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Evaluation of the conservation status of high Andean grasslands of the Chimborazo Fauna Production Reserve, by means of remote sensing and geostatistics

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Abstract

The conservation status of wetlands is poorly understood, and there is a need for basic information to inform their management. It has been demonstrated that an increase in temperature will result in changes to the amount of water in wetlands, which may affect their functionality and composition. The wetlands of the Reserva de Producción Faunística Chimborazo (RPFCH) are undergoing a degradation process as a result of anthropogenic activities. In light of this challenge, the objective of this study was to evaluate the conservation status of two wetlands within the RPFCH, with the aim of identifying optimal management strategies. This research is exploratory in nature, employing descriptive, analytical, and prospective approaches. The study was conducted through the characterization and description of the vegetation, soil, and water components of the wetlands. The study area included the Pampas de Salasaca and Sachahuayco wetlands. An ecological classification was established, and a series of biological, chemical, and physical analyses were conducted on the water and soil. Subsequently, the conservation status was determined by calculating the spectral index of Normalized Difference Vegetation (NDVI), calculating the condition with Parker's method, and comparing the results with the *t*-test for two independent samples. The results demonstrated a regular condition according to the Parker Method, and the NDVI classification was "not very vigorous vegetation".

Keywords: Conservation status, Comparison, Bofedales, Chimborazo Fauna Production Reserve.

Resumen

Estudios sobre el estado de conservación de los bofedales son limitados y se requiere información básica para su manejo. Bajo un escenario de aumento de temperatura, se ha comprobado que la cantidad de agua en los bofedales cambiará, pudiendo afectar su funcionalidad y composición. Los bofedales de la Reserva de Producción de Fauna Chimborazo (RPFCH) están atravesando por un proceso de degradación como consecuencia de actividades antrópicas. Ante esta problemática, el propósito de esta investigación fue comparar el estado de conservación de dos bofedales de la RPFCH, para determinar estrategias de manejo. Se trata de una investigación de tipo exploratoria, a nivel descriptivo, analítico y prospectivo. Se la desarrolló por medio de la caracterización y descripción de los tipos de vegetación y los componentes suelo y agua de los bofedales: Pampas de Salasaca y Sachahuayco. Se estableció su clasificación ecológica, se realizó análisis biológicos, químicos y físicos del agua y suelo. Posteriormente, se determinó el estado de conservación, mediante el cálculo de índice espectral de Vegetación de Diferencia Normalizada (NDVI), cálculo de la condición con el método de Parker y se los comparó con la Prueba *t* para dos muestras independientes. Los resultados mostraron una condición regular mediante el Método de Parker y para el NDVI se los clasificó como vegetación poco vigorosa.

Keywords: Estado de conservación, Comparación, Bofedales, Reserva de Producción de Fauna Chimborazo**.**

1. Introduction

The term "bofedal," which is typical of Bolivia, Chile, Peru, and Ecuador, is used to identify highlands with natural evergreen, succulent vegetation, with high forage potential and with permanently moist soil. These ecosystems are characterized by humid environments with a permanent source of water, which results from the melting of glaciers, the presence of streams, rainfall, and springs. They are situated in a dispersed manner within the Altiplano and Altoandino bioregions, and they are highly productive, serving as a source of sustenance for significant populations of wild species. Furthermore, wetlands serve as a refuge for the maintenance of exceptional biodiversity of flora and fauna (Alzérreca et al., 2001; Contreras, 2007). Despite their limited extent, wetlands serve as a vital reserve of water and steppe during periods of drought. Nevertheless, despite the significance of these ecosystems, there is still a lack of essential information required for the conservation and sustainable management of these ecosystems (Alzérreca et al. 2001).

The wetlands of the Chimborazo Fauna Production Reserve (RPFCH) are situated within the hydrographic units of the Chimbo River, the Pastaza River, and the Chambo River, which are distributed across the provinces of Chimborazo, Tungurahua, and Bolívar (Lozano et al., 2016). These wetlands are of natural origin and can be classified as highland and high Andean in type. In some areas, they are characterized by a permanent presence of water, which is referred to as an udic water regime. In contrast, in other areas, they exhibit a temporary water regime, which is known as a mesic water regime (Delgado, 2018). As indicated by Lozano et al. (2016), these ecosystems are undergoing a process of degradation due to anthropogenic activities. Of the ecosystems within the RPFCH, 37.5% are classified as having a medium level of impact, while 31.3% are classified as having a high level of impact. This has resulted in the loss of habitat, a reduction in vegetation cover, the deterioration of natural water tributaries, the presence of inorganic waste, and the subsequent conversion of the ecosystem.

Additionally, Lozano et al. (2016) ascertain that the RPFCH wetlands have undergone a historical reduction in their area, with a decrease from 4091.21 ha in 1966 to 2824.90 ha in 2011. This indicated a reduction of 30.95% over approximately 50 years, which would precipitate an imminent collapse of the ecosystem. Accordingly, the IUCN Red List categorizes the RPFCH wetlands as Critically Endangered (CR), indicating a high risk of extinction (Andrade, 2016).

The objective of this research was to evaluate the conservation status of the Pampas de Salasaca and Sachahuayco wetlands in relation to the vegetation, soil, and water components. The findings of this study offer valuable insights into the conservation status of the wetlands, providing a basis for informed decision-making and the development of effective management strategies and actions.

2. Materials and methods

2.1. Study Area

The RPFCH encompasses an area of 52,683.27 hectares. The area is situated within the provinces of Chimborazo, Tungurahua, and Bolívar, spanning an altitudinal range of 3,800 to 6,263.47 meters above sea level (MAE, 2019). Of this area, approximately 5.36% is represented by wetlands, which are equivalent to 2,824.90 ha (Lozano et al., 2016). Furthermore, the study notes that between 1966 and 2011, as a consequence of anthropogenic activities that have resulted in degradation, this area has been reduced by 30.95% (Lozano et al., 2016). The wetlands of the RPFCH are primarily situated within the following ecosystems: The wetlands of the RPFCH are primarily classified into the following categories: ultra-humid sub-nival grassland of the paramo, upper high montane humid grassland of the paramo, floodable grassland of the paramo, and grassland of the paramo.

