CARRYING CAPACITY OF VICUNA IN THE CHIMBORAZO FAUNAL PRODUCTION RESERVE, ECUADOR

by

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April 2020

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Environmental Management

Faculty of Natural Resources Management

Lakehead University

April 2020

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ABSTRACT

Scott, D.T. 2020. Carrying capacity of vicunas in the Chimborazo Faunal Production Reserve, Ecuador.

Keywords: Vicuna, carrying capacity, Ecuador, Chimborazo Faunal Production Reserve

The Chimborazo Faunal Production Reserve (CFPR) and the reintroduction of the vicuna (*Vicugna vicugna*) is a success story for species conservation in South America. While the vicuna was once thought to be headed for extinction, its surprising population increase has led to a stable and widespread population. Within the CFPR, vicuna numbers have grown at a fast rate, prompting managers to consider the total carrying capacity of the reserve. Determining the carrying capacity of vicuna within the CFPR requires consideration for a variety of variables, including ecosystem use, water availability and interactions with livestock. Preliminary findings by this study indicate that distance to livestock is a very important factor in the distribution and habitat selection of vicuna and that vicuna appear to prefer areas near livestock. Areas of preferred habitat were found to be those in the *paramo* grassland (*herbazal de paramo*) ecosystem, near livestock and with adequate water sources nearby. In order to fully understand the complex relationship between vicuna and livestock in the CFPR, further studies should be conducted over longer periods of time.

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INTRODUCTION

The number of individuals that an environment can support at a given time is of great interest to wildlife managers. Aldo Leopold brought this question to the forefront in his 1933 work "Game Management," and described the factors affecting an area's "carrying capacity," popularizing the term first used by Verlhust. For Leopold, the main consideration, especially for hooved animals, was that of food supply (Leopold 1933). While much of what Leopold described still remains true to this day, modern wildlife managers have adapted his definition to meet the needs of practical application and complex management situations (Sayre 2008).

One such situation is that of the introduced vicuna (*Vicugna vicugna* Molina, 1782) in the Chimborazo Faunal Production Reserve (CFPR), Ecuador. The CFPR was established in 1987 and is located in central Ecuador, surrounding the tallest mountain in the country (MAE 2006). It is a high altitude, arid environment that supports several species of domesticated animals, as well as a healthy and increasing population of vicunas (McLaren et al. 2018). Interactions between livestock and vicunas do occur in the reserve, with livestock typically occupying areas of higher forage quality. One of the main challenges that managers in the CFPR face is determining how interactions with livestock affect the distribution and abundance of vicunas.

Vicunas are a territorial species that occur in family groups with a competitive reproductive hierarchy (Cassini et al. 2009). Males compete to control a harem, consisting of a group of females and their young. Males without a harem form bachelor groups, but can also be observed as solitary individuals. Vicunas normally inhabit a grassland habitat called the *puna,* an extensive area from the central part of Peru to Northern Chile and Argentina. The *puna* consists of a variety of grasses and ground plants (Koford 1957). In Ecuador, several of the most important forage species for the vicuna, such as *Poa,* are often rare in abundance (Vincent 2007). Ecuador is north of the range of *puna* and therefore has limited range for the vicuna, in higher elevation *paramo* ecosystems like that described for the CFPR.

RESEARCH QUESTION/HYPOTHESIS

Understanding how a variety of variables, such as livestock presence, forage abundance, and family group size influence vicuna density on the landscape will allow for better insight into future population expansion. While vicuna density estimates for certain areas of the CFPR have been completed before (Siavichay 2016), a complete analysis and determination of the total number of vicunas that could be supported has never been conducted. Therefore, it is my goal to use predictive mapping of sustainable vicuna densities to determine the carrying capacity for the Chimborazo Faunal Production Reserve, both currently and 10 years into the future.

APPROACH AND OBJECTIVE

The objective of my thesis is to create a predictive map of the CFPR to determine overall carrying capacity. I will use a variety of factors to create the map, including vegetation, areas near livestock or settlements, harem territory, and seasonal availability of habitat. The first step is confirming that these factors will be effective enough to determine abundance where vicuna family group size and structure have been previously surveyed. This step involves constructing a resource selection function (RSF). A final step is applying the RSF to the entire CFPR area, extending current density estimates to all habitats.

