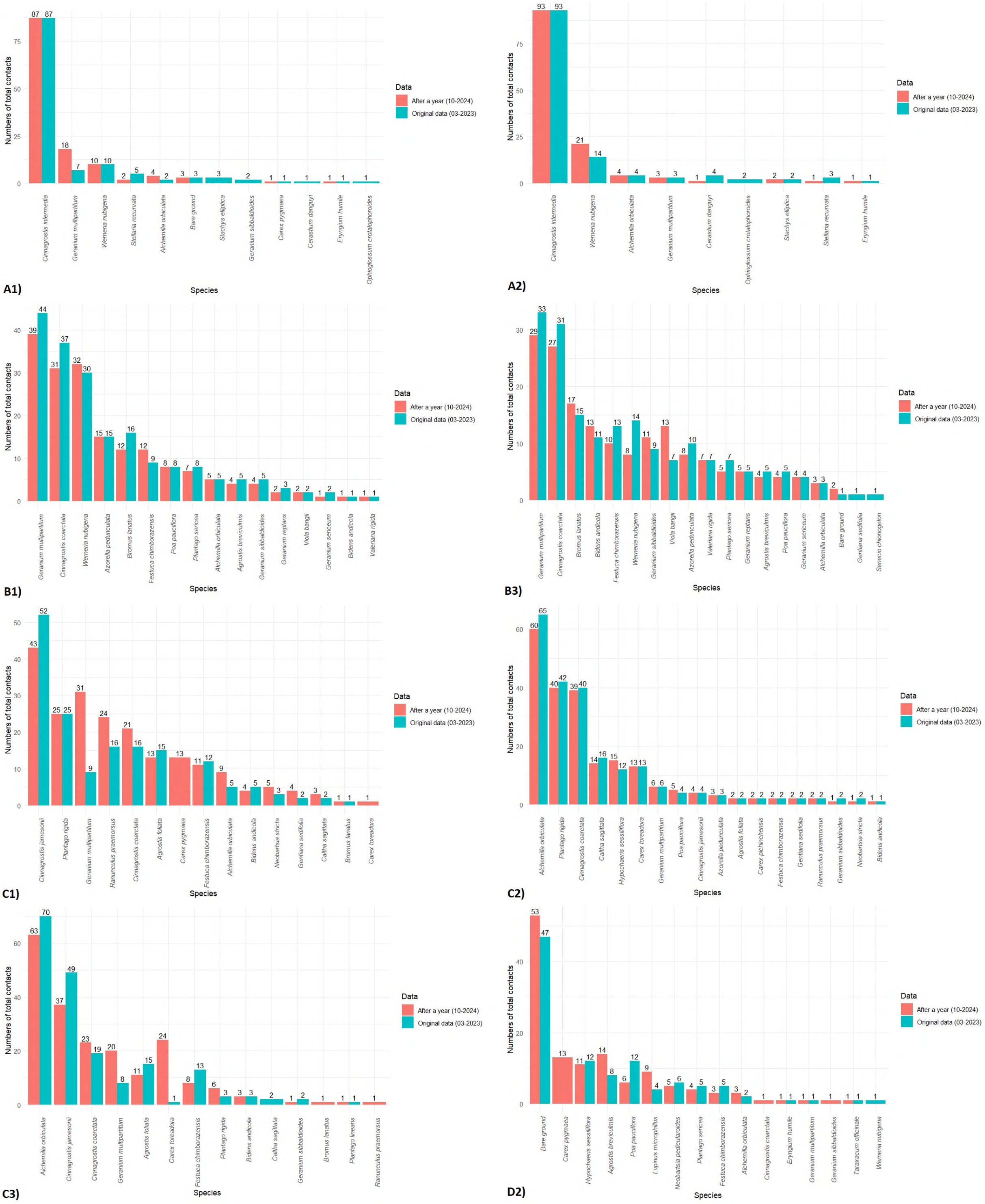


Figure 6.1: Difference of percentage of coverage of plant species at the control point in different habitats of Antisana Hydrological Conservation Area. a) Paramo grasslands, b) Dry herbaceous vegetation, c) Humid herbaceous vegetation, d) Exposed soil, and e) Cushion plants

Total contacts numbers of plant species in different exclusions and control points of Antisana Hydrological Conservation Area.