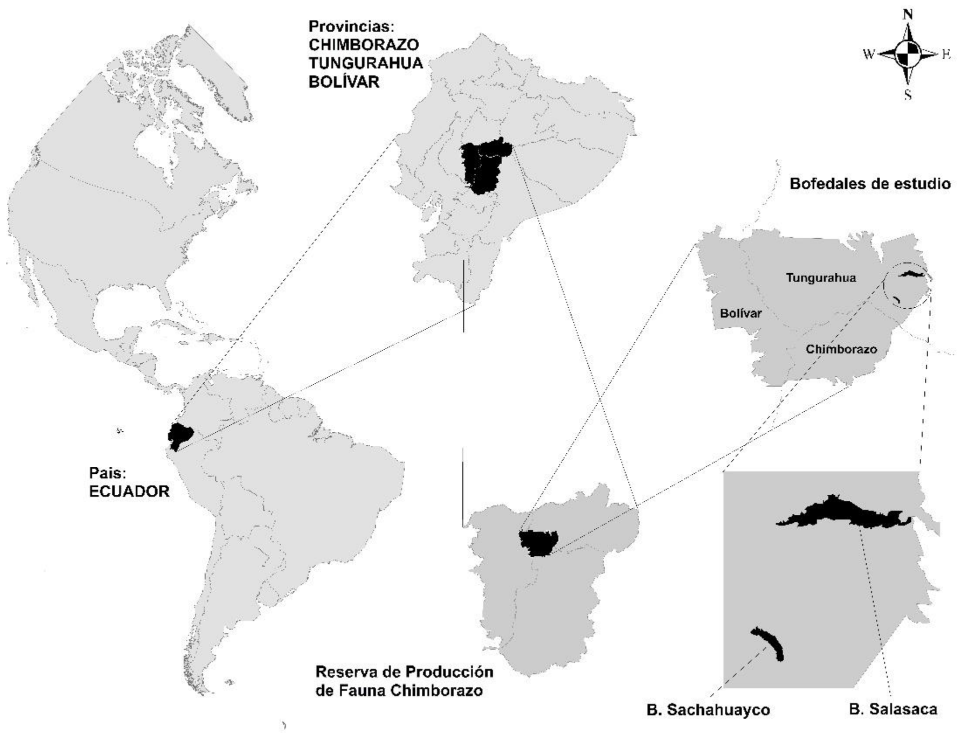

Figure 1. Location of the study area.

These ecosystems are characterized by high levels of plant productivity, the provision of fresh water, the purification and filtration of harmful waste in the water, and the formation of protective barriers against natural phenomena. They also serve as stabilizers and controllers of erosion and local climatic conditions, such as rainfall and thermal changes. Furthermore, they load and discharge groundwater, store carbon, and are essential for the preservation of biodiversity in the protected area (MAE,2019).

The Sachahuayco study wetland is situated at an altitude of between 4,000 and 4,040 meters above sea level and encompasses an area of approximately 25 hectares. The site is situated on a 140-hectare private property, owned by the Yana-Hurco Regional Water and Sewerage Board. The property was acquired 25 years ago with the objective of protecting the natural environment and ensuring a reliable water supply for the regional system. The Board has been granted a concession to use and exploit the site at a rate of 31.27 liters per second (Yanahurco Regional, 2018).

The Pampas de Salasaca wetland is of the natural altiplano type, as it is situated below an elevation of 4,100 meters above sea level. It exhibits a hydromorphic water regime, characterized by a high and constant level of humidity throughout the year (Andrade, 2016). The wetland is regarded as one that has undergone significant human intervention, with threats such as the presence of cattle, the diversion of water, and the introduction of machinery observed in certain areas of the vegetation cover (Lozano et al, 2016).

2.2. Methodological process

The methodology employed in this study was exploratory, analytical, and descriptive (Figure 1). Initially, the wetlands were characterized and described through the use of a bibliographic review and field exploration. Secondly, the state of conservation of the wetlands was evaluated through the analysis of soil water, biodiversity indices, and the use of remote sensors and spectral indices. In conclusion, the conservation status was evaluated through statistical analysis and the application of the grassland condition equation.

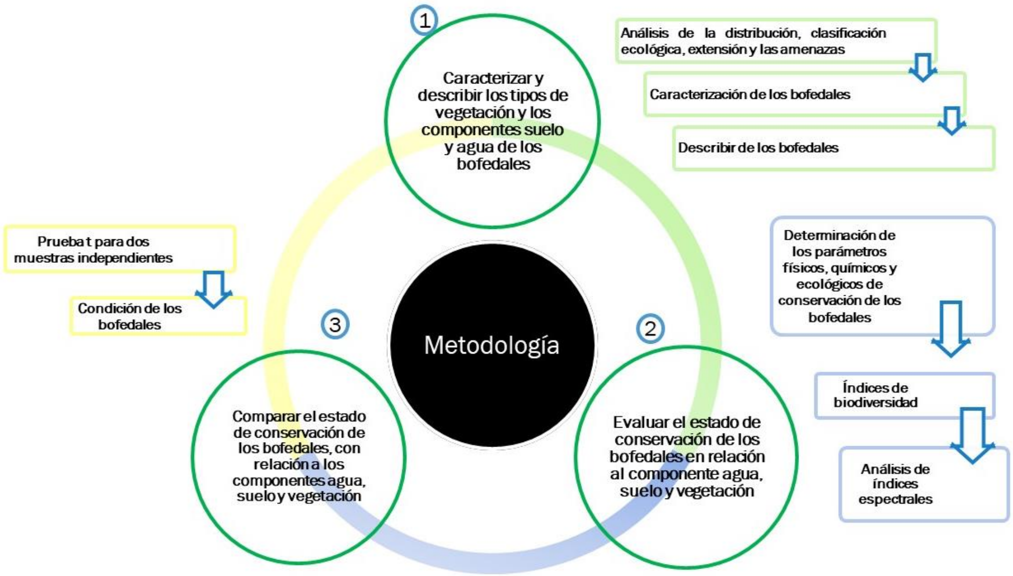

Figure 2. Methodological process for the fulfillment of the objects of this study.

2.2.1. Characterization and description of the types of vegetation and the soil and water components of the wetlands

The distribution and extension of the wetlands were determined through field research and the georeferencing of their surface with precision GPS technology. Subsequently, the ecological classification was determined through the analysis of the geographical data presented in the Vegetation Map of Ecuador Project.