LITERATURE REVIEW

VICUNA DIET AND HABITAT

Understanding the habitat and feeding patterns of a species or population is critical in determining high priority areas of protection (Law and Dickman 1998). The vicuna, a member of the camelid family, is found throughout the *puna* ecosystem of South America (Cassini et al. 2009). Vicunas inhabit high altitude areas of the Andes mountain range, an ecoregion characterized by rarefied air, long dry season, irregular precipitation, low temperatures with frequent frosts, rugged topography and poor soils. Due to the vicuna's habitat being at high elevations, forage resources are often scarce (Vincent 2007). Despite these extreme conditions, vicunas continue to increase their numbers across much of their range (Torres and Puig 2012).

Habitat use by vicunas is largely determined by the terrain, climatic factors, availability of resources, time of day, and social structure (Torres and Puig 2012). Prior studies indicate that while potential habitat areas may be vast, the vicuna will often only use a small percentage of what is available (Renaudeau d'Arc et al. 2000; Cassini et al. 2009). Surveys in the Pampa Galeras Reserve, Perú, found that 43% of the study area was considered to be unsuitable vicuña habitat, with food resources distributed infrequently (Franklin 1983). In the Los Andes Reserve, Argentina, vicunas only use areas with highly profitable plant species when abundance was high (during the wet season), and showed less preference overall when conditions limited plant growth (Torres and Puig 2012). Distribution is also influenced by distance to water sources, especially in the winter and dry season. Within both of these study areas, wetlands play an important role in determining vicuna density (Franklin 1983; Torres and Puig 2012).

Throughout most of the vicuna's range, its main forage preference is for ground plants and grasses, with grasses in the genera *Calamagrostis*, *Festuca*, *Poa* and *Stipa* being most of what is consumed (Koford 1957). The presence of these forage species is mainly determined by altitude (Arzamendia et al. 2006). As elevation increases, plant cover becomes more sparse and overall plant size decreases (Koford 1957). Thus, in most regions inhabited by vicunas, the majority of plants are perennial bunch grasses. At lower elevations, precipitation and temperature are both higher, leading to larger plants and shrubs that are part of the vicuna diet. Elevation also plays a role in vicuna territory selection (Bonacic 2006). Ascending slopes with a depression near the base provide an escape from predators, as well as an area for feeding and drinking.

CHIMBORAZO FAUNAL PRODUCTION RESERVE

The Chimborazo Faunal Production Reserve (CFPR) is delineated into three areas based on elevation, and four areas determined by soil type, all of which the vicuna inhabits (MAE 2007). The *pantano*, the humid *paramo*, the dry *paramo* and the *arenal* are classified by soil (Podwojewski 2001). The *arenal* is most similar to the *puna,* and contains 35% of the vicuna population in the CFPR (MAE 2007). This area is located between the Chimborazo mountain's snow cap and the upper treeline of the Andean forest (Podwojewski et al. 2006). Weather is harsh, with cold and humid conditions. Soils throughout the CFPR are volcanic with high water retention capacity (Luteyn 1999). Vegetation within the CFPR is composed of a variety of plants (Table 1), many of which are consumed by the vicuna (McLaren et al. 2018). The Environment Ministry uses a standard classification of ecosystems, eight of which are in the CFPR (Table 2).

VICUNA AND HUMAN CAUSED STRESSORS

The vicuna is prized for its fine wool and was hunted to the brink of extinction until the 1960s (Torres 1992). The fine fibers of the vicuna are considered to be the highest quality in the world, making the vicuna an economic and ecological resource (Lichtenstein 2009). Implementation of management programs in the 1960s led to a steady increase in several populations of vicunas (McNeill et al. 2009). The period from 1965 to 2005 saw an increase from 10,000 individuals to 250,000 in populations across South America. This successful conservation effort has led to the vicuna now being listed as “least concern” by the IUCN (2018).

In many countries, including Ecuador, and in particular in the CFPR, wildlife management is complicated by their interactions with domesticated animals (McLaren at el. 2018). In the case of the vicuna, they are chased and occasionally killed by dogs, mostly in areas frequented by livestock (Arzamendia and Vila 2015). The issue of feral dogs has led to a reduction in the use of high-quality areas by vicuna in the CFPR. However, there is also evidence that vicuna and livestock coexist without problems in the CFPR, a behaviour not seen in other wild populations of the species (McLaren et al.

Table 1. Vegetation cover and frequency in the *paramo* of the Chimborazo Faunal Production Reserve (CFPR; Paucar 1990).

