UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias Biológicas e Ingeniería

Estimation of Deer Population by Means of Indirect Methods: Distance method, Fecal Accumulation Rate, Fecal Standing Crop at the Antisana Paramo in Ecuador

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

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Urcuquí, agosto de 2019

UNIVERSIDAD
YACHAY
TECH

Urcuquí, 28 de agosto de 2019

SECRETARÍA GENERAL
(Vicerrectorado Académico/Cancillería)
ESCUELA DE CIENCIAS BIOLÓGICAS E INGENIERÍA
CARRERA DE BIOLOGÍA
ACTA DE DEFENSA No. UITEY-BIO-2019-00011-AD

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Dedication

To my mother Margod Palacios, her love has always been my unlimited source of inspiration.

To my father, for infecting me with a little bit of his unhuman attribute of hard word.

To my brother, for his giving me his trust and unconditional support.

Acknowledgments

This work is the result of the collaboration among various institutions and people. I want to thank Yachay Tech University and its teachers for making me fall in love with science, teaching me beyond the normal standards and giving me the tools to conduct a study like this one. I also want to thank FONAG and EPMAPS for their logistic and financial support, especially to Luna Delerue for being aware of the progress of my thesis and to the guardaparamo Isidro Bautista who accompanied me during the majority of my fieldwork. I thank my co-advisor Ernesto Ponsot who helped me with the statistical analyses, and finally, I am very grateful to my advisor Markus Tellkamp and his optimism despite of long travels, displeasing methods and really cold weather during the fieldtrips. This work would not have been possible without him.

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Abbreviations

INEC: Instituto Nacional de Estadísticas y Censos (National Institute of Statistics and Censuses)

ACHA: Área de Conservación Hídrica Antisana (Antisana Hydrological Conservation Area)

GAB: Guayllabamba Alto basin

VPCs: Vantage Point Counts

FSC: Fecal Standing Crop

FAR: Fecal Accumulation Rate

DSM: Distance Sampling Method

MAE: Ministerio del Ambiente (Ministry of Environment)

DMQ: Distrito Metropolitano de Quito (Metropolitan District of Quito)

FONAG: Fondo para la Protección del Agua (Fund for the Protection of Water)

EPMAPS: Empresa Pública Municipal de Agua Potable y Saneamiento (Municipal Public Company for Drinking Water and Sanitation)

NDVI: Normalized Difference Vegetation Index

PNNC: Parque Nacional Natural Chingaza (National Natural Park Chingaza)

GPS: Global Positioning System

Abstract

After years of intense hunting and grazing by thousands of livestock in the Área de Conservación Hídrica Antisana (ACHA), the white-tailed deer (*Odocoileous virginianus*) is making a comeback, arousing concerns about their possible effects on the ecosystem. This herbivore may alter the vegetation and thus the carbon and water cycles in this páramo, which is managed by the Fondo para la Protección del Agua (FONAG) and Empresa Pública Municipal de Agua Potable y Saneamiento (EPMAPS), institutions responsible for providing water to the Distrito Metropolitano de Quito (DMQ). As an initial step to better understand the ecological interactions involving deer in this ecosystem, four different methods, one direct and three indirect, were used to estimate the deer population: Vantage Point Counts (VPCs), Fecal Standing Crop (FSC), Fecal Accumulation Rate (FAR), and Distance Sampling Method (DSM). The first mentioned provided a minimum population size and insights about deer sex and age structure, whereas the other methods provided deer abundance and density estimates in each representative habitat within ACHA. Here, I report the first comprehensive population estimates for this species in ACHA and the second estimate for the Ecuadorean Andes. Besides, I compare the efficiency and reliability of the methods and discuss the results in the context of habitat use and preference.

Key words:

White-tailed deer, *Odocoileous virginianus*, population estimates, Fecal Standing Crop (FSC), Fecal Accumulation Rate (FAR), Distance, Vantage Point Counts (VPCs).

Resumen

Después de años de intensa caza y del pastoreo de miles de cabezas de ganado en el Área de Conservación Hídrica Antisana (ACHA), el venado de cola blanca (*Odocoileous virginianus*) está regresando, despertando preocupaciones sobre sus posibles efectos en el ecosistema. Este herbívoro podría alterar la vegetación y por lo tanto los ciclos del agua y carbono en este páramo, que es administrado por el Fondo para la Protección del Agua (FONAG) y la Empresa Pública Municipal de Agua Potable y Saneamiento (EPMAPS), instituciones responsables de proporcionar agua al Distrito Metropolitano de Quito (DMQ). Como paso inicial para comprender mejor las interacciones ecológicas que involucran a los venados en este ecosistema, se utilizaron cuatro métodos diferentes, uno directo y tres indirectos, para estimar la población de venados: Vantage Point Counts (VPCs), Fecal Standing Crop (FSC), Fecal Accumulation Rate (FAR) and Distance Sampling Method (DSM). El primer método mencionado proporcionó un tamaño mínimo de la población e información sobre la estructura por sexo y edad de los venados, mientras que los otros métodos proporcionaron estimaciones de abundancia y densidad del venado en cada hábitat representativo dentro de ACHA. Aquí reporto las primeras estimaciones de población integrales para esta especie en ACHA y la segunda estimación en los Andes ecuatorianos. Además, comparo la eficiencia y la fiabilidad de los métodos y analizo los resultados en el contexto de preferencia y uso de hábitat.

Palabras clave:

Venado de cola blanca, *Odocoileous virginianus*, estimaciones de población, Fecal Standing Crop (FSC), Fecal Accumulation Rate (FAR), Distance, Vantage Point Counts (VPCs).

1. Introduction

According to the last census carried out in Ecuador by the National Institute of Statistics and Censuses (INEC) in 2010, the Metropolitan District of Quito (DMQ) had 2,239,191 inhabitants and the projections are 2,781,641 inhabitants in 2020 (INEC, 2010). This tendency suggests that the demand of water will continue to increase. The estimated demand of water in the Guayllabamba Alto basin (GAB) of which DMQ forms part, is expected to increase by 14% by around 2023-2033 (Muñoz & Torres, 2013); meanwhile, an increase of 28.5% is expected between 2020 and 2040 for the DMQ (EPMAPS, 2011). Muñoz & Torres (2013) developed models to evaluate the water availability in the future (10-20 years) based on variations in current rainfalls and water demand. They show ten possible scenarios with an increasing demand, but acceptable availability of water in GAB and other micro-basins. However, water stress is expected to be locally severe in GAB and moderate to the south of Quito (Muñoz & Torres, 2013). In addition, these results can vary depending on patterns in water use and management of the resources.

One of the main water sources for Quito is the icecap runoff of the Antisana Volcano (Francou et al., 2004). This and other Andean glaciers have caught special attention in the last years because of their mass balance variability and increasing rate of retreat (Francou et al., 2004). Glaciers in the inner tropics are highly sensitive to climate change and may not only retreat, but disappear (Vuille et al., 2008). As glaciers increasingly lose mass, runoff increases provisionally, and downstream users quickly get used to the high water availability, which will disappear when the frozen water stocks become depleted. Especially during the dry seasons, changes in the streamflow will diminish water supply for agricultural irrigation, human consumption, ecosystem integrity, mining, and so forth (Vuille et al., 2008). Many cities in the Andes at high altitudes depend on this source of water and so does DMQ. Vuille et al. (2008) recommend to take some actions to be prepared in the future such as conservation or the creation of water reservoirs.

Another important natural source and reservoir of good quality water (Coronel, 2019) are the paramos that surround DMQ (Cuesta et al., 2014). Not only DMQ but indeed most of the Ecuadorian people depend on this ecosystem for water (Mena et al., 2001). Paramos are able to intercept and store water, as well as regulate both surface and underground water flows because of their elevation, temperature, vegetation type, and soil structure (Coronel, 2019; Vargas et al., 2012). Nevertheless, paramos are threatened by fire, urban expansion, advance of the agricultural frontier (e.g. potato and bean fields), intensive livestock grazing, road building, pine plantations, mining extraction and among others (Buytaert et al., 2006; Coronel, 2019; Cuesta et al., 2014). Although Andean paramo has been recognized as an important water source (Rodríguez et al., 2013), the role of the climatic, edaphological, ecological, geological and human factors in the paramo's hydrological cycle are not well understood (Cuesta et al., 2014).

To protect the water sources for DMQ, the Empresa Pública Municipal de Agua Potable y Saneamiento (EPMAPS) and the Fondo para la Protección del Agua (FONAG) manage priority areas that together encompass about 20,000 ha. These are the Área de Conservación Hídrica Alto Pita, Área de Conservación Hídrica Paluguillo and Área de Conservación Hídrica Antisana (ACHA). Together these areas protect the availability of drinking water for at least 60% of the DMQ population (Coronel, 2019). ACHA and its water sources are contributors to the Mica-Quito Sur System that has a capacity to transport 1,700 l/s (Coronel, 2019; EPMAPS, 2011). It is located 70 Km east of the city of Quito in Napo and Pichincha provinces (Figure 1). It includes sections of the parroquias (Parishes) of Papallacta, Cotundo and Archidona and has an estimated area of 8457 ha. ACHA was selected as the study area for this thesis because of its importance for the water supply of Quito and reports of large numbers of deer.

In the past, most paramos were used by hunter-gatherers until the Spanish colonization. At that time the paramos' vegetation started to be used as forage by livestock (Molinillo & Monasterio, 2002). Being part of large haciendas the paramos of Ecuador were rapidly dedicated to the breeding of bulls, horses and sheep. In addition, cattle were raised for the production of meat and milk (Hess, 1990). Indigenous communities previously using this area for hunting and gathering were marginalized. Towards the end of the 20th century, the economic income produced by sheep and cattle livestock became as much or more important than agricultural production in some paramos of Ecuador (Hess, 1990;

White & Maldonado, 1991). For instance, ACHA was part of a large hacienda that supported tens of thousands of livestock (Aguirre et al., 2013).

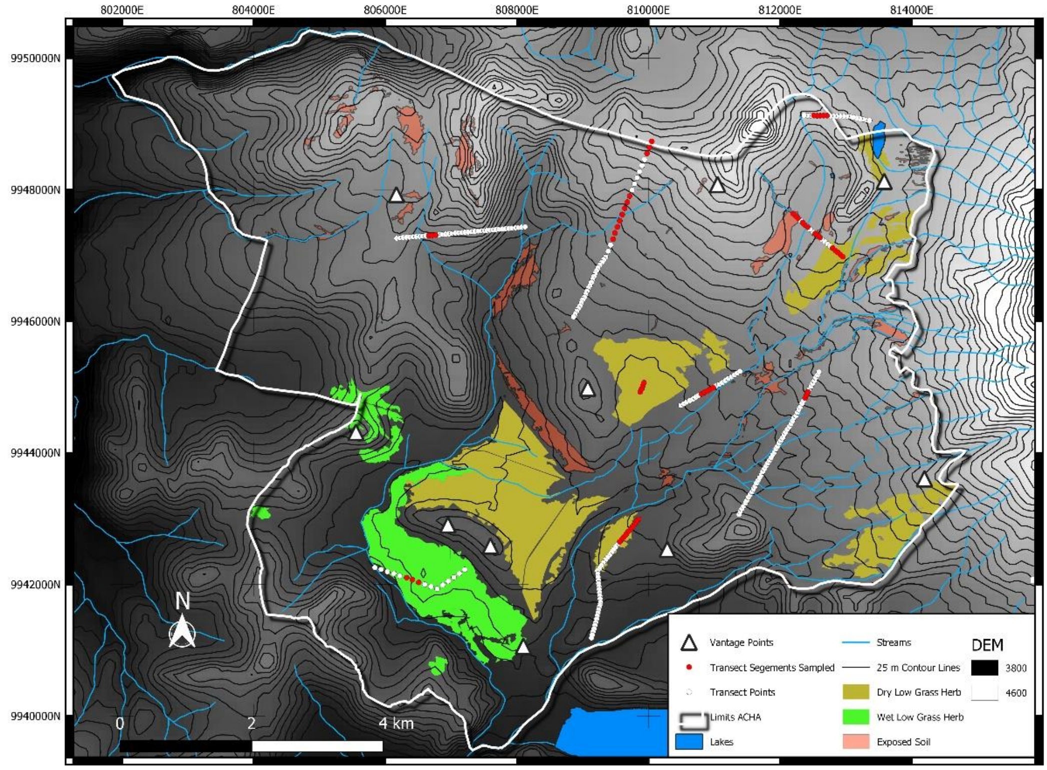

Figure 1. Study area (ACHA), transects used for indirect methods and vantage points for the direct method.

Although paramos superficially seem to be good place for grazing, the dominant natural vegetation -dominated by rossettes, bunch grasses, shrubs and cushion plants on deep organic soils- has low palatability for livestock (Molinillo & Monasterio, 2002). To improve the accessibility and palatability of the forage burning of paramo grasslands became a common activity. In addition, the poor livestock management allowed for overgrazing of areas close to water sources or with more accessible forage (Molinillo & Monasterio, 2002). In Ecuador this fire-grazing became an widely used strategy that acted as a selective factor favoring the expansion of certain species such as bunchgrasses or more cespitous growth forms in areas of greater stress (Molinillo & Monasterio, 2002). At ACHA, overgrazing may also have created large areas dominated by cushion plants.

ACHA seems to be different from other paramos in Ecuador because of its unusual mixture of habitats. Instead of being dominated by *Calamagrotis* *intermedia* bunchgrasses, the landscape is composed of large areas of cushion plants (e.g. *Plantago rigida*) and herbaceous vegetation (e.g. *Werneria nubigena*), mixed in with a low *Calamagrostris* (cf. *C. fibrovaginata*) grass. This composition has relevant implications for the water cycle. For example, cushion plants and wetlands have a positive water balance, this means that loss of water by evapotranspiration and watercourses is less than the income of water by runoffs or rainfalls (Bosnian et al., 1993; Cleef, 1981). Likewise, a study made by Buytaert et al. (2006) showed that natural paramo soils experienced an overall decrease of 16% in their water retention at wilting point after two years of cultivation, and when the samples were dried in the laboratory the average decrease was 35%. They also highlight the importance of natural vegetation in the water buffering capacity and the organic litter layer. Another example is the interception of water by vegetation; although the amount of water captured is unknown, this process is important in forested areas such as *Polypelis* woodlands (Buytaert et al., 2006).

In this sense, the conservation and proper restoration of the vegetation is fundamental to protect ACHA and its water sources. This has become a priority for the FONAG that has been working on a reference ecosystem to recover integrity of the current ecosystem and its services (Aguirre et al., 2013). In addition, socio-economic and ecological barriers for restauration have been evaluated, such as the absence of social articulation or limited dispersion, establishment and development of plants. Herbivory by big mammals can cause serious damage to community structure and composition of plants (Pettit et al., 1995). This is the reason why FONAG constantly monitors the remaining populations of livestock at ACHA either through direct observation or the use of drones. The decrease in grazing pressure by cattle has had a positive impact on the ecological integrity of terrestrial and aquatic ecosystems; recent studies show that the average coverage of shrubby vegetation has increased and the area of exposed soils has diminished (FONAG, 2017, 2018).

The removal of livestock, however, can have important consequences for food chains based on carrion and has the potential to affect the populations of iconic species, such as the Andean Condor (*Vultur gryphus*) and the curiquingue or Carunculated Caracara (*Phalcoboenus carunculatus*) (Figure 2). These animals might have modified their feeding habits in the past, now preferring livestock (Donázar, 1993; Sánchez-Zapata et al., 2003). In Patagonia, Argentina, condors depend mainly on exotic mammals and the most consumed food seems to be the managed livestock (Chamberlain et al., 2005). The same situation appears to be happening to the Andean Condors living close to ACHA. Other species such as the Culpeo Fox (*Pseudalopex culpaeus*) could be affected too. The diet of this species has changed towards introduced mammals in the Argentine Patagonia (Novaro, Funes, & Susan Walker, 2000). However, there is no current available information about the diet of this animal at ACHA. In this sense, the strategies implemented by FONAG or other institutions need to include an analysis of proper food supplies for the mentioned species, as dietary shifts can have serious consequences for their conservation (Chamberlain et al., 2005). A good strategy may be to exclude exotic species gradually so native species populations can recover (Lambertucci et al., 2009). Lambertucci et al. (2009) points out that native fauna in protected areas can become an important source of healthy food for scavengers and carnivores.