The threats were identified by a review of the database of Smart reports of control and surveillance patrols conducted by personnel of the Chimborazo Reserve in 2018, 2019, and 2020. Finally, samples were taken for analysis to characterize the components of the bofedal, namely water, soil, and vegetation. The sampling area was delimited by establishing cells of 100 X 100 m in the study areas using ArcGIS 10.8 software. The intensity, size, and intensity of the sampling were calculated by applying the equation proposed by Rodríguez et al. (2004). The sampling period was between February 1, 2021 and July 31, 2021.
The plant component **was sampled using** the transect-to-pass method, with a line of 100 double crossings (100 meters in a north-south direction) traversed. In each instance of double crossing, the following species were documented: mulch, moss, bare soil, rock, or erosion pavement (Tapia and Flores, 1984). In the sampling of the **soil component, samples were taken** at a depth of 20 to 30 cm, with consideration given to the type of vegetation, and with due care taken to ensure the integrity and health condition of the samples. For the purpose of **sampling the water component**, the containers were filled to a level of up to 3/4 (three-quarters) of their maximum capacity, in order to allow for aeration. The sample is obtained by submerging the container in a counter-flow manner, thereby preventing the inclusion of air due to turbulent flow and taking photographs of the sampling site. Furthermore, the parameters were measured in situ in order to determine the temperature, pH, and conductivity.

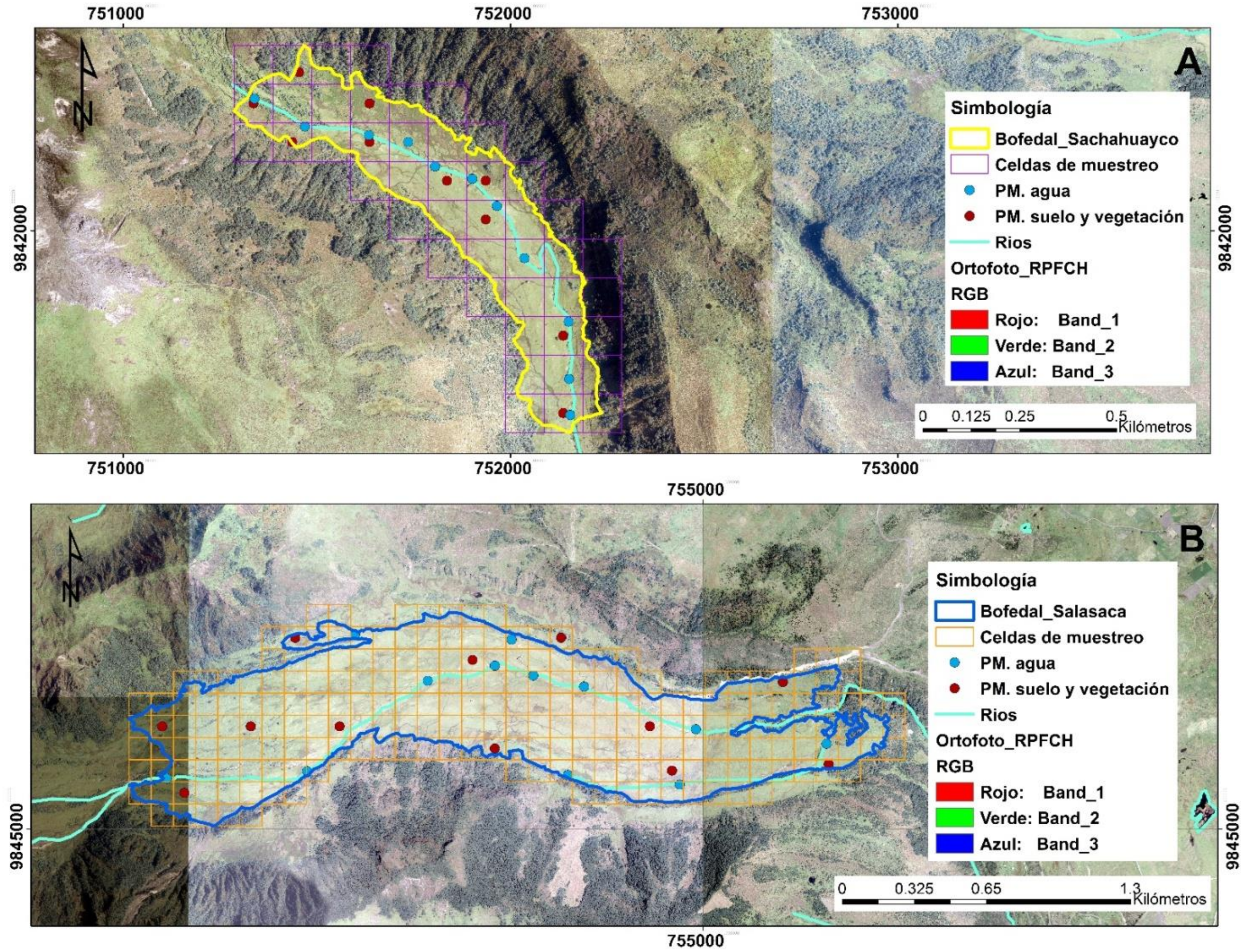

Figure 3 (a) Map of the 222 cells for Salasaca where 12 sampling points and transects are identified, (b) Map of the 46 sampling cells for Sachahuayco where 12 sampling points and transects are identified**.**

In conclusion, the vegetation was described in detail, indicating the genus, family, and species. The results of the soil analysis are detailed for the following parameters: temperature, pH, chloride, calcium, magnesium, potassium, and sodium, as well as organic matter. The results of the analysis of the physical characteristics of the water, including conductivity, hardness, and temperature, were detailed. The chemical characteristics of the water were also analyzed. The pH level was also determined. In addition, the biological parameters of calcium and magnesium, chlorides, total suspended solids (TSS), and total dissolved solids (TDS) were analyzed. The total solids content was also evaluated.

2.2.2. State of conservation of the wetlands

In order to ascertain the physical, chemical, and ecological parameters pertinent to the conservation of the wetlands, an investigation was conducted into the floristic composition and ecological condition, encompassing aspects such as composition, abundance, diversity indices, and the various types of soil cover. Furthermore, a classification system was devised, categorizing the species as either desirable or undesirable, based on data obtained from secondary sources.