Family	Genus	Percent Cover	Percent Frequency
Araliaceae	*Azorella*	2.04	3.20
Asteraceae	*Artemisia*	1.00	2.95
	Chuquiragua	0.78	1.55
	Diplostephium	0.16	1.15
	Hipochoeris	3.17	4.99
	Loricaria	0.34	1.37
	Senecio	2.15	2.56
	Werneria	3.04	4.83
Clusiaceae	*Hypericum*	0.43	0.51
Fabaceae	*Adesmia*	2.11	3.13
	Trifolium	0.46	0.40
Geraniaceae	*Geranium*	9.21	9.14
Juncaceae	*Distichia*	0.42	0.34
	Luzula	10.20	11.07
Lycopodiaceae	*Lycopodium*	0.71	0.27
Plantaginaceae	*Plantago*	0.94	0.77
Poaceae	*Agrostis*	5.76	6.14
	Bromus	1.51	2.67
	Calamagrostis	6.61	13.49
	Festuca	6.99	9.56
	Muhlenbergia	0.52	0.63
	Poa	0.67	0.79
	Stipa	11.54	17.39
Rosaceae	*Alchemilla*	0.51	1.10

Table 2. List of ecosystems in the CFPR from Ecuador's national classification system (MAE 2018). Acronyms used in this thesis are listed only for those ecosystems occupied by vicunas.

Description in Spanish	English translation	Acronym used in this thesis
Arbustal siempre verde y herbazal de paramo	*Paramo* evergreen shrubs and grassland	LOWSHRUB
Herbazal de paramo	*Paramo* grassland	XERIC
Herbazal húmedo montano alto superior del paramo	*Paramo* high-elevation wet grassland	HUMID
Herbazal húmedo subnival del paramo	*Paramo* subnival wet grassland	SUBNIVAL
Herbazal ultrahúmedo suvnival del paramo	Subnival very wet *paramo* grassland	VERYWET
Herbazal y arbustal siempre verde subnival del paramo	*Paramo* subnival grassland with evergreen shrubs	HIGHSHRUB
Herbazal inundable del paramo	*Paramo* flooded grassland	
Bosque siempre verde de paramo	*Paramo* evergreen forest	

2018). One possible reason is the way vicunas were introduced to the CFPR; they were in close proximity to livestock for their first 40 days in the reserve. Another explanation is that the moderate amount of grazing by livestock in the reserve allows for minimal competition, with vicunas being less selective once forage quality declines (Arzamendia et al. 2006); this 'grazing lawn hypothesis' that suggests moderate grazing increases forage plant productivity (McLaren et al. 2018). As vicunas have yet to reach their carrying capacity in the CFPR, it is assumed that negative effects and competition between vicunas and livestock have yet to be fully determined, with more time and research needed.

MATERIALS AND METHODS

FIELD SAMPLING

Fieldwork to identify distribution of vicuna and family groups in the CFPR was conducted in 2015 and 2018. In 2015, stratified random survey transects of 2-3 km were walked, and crossed areas where livestock were present, as well as areas where they were not (Siavichay 2016). Transects also crossed wetlands, and vicuna locations were classified into two habitats, upland or wetland. Family groups were identified, as well as age and sex if possible. The distance of livestock and vicunas from the transect was determined using a HALO model XRT6 Rangefinder and Garmin GPS (model 60CSX). If vicuna were found to be <30 m from livestock, they were recorded as “coexisting.” Densities were then determined using the program DISTANCE for both habitat types and livestock presence (Buckland et al. 2015). These densities formed the basis for calculating carrying capacity.

The second set of surveys was the Ecuador’s approximately biannual attempt to census the entire CFPR, which last took place in July 2018 (MAE 2018). Vicuna groups were spotted by foot and horseback traversing paths of 8-10 km by teams equipped with binoculars working over a period of thirteen days (July 17 to 29). The observers were experienced wardens of the CFPR, other Environment Ministry staff, members of the Chimborazo Polytechnic University (ESPOCH) community, and local people organized as the Association of Vicuna Managers. The total count was 6,743 vicunas, and their locations were mapped in six of the eight ecosystems shown in Table 2. These locations formed the basis for calculating the RSF in this thesis.

Forage plant sampling was conducted by a group of trained local people along fifteen transects in October and November 2012 (dry season) and January to March 2013 (wet season). Four transects of 25 m were sampled with a point each metre in four compass directions for a total of 100 points (McLaren et al. 2018). At these points, the presence of living leaves and leaves with vicuna bites was determined, as well as the cover of all forage plant species. Vicuna bites could be identified by their small size relative to other livestock found in the CFPR. Dead leaves were also observed and recorded and were used to determine the ease of access that vicuna had to those areas. Secondary vegetation data was collected in 2015 by researchers from ESPOCH (Caranqui et al. 2016). Sampling occurred at nine locations, each with four 1 × 1 m plots to determine percent covered by each species. A plant list was created showing each species recorded, as well as a map of plot locations.