Figure 2. A juvenile Carunculated Caracara (*Phalcoboenus carunculatus*) observed at ACHA.

This healthy source of food at ACHA could be the white-tailed deer (*Odocoileus virginianus ustus*), whose presence in South America is dated to the Middle Pleistocene (Webb, 1985). However, there is no available information about its current population status in the Ecuadorian Andes. In the past, native species from the Argentine Patagonia have decreased notoriously because of degradation of their habitats (overgrazing by sheep), competition with exotic species, and hunting (Baldi et al., 2001; Lambertucci et al., 2009). The situation for the white-tailed deer in ACHA might be similar. In Ecuadorian paramos, deer were intensely hunted, even in protected areas and national parks. This is the case of the paramos of Cotopaxi, Azuay, Cayambe, Cotacachi, El Ángel, Sangay and Antisana. In the latter, hunters used to enter from different sectors despite the previous owners' control of access to the area. This may be reason why deer populations were reduced remarkably in certain areas of the Antisana plateau and adjacent paramos (Albuja, 2007).

However, nowadays this species is making a comeback due to low pressures from hunting, competition and predation. Most livestock have been removed from ACHA, and their potential predators *Pseudalopex culpaeus* and *Puma concolor*, considered vulnerable in Ecuador (Arcos et al., 2011; Armijos et al., 2011), have become rare at ACHA. In the case of pumas, many attacks to domestic livestock have been documented across its range, and these human-feline conflicts have been used as a reason to persecute them.

Nevertheless, the recovery and conservation of white-tailed deer populations have to be approached carefully because large herbivores may also have a detrimental impact on the recovering paramo ecosystem. Low levels of grazing do not seem to cause a significant change on the hydrology of paramo soils but overgrazing seem to cause an important loss of water regulation (Crespo et al., 2010). At ACHA it is still unclear what the magnitude of the impact caused by deer after decades of grazing is. White-tailed Deer (*Odocoileus virginianus ustus*) can determine vegetation structure and composition (see Figure 3), especially when overabundant (Côté, 2011). A study carried out in northeastern Pennsylvania to evaluate the effects of this species of deer, showed that fenced plots contained a higher number of seedlings compared to open control plots. In addition, the average number of stems, crown spreads and heights of sprout clumps were significantly reduced in open plots. Moreover, the sprouts and seedlings that were outside the fenced plots were characterized by shrubby and aberrant growth due to constant browsing pressure compared to the relatively straight stems of the same species found inside fenced plots (Shafer et al., 1961). Another study in the same state also showed that the absence of deer browsing increased the number and height of seedlings of some tree species. Moreover, even though all tree species where found in fenced and unfenced plots, the species richness of trees in the fenced plots was higher, because fences protected the most palatable species. On the other hand, grasses and ferns were more abundant in unfenced plots, possibly because the species in there are less palatable, but it also could mean that the presence of woody vegetation inside fenced plots limited the growth of herbaceous vegetation (McCormick et al., 1993).

Figure 3. White-tailed Deer (*Odocoileus virginianus*) at ACHA.

Another study with another species of deer in central Japan reported that total plant biomass was larger inside the exclosure plots than outside them. Furthermore, only the biomass of woody species increased in all exclosures, which means the effective regeneration of this kind of vegetation when deer are excluded. Moreover, the biomass of palatable plants decreased severely outside the exclosures, only the tolerant and unpalatable species were able to survive even under excessive deer grazing. This study also found that the intensity of grazing depends on the height of the seedlings, those less than 5 cm can be difficult for deer to find in the forest floor vegetation. As in the studies mentioned above, this one also concluded that deer exclusion favored tree regeneration, decreased the mortality of seedlings, and increased growth rate (Nomiya et al., 2003).

The same study in central Japan demonstrated that biodiversity stayed the same for forest floor vegetation in fenced and unfenced plots (Nomiya et al., 2003). A long-term study on the grasslands of the Rocky Mountains reported that there was no significant change in biodiversity under moderate grazing of large herbivores while spatial variation was substantial (Stohlgren et al., 1999). However, Pettit et al. (1995) noted that biodiversity recovered rapidly after deer were excluded in a remnant forest. In addition, red deer (*Cervus elapus*) grazing pressure in grasslands of the Swiss Alps tended to increase diversity of plants; most plants able to resist the deer were low growing, had anti-herbivore protection mechanisms or had short life spans (Schütz, Risch, Leuzinger, Krüsi, & Achermann, 2003). Nomiya et al. (2003) argue that the duration and/or intensity of grazing could explain the variations in plant biodiversity.

Previous research has shown that the large herbivore-ecosystem interactions are complex and not easily predictable. For example, in North American rangelands, changes in grazing pressures have been shown to exhibit non-linear effects in vegetation: plant communities may reach multiple stable states and a decrease in grazing might not necessarily lead to recuperation of the ecosystem to a former climax-like state (Laycock, 1991). Once a disturbed ecosystem has crossed a “threshold”, improvement can only be obtained with greater management and intervention (Friedel, 1991). Management actions also depends on the kind, duration, and intensity of the disturbance (Laycock, 1991). Similar non-linear changes have been observed for other ecosystems as well (Côté et al., 2004). For the páramo grasslands of Ecuador we still lack a basic understanding of the herbivore-plant community interactions, both for domestic and wild ungulates. In other words, we do not even have a basic understanding of how herbivores affect páramo vegetation. At ACHA, it seems reasonable to expect that deer will benefit unpalatable or rapidly growing species and reduce palatable and/or slowly growing species.

All these studies elucidate the necessity to monitor the population of deer at ACHA and its potential impact on the vegetation, soil composition, water sources, and thus the entire ecosystem. Deer have been a natural component of páramo grasslands for millions of years, but we do not fully understand its ecological role in a poorly understood ecosystem. The first step in determining the role of white-tailed deer is knowing the current status of its population. There are many ways by which terrestrial animal populations can be studied: ground, aerial and remote sensing surveys (Guo et al., 2018). The former is the most used method and can be divided in direct and indirect methods. Direct methods are based on visual detection of individuals while indirect methods are based on counts of signs or marks, usually fecal pellet groups (Marques et al., 2001).

In order to estimate the population of white-tailed deer at ACHA, one direct method and three indirect methods were used in this study. Vantage Point Counts (VPCs) was the selected direct method, whereas Fecal Standing Crop (FSC), Fecal Accumulation Rate (FAR) and Distance Sampling Method (DSM) were the indirect methods used. The objective of this thesis is to provide the first population estimates for white-tailed deer at ACHA, using direct and indirect methods. Two corollary objectives were to evaluate deer habitat preference, as well as to determine the most practical, reliable and effective methodology for long-term monitoring of the deer population at ACHA.

2. Methods and Materials

The vegetation at ACHA was classified into six representative habitats: humid herbaceous vegetation, dry herbaceous vegetation, exposed soil, cushion plants, shrubby páramos and páramo grasslands (Table 1). In order to calculate the areas that correspond to these areas, polygons were digitized on the basis of RapidEye satellite images, particularly the blue band and calculation of the Normalized Difference Vegetation Index (NDVI) in QGIS software (see Figure 1). At this point only areas for three habitats are available. The area for each of the other three habitats has not been estimated yet, but since they show similar densities based on fecal group analysis, they were pooled into category called “other habitats”.

Table 1. Deer habitat categories within ACHA

Humid herbaceous vegetation	A mixture of small herbaceous plants with a 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 and 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 are 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 in humid valley bottoms, near streams; dominant species in this category are *Baccharis caespitosa*, *Plantago rigida*, *Valeriana aretioides*, *Xenophyllum humile*, *Azorella pedunculata*, and *Gentiana sedifolia*.
Shrubby páramos	A mixture of *Calamagrostis intermedia*, various herbs, such as *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.

Nine transects, totaling 14,150 meters, were placed systematically in order to allocate enough effort to each habitat, but also to maximize coverage of the altitudinal gradient (Figure 1; Marques et al. 2001). All transects were marked every 100 m in order to facilitate the setting of line transects or sampling plots depending on the method applied. PVC tubes of 50 cm in length were used to mark all the transects and their subdivisions, and their coordinates were recorded using a global positioning system (GPS). Once the starting point was placed, the direction was determined by a compass bearing (Figure 4). A measuring tape was used to make sure the distance between the points was 100 m. During data collection a rope of more than a 100 m in length was tied from one tube to the next and stretched as much as possible to create straight line. Because the wind can be strong at high altitudes, metal hooks were buried every 10-20 m to secure the rope.

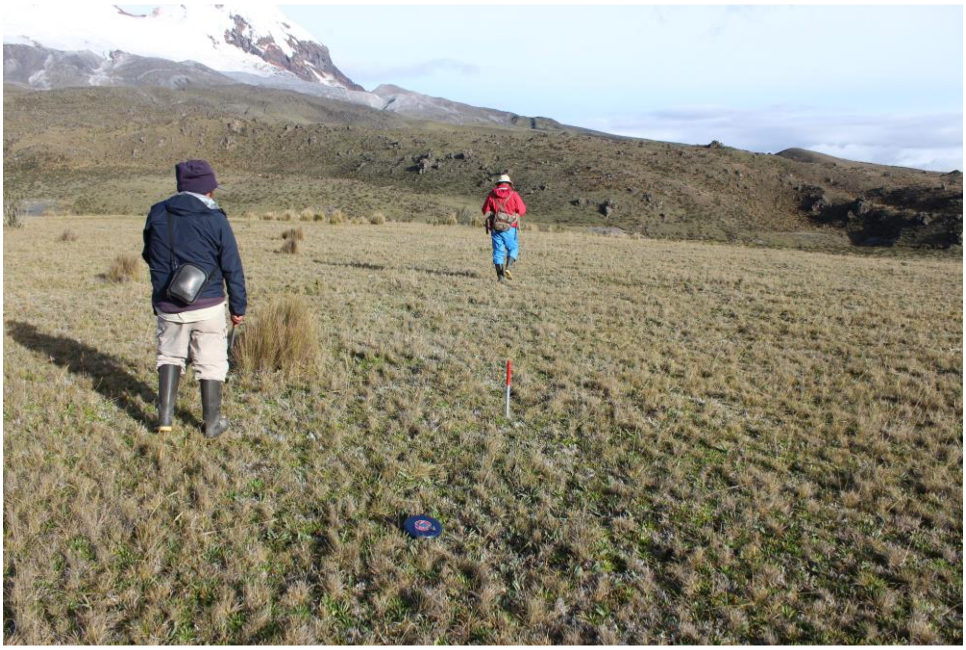

Figure 4. Establishing transects using tubes, a compass and measuring tape.

2.1 Indirect Methods

Indirect methods to measure deer populations consider signs such as tracks, scrapes, fraying stocks, browsing impact levels or fecal pellet groups. However, not all them are practical to estimate deer densities. Scrapes and fraying stocks may be useful to indicate where territorial males are present, and the grazing impact levels and track/slot counts could be best used to give an index of deer presence: low, medium or high (Mayle et al., 1999a). The advantage of fecal pellet groups counts is that they can also provide an estimate of population density. The most used methods are the fecal standing crop (FSC) and fecal accumulation rate (FAR) methods (Staines & Ratcliffe, 1987). The advantage of using indirect methods is that their estimates usually represent an average population size over several months (Marques et al., 2001). Both methods belong to the classical finite population theory that assumes all objects (pellet groups) inside the sampling plots are detected, a complete census is carried out (Burnham & Anderson, 1984). An alternative approach to these methods is the use of line transect surveys, specifically a distance sampling method (DSM). In this method only a proportion of the fecal pellet groups are detected and therefore the strict assumption of detecting all deer signs is avoided. On the other hand, FSC and FAR could be considered as specific cases of distance sampling in which the proportion of detected pellet groups is equal to 1 (Buckland, 1993).

These three methods require the adequate identification of the fecal pellet groups; therefore, some considerations were taken into account before data collection. A fecal pellet group was defined as a collection of six or more pellets (Smart et. al., 2004); when less than six pellets were found, they were discarded. Another important aspect was the appropriate identification of the center of the pellet group. Thus, when the pellets were loose and dispersed, the average position was selected as the center of the group and when the pellets were compacted and dispersed, the biggest cluster was selected as the center of the group. Only the pellet groups whose center were inside the sampling plots or searched area were recorded. In addition, special attention was required at sites with very high pellet densities were observed because two or more pellet groups could be intermingled. Color, size and texture of the pellets were evaluated in order to distinguish one group from another. All the information was recorded using a waterproof pen and notebook because the weather is highly variable at the study site. Additional variables recorded were date, location on the transect, weather conditions and vegetation.

2.1.1 Fecal Standing Crop (FSC)

FSC is based on counting accumulated pellets groups within sampling plots, regardless of the age (Smart et al., 2004). This method is suitable for large areas and most habitat types. Besides, it requires only one visit, few observers, and inexpensive equipment, and the method allows for assessing habitat use (Mayle et al., 1999a). According to Marques et al. (2001), FSC is the most cost-effective method when there are limited resources. On the other hand, because FSC it is an indirect method, it cannot provide information about the sex or age structure of the population. However, in this study a direct method was also applied to compensate for this shortcoming. The data for FSC was obtained during ten months from July, 2018 to May, 2019. The width of the sampling plots was 4 meters to facilitate the search of the pellet groups. Two observers walked along the sampling plot; one observer covered 2 m to the left of the transect and the other 2 m to the right (Figure 5).

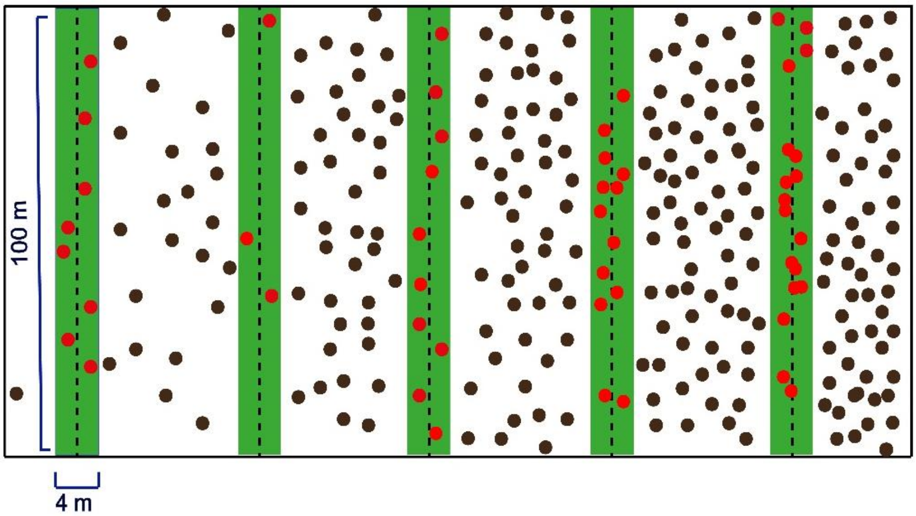

Figure 5. A simplified scheme showing the setup for the Fecal Standing Crop method.

For this method a total of 24.5 sampling plots were surveyed, having covered 2450 meters of the transects for a total sample area of 9400 m^2. Table 2 shows the number of sampling plots and the sample area covered for each habitat. For this method the number of fecal pellet groups for each habitat was obtained. This value was then divided by the sample area within each habitat to calculate the fecal pellet group density as it follows:

$$\widehat{P_i} = \frac{n_i}{2wL_i} \qquad \text{Equation (1)}$$

where i denotes the habitat, n_i is the number of pellet groups, L_i is the sum of the length of sampling plots ($\sum li$), w is the half-width of a sampling plot, and $\widehat{P_i}$ is the estimated the pellet group density for the habitat i. $2wL_i$ is the sample area for the habitat i. Furthermore, the resulting dung density estimates together with the deer defecation rate and the pellet group decay rate were used to calculate deer population density (Smart et al., 2004) for each habitat as it follows:

$$\widehat{D_i} = \frac{\widehat{P_i}}{\hat{r} \cdot \hat{s}} \qquad \text{Equation (2)}$$

where $\hat{r}$ is the estimate of deer defecation rate and $\hat{s}$ is the estimated time for a pellet group decay, and $\widehat{D_i}$ is deer density for the habitat i. Afterwards, deer density was multiplied by habitat area within ACHA in order to obtain the deer abundance for each habitat.

$$\widehat{N_i} = \widehat{D_i} \cdot A_i \qquad \text{Equation (3)}$$

where A_i is the area that corresponds to the habitat i and $\widehat{N_i}$ is the deer abundance for the habitat i. Deer densities of each habitat were summed and then multiplied by the area of the study site to obtain the total deer abundance for ACHA. Confidence limits at the 90% level were calculated using a *t-test* for unknown variance and small samples. A code was written for the R-Statistical Software (R Core Team, 2017) to estimate all the parameters (see Annex 1).