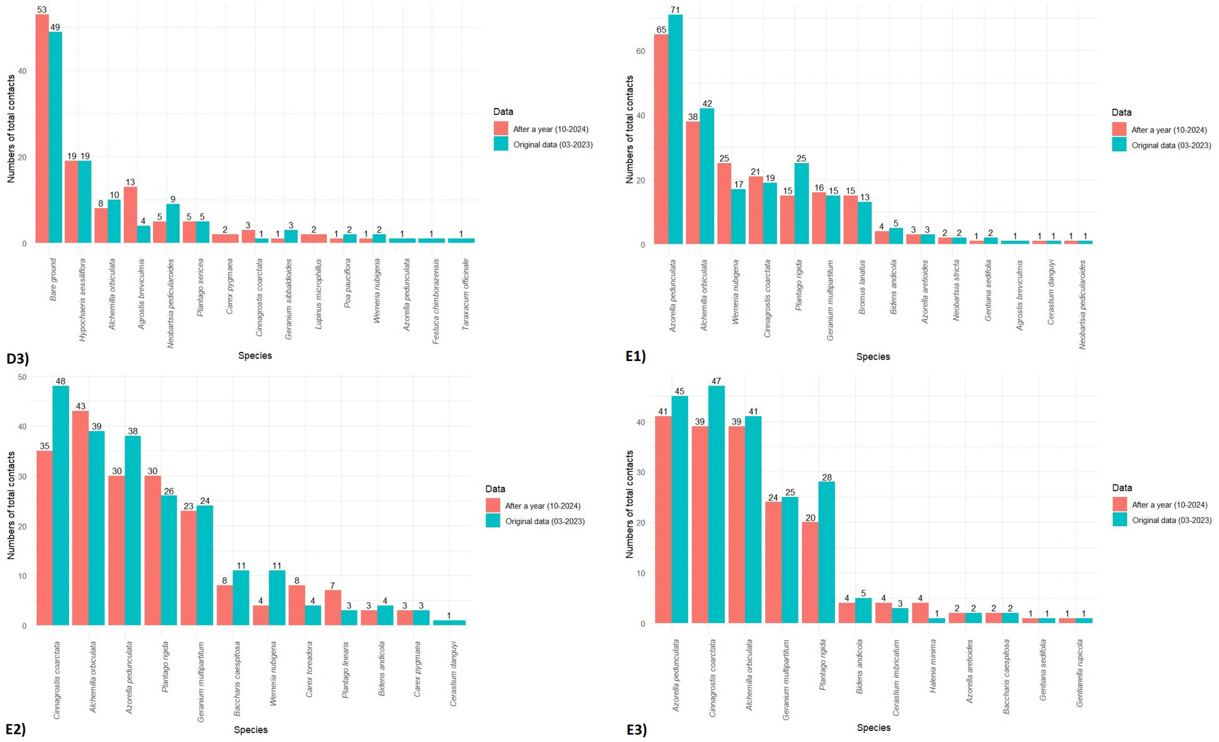


Figure 6.2: Total contact numbers of plant species in different exclusions and control points of Antisana Hydrological Conservation Area. a) Páramo grasslands, b) Dry herbaceous vegetation, c) Humid herbaceous vegetation, d) Exposed soil, and e) Cushion plants; 1. Exclusion of Deer, 2. Control point, 3. Exclusion of rabbits and deer.

Percentage coverage of each species in the different habitats of Antisana Hydrological Conservation Area.