HABITAT AND RANGE MAPPING

Shapefiles depicting the ecosystem classification within the CFPR were created by the Environment Ministry and provided to me by Patricio Lozano of ESPOCH. They included hundreds of polygons each relating to the eight ecosystems in Table 2. Another set of maps showed altitude and land use, including a disturbance category that was mostly livestock pasture. The area of each polygon was calculated in ArcGIS using the "Calculate Geometry" tool and added to the ecosystem record. Point shapefiles depicting vicuna locations from the 2018 census were provided to me by the Environment Ministry, and included population information such as number of family groups, family group composition and number of solitary males. In addition, shapefiles containing water features were obtained via the Ecuador's online database. All of this information was viewed and mapped in ArcGIS Desktop.

Average home range or defended territory of vicuna family groups in the CFPR was determined to be 4 ha based on the densities calculated from the surveys in 2015. In ArcGIS, these were drawn graphically by creating a 4-ha circular buffer around each point that corresponded to one or more family groups (sometimes mapped together). These simulated home ranges were divided based on ecosystem where applicable using the "Buffer" and "Intersect" tools in ArcMap. Unused or generally unusable ecosystems such as "Glacier," "Disturbed," and "Other Areas" were not included in this calculation.

RESOURCE SELECTION FUNCTION

The approach chosen for the RSF calculation was a generalized linear model (GLM) in R Studio. A set of randomly located points were created across all ecosystems in the CFPR where vicuna family groups occurred, at a rate of five random points for every family group point. These random points also included the 4-ha range buffer and proportional ecosystem calculation. Shortest distance to water (rivers, lakes and other wetlands) and shortest distance to the disturbance category (hereafter, "distance to livestock") most were calculated for all points, family groups and random locations, using the "Near" function in ArcMap and added to the database after a square-root transformation that emphasized the potential value of being close to these areas. The

GLM used XERIC as the reference habitat. Four models were compared using the Akaike Information Criterion (AIC) calculated in the GLM. The first model was limited to the preference for ecosystem by vicuna family groups compared to the random case. The second added distance to livestock to the GLM, i.e., also comparing these distances from the vicuna family groups to the random locations; the third replaced distance to livestock with distance to water, and the last GLM included all variables.

CALCULATION OF CARRYING CAPACITY

Carrying capacity was estimated based on 100% occupancy of the preferred areas of the CFPR, referencing the best RSF and the 4-ha average family group home range. Occupancy by family groups of less preferred areas was calculated at 50%. The total estimated number of vicunas estimated at carrying capacity was corrected by adding the overall fraction of solitary males and bachelor groups from the 2018 census to the carrying capacity of family groups by ecosystem.

RESULTS

High concentrations of vicunas occurred in 2018 in the wetland ecosystems in the CFPR, with the HUMID and VERYWET categories supporting 64% of all vicunas and 66% of the family groups (Table 3). However, these two categories comprise the most expansive areas of the CFPR and some of it was unoccupied area.

Table 3. Area of the CFPR and distribution of vicunas and family groups by ecosystem (MAE 2018).

Ecosystem	Area (ha)	Percent of area	Number of vicunas	Percent of total	Number of family groups	Percent of family groups
LOWSHRUB	2,574	5.2	357	5.5	55	4.6
XERIC	6,246	12.8	464	7.2	56	4.7
HUMID	16,366	33.4	1,410	21.8	258	21.7
SUBNIVAL	4,163	8.5	839	12.9	171	14.4
VERYWET	11,067	22.6	2,733	42.2	527	44.3
HIGHSHRUB	6,098	12.4	435	6.7	75	6.3
OTHER	2,480	5.1	242	3.7	47	4.0
Totals	48,994	100.0	6,480	100.0	1,189	100.0

Habitat selection by vicunas in the CFPR is positively related to both disturbance and water features across the reserve's landscape. Model 1 contains only information on ecosystem use, while models 2 through 4 add distance to disturbance and water. AIC scores were very similar across models 2, 3 and 4 and show that while minimal, the distance to disturbance has a greater overall effect on habitat selection than distance to water, while both combined are considered the optimal model.