Table 2. Details of the transects surveyed for FSC and DSM through counts of pellet groups.

Habitat	Area (Km^2)	Length of Surveyed Transects (m)	No. Plots Sampled	Sampled Area (m^2)
Humid Herbaceous Vegetation	3.26	200	2	800
Dry Herbaceous Vegetation	7.78	800	8	3200
Exposed Soil	2.16	200	2	800
Other habitats	71.37	1250	12.5	5000
TOTAL	**84.57**	**2450**	**24.5**	**9800**

2.1.2 Fecal Accumulation Rate (FAR)

FAR is similar to FSC because both are based on the counting of deer fecal pellet groups. However, in FAR the sampling plots are first cleared of any deer dung, and after a fixed time the sampling plots are revisited to count the new pellet groups that have accumulated in the time in between (Laing et al., 2003; Smart et al., 2004). The second visit has to occur before the pellet groups have had time to decay; in this way only the defecation rate has to be estimated as the decay rate no longer is required (Laing et al., 2003; Marques et al., 2001). The number of days between clearing and counting is used instead of the length of time for pellet groups to decay. This is an important advantage because experiments to determine decay rate are not required. These experiments consist of collecting fresh pellet groups, placing them in different habitats and monitor them over a long period of time (Laing et al., 2003). Other advantages is that FAR is suitable for all habitats, requires only 1-2 people and the equipment is relatively inexpensive (Mayle et al., 1999a). However, FAR may require surveying larger sampling plots in areas of low deer density because many plots may have zero pellet groups (Marques et al., 2001). Although the search for the pellet groups is faster during the second visit because the dung is not covered much by the vegetation, FAR is more time consuming due to the effort required to remove all pellets.

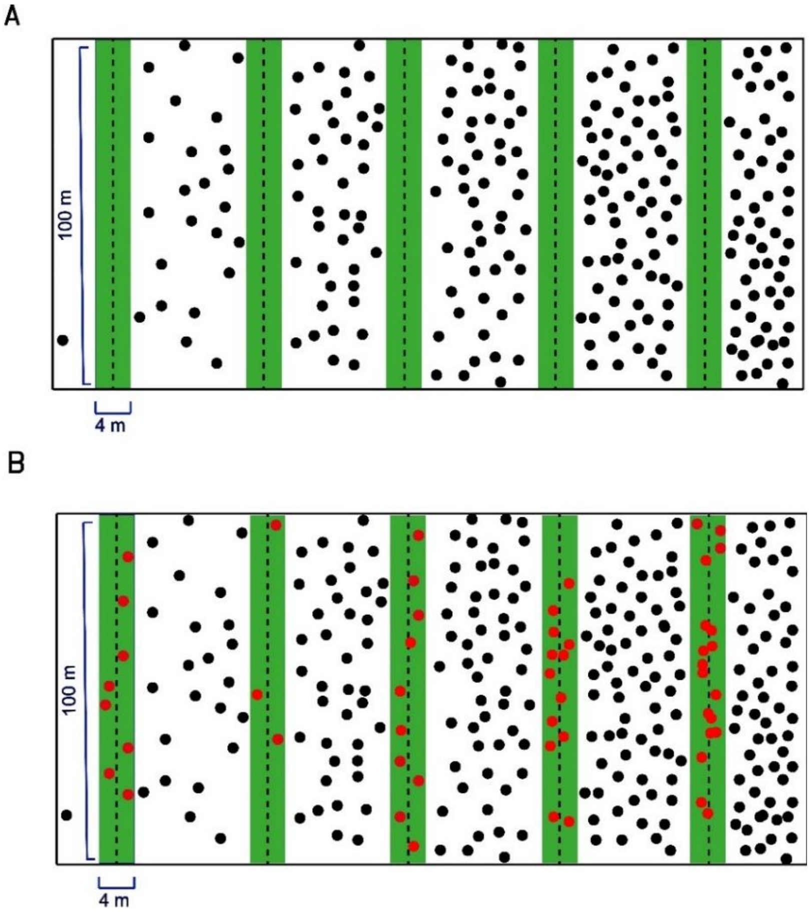

Figure 6. Scheme of the Fecal Accumulation Rate method. A represents the initial cleaning stage and B represents the second stage during which fecal pellet groups were counted.

The FAR cleaning stage was conducted between July and October in 2018 and between January and May in 2019, while the counting stage occurred between March and May in 2019. The shortest time period between visits was 59 days in areas of high deer density while the longest time period between the visits was 235 days in areas of low and medium deer density. The width of the sampling plot defined for this method was also 4 m with one observer covering 2 m to one side of the transect and the other observer 2 m to the other independently. The cleaning stage was the most complicated part because observers had to identify and clean carefully all the pellet groups. The pellet groups that were close to the edge of the plot were also cleaned in case transects deviated a bit in the second visit. Sometimes the cleaning took quite long because of the presence of spiky vegetation, especially the rosette *Valeriana rigida*. Figure 6 shows a scheme of what FAR is about.

For this method a total of 20 sampling plots were cleared and examined, having covered 2000 m of transect equivalent to a sample area of 8000 m^2 (Table 3). The procedure to obtain the fecal pellet group density for FAR was the same as for FSC using the equation (1). However, to estimate the deer population density for FAR, the time between visits is used instead of the length of time to pellet group decay, therefore equation (2) changes a little bit as it follows:

$$\widehat{D_i} = \frac{\widehat{P_i}}{\hat{r} \cdot t} = \frac{\frac{n_i}{2wL_i}}{\hat{r} \cdot t} \qquad \text{Equation (4)}$$

where i denotes the habitat, t is the time between the first visit (cleaning) and the second visit (counting) and $\widehat{D_i}$ is again the deer density for the habitat i. Likewise, to estimate deer abundance for each habitat equation (3) was used. To estimate the total deer abundance for ACHA, deer densities corresponding to each habitat were summed and multiplied by the area of the study site. Finally, a *t-test* for unknown variance and small samples was used to calculate the confidence limits at the 90% level. Another code was written in R-Statistical Software to perform these analyzes (see Annex 2).

Table 3. Habitats surveyed in the transects by the FAR method.

Habitat	Length of Surveyed Transects (m)	No. Plots Sampled	Sampled Area (m^2)
Humid Herbaceous Vegetation	200	2	800
Dry Herbaceous Vegetation	650	6.5	2600
Exposed Soil	200	2	800
Other habitats	950	9.5	3800
TOTAL	**2000**	**20**	**8000**

2.1.3 Distance Sampling Method (DSM)

DSM is also referred as standing crop line transect counts (Mayle et al., 1999a), suggesting that this method is similar to FSC. The difference lies in that DSM does not require finding all fecal pellet groups and uses line transects instead of sampling plots. This method is not only based on the counting of fecal pellet groups, but also on the perpendicular distances of the detected pellet groups to the transect line. The number of pellet groups in the sample area are then modelled as a function of those distances (Marques et al., 2001). DSM has many advantages, such as its suitability for large areas and different habitats, great speed of application when deer densities are low, low requirement of observers and low cost. In addition, this method gives more accurate estimations in dense vegetation (Mayle et al., 1999a).

Figure 7. Measuring the perpendicular distance of a fecal pellet group to the transect. The transect line looks uneven due to the angle at which the picture was taken.

At the heart of this method lies the concept of the detection function $g(x)$ that represents the probability of detecting a fecal pellet group at distance x from the transect line. FSC and FAR assume that $g(x) = 1$ for all distances $0 \leq x_i \leq w$. However, that is not true because many variables can influence the detection of pellet groups. For example, some variables related to the observers such as inexperience, poor eyesight, tiredness, or lack of enthusiasm. Other variables related to the physical setting, such as the width of the transect, time of the day, vegetation, sun angle, presence of fog or rain and even variables related to fecal pellets, such as the color, size or shape (Burnham & Anderson, 1984). DSM does not rest on the assumption that all pellets are detected but on a weaker one that $g(0) = 1$. In other words, only all pellet groups on the centerline of the transect have to be detected. In addition, the perpendicular distances have to be measured accurately (e.g. avoiding rounding). In this sense, if DSM is applied correctly, the confounding variables discussed above become irrelevant (Burnham & Anderson, 1984; Marques et al., 2001).

The data obtained by this method was recorded during 10 months from July, 2018 to May, 2019. The width of the area searched on either side of the transect line was 2 m, totaling 4 m in width as in the other methods. In fact, these distances were chosen in order to apply DSM, FSC and FAR (first visit) at the same time. In DSM, observers walk along the transect line and when a pellet group is detected the perpendicular distance (cm) from the center of the pellet group to the line transect is measured and recorded (Figure 7, 8). Since the three methods were applied at the same time, observers not only recorded the perpendicular distances, but proceeded to clean the pellet groups. Once observers reached the end of the transect line, they walked back towards the beginning of the transect surveying the entire sampling plots to look for the pellets groups that were missed during DSM. When a pellet group was found, it was removed. In this way, the three indirect method were applied at the same time. It is important to remember that a second visit is required for FAR.

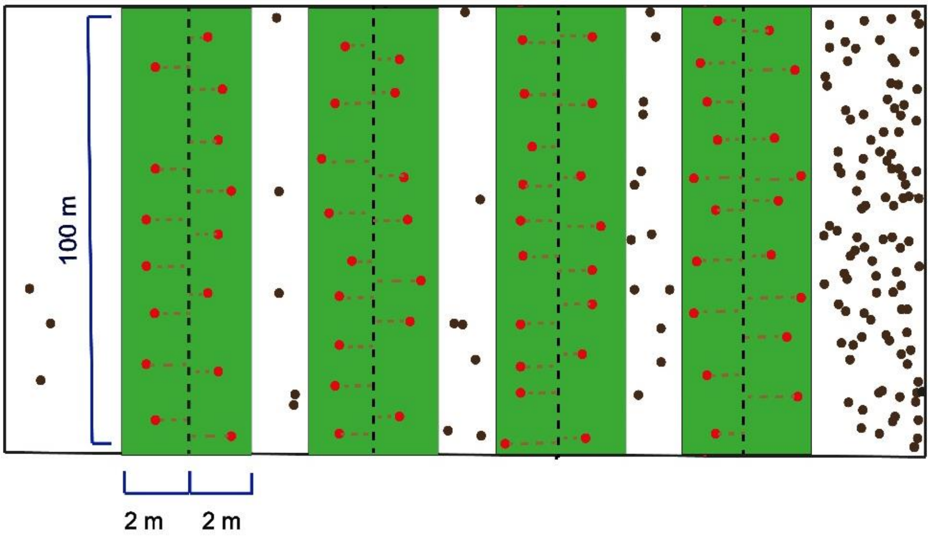

Figure 8. A hypothetical scheme for the Distance Sampling Method.

For DSM 24.5 sampling plots, covering 2450 m in length and a sample area of 9400 m^2 were surveyed (Table 2). Deer density using this method was estimated using equation (2) with a small modification. The pellet group density ($\widehat{P_\iota}$) was multiplied by a correction factor to obtain an estimate of the real pellet group density as shown in the next equation:

$$\widehat{D_\iota} = \frac{\widehat{P_\iota} \cdot \frac{1}{\hat{k}_i}}{\hat{r} \cdot \hat{s}} \qquad \text{Equation (5)}$$

where $\hat{k}_i$ is the proportion of pellets groups detected inside the surveyed area for the habitat i; in other words, it represents the probability of detecting a pellet group inside the surveyed area for each habitat (Buckland, 1993). This parameter can be estimated as it follows:

$$\hat{k}_i = \frac{\int_0^w g(x)dx}{w} \qquad \text{Equation (6)}$$

where $g(x)$ is the detection function. This function is related to probability density function of the perpendicular distances of the detected pellet groups as illustrated in the following equation:

$$f(x) = \frac{g(x)}{\int_0^w g(x)dx} \qquad \text{Equation (7)}$$

Because DSM assumes that $g(0) = 1$ then the probability density function evaluated at zero is:

$$f(0) = \frac{1}{\int_0^w g(x)dx} \qquad \text{Equation (8)}$$

This can be rewritten in the following way:

$$\int_0^w g(x)dx = \frac{1}{f(0)} \qquad \text{Equation (9)}$$

Now, if substitute equation (9) in equation (6), the following is obtained:

$$\hat{k}_\iota = \frac{1}{f(0) \cdot w} \qquad \text{Equation (10)}$$

Finally, when equation (10) is substituted in equation (5), deer density using DSM could be estimated with the following equation:

$$\widehat{D} = \frac{\frac{n}{L} \cdot \hat{f}(0) \cdot \frac{1}{2}}{\hat{r} \cdot \hat{s}} \qquad \text{Equation (11)}$$

However, before using equation (11), the detection function has to be modelled. Models are evaluated based on several properties such as model robustness, a shape criterion, and efficiency. Model robustness means that the model is a flexible function that can adopt different shapes; in other words, models with restricted shapes are not robust. Commonly, models with more than one parameter are recommended (Buckland, 1993). In turn, the shape criterion makes reference to a “shoulder” that the detection function should have as it approaches zero distance from the transect line because the detectability there should be certain. This is the reason why functions that are spiked close to zero distance were excluded. The other important feature is the efficiency as the model selected should be precise. Of course, models that are robust and have a favorable shape criterion tend to be efficient as well (Buckland, 1993).

The first step to create robust models is to choose a “key function” based on the visual analysis of histogram of the perpendicular distances trying various numbers of classes or bins. This visual inspection of the data can reveal the presence of outliers, heaping, or important errors. If necessary, the distance data can be truncated; Buckland et al. (1993) recommend to truncate the 5-10% of the greatest distances or truncate the data when $g(x) = 0.15$. In this study, most of the key functions recommended by the literature were tested. The next step is to choose a “series expansion” to adjust the key function; this reduces the bias and improves the fit of the model to the perpendicular distance data. However, more parameters are added so the variance can increase. Here it is necessary to follow the principle of parsimony that suggests choosing sufficient parameters but not too many as precision will decrease (Buckland, 1993). The models followed this this general form:

$$g(y) = key(y)[1 + series(y)]$$

The Akaike’s Information Criterion (AIC) was used to evaluate the relative fit of a specific model to its data as more parameters were added. AIC was also used to choose the best model among all the considered models (Table 4). The criterion is:

$$AIC = -2 \cdot [\log_e(\mathcal{L}) - q] \qquad \text{Equation (12)}$$

where $\log_e(\mathcal{L})$ is the log-likelihood function evaluated at the estimated parameters of the model with maximum likelihood and q is the number of parameters present in the model. The model with the lowest AIC was selected in all analyses. Although the AIC allows to choose the best model among those considered, it does not mean that the model fits well the perpendicular data, especially close to the zero distance (Buckland, 1993). Therefore, Kolmogorov-Smirnov test and the χ^2 goodness of fit test were used as the final selection criterion. The program DISTANCE 7.2 (Thomas et al., 2010) was used to carry out all the analyses.

Table 4. Some of the models considered for the detection function.