Additionally, the vegetation cover was examined using spectral indices, wherein the temporality was defined by analyzing data on temperature and average precipitation for the year 2020 from the WorldClim historical climate data platform. Global rasters were downloaded at a spatial resolution of

30s (1 km²) and subsequently extracted from the raster to the study area. Subsequently, the average monthly data was subjected to analysis, with the objective of identifying the months with higher, lower, and medium ranges. Subsequently, the NDVI (Normalized Difference Vegetation Index) was calculated using data obtained from the Google Earth Engine platform. Images were downloaded from this platform, comprising scenes captured at different points in time, and were used to monitor changes in vegetation cover. Next, the NDVI equation NDVI=(NIR-Red) /(NIR+Red) was applied; the analysis was carried out for the monthly averages of October, April, and January of the years 2020, 2019, and 2015 using: 1) Region: Draw rectangular, 2) Format: GeooTiFF (File per band), 3) Band: B1, 4) Projection: WGS 8, and Resolution: 150.

After entering the Arcgis software, where the selection of colors in symbology was managed, the raster was cut to the study area with the following route: ArcToolbox> Data Management Tools >Raster > Raster processing > for all periods.

2.2.3. To compare the state of conservation of the wetlands

A quantitative comparison was conducted using the t-test, with consideration given to the effects of both equal and unequal variances, as well as the 95% confidence interval for the mean difference (Hurtado, 2012). The data on temperature and precipitation, ash content, organic matter, calcium, magnesium, pH, and soil temperature were compared. Additionally, the data on total suspended solids, total dissolved solids, total solids, total hardness, percent chlorides, pH, conductivity, and water temperature were also analyzed.

Furthermore, the condition of the wetlands was evaluated using Parker's three-step method:

Pampas de Salasaca Wetland
Score (0-100) = 0.5*(35.3) +0.2*(64.7) + 0.2*(94) +0.1*(8.8) = 50.37% Breutelia tomentosa

BofedalSachahuayco
Score (0-100) = 0.5*(31.6) +0.2*(68.4) + 0.2*(82) +0.1*(8.9) = 46.77 % Breutelia tomentosa

Where, the percentage values of desirable species were multiplied by 0.5). The forage index resulting from the sum of desirable species plus undesirable species is multiplied by 0.2. The vegetation cover resulting from the sum of desirable, undesirable, and undesirable species, plus the census values for mulch and moss is multiplied by 0.2. And the vigor index that results from the average height of an important species with respect to its height at climax; it was evaluated every 10 points of the transect and multiplied by 0.1 (Ruyle & Dyess, 2010).

Score (0–100) = 0.5D% + 0.2 IF% +0.2 (CV%) + 0.1 IV% (Flórez and Malpartida, 1980)
Where:
D (%): Percentage of desirable species
FI (%): Percentage of forage species (desirable and undesirable species)
CV (%): Percentage of vegetation cover
IV (%): Percentage of vigor index of key plants

3. Results

3.1. Characterization and description of the wetlands

The study wetlands are situated in the Tungurahua province, located to the northeast of the RPFCH, on the slopes of the Carihuairazo volcano. The Sachahuayco wetland is situated within the Mocha parish, Mocha canton, Tungurahua province, encompassing an area of 25.24 hectares. The Pampas de

Salasaca wetland is situated within the parishes of Mocha, Mocha canton, as well as Tisaleo and Quinchicoto of the Tisaleo canton, in the province of Tungurahua. The total area of the site is 164 hectares.

In Sachahuayco, two distinct types of vegetation are present. The first is 1.8 hectares of sub-nival humid grassland of the páramo, and the second is 23.4 hectares of upper high montane humid grassland of the páramo (MAE, 2013). Furthermore, the study area is traversed by a number of minor streams, with a single, principal waterway crossing the wetland from the northwest to the south. In Salasaca, two distinct types of vegetation are present: the evergreen forest of the páramo, comprising 0.5 ha, and the upper montane humid grassland of the páramo, which covers an area of 163.7 ha (MAE, 2013). Furthermore, the wetland is traversed by two principal streams, which flow from west to east.

As reported by Smart (MAAE, 2020), the presence of four exotic species of cattle is affecting Sachahuayco. Furthermore, the Salasaca area is home to 32 cattle, four horses, a shift in vegetation, and the accumulation of inorganic waste products resulting from tourist activities.

3.1.1. Sampling of plant components of wetlands

In Salasaca, a total of 1200 individuals were recorded, grouped into 17 families, 32 species. There is a notable presence of the species Breutelia tomentosa with 312 plant species, Plantago rigida with 271 plant species and in smaller numbers the species Cerastiumdanguyi with 1 plant species. The Asteraceae family with 6 plant species, reaches 9.6% which represents the highest percentage of individuals per species and the Sphaerophoracea family with one species achieves 0.001% representing the lowest percentage of individuals per species.

In the Sachahuayco, a total of 1113 individuals were recorded, grouped into 19 families, 39 plant species. There is a notable presence of the species Breutelia tomentosa with 189 plant species, Gunneramagellanica with 147 plant species and in smaller numbers the species Elaphoglossumalbescens with 1 plant species. The family: Asteraceae and Poaceae with 8 plant species represents 13.5% and 9.5% of individuals per species, and the Caprifoliaceae family with one species achieves 0.001%, representing the lowest percentage of individuals per species.