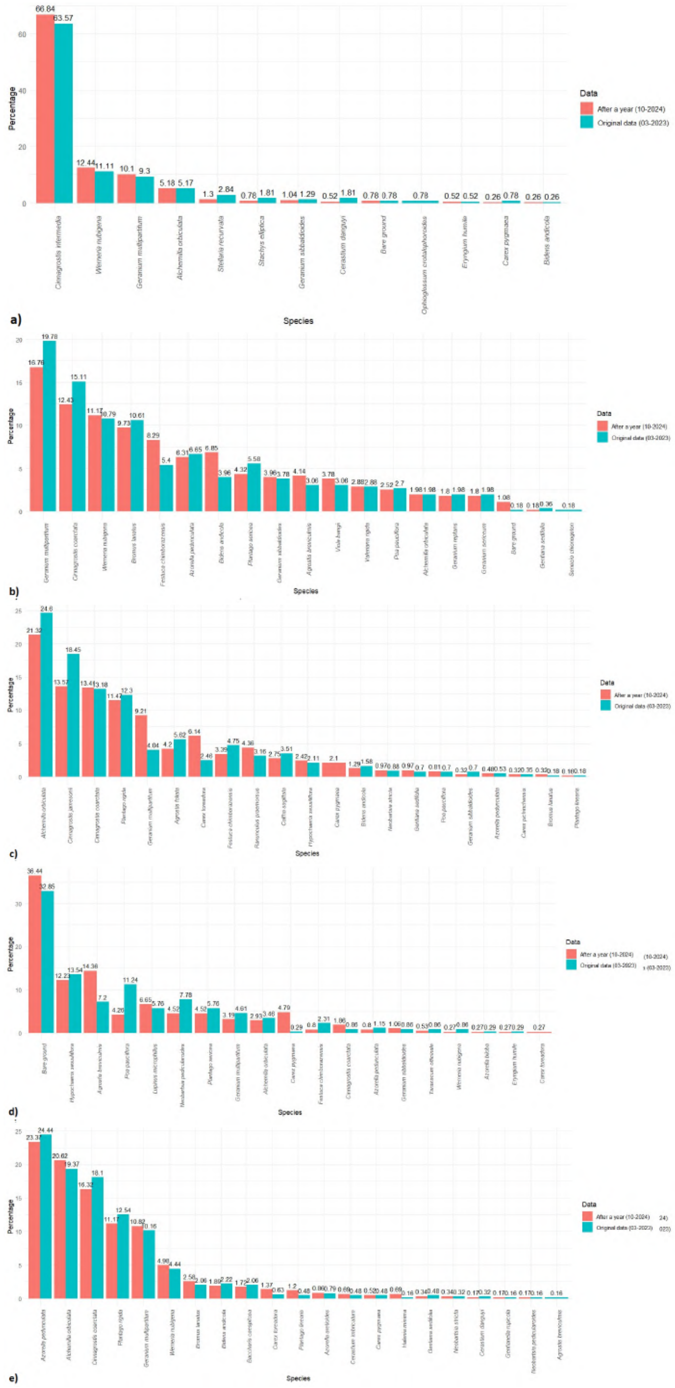