Key function	**Series expansion**
$Uniform, 1/w$	$Cosine, \ \sum_{j=1}^{m} a_j \cos\left(\frac{j\pi y}{w}\right)$
$Uniform, 1/w$	$Simple\ polynomial, \ \sum_{j=1}^{m} a_j \left(\frac{y}{w}\right)^{2j}$
$Half-normal, \exp\ (-y^2/2\sigma^2)$	$Cosine, \ \sum_{j=2}^{m} a_j \cos\left(\frac{j\pi y}{w}\right)$
$Half-normal, \exp\ (-y^2/2\sigma^2)$	$Hermite\ polynomial, \ \sum_{j=2}^{m} a_j\ H_{2j}(y_s)$ $where\ y_s = y/\sigma$
$Hazard-rate, 1-\exp\ (-(y/\sigma)^{-b})$	$Cosine, \ \sum_{j=2}^{m} a_j \cos\left(\frac{j\pi y}{w}\right)$
$Hazard-rate, 1-\exp\ (-(y/\sigma)^{-b})$	$Simple\ polynomial, \ \sum_{j=2}^{m} a_j \left(\frac{y}{w}\right)^{2j}$

2.2 Direct Methods

2.2.1 Vantage Point Counts (VPCs)

Vantage Point Counts (VPCs) consist of observing animals from a point with clear vision of all the surroundings (Mayle et al., 1999) and is perfectly suited to the mountainous grasslands found at the ACHA. VPCs were repeated four times as recommended by Mayle et al. (1999), in 7-9 areas within ACHA from dawn to 09:00 and 15:00 to dusk on 12 December 2018 and 13 December 2018. Observations were conducted simultaneously by groups of 2-3 individuals and lasted at least three hours to guarantee that deer which had settled to ruminate before, had time to rise up and feed during the count (Mayle et al., 1999). Each team carefully and silently scanned the surrounding area for the presence of deer with binoculars (Figure 9). Three groups were also equipped with spotting scopes (Figure 10). Information recorded included deer activity, number of individuals, sex, age, habitat and weather. All groups were provided with medium range two-way radios to report deer movements and thus avoid double counting deer coming from other areas.

Figure 9. Observers located at a vantage point scanning the landscape for deer.

Figure 10. Setting up of a spotting scope at a vantage point.

The vantage points were located in areas known for having high or medium deer densities (Figure 1) according to the guardaparamos of FONAG, EPMAPS, and the Ministry of Environment (MAE). The main criterion for the selection was to find largest number of deer possible within ACHA with a limited number of observers due to complex and expensive field logistics (Zaccaroni et al., 2018). Nichols et al. (2000) also point out that random location of vantage points to cover the whole study area is a challenge (Nichols et al., 2000). In addition, high-altitude environments with low levels of oxygen pose additional constraints on intense sampling within a large area (Singh & Milner-Gulland, 2011). Each vantage point covered an area within a radius of approximately one kilometer; nonetheless, a more precise estimation of the area covered in each vantage point is required.

After the field work the information was saved on a Microsoft Excel sheet to avoid the loss of information and to review any inconsistency in the data. The number of deer of each sex or age classification from all vantage points was summed up in order to obtain the minimum number of males, females, adults, juveniles and calves, as well as the minimum population of deer within ACHA. A code was written in R-Statistical Software to carry out the data analysis and to graph the results (see Annex 3).

2.3 Pellet Decay Rate and Defecation Rate

FSC and DSM require the deer defecation rate and the length of time for a pellet group to decay to estimate deer density (Smart et al., 2004). The value of the defecation rate was taken from estimations made by Mateus (2014) who monitored 47 wild deer in Parque Nacional Natural Chingaza (PNNC), Colombia, whose habitat is mainly composed by paramo and high Andean forest. The estimate obtained was 23.26 pellet groups/deer/day. To calculate the dung persistence time, seven fresh fecal pellet groups were placed in each of the six habitats of ACHA. Several visits were made to document the disappearance of the pellet groups. This methodology has provided a preliminary ‘prospective’ estimate (Laing et al., 2003) of 240 days.

3. Results

3.1 Indirect Methods

3.1.1 Fecal Standing Crop

Estimates of the pellet group density, deer density and deer abundance for each habitat are shown in Table 5. Humid herbaceous vegetation has the highest pellet group density and therefore the highest deer density (94.05 deer/Km^2). However, because its area represents only 3 % of the study area this habitat does not have the highest deer abundance (307 deer). On the other hand, although paramo grasslands, cushion plants and shrubby páramos have a relatively low deer density (4.26 deer/Km^2), the deer abundance (304 deer) is similar to the humid herbaceous vegetation because those habitats represent 84 % of the entire area. It can be inferred from equation (2), as pellet group density increases, deer density also increases; however, the habitat's area within ACHA also plays an important role when evaluating deer abundance. That is why dry herbaceous vegetation, with only the second highest deer density (43.38 deer/Km^2), but with an area representing the 9 % of the whole area, has the highest deer abundance (338 deer). The total density of deer in ACHA estimated by FSC is 11.27 ± 4.35 deer/Km^2 (Figure 11) and the total number is estimated at 953 ± 368.

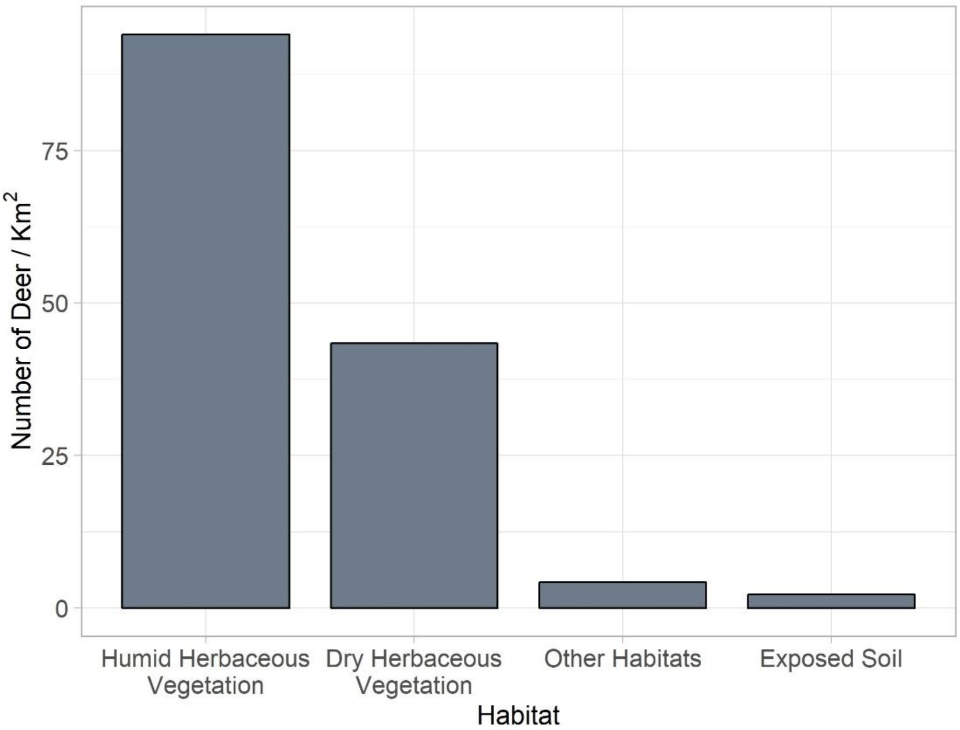

Figure 11. FSC estimates of deer density for each habitat category within ACHA.

Table 5. Pellet numbers and densities and their corresponding estimates for deer densities and abundances in different habitats using FSC.

Habitat	No. Pellet Groups	Pellet Groups/ Km^2	Deer/Km^2	Deer Abundance
Humid Herbaceous Vegetation	420	525,000	94.05	306.56
Dry Herbaceous Vegetation	775	242,188	43.38	337.54
Exposed Soil	10	12,500	2.24	4.85
Other habitats	119	23,800	4.26	304.27
Total ACHA	1,324	135,102	11.27	953.21

3.1.2 Fecal Accumulation Rate

The estimates of pellet group density, deer density and deer abundance for each habitat using FAR is shown in Table 6. In this method, humid herbaceous vegetation also has the highest deer density (95.64 deer/Km^2), with the estimate being slightly higher than the deer density estimated by the FSC method (94.05 deer/Km^2). Something similar happens for páramo grasslands, cushion plants and shrubby páramos, but the estimate of FAR (3.19 deer/Km^2) is lower than the estimate of FSC (4.26 deer/Km^2). The same is true for exposed soils whose estimates using FAR and FSC are 0.56 deer/Km^2 and 2.24 deer/Km^2, respectively. On the other hand, the deer density estimation made by FAR for the dry herbaceous vegetation (16.41 deer/Km^2) seems to be significantly lower than the estimation made by FSC (43.38 deer/Km^2). In terms of abundance this difference in densities translates to a difference of about 209 deer. One of the reasons for this difference may be the sample size; FAR samples did not include three plots that showed high pellet group density when FSC was applied.

Table 6. Pellet numbers and densities and the corresponding estimates for deer densities and abundances in different habitat categories based on FAR.

Habitat	No. Pellet Groups	Pellet Groups/ Km^2	Deer/Km^2	Deer Abundance
Humid Herbaceous Vegetation	105	131,250	95.64	311.76
Dry Herbaceous Vegetation	235	90,385	16.41	127.68
Exposed Soil	55	2,500	0.56	1.22
Other habitats	2	14,474	3.19	227.90
Total ACHA	397	49,625	7.91	668.55

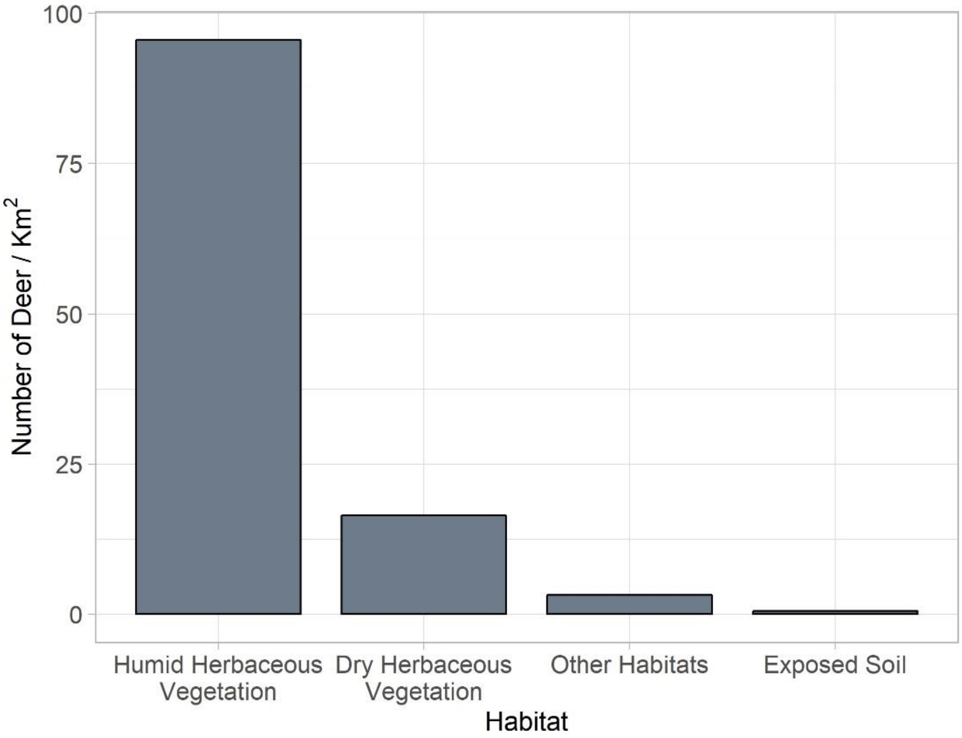

Figure 12. FAR estimates of deer density for each habitat category within ACHA.

Moreover, the pellet group density estimated by FAR (49,625 pellet groups/Km^2) is much lower than that estimated by FSC (135,102 pellet groups/Km^2). Therefore, the deer density estimated by FAR within ACHA (7.91 ± 3.72 deer/Km^2) is also lower than the one estimated by FSC (11.27 deer/Km^2). Likewise, the deer abundance estimated by FAR within ACHA (668.55 ± 315 deer) is 285 individuals lower than the estimation by FSC (953.21 deer). These lower estimations are not only because less plots were sampled, but also because fewer pellet groups were found per plot. According to Mayle et al. (1999), at least 100 pellet groups need to be encountered to a achieve a precision of ± 20%. Another factor to take into consideration is that both methods were sampled at different time periods. FAR was applied at least three months later than FSC and some environmental variables could have affected the sampling.

3.1.3 Distance Sampling Method

After the examination of the histogram for 20 cm bins of perpendicular distances for humid herbaceous vegetation, no rounding or outlier problems were identified. To help with model fit, 10% of the largest observations were truncated (Buckland et al. 1993). Table 7 shows the models tested for this habitat; some models just consist of the key function because the addition of adjustment terms did not seem to improve model fit. An adjustment term was added only when the AIC value decreased. Likewise, the final model selection was based on the lowest AIC value, but also on the variation coefficients of the estimated deer density. The hazard-rate key function showed the lowest AIC value (3267.77) and the lowest variation coefficient (0.22), which is why it was chosen as the detection function for the humid herbaceous vegetation (Figure 13).

Table 7. Number of parameters, AIC values and deer density estimates (with their corresponding variation coefficients) for the models evaluated for humid herbaceous vegetation.

Model	**No. of parameters**		**AIC**	**Delta AIC**	$\hat{D}$	$\hat{D}$ **CV**
	Key	**Series**				
Hazard-rate	2	0	3267.77	0	85.04	0.22
Uniform + simple polynomial	0	2	3269.22	1.46	86.36	0.23
Half-normal + simple polynomial	1	1	3269.23	1.46	86.36	0.22
Uniform + hermite polynomial	0	1	3269.23	1.46	88.99	0.23
Half-normal	1	0	3269.65	1.88	88.50	0.23
Uniform	0	0	3271.56	3.79	78.37	0.22

The Hazard-rate key function was the best model among all the considered methods; however, that does not necessarily mean the model fits the recorded perpendicular distances adequately. Therefore, other tests that evaluate the goodness of fit were performed using the software DISTANCE 7.3. The p-values for the Kolmogorov-Smirnov test and χ^2 goodness of fit test (10 classes) were 0.6162 and 0.429, respectively. These p-values cannot be rejected the null hypothesis of a good model fit. All methods used suggest that the hazard-rate key function fits the perpendicular distances in humid herbaceous vegetation well (Figure 13).

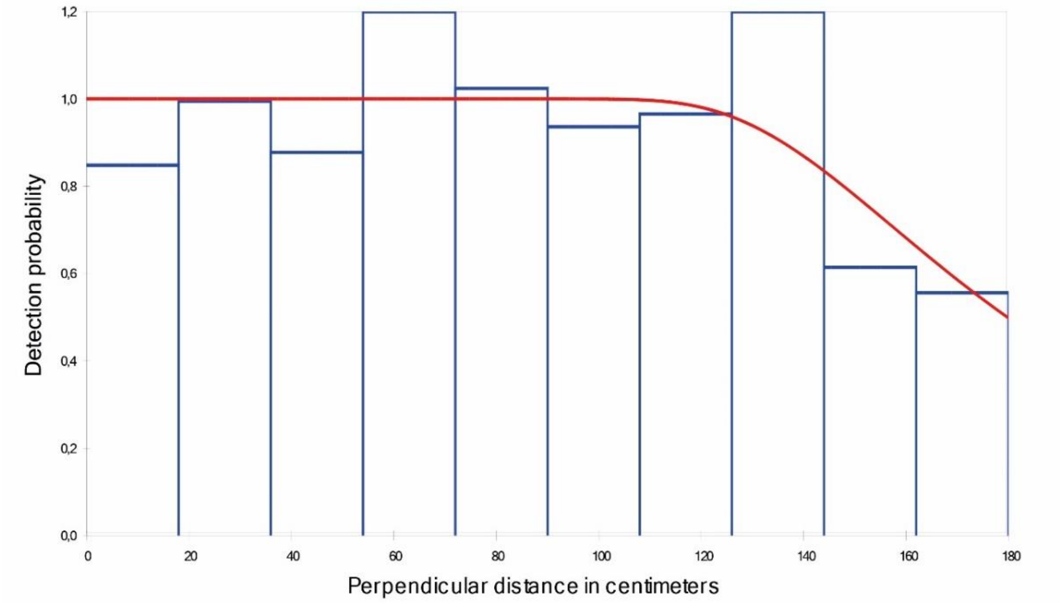

Figure 13. Histogram of the recorded perpendicular distances in 20 cm bins and the fitted detection function for humid herbaceous vegetation.