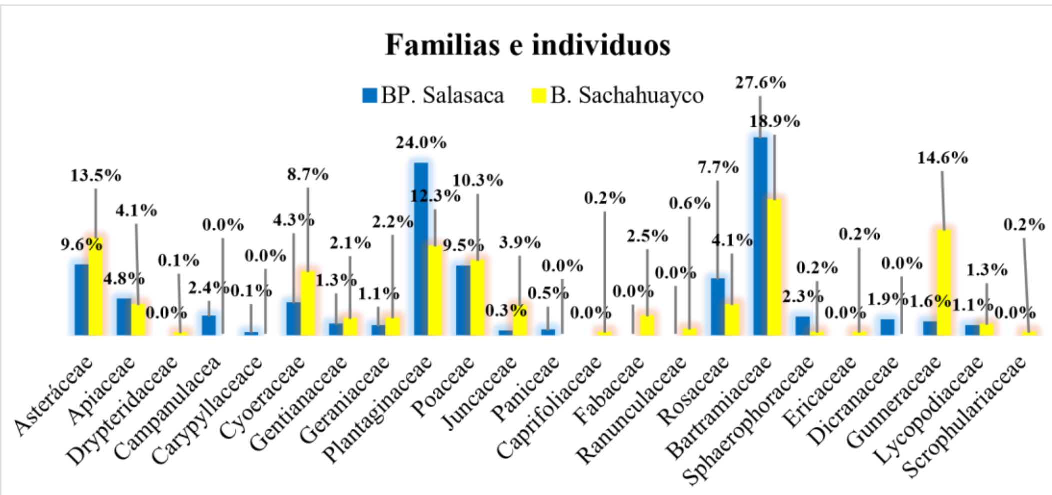

Figure 4 Families and individuals sampled in the wetlands

3.2. State of conservation of the wetlands

3.2.1. Land cover in reference to transect data

The soil cover of the Salasaca presented 94% with plant species, 3% water, 2% bare soil and 1% rock. For Sachahuayco, he showed that 82% corresponds to plant species, 7% organic mulch, 5% water, 3% bare soil and 3% rock.

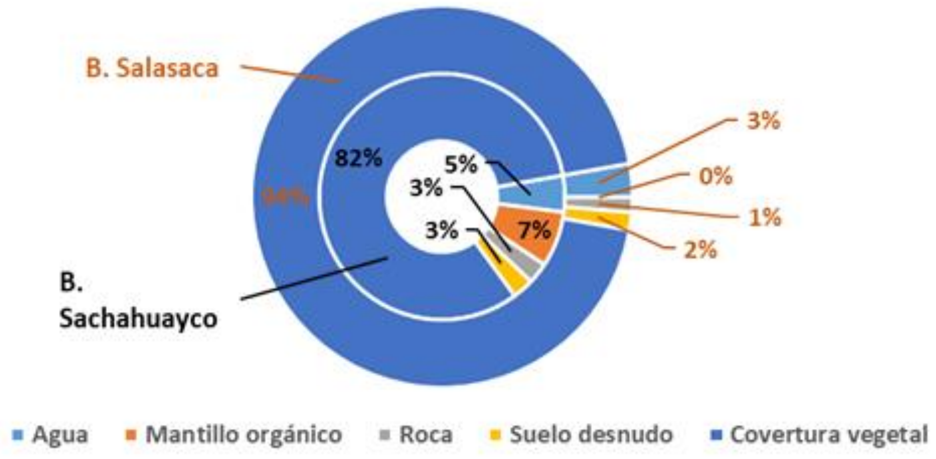

Figure 4 Soil cover of the wetlands under study

3.2.2. 3.2.2. Classification of species into desirable, low desirable and undesirable species

The plant species in Salasaca in 23.5% correspond to undesirable, 41.2% low desirable and 35.3% desirable; for Sachahuayco it was determined that 23.7% correspond to undesirable, 44.7% low desirable and 351.6% desirable.

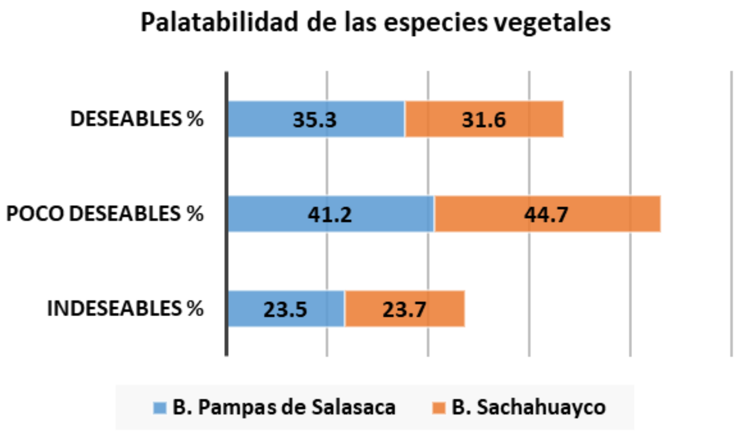

Figure 5 Ground cover of the study wetlands

3.2.3. Biodiversity indices

The results of the biodiversity indices for Salasaca and Sachahuayco determine that, according to the Margalef index, the specific richness (number of species) was 6.77 for Salasaca and 5.66 for Sachahuayco; the Simpson index was 0.84 for Salasaca and 0.89 for Sachahuayco. Finally, and the Shannon-Wiener equity index was 2.74 for Salasaca and 3.37 for Sachahuayco.

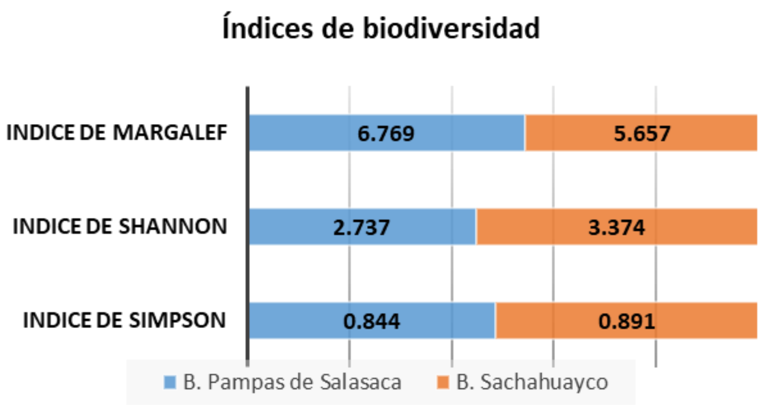

Figure 6 Biodiversity indices

3.2.4. Analysis of vegetation cover with spectral indices

To determine the temporality of the analysis of the vegetation cover with spectral indices, the average monthly temperature in degrees Celsius (°C) of the year 2020 of the wetlands was calculated,Where March and April presented the highest temperature (5.2 °C in Sachahuayco and 6.6 °C for Salasaca), August with the lowest temperature (3.8 °C for Sachahuayco and 4.8 °C in Salasaca) and, September and June with the average temperature (4.4 °C in Sachahuayco and 5.4 °C in Salasaca). The average annual temperature is 5.8 °C for Salasaca and 4.9 °C for Sachahuayco.