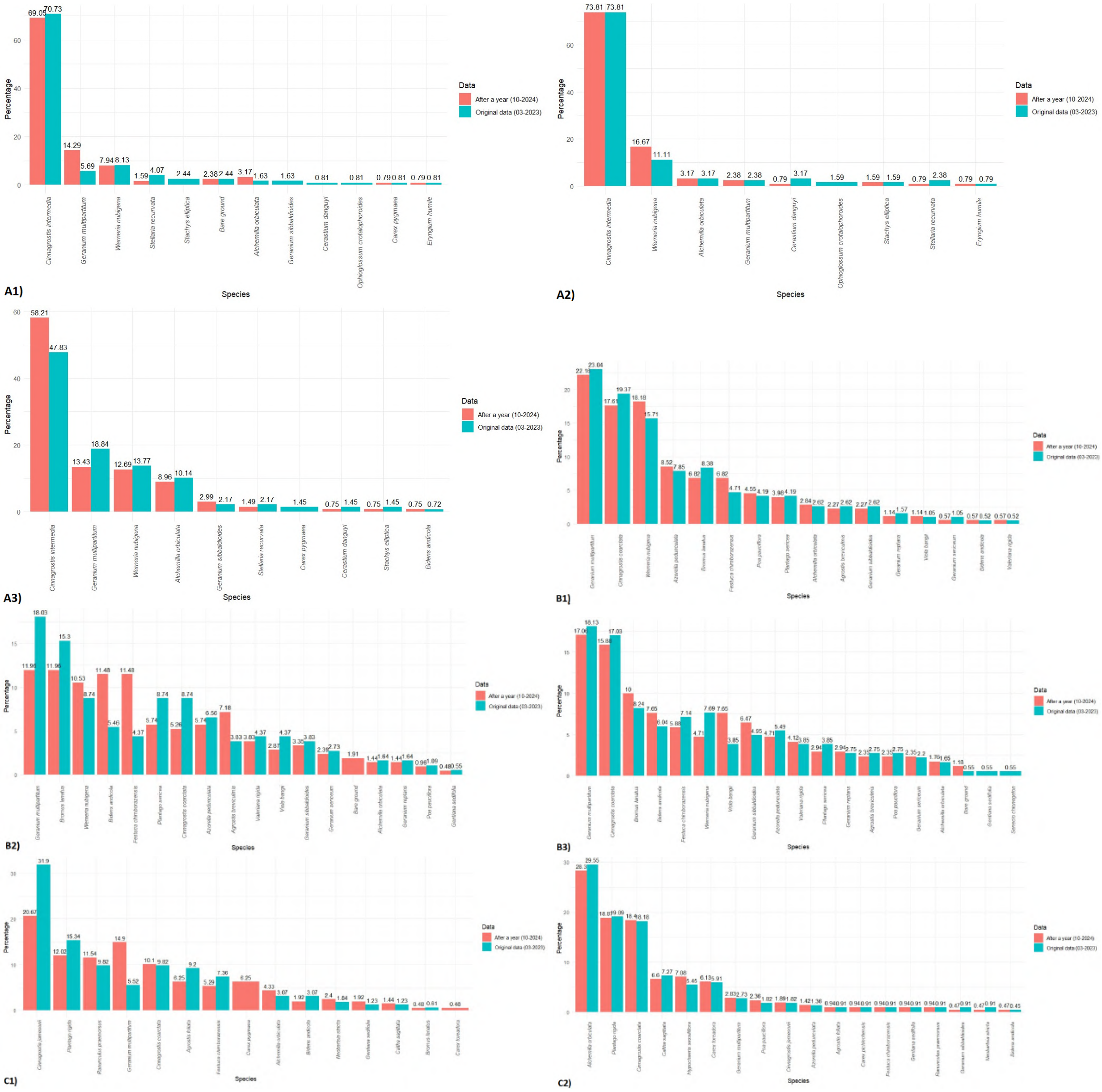