The same analysis was performed for the dry herbaceous vegetation. No rounding or outlier problems were identified and 10 % of the largest observations were truncated based on the exploratory examination of the histograms of the perpendicular distances. Table 8 shows the models considered for this habitat and other parameters related to them. The uniform + cosine is the model with the lowest AIC value (5953.58) and also the lowest variation coefficient of deer density (0.34); therefore, it was chosen as the detection function for the dry herbaceous vegetation (Figure 14). Notice that all models result in similar deer density estimates; however, the selected model produces the highest estimate.

Table 8. Number of parameters, AIC values and deer density estimates (with their corresponding variation coefficients) for the models evaluated for dry herbaceous vegetation.

Model	**No. of parameters**		**AIC**	**Delta AIC**	$\hat{D}$	$\hat{D}$ **CV**
	Key	**Series**				
Uniform + cosine	0	1	5953.58	0	42.27	0.34
Half-normal	1	0	5954.77	1.20	40.83	0.34
Uniform + hermite polynomial	0	1	5955.15	1.58	40.34	0.34
Uniform + simple polynomial	0	1	5955.15	1.58	40.34	0.34
Hazard-rate	2	0	5955.96	2.38	41.56	0.34

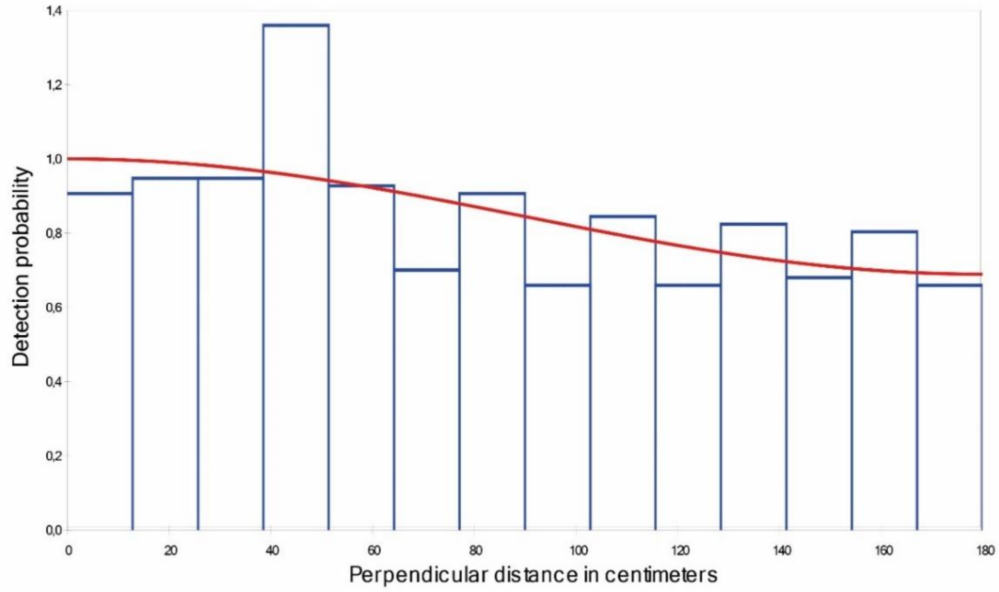

Figure 14. Histogram of the recorded perpendicular distances in 20 cm bins and the fitted detection function for dry herbaceous vegetation.

As in the last habitat, the fit of the model (uniform + cosine) for the dry herbaceous vegetation was evaluated by a Kolmogorov-Smirnov test and χ^2 goodness of fit test (14 classes). The p-value of the former test was 0.5493 whereas the p-value for the latest test was 0.2406. The null hypothesis of good model fit can therefore not be rejected. Thus, the uniform + cosine model fits the recorded perpendicular distances well for the habitat with dry herbaceous vegetation (Figure 14).

In the case of the habitat category of páramo grasslands, cushion plants and shrubby paramos, the examination of the histogram of perpendicular distances did not show heaping problems or outliers. As in the previous habitats, 10% of the largest observations were truncated despite of the relatively low number of pellet groups found in the sampling plots; however, only 5 pellet groups were discarded because of truncation. Of all the models considered (Table 9), the model with a uniform key function and one cosine adjustment best represent the perpendicular distances for this habitat (Figure 15). This model had the lowest AIC value (1016.66) and the second lowest variation coefficient of the deer density estimate (0.29). The uniform key function without adjustment had the lowest variation coefficient, but also one of the highest AIC values, which is why it was discarded.

Table 9. Number of parameters, AIC values and deer density estimates (with their corresponding variation coefficients) of the models evaluated for paramo grasslands, cushion plants and shrubby paramos.

Model	No. of parameters		AIC	Delta AIC	$\widehat{D}$	$\widehat{D}$ CV
	Key	Series				
Uniform + cosine	0	1	1016.66	0	4.85	0.29
Half-normal + cosine	1	1	1017.27	0.61	5.55	0.32
Half-normal	1	0	1017.65	0.99	4.58	0.29
Uniform	0	0	1017.82	1.16	3.90	0.27
Hazard-rate	2	0	1019.04	2.38	5.10	0.32

The fit of the model (uniform + cosine) selected for the "other habitats" was also evaluated by the Kolmogorov-Smirnov test and χ^2 goodness of fit test (6 classes). The former test had a p-value equal to 0.3784 and the latter had a p-value equal to 0.6231; thus, the null hypothesis of good model fit could not be rejected.

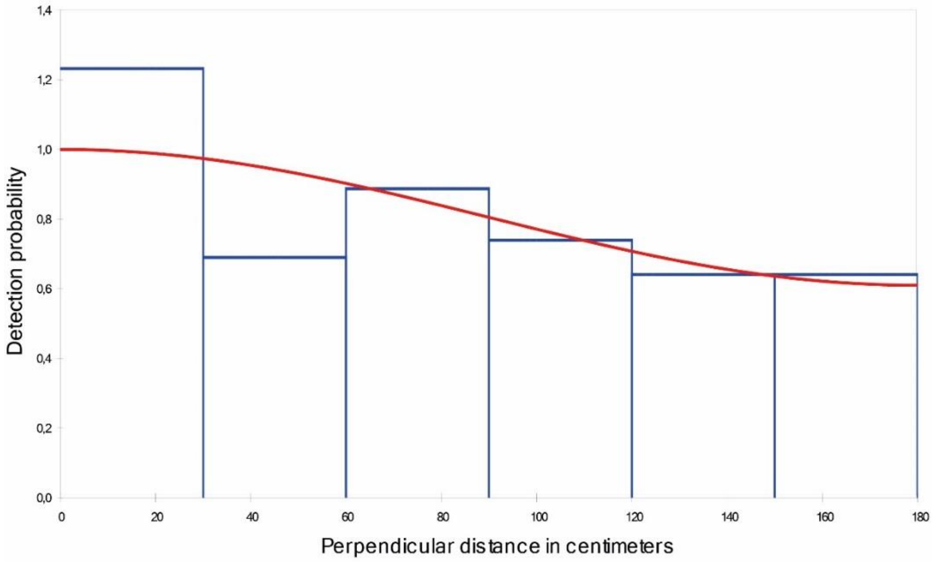

Figure 15. Histogram of the recorded perpendicular distances in 20 cm bins and the fitted detection function for paramo grasslands, cushion plants and shrubby paramos.

The selection of the model for the habitat with exposed soils was different from the rest of the habitats because of the low number of pellet groups found during the survey (Table 11). Regardless of the model evaluated, the software DISTANCE 7.3 always showed a warning message saying, "The number of observations is small. Do not expect reasonable results." Despite of this warning, the recorded perpendicular distances for this habitat were modelled by the best detection function among all available (Table 10). The truncation point was at 121 cm and only one observation was discarded. The uniform key function was selected as the detection function for exposed soils (Figure 16) because it showed the lowest AIC value (57.55) and variation coefficient of the deer density estimate (0.67).

Table 10. Number of parameters, AIC values and deer density estimates (with their corresponding variation coefficients) of the models evaluated for exposed soils.

Model	No. of parameters		AIC	Delta AIC	$\widehat{D}$	$\widehat{D}$ CV
	Key	Series				
Uniform	0	0	57.55	0	2.22	0.67
Half-normal	1	0	59.55	2.00	2.22	0.83
Hazard-rate	2	0	61.55	4.00	2.22	0.67

Despite of the limitations, the model fit for this habitat was also evaluated by the goodness of fit tests. The p-values for the Kolmogorov-Smirnov test and χ^2 goodness of fit test (2 classes) were 0.1269 and 0.9516, respectively. The p-value of the χ^2 test is high because of proper truncation and selection of only two classes. The p-values of both tests and inspection of Figure 16 suggest that the uniform key function fits the perpendicular distances of exposed soils well.

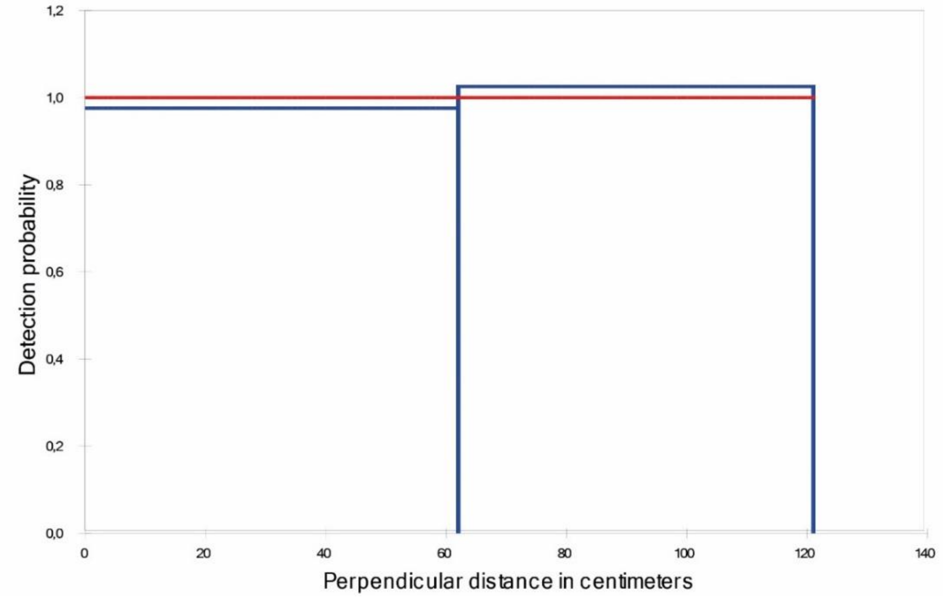

Figure 16. Histogram of the recorded perpendicular distances in 60 cm bins and the fitted detection function for exposed soils.

Table 11 summarizes of the number of pellet groups, the estimated probability density function evaluated at zero distance as well as the estimates of deer density and abundance. In DSM, the humid herbaceous vegetation also shows the highest deer density (85.04 deer/Km^2), although slightly lower than those calculated by FSC (94.05 deer/Km^2) or FAR (95.64 deer/Km^2). In the case of the dry herbaceous vegetation, the deer density estimated by DSM (42.27 deer/Km^2) is very similar to that estimated by FSC (43.38 deer/Km^2) but quite different from the FAR estimate (16.41 deer/Km^2). Now, two indirect methods support a deer density higher than 40 deer/ Km^2 for the dry herbaceous vegetation. In the case of the habitat with paramo grasslands, cushion plants and shrubby paramos, the deer density estimated by DSM (4.85 deer/Km^2) is very similar to the FSC estimate (4.26 deer/Km^2) and just slightly higher than FAR estimate (3.19 deer/Km^2). Likewise, the deer density estimated by DSM for exposed soils (2.22 deer/Km^2) is very similar to the FSC estimate (2.24 deer/Km^2) but higher than the FAR estimate (0.56 deer/Km^2). Figure 17 illustrates the deer densities estimated by DSM for each habitat.

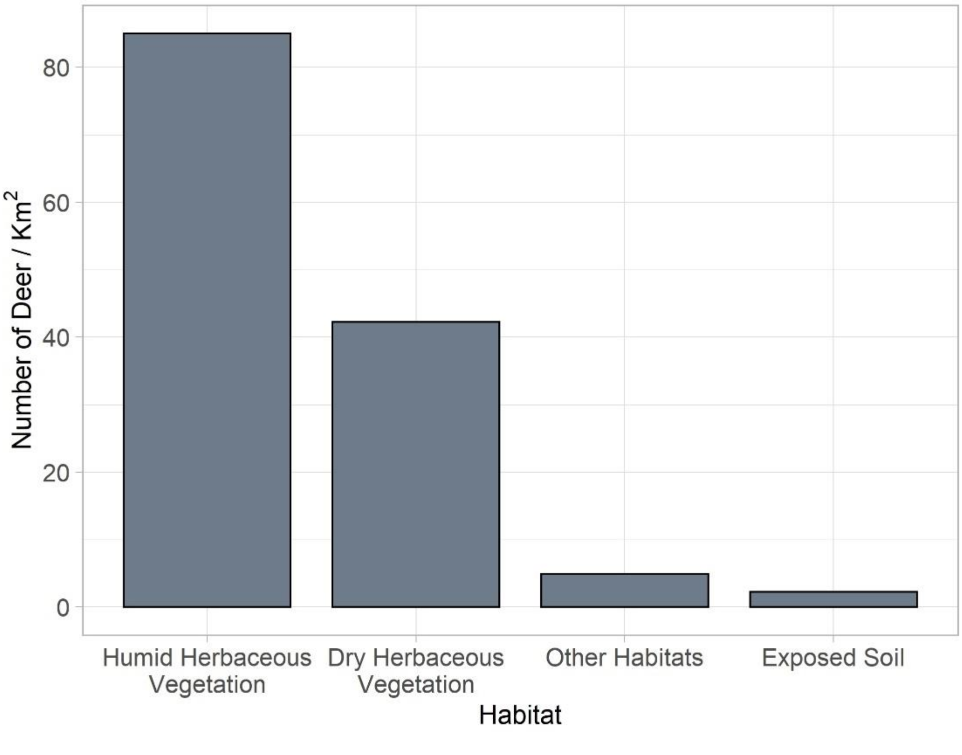

Figure 17. DSM estimates of deer density for each habitat within ACHA.

Table 11. Pellet numbers and densities and their corresponding estimates for deer densities and abundances in different habitats using DSM.

Habitat	No. Pellet Groups	$\hat{f}(0)$	Deer/Km^2	Deer Abundance
Humid Herbaceous Vegetation	315	0.60281E-02	85.04	277.20
Dry Herbaceous Vegetation	574	0.65771E-02	42.27	328.85
Exposed Soil	6	0.82645E-02	2.22	4.81
Other habitats	98	0.69006E-02	4.85	345.82
Total ACHA	993	-	11.31	956.67

DSM estimated a total number of 957 ± 374 deer within ACHA and a deer density of 11.31 ± 4.42 deer/Km^2. This estimate is coherent with the deer density calculated by FSC (11.27 deer/Km^2), but different from the deer density estimated by FAR (7.91 deer/Km^2). Nevertheless, there are also similarities between all methods. For example, the highest deer densities were estimated in habitats with herbaceous vegetation. Another example is that habitats with paramo grasslands, cushion plants, shrubby paramos show low deer densities. Likewise, exposed soils present the lowest deer density estimates.

3.2 Direct Methods

3.2.1 Vantage Point Counts

A maximum of 760 deer were observed during the two-day census (Table 12). This number represents the minimum number of deer at ACHA. Fewer deer were observed in the mornings than in the afternoons. Detectability of animals is quite variable at high altitudes and may be influenced by weather conditions, agricultural practices, experience of the observers and/or the type of vegetation (Singh & Milner-Gulland, 2011; Zaccaroni et al., 2018). The first day at dawn, for example, fog and rain at most vantage points severely decreased deer detectability. In contrast, during the second day in the afternoon, more deer were observed because it was sunny at most vantage points. The maximum number of deer at all VPCs was 760, and was recorded on the afternoon of 13 December. Only a portion of entire area was covered in VPCs, so the deer abundance in ACHA is expected to be higher. The vantage point Mangahurco registered the highest number of sightings with 259 deer, followed by Antena with 225 deer. At most of the remaining vantage points between 40 and 60 deer were registered, except for Laguna Santa Lucía where only 22 deer were counted (Table 12; Table 13).