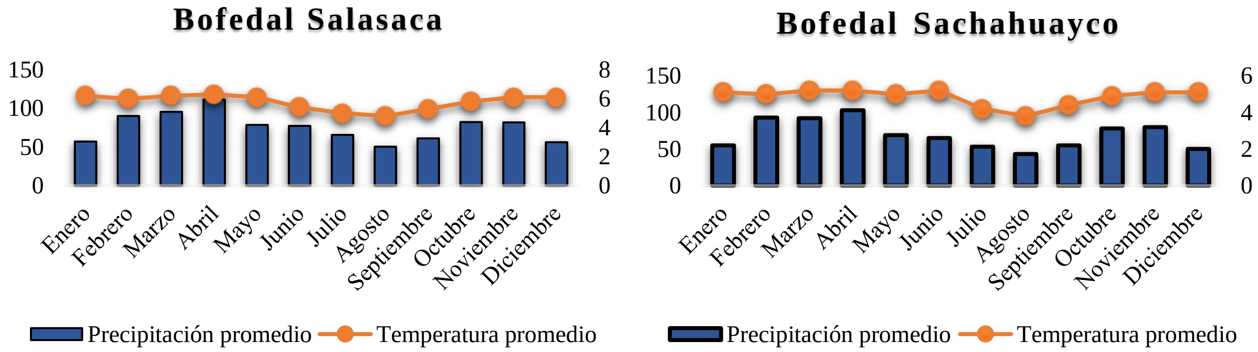

Figure 7 (a) Values of the average monthly temperature and precipitation in Salasaca; **(b)** Average monthly temperature and precipitation values in Salasaca

Likewise, the average monthly rainfall in millimeters per square meter (mm/m^2) of Salasaca and Sachahuayco, for the year 2020, was calculated,where April presents the highest rainfall (111.2 mm/ m^2/ month in the B.P. Salasaca and 103 mm/ m^2/ month B. Sachahuayco), January with the lowest rainfall (58 mm/ m^2/ month in the B.P. Salasaca and 55 mm/ m^2/ month B. Sachahuayco) and October with the average rainfall (83 mm/m^2/month in the B.P. Salasaca and 78 mm/m^2/month B. Sachahuayco). The average annual rainfall is 75.5 mm/m^2/year for BP. Salasaca and 69.7 mm/m^2/year for B. Sachahuayco.

4.2.4.1. Calculate it from the Normalized Difference Vegetation Index (NDVI) of the Bofedales

The NDVI index showed the variation in vegetation cover over time, in response to water availability; with a high reflectance in the near-infrared, making it easier to estimate.

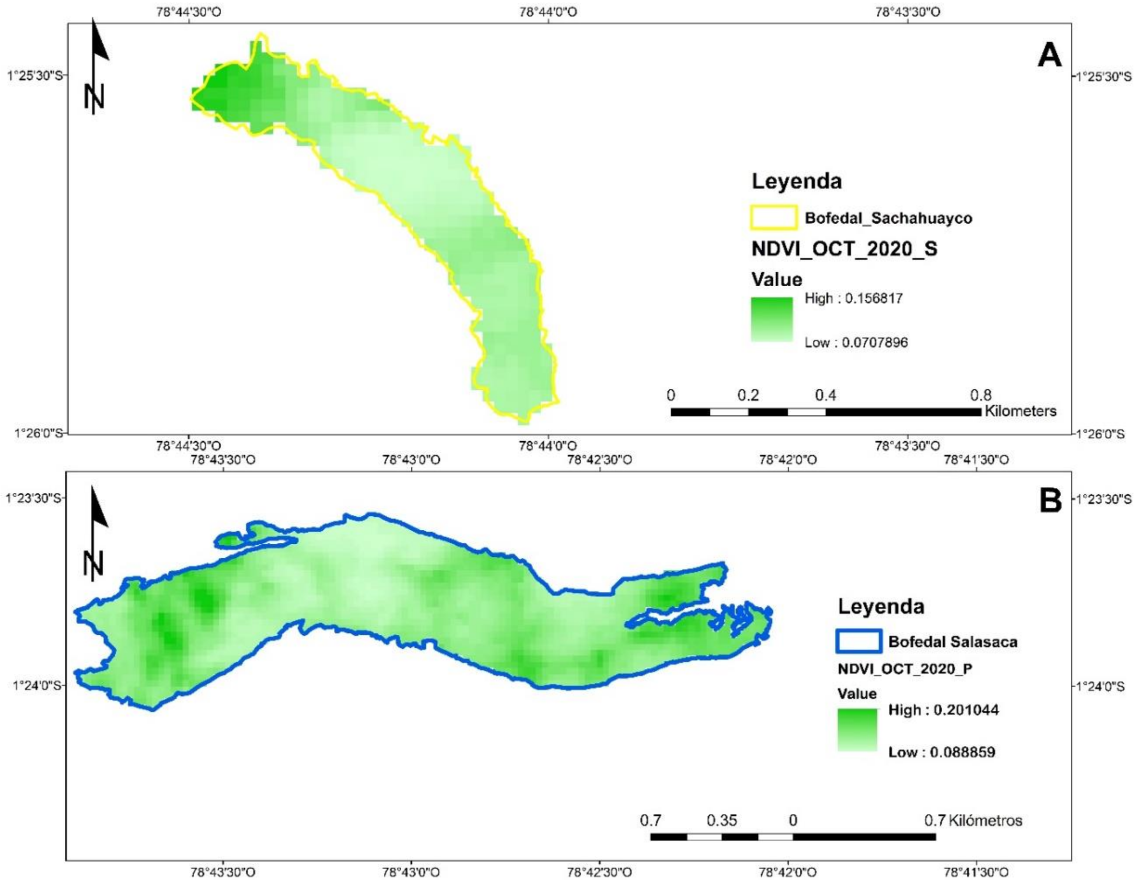

Figure8 (a) NDVI Index of B. Sachahuayco- October 2020; (b) NDVI Index of B. Pampas- October 2020

Table 1 NDVI in Salasaca and Sachahuayco

	Salasaka of NDVI-BP				**NDVI- B. Sachahuayco**			
	Minimal	**Maximum**	**Media**	**Standard deviation**	**Minimal**	**Maximum**	**Media**	**Standard deviation**
2020/ October	0.088	0.21	0.13	0.02	0.07	0.15	0.09	0.01
2019/ October	0.033	0.735	0.297	0.238	0.102	0.173	0.128	0.014
2015/ October	0.011	0.182	0.034	0.022	0.035	0.059	0.043	0.003
2020/ April	0.061	0.429	0.123	0.034	0.071	0.569	0.314	0.129
2019/ April	0.045	0.265	0.118	0.05	0.064	0.088	0.075	0.006
2015/ April	0.034	0.799	0.435	0.245	0.044	0.556	0.303	0.185

2020/ January	0.021	0.079	0.032	0.005	0.015	0.037	0.029	0.004
2019/ January	0.047	0.615	0.341	0.189	0.043	0.763	0.378	0.246
2015/January	0.025	0.116	0.051	0.016	0.025	0.038	0.032	0.002

The values of the average NDVI in Salasaca presented the highest value in April 2015 (0.435) and in January 2020 the lowest value (0.32). The values of the average NDVI in Sachahuayco presented in January 2019 the highest value (0.378) and in January 2020 the lowest value (0.029).