Figure 6.3: Total percentage of coverage of each species in the different habitats of Antisana Hydrological Conservation Area. a) Páramo grasslands, b) Dry herbaceous vegetation, c) Humid herbaceous vegetation, d) Exposed soil, and e) Cushion plants

Percentage coverage of each species in the different exclusions and control points of Antisana Hydrological Conservation Area.



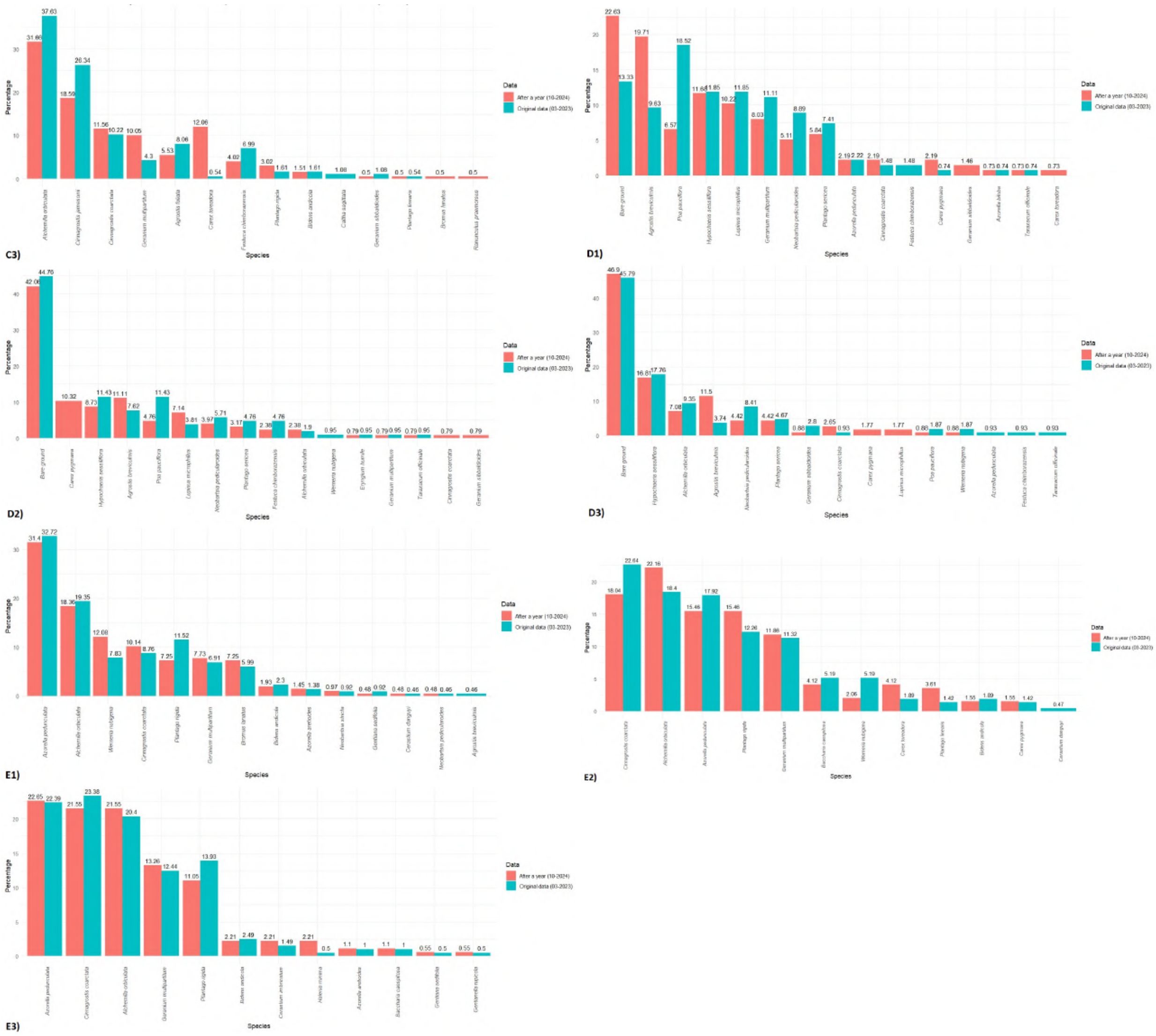


Figure 6.4: Total percentage of coverage of each species in the different exclusions and control points of Antisana Hydrological Conservation Area: a) Paramo grasslands, b) Dry herbaceous vegetation, c) Humid herbaceous vegetation, d) Exposed soil, and e) Cushion plants; 1. Exclusion of Deer, 2. Control point, 3. Exclusion of rabbits and deer.

Species richness accumulation curves for each habitat of Antisana Hydrological Conservation Area