Table 4. Comparison of Resource Selection Functions (RSFs) used to match 2018 vicuna census data to six ecosystems, distance to livestock and distance to water or wetlands in the CFPR. The top models both included distance to livestock.

Model	AIC	Δ AIC	AIC weight
Three variable model	988.9	0.0	0.39
Ecosystem + Distance to livestock	989.0	0.1	0.37
Ecosystem + Distance to water	990.8	1.9	0.15
Ecosystem only	991.6	2.7	0.10

Carrying capacity calculations show an estimated population 10 times greater than what currently exists in the CFPR, with the XERIC, HUMID and VERYWET ecosystems containing the majority of vicuna at 72%. Preferred habitats mapped in ArcMap follow a similar distribution to what is currently occupied by vicuna in the CFPR. *Calamagrostis intermedia* and *Stipa ichu*, preferred plants according to McLaren et al. (2018) remained relatively common in the reserve, while other preferred plants, *Bidens humilis*, *Paepalanthus ensifolius* and *Poa annua*, did not occur at all in the 2016 plant survey (Caranqui et al. 2016).

Table 5. Calculations based on the best RSF from the 2018 vicuna census in the CFPR. Ecosystems are in order from most to least preferred. Preference ratios from parameter estimates in the RSF compare the value of the ecosystems to vicunas, reading across, with XERIC the reference habitat; for example, it should be 6.8 times more likely to find a vicuna family group in the SUBNIVAL ecosystem comparing the VERYWET ecosystem. The projected number of vicunas matches these ratios to the densities calculated by Siavichay (2016).

	Preference ratios				Projected number of vicunas	Percent of total vicunas
Ecosystem	VERYWET	LOWSHRUB	HIGHSHRUB	HUMID		
XERIC					8,510	13.4
SUBNIVAL	6.8	21.4	39.1	85.8	5,645	8.9
VERYWET		3.1	5.7	12.6	15,073	23.8
LOWSHRUB			1.8	4.0	3,488	5.5
HIGHSHRUB				2.2	8,332	13.2
HUMID					22,299	35.2
Total					63,347	100.0

DISCUSSION

Distance to disturbance had the greatest influence on vicuna habitat selection, with vicunas preferring areas adjacent or near disturbance and livestock. This is contrary to findings elsewhere in South America, where vicunas are found to avoid areas of pasture and livestock. Vicuna in the CFPR may be foraging closer to livestock due to the fact that farmed animals often occupy the most favorable habitat. Wet areas and areas of cultivated pasture are found throughout the reserve and they often support the highest