4.3. Comparison of the state of conservation of the wetlands

3.2.5. Temperature in the wetlands

Temperatures in the wetlands differ significantly. The value of the ambient temperature in Salasaca was 4.85±0.46 and in Sachahuayco 5.68±0.50; considered extremely low temperatures, but with the presence of plant and animal species adapted to this environment.

4.3.2. Comparison of soil characteristics

Table 2 Soil characteristics in the wetlands in Pampas and Salasaca.

Variables	**Salasaca**	**Sachahuayco**	**T Student**	**Prob.**
Ash %	27.80±17.96	24.60±20.41	0,40	0,34991185
Organic matter %	72.20±17.96	75.40±20.41	0,40	0,34991185
Calcium (mg)	0,00011±0,00004	0,00009±0,00003	1,42	0,09118781
Magnesio (mg)	0,00007±0,00002	0,00005±0,00002	1,42	0,09118781
pH	5.30±0.73	5.35±0.34	0,22	0,41558982
Temperature	12.74±0.53	12.85±0.21	0,67	0,25816590

The ash content of the soil in Salasaca and Sachahuayco was found to be 27.80 ± 17.96 and 24.60 ± 20.41%, respectively. These values were found to be statistically insignificant (p>0.05) despite apparent differences in mineral content between the two locations.

In both Sachahuayco and Salasaca, the organic matter content was recorded at 75.40 ± 20.41 and 72.20 ± 17.96%, respectively. These values are statistically significant (p > 0.05). This indicates that despite the apparent high organic matter content of the soil, the lack of rainfall and temperatures that prevent demineralization result in the soil not functioning optimally.

The concentration of calcium in the soil of Salasaca and Sachahuayco was found to be 1.10E-04 ± 4.00E-05 and 9.00E-05 ± 5.00E-05 mg, respectively. The values in question do not differ significantly ($p > 0.05$), although a slight superiority can be observed in Salasaca. Furthermore, the concentration of calcium in these regions is notably low.

Additionally, the magnesium content in Salasaca and Sachahuayco was 7.00E-05 ± 2.00E-05 and 5.00E-05 ± 2.00E-05 mg, respectively. The values in question do not exhibit significant differences ($p >0.05$), and the same is true of the absorption of these substances by plants, which is driven by the transpiration current.

The soils of Sachahuayco and Salasaca are acidic, with a pH of 5.35 ± 0.34 and 5.30 ± 0.73, respectively. The data indicate no significant differences ($p > 0.05$) between the samples, suggesting a low calcium content. Additionally, microflora contribute to soil acidification.

The soil temperature of Sachahuayco and Salasaca was 12.85 ± 0.21°C and 12.74 ± 0.53°C, respectively. These values exhibited no statistically significant difference ($p > 0.05$), although Sachahuayco exhibited a slight superiority.

4.3.3. Comparison of water characteristics

Table 3 Characteristics of water in the laboratory.

Variables	**B.P. Salasaca**	**B. True**	**T Student**	**Prob.**
Total Suspended Solids (TSS)	110.92±77.43	1.65±0.98	4,90	0,00023487
Total Dissolved Solids (TDS)	0.68±0.53	66.95±155.66	1,48	0,08410868
Total solids	1.65±0.68	68.61±156.36	1,48	0,08288504
Total hardness	1341,81±702,45	583,80±364,75	3,52	0,00238209
% Chlorides	0.003±0.003	0.001±0.001	2,50	0,01469744
pH	7.57±0.59	7.87±0.16	1,93	0,04022296
Conductivity	708,33±551,05	224.17±72.04	2,90	0,00717462
Temperature °C	15.44±1.10	12.59±1.81	6,64	0,00001839

In the laboratory setting, the total suspended solids (TSS) in Salasaca were found to be 110.92 ± 77.43. The values observed differ significantly ($p < 0.01$) from those recorded for the water of Sachahuayco, which exhibited a total suspended solids concentration of 1.65 ± 0.98. This discrepancy may be attributed to the proximity of the B. Sachahuayco sources to the sampling site, which are relatively undisturbed, whereas the Salasaca sources are more polluted and traverse a longer trajectory, resulting in turbid waters with elevated suspended solids.

The concentration of dissolved solids in the water of Sachahuayco was 66.95 ± 155.66 mg/L (TDS). This value is statistically significant ($p < 0.01$) when compared to the data from Salasaca, which yielded a TDS of 0.68 ± 0.53. This indicates that the minerals in Sachahuayco are dissolved in the water, which is not the case in Salasaca. The latter is therefore more straightforward to purify.

The total solids content of Sachahuayco B. and Salasaca B.P. was found to be 68.61 ± 156.36 and 1.65 ± 0.68, respectively. The values in question do not differ significantly ($p > 0.05$), and thus, it can be observed that there is a greater number of solids present in B. Sachahuayco than in B.P. Salasaca. This discrepancy may be attributed to the various factors encountered along the water's path.

In Salasaca, the water is classified as hard with an index of 1341.81 ± 702.45, which differs significantly ($p < 0.01$) from the waters of Sachahuayco, which are classified as moderately hard with an index of 583.80 ± 364.75. It is noteworthy that the waters of Sachahuayco are less harsh than those of Salasaca, potentially attributable to the differing quantities and types of minerals present in the two study areas.

The chloride content in Salasaca was 0.003 ± 0.003, while in Sachahuayco a content of 0.001 ± 0.001 was recorded, yielding a statistically significant difference ($p < 0.05$). The highest concentration of chloride was observed in Salasaca. This discrepancy may be attributed to disparate watershed management practices at each site.