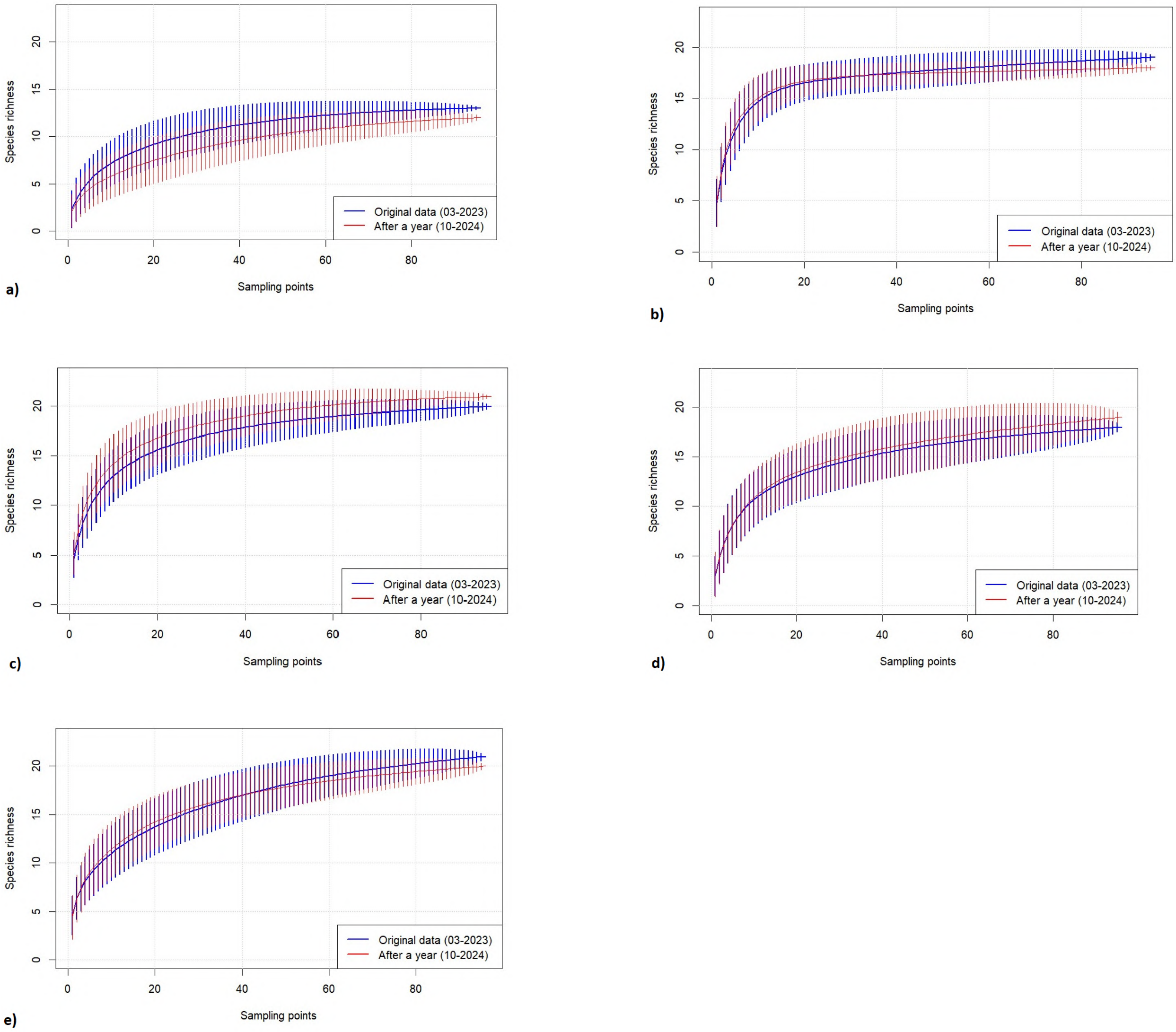
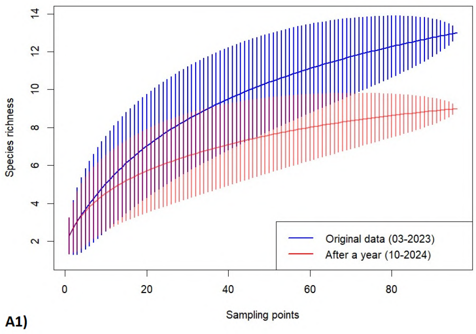


Figure 6.5: Species richness accumulation curves for each habitat of Antisana Hydrological Conservation Area. a) Páramo grasslands, b) Dry herbaceous vegetation, c) Humid herbaceous vegetation, d) Exposed soil, and e) Cushion plants

Species richness accumulation curve at each exclusion and control point of Antisana Hydrological Conservation Area.