Table 12. Number of deer counted at the different sites during the vantage point counts.

Vantage Point	12 December 2018		13 December 2018	
	Dawn	**Sunset**	**Dawn**	**Sunset**
Mangahurco	95	231	175	259
Contadero Grande	12	12	26	43
Avión	17	66	47	66
Antena	35	177	130	225
Chozalongo	14	44	-	-
Patucllana	14	74	25	48
Cuscungo	40	36	44	51
Laguna	-	-	41	22
Santantón	-	-	20	46
TOTAL	**227**	**640**	**508**	**760**

These numbers also provide information about deer habitat use and preference. The Mangahurco and Santantón vantage points provided easy viewing conditions mostly of the humid herbaceous vegetation and a small area of dry herbaceous vegetation. Both vantage points together registered 305 white-tailed deer. This number supports the abundance estimated by indirect methods for the humid herbaceous vegetation, especially the estimation calculated by DSM. It is not possible to compare with other habitats because the vantage points sampled small areas of each habitat. Nevertheless, it is possible to say that the number of deer counted in habitats mostly composed of dry herbaceous vegetation (Contadero, Avión and Patucllana) was higher than the number of deer in habitats with paramo grasslands and cushion plants (Laguna and Cuscungo). This information also corroborates the results obtained by means of indirect methods.

Moreover, VPCs also provide insights about the number of males (Figure 18) and females (Figure 19) as well as the number of adults, juveniles and fawns in the study area (Table 13). The number of female deer observed in VPCs is higher than the number of male deer (Figure 20). Likewise, the number of adult deer recorded in VPCs is significantly higher than the number of juveniles and fawns (Figure 21). The vantage point Antena has an unusual number of female deer and fawns so this may be the preferred site for female deer to nurse their calves (Table 13). On the other hand, no juveniles were observed in this place even though the total number of individuals was high compared to other vantage points. Nevertheless, these results have to be interpreted carefully. For example, the recorded number of adults is very high and the observers could have confused adult females with young males.

Table 13. Sex and age groups of deer by vantage point.

Vantage Point	Male	Female	Unknown	Adult	Juvenile	Fawn	Total
Mangahurco	59	70	130	136	43	10	259
Antena	19	119	87	181	0	44	225
El Avión	4	23	38	63	0	2	65
Cuscungo	5	32	14	37	12	2	51
Santantón	8	30	9	38	9	0	47
Patucllana	10	32	6	21	0	3	48
Contadero	6	24	13	37	6	0	43
Laguna	6	13	2	8	4	0	22
TOTAL	**117**	**343**	**299**	**521**	**74**	**61**	**760**

Figure 18. A male white-tailed deer observed at ACHA during the VPCs.

Figure 19. Two female white-tailed deer observed at ACHA during the VPCs.

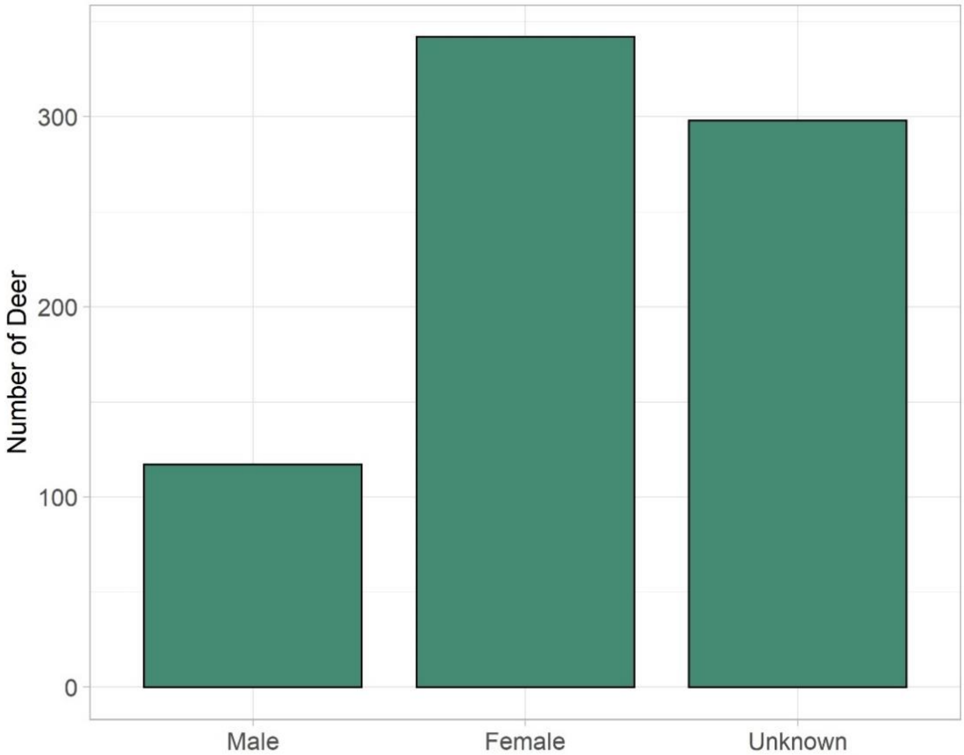

Figure 20. Minimum number of deer in each sex class within ACHA.

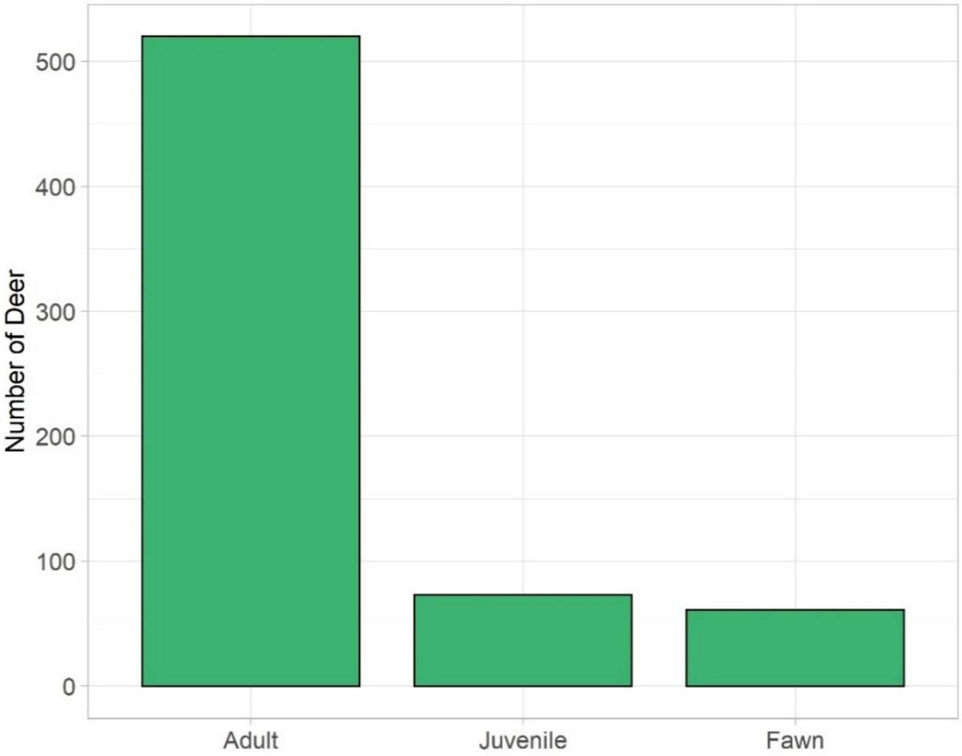

Figure 21. Minimum number of deer by each age class within ACHA.

4. Discussion

This work is only the second study that estimates deer populations in the Ecuadorian paramos and the first to provide abundance and density estimates in ACHA. Moreover, it is the first time that two indirect methods based on fecal pellet groups (FSC and FAR) have been applied in Ecuador. The results from the only direct method (VPCs) suggest a minimum population of 760 individuals within ACHA. On the other hand, the indirect methods DSM, FSC and FAR suggest an abundance of 957, 953 and 669 individuals, respectively (Table 14). All methods indicate that the habitat with humid herbaceous vegetation has the highest deer density (85.04 – 95.64 deer/Km^2), followed by the habitat with dry herbaceous vegetation (16.41 – 43.38 deer/Km^2), then the “other habitats” (3.19 – 4.85 deer/Km^2), and lastly exposed soils (0.56 – 2.24 deer/Km^2).

The medium-high densities estimated for herbaceous vegetation suggest that these are the habitats most used and preferred by deer. Both herbaceous habitats seem to provide this species with plenty of food and nearby opportunities to hide during the day, i.e. nearby presence of tall paramo grass. On the other hand, the low densities reported for páramo grasslands, cushion plants, shrubby páramos and exposed soils indicate that these habitats are not much used and preferred by deer. Another aspect to note is that the location of habitats with herbaceous vegetation coincide with lowest lying and flattest areas within ACHA. It is possible that the altitude and high humidity of these areas, together with the intense, past grazing by livestock could favor the establishment of the herbaceous vegetation that seems to be the preferred food for deer.

Table 14. Density and abundance of the white-tailed deer estimated by the three indirect methods applied in this study.

	Deer Density			**Deer Abundance**		
Habitat \ Method	**DSM**	**FSC**	**FAR**	**DSM**	**FSC**	**FAR**
Humid Herbaceous Vegetation	85.04	94.05	95.64	277.20	306.56	311.76
Dry Herbaceous Vegetation	42.27	43.38	16.41	328.85	337.54	127.68
Other habitats	4.85	4.26	3.19	345.82	304.27	227.90
Exposed Soil	2.22	2.24	0.56	4.81	4.85	1.22
Total ACHA	11.31	11.27	7.91	956.67	953.21	668.55

Table 14 shows a summary of the estimates of deer population calculated by the three indirect methods. DSM and FSC suggest almost the same deer density and abundance for both ACHA and each of its habitats. However, FAR shows lower estimates compared to DSM and FSC, except for the habitat with humid herbaceous vegetation. DSM and FSC estimated an average of 955 individuals within ACHA, whereas FAR estimated 669 individuals, a difference of 286 individuals. According to the results obtained by VPCs, there is a minimum population of 760 individuals in ACHA. This may mean that FAR is underestimating deer population in ACHA and its habitats. Nevertheless, this does not mean that FAR is not a suitable method for paramo ecosystems, but that the sample size may not be large enough to get results like DSM and FSC. Laing et al. (2003) argue that more or wider sampling plots should be surveyed when using FAR in order to get results with the precision of FSC. FAR tends to provide estimates with poor precision when deer density is low (Marques et al., 2001) and it is commonly considered efficient when the deer density is high (Buckland, 1992). FAR seems to be more suitable for the habitat with humid herbaceous vegetation and if it were to be used to estimate deer population in ACHA, more sampling plots would be needed to be surveyed.

According to Smart et al. (2004), data collection using FAR took three times longer than FSC and Campbell et al. (2004) showed that FAR studies took 1.6 - 1.9 times longer than FSC surveys. In this study FAR also required more time than FSC, especially because all pellet groups had to be removed from the sampling plots with a dense and spiky ground vegetation. The time needed to apply this method and the evidence that medium-high deer densities are mainly found in habitats with herbaceous vegetation (13 % of the entire study area) indicate that FAR may not be the most effective method to monitor deer populations at ACHA in the medium and long term.

On the other hand, the results obtained from VPCs support the estimates provided by DSM and FSC. VPCs only sampled a portion of the entire area and the number of deer counted represent a minimum abundance estimate. Hence, the abundance estimate for the entire area is expected to be higher. Only DSM and FSC provide estimates of deer abundance higher than VPC estimates;

therefore, they are reliable estimates for the deer population in ACHA. The similarities between the methods can be also explained by the fact that FSC is as a specific case of DSM in which the proportion of detected pellet groups ($\hat{k}$) is equal to one. Which of these methods is the most suited for the future monitoring of white-tailed deer in ACHA?

Burnham and Anderson (1984) recommend the use of line transect surveys. They argue that strip transects (sampling plots methods) tend to give biased estimates because not all the objects are detected; there are many variables that can contribute to this undercount. They assure that perpendicular distances alone are able to correct this undercount if $g(0) = 1$; in other words, if all pellet groups on the line are detected. When line transect surveys (DSM) are conducted properly, a considerable number of objects can go undetected and the estimates will still be valid (Burnham & Anderson, 1984). Marques et al. (2001) mention that the bias associated with the edge effects (pellet groups missed close to the borders of the sampling plots) is reduced by the use of line transect methods. Campbell et al. (2004) state that the precision of FSC could be improved by the application of line transects because a wider area can be surveyed for a given effort. In this study, 1324 pellet groups were found using FSC and 993 pellet groups applying DSM. Although, 331 fewer pellet groups were counted, DSM produced similar results to those of FSC. All these considerations suggest that DSM is the most appropriate and effective method to use in ACHA in the medium and long term, because a greater area can be searched in less time, and the results are less biased.

The deer estimates of this study are considerably higher than those reported by Albuja (2007) in the Oyacachi-Papallacta paramo (data collected in 1996-1997). Using three different methods based on distance sampling he estimated an average density of 1.6 deer/Km^2. This difference could be explained by temporal differences between both studies, the location of the study areas, and the use of different estimates for defecation rates as well as the length of time for pellet groups to decay. In the past, deer populations declined noticeably because of competition with livestock and hunting (4 or 5 deer used to be extracted monthly) in the poorly controlled Antisana paramo (Albuja, 2007; Sánchez Osorio, 2017) and therefore in ACHA. However, deer populations have been recovering in the last years as this study demonstrates. The reasons for this increase in the population size are the creation of FONAG in 2000, the purchase of the Antisana-Contadero property in 2010 by EPMAPS, and the creation and application of institutional policies in ACHA, such as the removal of livestock, restoration of the vegetation, surveillance of the area, and so forth (Sánchez Osorio, 2017).

Albuja (2007) agrees that the preferred habitat for deer are the open and low-lying zones, that is, the habitats with herbaceous vegetation in ACHA. He also agrees that shrubby paramos are not to the taste of deer because of the dense vegetation and soil irregularity. Moreover, other studies using direct counts along line transects in Colombian paramos have resulted in densities between 11-44 deer/Km^2 (Hewitt, 2011). Mateus (2014) estimated 11.56 deer/Km^2 and 15.075 deer/Km^2 for the sectors of La Mina and La Monterredon, respectively, at PNNC. Another study also made in PNNC by Gómez (2017) suggest lower deer densities; the highest density estimation in this study is 8.9 deer/Km^2. In this sense, the results obtained from this study are not so different from the deer population studies in the Colombian paramos. There are other studies in paramo ecosystems that are not that recent and show both higher and lower deer density estimates. For example, 39-46 deer/Km^2 was estimated in Mucubají, Venezuela (Correa-Viana, 1994). Alarcón (2009) estimated 3.54 deer/Km^2 in Soatá, Colombia, and Rodríguez et al. (2004) estimated 28.5 deer/Km^2 in the paramo of PNNC. Therefore, deer densities can vary greatly, because estimates depend greatly on many factors such as the region, vegetation type, hunting intensity, the methods applied in sampling and analysis, ecological variables that determine the carrying capacity and so forth (Hewitt, 2011).

The creation of ACHA and the institutions that manage it have the mission to protect the watersheds that provide water for the DMQ. Thus, decision-making and the application of programs and projects related to habitat conservation or restauration need to maximize this ecosystem service. What is the optimal population size of the white-tailed deer that allows managers to meet this mission? At this point, it is difficult to answer this question because more studies are needed. However, the results of this study are an important first step to ascertain the impact of deer on the ACHA ecosystem.