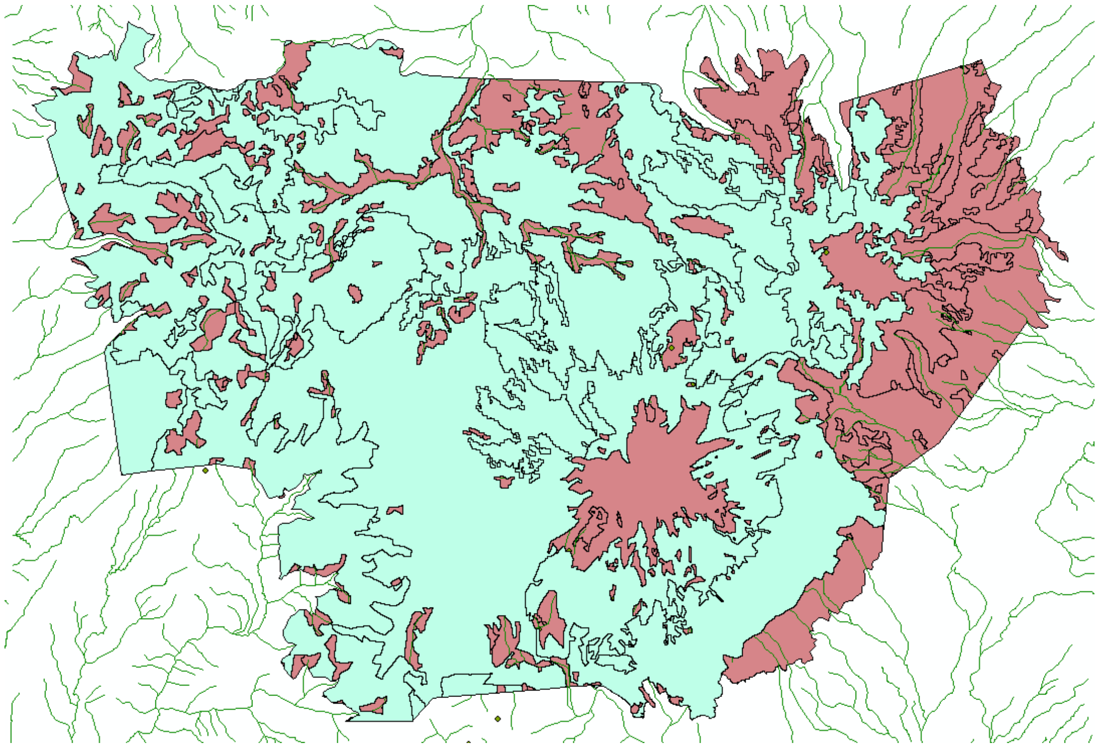

Figure 1. Distribution of vicuna in the Chimborazo Faunal Production Reserve (CFPR). Blue indicates areas occupied by vicuna; red areas currently do not support vicuna.

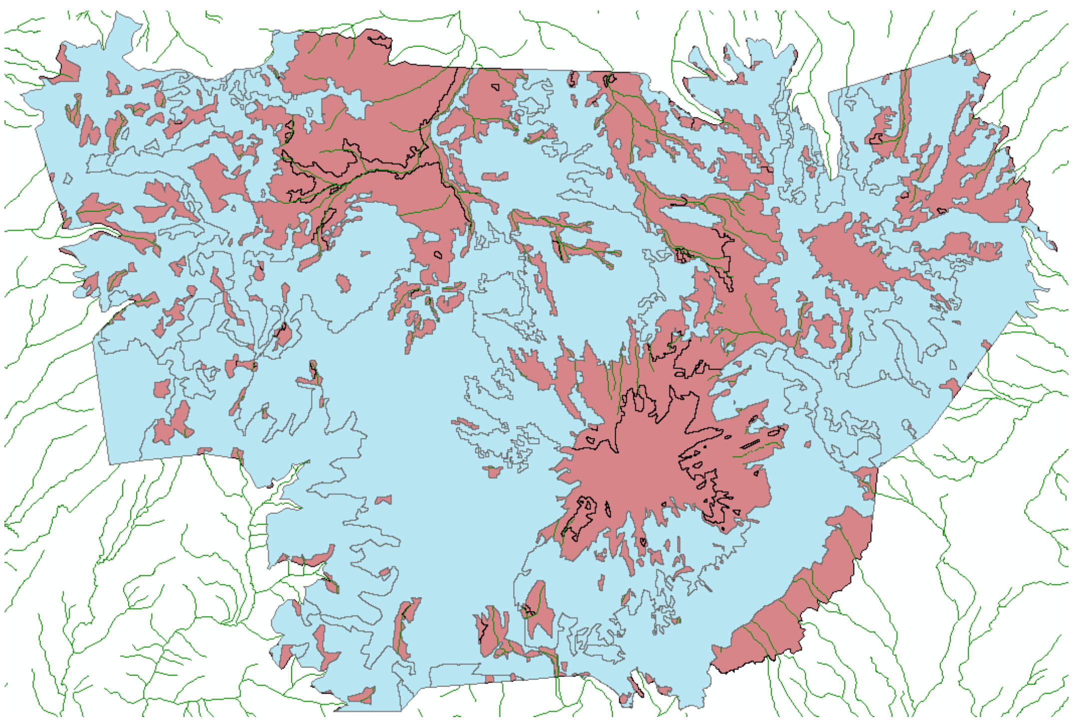

Figure 2. Preferred (blue) and non-preferred or unused (red) ecosystems in the CFPR shown in ArcMap as determined by distance to disturbance and distance to water.

abundance of important forage species (McLaren et al. 2018). Attraction of vicunas to livestock may also be explained by the nature of their introduction to the reserve, as vicuna were originally quarantined in areas near livestock. Livestock are also considered to be at low density within the reserve, a factor found to facilitate camelid and livestock interactions in Argentina (Wurstten et al. 2014). If vicunas are to reach their carrying capacity in the CFPR, their high density and competition with livestock may negatively influence habitat availability and selection.