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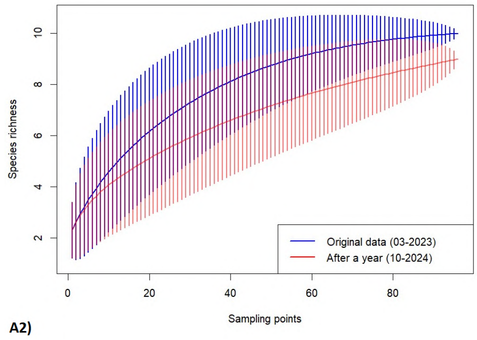
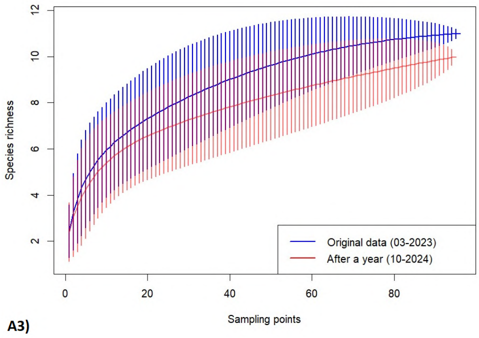
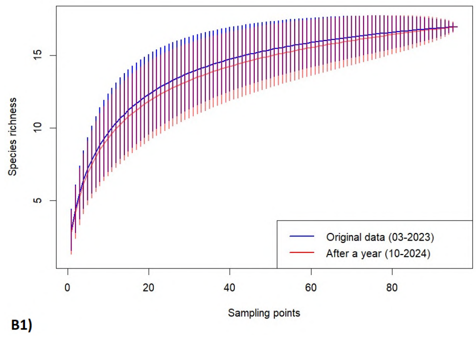


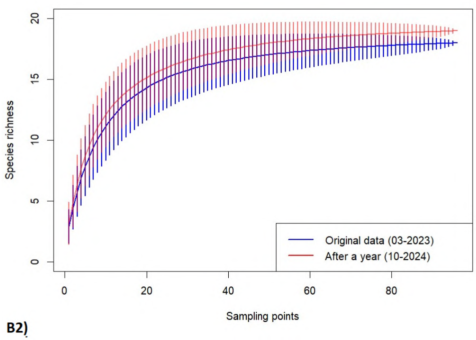
A2)



A3)



B1)



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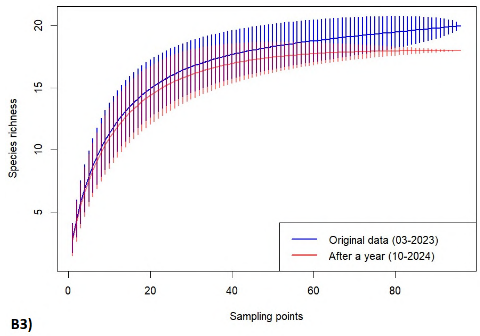

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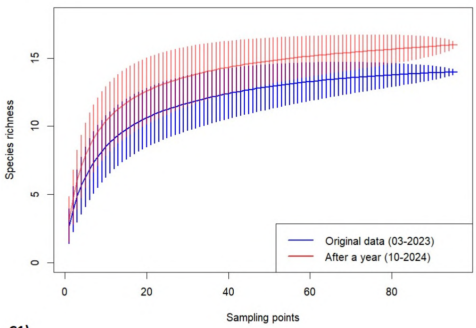
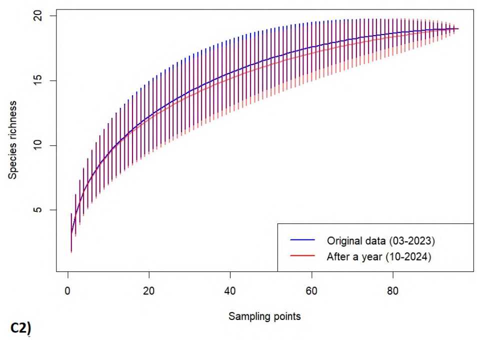


C1)



C2)