In low numbers, white-tailed deer may play an important role in the ecosystem as seed dispersers of many plant species as well as promotors of the functional connectivity of fragmented patches because they are long-distance dispersers; deer can even help some species to find new habitats in response to climate change (Jara-Guerrero et al., 2018). A very small deer population may not be adequate because livestock have been removed during the last years (FONAG, 2017, 2018) and deer could become an important food source for carrion birds and carnivores. One study showed that that domestic stock consumes 4.5 times more vegetation than large wild herbivores (Guo et al., 2018). In this sense, it seems logical to remove the domestic animals from ACHA; however, this needs to happen gradually because other animals could have to change their feeding habitats (e.g. Andean Condor that according to local accounts now prefers domestic animals as food).

On the other hand, large deer populations can devastate the vegetation, changing the composition of species and thus the hydrological and carbon cycles (Côté, 2011; Crespo et al., 2010). Some studies have demonstrated that deer can affect the growth, structure, biomass, richness and biodiversity of plants (Shafer et al., 1961; McCormick et al., 1993; Nomiya et al., 2003). In the future, deer overpopulation -and the implicit overgrazing- could have a detrimental impact on the paramo soils and their water retention, water buffering capacity and organic litter layer (Buytaert et al., 2006). The population estimated in this study is not unusually high, within the bounds of what has not raised any concerns in Colombia and Venezuela. However, ACHA is already a heavily altered ecosystem because of the intense past grazing history by livestock (Aguirre et al., 2013; Sánchez Osorio, 2017).

Moreover, a medium-high deer density could bring back the puma, which probably was the natural predator of the white-tailed deer in the past. Guardaparamos of FONAG have spotted these felines close the vantage point “El Avión” in the first months of 2019. A natural predator-prey relationship might naturally control the deer population in the future. Besides, the population of the Culpeo Fox (*Pseudalopex culpaeus*) that is considered vulnerable in Ecuador, could also increase. Likewise, the Andean Condor (*Vultur gryphus*) that is considered in critical danger could benefit from the deer carrion. In August, 2019 the condor was recorded feeding on deer carrion for the first time at ACHA.

As mentioned previously, deer impact on the ecosystem depends on population numbers, possibly in a non-linear fashion (Friedel, 1991; Laycock, 1991). The optimal number of deer in ACHA will depend on the habitats that FONAG and EPMAPS want to preserve in the future. This in turn will depend on the capacity of different types of vegetation to capture and slowly release water. For instance, cushion plants have been found to contribute to a positive water balance (Bosnian et al., 1993; Cleef, 1981), and, therefore, it could be detrimental to convert the large expanses of cushion plants to tall paramo grasslands. It is necessary to determine if deer play an important role in creating or maintaining these large and open expanses of cushion plants. In any case, the Andean Rabbit (*Sylvilagus brasiliensis*) seem to be detrimental to these areas (Francisco Black and Manuel Simba, personal comments).

Moreover, deer seem to favor the habitats with humid and dry herbaceous vegetation, areas that also seem to be preferred by the Black-faced Ibis (*Theresticus melanopis*) and Curiquingues (*Phalcoboenus carunculatus*). It is necessary to study how important these habitats are for these range-restricted species and water resources before they are replaced by other plant species. Likewise, it is important to know is these habitats are artifacts of intensive livestock grazing. In order to answer that question, exclusion studies could be conducted. Even with good estimations for the deer population, many other factors have to be taken into account to take the appropriate management decisions for this species and ACHA.

Although the results of this study are reliable, the defecation rate should be estimated with the deer present in ACHA. It is recommended to estimate this parameter in different seasons. On the other hand, the length of time for pellet groups to decay should be estimated using a retrospective approach and in each representative habitat of ACHA (Laing et al., 2003). Deer have plenty of food throughout the year in ACHA so no important changes in defecation rates are expected. Likewise, only herbaceous vegetation seems to cover the pellet groups relatively faster compared to the other habitats; therefore, the dung disappearance time should be studied in more detail in this habitat.

It is hoped that the deer population estimates, the evidence for habitat use and preference, the insights about sex and age structure, and the detailed information on the application of the different methods applied in this study (especially DSM) will help the FONAG and EPMAPS monitor the white-tailed deer in the long-term at ACHA. This study is the beginning to find answers to some of the pressing questions regarding the long-term conservation of this habitat and the water supply of Quito.

5. Conclusions

- VPCs estimated a minimum population of 760 white-tailed deer within ACHA, FAR a deer density of 7.91 deer/Km^2 (668.55 deer in ACHA), FSC of 11.27 deer/Km^2 (953.21 deer in ACHA), and DSM of 11.31 deer/ Km^2 (956.67 deer in ACHA).
- The habitats most preferred by white-tailed deer are the humid herbaceous vegetation followed by the dry herbaceous vegetation, whereas the habitats less preferred are paramos grasslands, cushion plants, shrubby paramos, and exposed soils.
- DSM and FSC are the most reliable methods; however, DSM is faster, does not have to make strong assumptions, allows many pellet groups to go undetected, permits large areas to be searched, and, therefore, it is the most adequate method to monitor deer populations at ACHA in the future.

6. References

Aguirre, N., Torres, J., & Velasco, P. (2013). *Guía para la restauración ecológica en los páramos del Antisana*.

Alarcón, S. M. (2009). *Estado Poblacional del Venado Cola blanca (Odocoileus virginianus) en la Vereda Molinos, Municipio de Soatá, Boyacá* (Tesis de pregrado, Proyecto Curricular de Licenciatura en Biología, Facultad de Ciencias y Educación). Universidad Distrital Francisco José de Caldas, Bogotá.

Albuja, L. H. (2007). *Biología y Ecología del Venado de Cola Blanca (Odocoileus virginianus ustus Gray, 1874) en un sector de páramo*. Retrieved from http://bibdigital.epn.edu.ec/handle/15000/4746

Arcos, D., Tirira, D. G., & Zapata R., G. (2011). Puma (*Puma concolor*). Retrieved June 4, 2019, from Libro Rojo de los mamíferos del Ecuador website: http://librorojo.mamiferosdelecuador.com/lista-de-especies-/carnivora/felidae/590-puma-concolor-corto.html

Armijos, R., Cisneros, V., Tirira, D. G., & Zapata R., G. (2011). Lobo de páramo (Lycalopex culpaeus). Retrieved June 4, 2019, from Libro Rojo de los mamíferos del Ecuador website: http://librorojo.mamiferosdelecuador.com/lista-de-especies-/carnivora/canidae/593-lycalopex-culpaeus-corto.html

Baldi, R., Albon, S., & Elston, D. (2001). Guanacos and sheep: Evidence for continuing competition in arid Patagonia. *Oecologia*, *129*(4), 561–570. https://doi.org/10.1007/s004420100770

Bosnian, A. F., Molen, P. C. van der, Young, R., & Cleef, A. M. (1993). Ecology of a paramo cushion mire. *Journal of Vegetation Science*, *4*(5), 633–640. https://doi.org/10.2307/3236128

Buckland, S. T. (1992). Review of deer count methodology. *Unpublished Report to the Scottish Office, Agriculture and Fisheries Department, Edinburgh, UK*.

Buckland, S. T. (Ed.). (1993). *Distance sampling: Estimating abundance of biological populations* (1st ed). London ; New York: Chapman & Hall.

Burnham, K. P., & Anderson, D. R. (1984). The Need for Distance Data in Transect Counts. *The Journal of Wildlife Management*, *48*(4), 1248–1254. https://doi.org/10.2307/3801785

Buytaert, W., Célleri, R., De Bièvre, B., & Cisneros, F. (2006). *Hidrología del páramo andino: propiedades, importancia y vulnerabilidad*.

Buytaert, W., Deckers, J., Dercon, G., Bièvre, B., Poesen, J., & Govers, G. (2006). Impact of land use changes on the hydrological properties of volcanic ash soils in South Ecuador. *Soil Use and Management*, *18*(2), 94–100. https://doi.org/10.1111/j.1475-2743.2002.tb00226.x

Chamberlain, C. P., Waldbauer, J. R., Fox-Dobbs, K., Newsome, S. D., Koch, P. L., Smith, D. R., … Risebrough, R. (2005). Pleistocene to recent dietary shifts in California condors. *Proceedings of the National Academy of Sciences*, *102*(46), 16707–16711. https://doi.org/10.1073/pnas.0508529102

Cleef, A. M. (1981). *The vegetation of the Páramos of the Columbian Cordillera Oriental*. Vaduz.

Coronel, L. (2019). *Los Caminos del Agua - FONAG: trabajos y aprendizajes*.

Correa-Viana, M. (1994). Actividad diaria y selección de hábitat por el venado caramerudo, Odocoileus virgini anus. *Masaguaral, Edo. Guárico, Venezuela. Biollania*, *10*, 33–42.

Côté, S. D. (2011). Impacts on ecosystems. *Biology and Management of White-Tailed Deer. CRC Press, Boca Raton, FL*, 379–398.

Côté, S. D., Rooney, T. P., Tremblay, J.-P., Dussault, C., & Waller, D. M. (2004). Ecological Impacts of Deer Overabundance. *Annual Review of Ecology, Evolution, and Systematics*, *35*(1), 113–147. https://doi.org/10.1146/annurev.ecolsys.35.021103.105725

Crespo, P., Celleri, R., Buytaert, W., Feyen, J., Iñiguez, V., Borja, P., & Bievre, B. D. (2010). *Land use change impacts on the hydrology of wet Andean páramo ecosystems*. 6.

Cuesta, F., Sevink, J., Llambí, L. D., De Bièvre, B., & Posner, J. (2014). Avances en investigación para la conservación de los páramos andinos. *CONDESAN. Quito, Ecuador*.

Donázar, J. A. (1993). *Los buitres ibéricos: biología y conservación*. JM Reyero.

EPMAPS. (2011). Captación. Retrieved May 28, 2019, from Bienvenido a EPMAPS website: https://www.aguaquito.gob.ec/captacion/

FONAG. (2017). *Informe de Cumplimiento de Metas*. Retrieved from http://www.fonag.org.ec/web/wp-content/uploads/2018/02/INFORME-DE-CUMPLIMIENTO-DE-METAS-FONAG-2017-1.pdf

FONAG. (2018). *Informe de Cumplimiento de Metas*. Retrieved from http://www.fonag.org.ec/web/wp-content/uploads/2019/04/INFORME-DE-CUMPLIMIENTO-DE-METAS-2018.pdf

Francou, B., Vuille, M., Favier, V., & Cáceres, B. (2004). New evidence for an ENSO impact on low-latitude glaciers: Antizana 15, Andes of Ecuador, 0°28′S. *Journal of Geophysical Research: Atmospheres*, *109*(D18). https://doi.org/10.1029/2003JD004484

Friedel, M. H. (1991). Range condition assessment and the concept of thresholds: A viewpoint. *Rangeland Ecology & Management / Journal of Range Management Archives*, *44*(5), 422–426.

Gómez Castellanos, Y. (2017). *Efecto de la Oferta de Recurso en la Distribución y Densidad del Venado Cola Blanca en Tres Zonas del Ecotono del Bosque Altoandino y Páramo*. Retrieved from http://repository.udistrital.edu.co/handle/11349/6981

Guo, X., Shao, Q., Li, Y., Wang, Y., Wang, D., Liu, J., … Yang, F. (2018). Application of UAV Remote Sensing for a Population Census of Large Wild Herbivores—Taking the Headwater Region of the Yellow River as an Example. *Remote Sensing*, *10*(7), 1041. https://doi.org/10.3390/rs10071041

Hess, C. G. (1990). “Moving up-Moving down”: Agro-Pastoral Land-Use Patterns in the Ecuadorian Paramos. *Mountain Research and Development*, *10*(4), 333. https://doi.org/10.2307/3673495

Hewitt, D. G. (2011). *Biology and management of white-tailed deer*. CRC Press.

INEC, I. (2010). *Resultados del Censo 2010 de población y vivienda en el Ecuador*.

Jara-Guerrero, A., Escribano-Avila, G., Espinosa, C. I., De la Cruz, M., & Méndez, M. (2018). White-tailed deer as the last megafauna dispersing seeds in Neotropical dry forests: The role of fruit and seed traits. *Biotropica*, *50*(1), 169–177. https://doi.org/10.1111/btp.12507

Laing, S. E., Buckland, S. T., Burn, R. W., Lambie, D., & Amphlett, A. (2003). Dung and nest surveys: Estimating decay rates. *Journal of Applied Ecology*, *40*(6), 1102–1111. https://doi.org/10.1111/j.1365-2664.2003.00861.x

Lambertucci, S. A., Trejo, A., Di Martino, S., Sánchez-Zapata, J. A., Donázar, J. A., & Hiraldo, F. (2009). Spatial and temporal patterns in the diet of the Andean condor: Ecological replacement of native fauna by exotic species. *Animal Conservation*, *12*(4), 338–345. https://doi.org/10.1111/j.1469-1795.2009.00258.x

Laycock, W. A. (1991). Stable States and Thresholds of Range Condition on North American Rangelands: A Viewpoint. *Journal of Range Management*, *44*(5), 427. https://doi.org/10.2307/4002738

Marques, F. F. C., Buckland, S. T., Goffin, D., Dixon, C. E., Borchers, D. L., Mayle, B. A., & Peace, A. J. (2001). Estimating deer abundance from line transect surveys of dung: Sika deer in southern Scotland. *Journal of Applied Ecology*, *38*(2), 349–363. https://doi.org/10.1046/j.1365-2664.2001.00584.x

Mateus, C. (2014). *Efecto de la estructura del hábitat sobre las características demográficas de dos poblaciones locales de Venado Cola Blanca, Odocoileus virginianus goudotii, en el Parque Nacional Natural Chingaza (Colombia)*. 127.

Mayle, B. A., Peace, A. J., & Gill, R. M. A. (1999a). *How many deer? A field guide to estimating deer population size*. Edinburgh: Forestry Commission.

Mayle, B. A., Peace, A. J., & Gill, R. M. A. (1999b). *How many deer? A field guide to estimating deer population size*. Edinburgh: Forestry Commission.

McCormick, L. H., Groninger, J. W., Penrod, K. A., & Ristau, T. E. (1993). *Deer Exclusion Effects on Understory Development Following Partial Cutting in a Pennsylvania Oak Stand*. 13. M

Mena, P., Medina, G., & Hofstede, R. (2001). *Los páramos del Ecuador: Particularidades, problemas y perspectivas*.

Molinillo, M., & Monasterio, M. (2002). Patrones de vegetación y pastoreo en ambientes de páramo. *Ecotropicos*, *15*(1), 19–34.

Muñoz, Á. G., & Torres, W. (2013). *ACTUALIZACIÓN Y AUTOMATIZACIÓN DEL MODELO HIDROLÓGICO FONAG PARA LA CUENCA ALTA DEL RIO GUAYLLABAMBA Y MICROCUENCAS OYACACHI, CHALPI GRANDE, PAPALLACTA Y ANTISANA*.

Nichols, J. D., Hines, J. E., Sauer, J. R., Fallon, F. W., Fallon, J. E., & Heglund, P. J. (2000). A Double-Observer Approach for Estimating Detection Probability and Abundance From Point Counts. *The Auk: Ornithological Advances*, *117*(2), 393–408. https://doi.org/10.1642/0004-8038(2000)117[0393:ADOAFE]2.0.CO;2

Nomiya, H., Suzuki, W., Kanazashi, T., Shibata, M., Tanaka, H., & Nakashizuka, T. (2003). The response of forest floor vegetation and tree regeneration to deer exclusion and disturbance in a riparian deciduous forest, central Japan. *Plant Ecology*, *164*(2), 263–276. https://doi.org/10.1023/A:1021294021438

Novaro, A. J., Funes, M. C., & Susan Walker, R. (2000). Ecological extinction of native prey of a carnivore assemblage in Argentine Patagonia. *Biological*

Conservation, *92*(1), 25–33. https://doi.org/10.1016/S0006-3207(99)00065-8

Pettit, N. E., Froend, R. H., & Ladd, P. G. (1995). Grazing in remnant woodland vegetation: Changes in species composition and life form groups. *Journal of Vegetation Science*, *6*(1), 121–130. https://doi.org/10.2307/3236263

R Core Team. (2017). *R: A language and environment for statistical computing*. Retrieved from https://www.R-project.org/

Rodríguez, G., Rodríguez, A., Vargas, Y., & Zuluaga, A. (2004). *Comparación de la densidad de población y características del hábitat entre dos zonas específicas del Parque Nacional Natural Chingaza, Colombia* (Proyecto de Ecología Regional Continental). Universidad Nacional de Colombia.