Contrary to what one would expect, distance to water was not the most influential factor in habitat selection. Most mammals, and certainly vicuna, require a source of freshwater that can be accessed regularly (Koford 1958). Vicuna have been documented using water resources daily and systematically, related to diel climatic fluctuations (Vila and Cassini 1993). In the RSF, however, the inclusion of distance to water improved the model a very small amount when compared to distance to disturbance. The total model, which incorporated all three variables (ecosystem, disturbance and water), showed very little improvement as well. The model with only distance to disturbance added proved to be just as influential in predicting vicuna resource selection as the total model. This could be due to the large number of water resources (ponds, rivers, streams) within the reserve, as most vicuna are never far from a wetland and current distribution shows a water source in most home ranges. Vicunas were still found nearer to wetlands than randomly, however, indicating that water is still an important piece in determining carrying capacity.

Carrying capacity is of great importance and interest to all wildlife managers, especially those monitoring a new and growing population. Using the approach of the

RSFF, my carrying capacity calculations showed a similar distribution of vicuna to what is currently found within the reserve. The HUMID ecosystem is projected in 10 years to support the most vicuna, largely because of its expansive area, followed by the VERYWET and XERIC ecosystems. Even though XERIC was used as a reference habitat implying its current importance in supporting vicunas, its small area means it will not continue to support as many more vicuna as other ecosystems. Its proximity of HUMID areas to areas occupied by livestock rather than its forage resources is what makes this prediction. Interaction with livestock is perhaps the most interesting finding, and supports the findings of Siavichay (2016) and McLaren et al. (2018), even though other studies find that vicunas avoid areas of livestock (Arzamendia and Vila 2015). One would think that competition for resources and human avoidance would have pushed vicuna out of prime feeding areas, but instead it appears that they are comfortable with these added elements. This led to a higher carrying capacity than what would normally be expected, as areas near livestock were considered preferred and areas not near livestock were not preferred. Another reason vicuna may not be afraid of humans and livestock is the fact that they are protected within the CFPR (MAE 2006). In other countries, vicunas are often on private land, even on ranches, making them vulnerable to greater interactions with people (Bonacic et al. 2006). Capture and herding of wild vicunas create high levels of animal stress.

The preferred XERIC or *paramo* grassland habitats were considered the most important of the ecosystems and considered to be fully occupied in my projection. This ecosystem is known to contain more of the important forage plant groups, such as *Poa* and *Stipa* (Paucar 1990). Findings by Caranqui et al. (2016), however, showed that

Calamagrostis, less palatable (McLaren et al. 2018) was more common than *Poa* and *Stipa*. Caranqui et al. (2016) speculated that favoured grasses may be reduced in the future due to anthropogenic practices, including livestock grazing but also grassland burning. Carrying capacity estimations are based on current conditions within the reserve and do not include possible future deterioration of habitat.

Whether or not the CFPR can support the predicted carrying capacity of vicuna has yet to be determined. Increase in the vicuna population may largely depend on the continued sympatric relationship with livestock. If livestock continue to occupy higher quality forage areas, avoidance by vicunas of these areas may begin to emerge. Furthermore, vicunas may disperse into less favorable habitats when high quality areas are unavailable, a finding that was presented in McLaren et al. (2018). Further studies could explore a gradient of habitat use, in order to identify which habitats that are currently not occupied may be in the future. Additional factors, such as vehicle use of roadways, foot and bicycle traffic on hiking paths, and tourism in general, should all be explored as possible influences on vicuna behavior and carrying capacity. The CFPR presents a complicated and complex ecosystem that requires further work to fully understand.

CONCLUSION

The CFPR and the reintroduction of the vicuna represent a success story for species conservation in South America. While the vicuna was once thought to be headed for extinction, its surprising population increase has led to a stable and widespread population. Determining the carrying capacity of vicuna within the CFPR requires consideration for a variety of variables, including ecosystem use, water availability and interactions with livestock. Preliminary findings by this study indicate that distance to livestock is a very important factor in the distribution and habitat selection of vicuna and that vicuna appear to prefer areas near livestock. Areas of preferred habitat were found to be those in the XERIC or *paramo* grasslandecosystem, near livestock and with adequate water sources nearby. In order to fully understand the complex relationship between vicuna and livestock in the CFPR, further studies should be conducted over longer periods of time.