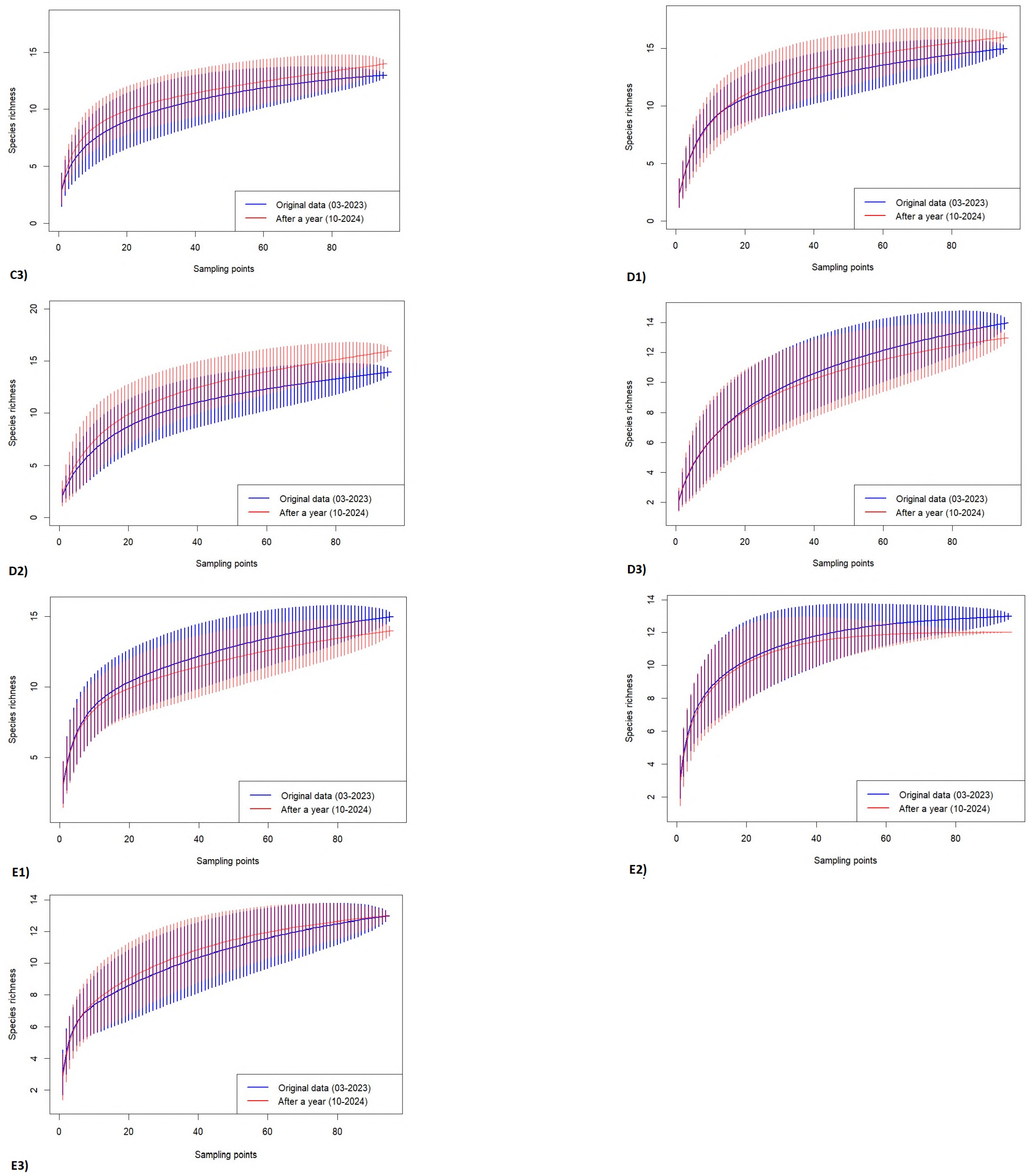


Figure 6.6: Species richness accumulation curve at each exclusion and control point of Antisana Hydrological Conservation Area: a) Páramo grasslands, b) Dry herbaceous vegetation, c) Humid herbaceous vegetation, d) Exposed soil, and e) Cushion plants; 1. Exclusion of Deer, 2. Control point, 3. Exclusion of rabbits and deer.