Rodríguez Morales, M., Acevedo N., D. R., Buytaert, W., Ablan Bortone, M., & De Bievre, B. (2013). *El páramo andino como productor y regulador del recurso agua. El caso de la microcuenca alta de la Quebrada Mixteque, Sierra Nevada de Mérida,Venezuela*. Retrieved from http://www.saber.ula.ve/handle/123456789/39578

Sánchez Osorio, A. R. (2017). *Estrategias de gestión del recurso hídrico para Quito y su contribución a la disponibilidad: Análisis de los casos Oyacachi y Antisana desde la economía ecológica* (Quito, Ecuador: Flacso Ecuador). Retrieved from http://repositorio.flacsoandes.edu.ec/handle/10469/13001

Sánchez-Zapata, J. A., Carrete, M., Gravilov, A., Sklyarenko, S., Ceballos, O., Donázar, J. A., & Hiraldo, F. (2003). Land use changes and raptor conservation in steppe habitats of Eastern Kazakhstan. *Biological Conservation*, *111*(1), 71–77. https://doi.org/10.1016/S0006-3207(02)00251-3

Schütz, M., Risch, A. C., Leuzinger, E., Krüsi, B. O., & Achermann, G. (2003). Impact of herbivory by red deer (Cervus elaphus L.) on patterns and processes in subalpine grasslands in the Swiss National Park. *Forest Ecology and Management*, *181*(1), 177–188. https://doi.org/10.1016/S0378-1127(03)00131-2

Shafer, E. L., Grisez, T. J., & Sowa, E. (1961). Results of deer exclosure studies in northeastern Pennsylvania. *Forest Research Note NE-121. Upper Darby, PA: US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 1-7.*, *121*.

Singh, N. J., & Milner-Gulland, E. J. (2011). Monitoring ungulates in Central Asia: Current constraints and future potential. *Oryx*, *45*(1), 38–49. https://doi.org/10.1017/S0030605310000839

Smart, J. C. R., Ward, A. I., & White, P. C. L. (2004). Monitoring woodland deer populations in the UK: An imprecise science. *Mammal Review*, *34*(1–2), 99–114. https://doi.org/10.1046/j.0305-1838.2003.00026.x

Staines, B. W., & Ratcliffe, P. R. (1987). Estimating the abundance of red deer (Cervus elaphus L.) and roe deer (Capreolus capreolus L.) and their current status in Great Britain. *Symposia of the Zoological Society of London*, *58*, 131–152.

Stohlgren, T. J., Schell, L. D., & Heuvel, B. V. (1999). HOW GRAZING AND SOIL QUALITY AFFECT NATIVE AND EXOTIC PLANT DIVERSITY IN ROCKY MOUNTAIN GRASSLANDS. *Ecological Applications*, *9*(1), 45–64. https://doi.org/10.1890/1051-0761(1999)009[0045:HGASQA]2.0.CO;2

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strindberg, S., Hedley, S. L., … Burnham, K. P. (2010). Distance software: Design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, *47*(1), 5–14. https://doi.org/10.1111/j.1365-2664.2009.01737.x

Vargas, O., Díaz, J. E., Reyes, S. P., & Gómez, P. A. (2012). Guías técnicas para la restauración ecológica de los ecosistemas de Colombia. *Bogotá: Facultad de Ciencias, Departamento de Biología, Grupo de Restauración Ecológica-Universidad Nacional de Colombia. Recuperado de Https://Www. Researchgate. Net/Publication/260365693*.

Vuille, M., Francou, B., Wagnon, P., Juen, I., Kaser, G., Mark, B. G., & Bradley, R. S. (2008). Climate change and tropical Andean glaciers: Past, present and future. *Earth-Science Reviews*, *89*(3–4), 79–96. https://doi.org/10.1016/j.earscirev.2008.04.002

Webb, S. D. (1985). Late Cenozoic Mammal Dispersals between the Americas. In F. G. Stehli & S. D. Webb (Eds.), *The Great American Biotic Interchange* (pp. 357–386). https://doi.org/10.1007/978-1-4684-9181-4_14

White, S., & Maldonado, F. (1991). The Use and Conservation of Natural Resources in the Andes of Southern Ecuador. *Mountain Research and Development*, *11*(1), 37. https://doi.org/10.2307/3673526

Zaccaroni, M., Dell’Agnello, F., Ponti, G., Riga, F., Vescovini, C., & Fattorini, L. (2018). Vantage point counts and monitoring roe deer: Monitoring Roe Deer. *The Journal of Wildlife Management*, *82*(2), 354–361. https://doi.org/10.1002/jwmg.21385

7. Annex

Annex 1. Code for FSC analysis.

```
library(ggplot2)
library(tidyverse)
dat <- read.table("FSC_prueba_2.csv", header = TRUE,
                  sep = ";");dat
pel <- as.tibble(as.data.frame(cbind(tran=dat$Transecto, m=dat$m,
                              pn=dat$Pellet.number)));pel
pel$tran <- as.factor(pel$tran);pel$tran
levels(pel$tran)=c(paste("Humid Herbaceous", "Vegetation",sep = "\n"),paste("Dry Herbaceous", "Vegetation",sep="\n"),"Other Habitats","Exposed Soil")
str(pel)
summary(pel)
pel
pelGrp <- pel %>%
  group_by(tran) %>%
  mutate(mt=sum(m), pnt=sum(pn)) %>%
  select(tran,mt,pnt) %>%
  distinct()
pelGrp <- pelGrp %>%
  mutate(pnta=pnt/mt)
pelGrp
med <- mean(pelGrp$pnta)
ser <- sd(pelGrp$pnta)
med; ser
ggplot(pelGrp, aes(x=tran, y=pnta)) +
  geom_col(colour = "black", fill = "darkblue")
pelGrp
areaT <- 8457.09 # Total ha
w <- 2 # half-width (200cm)
r <- 23.26 # defecation rate
```

```
s <- 240 # length of time to pellet group decay (days)
ta <- areaT*10000 # Total area (m2)
pelGrp <- pelGrp %>%
  mutate(D_pellets=pnta/(2*w));pelGrp
pelGrp <- pelGrp %>%
  mutate(D_Deer=D_pellets/(r*s));pelGrp
#Assuming that the área of the transect 1 is 5% of the total and that the
#remaining transects all cover the same area (it is the same as averaging
#between them)

pelGrp <- cbind(pelGrp,
area=c(0.09199737,0.8438695,0.02558918,0.03854399));pelGrp

sum(pelGrp$area)

pelGrp <- pelGrp %>%
  mutate(D_FSC_T=D_Deer*ta*area)
pelGrp
Total <- round(sum(pelGrp$D_FSC_T),0)
Total
sd <- sd(pelGrp$D_FSC_T)
sd
#media
mm<-mean(pelGrp$D_FSC_T);mm
#coeficiente de variación
cv<-(sd/mm)*100;cv
df <- nrow(pelGrp) - 1
alpha <- 0.1
delta <- qt(1-alpha/2, df) * sd
Lo <- round(Total - delta, 0)
Up <- round(Total + delta, 0)
Lo;Up
# Rough estimation, assuming normality in the origin and using a t-test (for
#unknown variance and small samples) and a confidence level of 90% is:
```

```
cat(Total, "\u00b1", round(delta, 0))
#density
DLo<-Lo*100/areaT;DLo
DUp<-Up*100/areaT;DUp
dd<-D_ACHA-DLo;dd
dd1<-DUp-D_ACHA;dd1
pelGrp <- pelGrp %>%
  mutate(D_FSC_H=D_FSC_T/(areaT*0.01*area))
pelGrp
#Total Values
n_pellet_ACHA<-sum(pelGrp$pnt);n_pellet_ACHA
D_pellet_ACHA<-(sum(pelGrp$pnt))/(sum(pelGrp$mt*2*w)*0.000001);D_pellet_ACHA
D_ACHA<-sum(pelGrp$area*pelGrp$D_FSC_H);D_ACHA
N_ACHA<-sum(pelGrp$D_FSC_T);N_ACHA

jpeg("D_FSC1.jpg", width = 7.2, height = 5.5,units = "in",quality=100, res=300)
ggplot(pelGrp, aes(x=tran, y=D_FSC_H)) +
  geom_col(colour = "black", fill = "lightsteelblue4",width=0.8) +
  #ggtitle("Density (by Km^{2}) of deer per habitat") +
  xlab("Habitat") +
  ylab(expression(paste("Number of Deer / ",Km^2,"")))+ #+
  #theme(plot.title = element_text(hjust = 0.5))
  theme_light()+
  theme_light(base_size = 14)+
  theme(axis.text=element_text(size=13))+
  theme(axis.text.x = element_text(angle = 0, hjust = 0.5))
#geom_label(text.label=1)
dev.off()
```

Annex 2 – Code for FAR analysis.

```
library(ggplot2)
library(tidyverse)
#Reading of the data
dat <- read.table("FAR_data_H.csv", header = TRUE,
                  sep = ";");dat
pel <- as.tibble(as.data.frame(cbind(hab=dat$Habitat, m=dat$m,
                              pn=dat$Pellet.number, days=dat$Dias.entre.visitas)))
pel
rm(dat)
pel$hab <- as.factor(pel$hab);pel$hab
w <- 2 #Half-width of the sampling plots (200cm)
r <- 23.26 #Defecation rate
#Pellet group density of each sampling plot
pel <- pel %>%
  mutate(d=(pn/(2*w*m))/(r*days))
str(pel)
summary(pel)
pel
pelGrp <- pel %>%
  group_by(hab) %>%
  mutate(met=sum(m),d_avg=mean(d),n_pellet=sum(pn),
         D_pellet=(sum(pn)*1000000)/(sum(m)*2*w),se=sd(d*1000000)) %>%
#Km^2
  select(hab,d_avg,met,n_pellet,D_pellet,se) %>%
  distinct() %>%
  arrange(hab);pelGrp
km_hab <- c(3.2597, 7.7803, 71.3668, 2.1641)
km_tot <- sum(km_hab);km_tot
km_prop <- km_hab/km_tot
km_prop
sum(km_prop)
pelGrp <- cbind(pelGrp, prop=km_prop);pelGrp
```

```
ta <- 8457.09*10000;ta # Total area (m2):
pelGrp <- pelGrp %>%
  mutate(total=d_avg*ta*prop)
levels(pelGrp$hab) <- c(paste("Humid Herbaceous", "Vegetation",sep = "\n"),
                        paste("Dry Herbaceous", "Vegetation",sep="\n"),
                        "Other Habitats", "Exposed Soil")
pelGrp
tot <- sum(pelGrp$total);tot
se <- sd(pelGrp$total);se
alpha <- 0.1
df <- nrow(pelGrp) - 1;df
delta <- qt(1-alpha/2, df) * se
Lo <- round(tot - delta, 0)
Up <- round(tot + delta, 0)
Lo;Up
#Rough estimation, assuming normality in the origin and using a t-test (for
#unknown variance and small samples) and a confidence level of 90% is:

cat(round(tot,0), "\u00b1", round(delta, 0))
DLo<-Lo*100/areaT;DLo
DUp<-Up*100/areaT;DUp
dd<-D_ACHA-DLo;dd
dd1<-DUp-D_ACHA;dd1
pelGrp <- cbind(pelGrp,
area=c(0.03854399,0.09199737,0.8438695,0.02558918));pelGrp
areaT <- 8457.09
pelGrp <- pelGrp %>%
  mutate(D_H=total/(areaT*0.01*area))
pelGrp
#Final Values
n_pellet_ACHA<-sum(pelGrp$n_pellet);n_pellet_ACHA
D_pellet_ACHA<-
(n_pellet_ACHA/(sum(pelGrp$met)*2*w*0.000001));D_pellet_ACHA
N_ACHA<-sum(pelGrp$total);N_ACHA
```

```
D_ACHA<-sum(pelGrp$prop*pelGrp$D_H);D_ACHA
#Graph
jpeg("DFAR.jpg", width = 7.2, height = 5.5,units = "in",quality=100, res=300)
ggplot(pelGrp, aes(x=hab, y=D_H)) +
  geom_col(colour = "black", fill = "lightsteelblue4",width=0.8) +
  #ggtitle("Density (by Km^{2}) of deer per habitat") +
  xlab("Habitat") +
  ylab(expression(paste("Number of Deer / ",Km^2,"")))+ #+
  #theme(plot.title = element_text(hjust = 0.5))
  theme_light()+
  theme_light(base_size = 14)+
  theme(axis.text=element_text(size=13))+
  theme(axis.text.x = element_text(angle = 0, hjust = 0.5))
dev.off()
```

Annex 3 – Code for VPCs analysis.

```
library(ggplot2)
library(tidyverse)
dat <- read.table('Censo Prueba_1.csv', header = TRUE,
                 sep = ";");dat
pel <- as.tibble(as.data.frame(cbind(site=dat$Lugar, ma=dat$Macho,hem=dat$Hembra,
                 ns=dat$No.sabe,ad=dat$Adulto,ju=dat$Juvenil,cr=dat$Crío,to=dat$Total)));pel
pel$site <- as.factor(pel$site)
levels(pel$site)=c("El Avión","Laguna S. Lucía","Antena","Cuscungo","Contadero G.","Patucllana","Mangahurco","Santantón")
pel$site
str(pel)
summary(pel)
Vc <- pel %>%
  group_by(site) %>%
  mutate(mach=sum(ma, na.rm = TRUE), hemb=sum(hem, na.rm = TRUE),
         unknown=sum(ns, na.rm = TRUE), adu=sum(ad,na.rm = TRUE),
         juv=sum(ju,na.rm=TRUE),cri=sum(cr,na.rm=TRUE),tot=sum(to,na.rm=TRUE)) %>%
  select(site,mach,hemb,unknown,adu,juv,cri,tot) %>%
  distinct()
Vc
N_ACHA<-sum(Vc$tot);N_ACHA
N_MALE<-sum(Vc$mach);N_MALE
N_FEMALE<-sum(Vc$hemb);N_FEMALE
N_UNKNOWN<-sum(Vc$unknown);N_UNKNOWN
N_ADULT<-sum(Vc$adu);N_ADULT
N_JUVENILE<-sum(Vc$juv);N_JUVENILE
N_FAWN<-sum(Vc$cri);N_FAWN
#Deer Sex
```

```
Sex<-as.integer(c(1,2,3));Sex
Number<-c(sum(Vc$mach),sum(Vc$hemb),sum(Vc$unknown));Number
t<-as.tibble(as.data.frame(cbind(Sex,Number)));t
t$Sex<- as.factor(t$Sex);t$Sex
levels(t$Sex)=c("Male","Female","Unknown")
t
jpeg("censosexo1.jpg", width = 7.3, height = 6,units = "in",quality=100, res=300)
ggplot(t, aes(x=Sex, y=Number)) +
  geom_col(colour = "black", fill = "aquamarine4",width=0.8) +
  #ggtitle("Density (by Km^{2}) of deer per habitat") +
  ylab(expression(paste("Number of Deer")))+
  theme_light()+
  theme_light(base_size = 14)+
  theme(axis.text=element_text(size=13))
dev.off()
#Deer Age
Age<-as.integer(c(1,2,3));Age
Number1<-as.integer(c(sum(Vc$adu),sum(Vc$juv),sum(Vc$cri)));Number1
g<-as.tibble(as.data.frame(cbind(Age,Number1)));g
g$Age<- as.factor(g$Age);g$Age
levels(g$Age)=c("Adult","Juvenile","Fawn")
g
jpeg("censoedad5.jpg", width = 7.3, height = 6,units = "in",quality=100, res=300)
ggplot(g, aes(x=Age, y=Number1)) +
  geom_col(colour = "black", fill = "mediumseagreen",width=0.8) +
  ylab(expression(paste("Number of Deer")))+
  theme_light()+
  theme_light(base_size = 14)+
  theme(axis.text=element_text(size=13))
dev.off()
```