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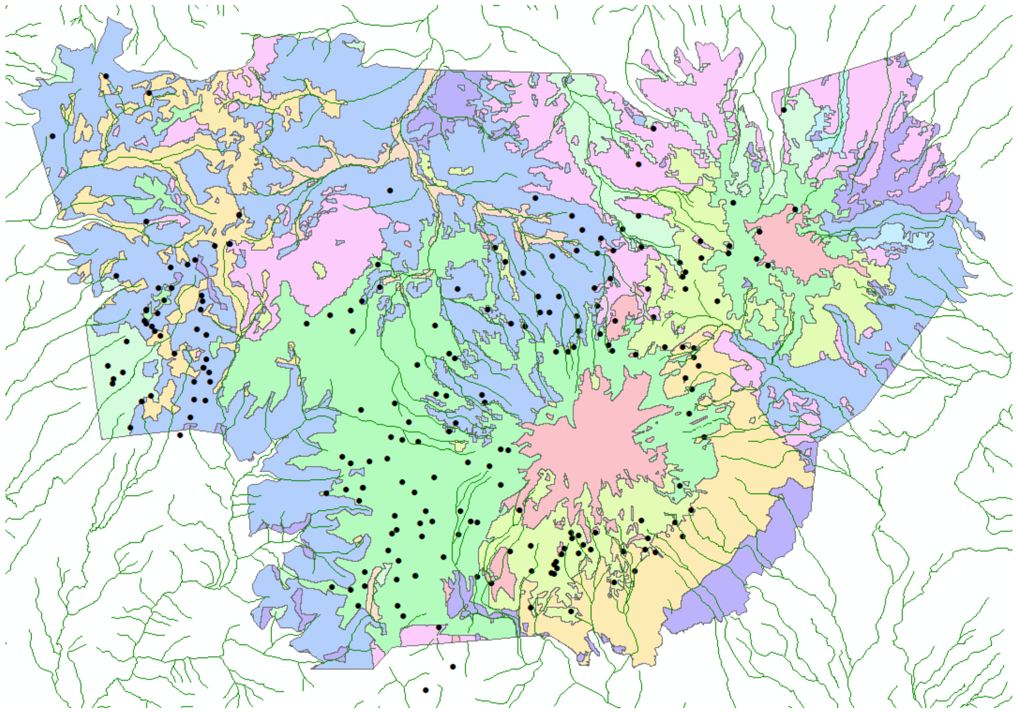
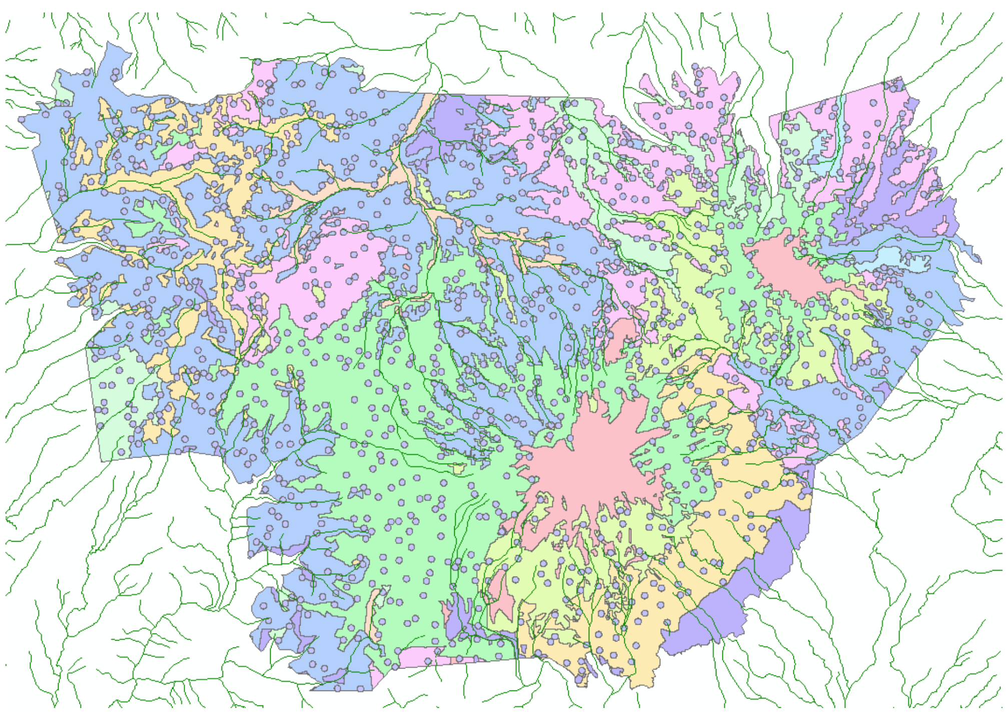
APPENDIX



Ecosystems and rivers within the CFPR and vicuna census points



Ecosystems and rivers within the CFPR with random points and buffers created for RSF