The pH of the Sachahuayco waters was 7.87 ± 0.16, a value that differs significantly ($p < 0.05$) from that of the Salasaca waters, which exhibited a pH of 7.57 ± 0.59. While both pH values exhibit an alkaline tendency, Sachahuayco displays a significantly higher pH value. This particularity may permit the isolation of waters with fewer microorganisms.

In Salasaca, there is evidence of a water with a higher conductivity value, 708.33 ± 551.05, which is significantly higher ($p < 0.01$) than the conductivity value of the water in Sachahuayco, 224.17 ± 72.04. This discrepancy may be attributed to the differing mineral compositions of the waters in each region.

The temperature of the water in Salasaca at the laboratory level was recorded at 15.44 ± 1.10. This value differs significantly from that of Sachahuayco, which had a temperature of 12.59 ± 1.81, indicating that the water in this area is colder.

Table 4 Characteristics of water in the countryside.

Variables	**B. Salasaca**	**B. True**	**T Student**	**Prob.**
pH	7.79±0.20	8.31±0.37	3,92	0,00120270
Conductivity	645.42±325.41	173.42±78.29	4,44	0,00049449
Temperature °C	12.61±1.41	11.67±3.66	0,08	0,46971136

The pH of the water in the Sachahuayco field was found to be 8.31 ± 0.37, which differs significantly ($p < 0.01$) from that of the Salasaca water, which had a pH of 7.79 ± 0.20. This indicates that the water is alkaline in both locations, with greater significance in Sachahuayco. The alkalinity of the water is likely due to the presence of calcium in the springs, which causes the water to become alkaline. Alternatively, the water may be collecting alkaline salts along its path of travel.

In the field, the water of Salasaca exhibited a conductivity of 645.42 ± 325.41, which differed significantly ($p < 0.01$) from the conductivity of the water of Sachahuayco, which demonstrated a value of 173.42 ± 78.29. This discrepancy may be attributed to the presence of elevated levels of suspended solids in the water of Salasaca, in comparison to the water of B. Sachahuayco.

The temperature of the water in the Salasaca field and Sachahuayco was recorded at 12.61 ± 1.41 and 11.67 ± 3.66 °C, respectively. The values in question do not differ significantly ($p > 0.05$), although a slight superiority is observed in the Salasaca BP.

4. Discussion

4.1. Conservation status assessment

The calculation of the biodiversity indices enabled the determination of the ecological conditions conducive to conservation. The Shannon index for B.P. Salasaca yielded a value of 2.73, while that for B. Sachahuayco was 3. 37. This indicates a high degree of equity in the composition of flora. Delgado (2018) conducted a study in the Río Blanco, Puente Ayora, Pachancho, and Portal Andino wetlands in the Chimborazo Reserve. He determined a 3.26 of equity in the composition of flora due to the environmental factors that allow for vast vegetation cover of herbaceous plant species, mainly pad.

The Simpson index indicates that in Salasaca, there are 0.84 species of flora, and in Sachahuayco, there are 0.89 species of flora that dominate the plant composition. These findings are comparable to those reported by Delgado (2018), who determined that 0.94 species of flora dominate the plant composition of the Río Blanco, Puente Ayora, Pachancho, and Portal Andino wetlands in the Chimborazo Reserve.

The results of the Margaret's index indicate that the average number of individuals observed in Salasaca was 6.76 per species, while in Sachahuayco it was 5.65. In his 2018 study, Delgado reports an average of 5.89 individuals per species in the Río Blanco, Puente Ayora, Pachancho, and Portal Andino wetlands within the RPFCH. These are areas that exhibit a high degree of plant diversity.

Subsequently, the species were classified as desirable, undesirable, or neither. The proportion of desirable species is, on average, 35.3% in the B.P. of Salasaca and 31.6% in the B. Sachahuayco. The following species are included: The following species were identified: Alchemilla diplofila, Alchemilla pinnata, Carexequadorica, Carex sp., Castilleja cotulamexicana, Eryngium humile, Phylloscirpus acaulis, Geranium multipartitum, Agrostis breviculmis, Distichiamuscoides, Lolium multiflorum, Poa annua L, Pennisetum clandestinum, Lachimellaorbiculata, Alchemilla pinnata, Lachemillauniflora. The following species were identified: Hypochaeris sessiliflora, Geranium sessiliflorum, Poa annua L., and Juncus stipulatus.

It was determined that 41.2% of the species were undesirable in Salasaca and 44.7% in Sachahuayco, respectively. These species are of secondary importance in well-maintained wetlands, exhibiting less palatability but greater resistance to grazing. Huperziacrassa, Deyeuxiarigescens, Plantago rigida, Geranium sessiliflorum, Haleniaweddelliana, Gentinasedifolia, Cerastiumdanguyi, Lobelia oligophylla, Culcitium sp., Gynoxyssodiroi, Baccharis caespitosa, Hypochaeris sessiliflora The following species were identified: Taraxacum officinale, Elaphoglossumalbescens, Stipa ichu, Calamagrostis intermedia, Calamagrostis rigescens, Calamagrostis fibrovaginata, Lachemillahispidula, Pernettyaprostrata, and Buddleja bullata.

Furthermore, the presence of undesirable species was identified in 23.5% of the Salasaca area and 23.7% of the Sachahuayco area. The species in question are characterised by a hard and thorny build. The most prevalent undesirable species in the wetlands are as follows: The following species were identified as undesirable: Wernerianubigena, Azorella tridentata, Aciachneacicularis, Breutelia tomentosa, Bunodophoron, Campylopusnivali, Gunneramagellanica, Valeriana microphylla, Trifolium repens, Breutelia tomentosa, Bunodophoron, and Gunneramagellanica.

These values are comparable to those obtained by Calvo (2020) in his study of three wetlands in Quilcayhuacan, Huaraz, where the desirable species exhibited percentages of 41%, 55%, and 49%. In the wetlands of Santa Ana, Huancavelica, the desirable species exhibited percentages of 29%, 38%, and 40%. In the wetlands of Mazocruz, Puno, the desirable species exhibited percentages of 76%, 79%, and 5%.

The analysis of the coverage with the spectral indices revealed that the NDVI values in the wetlands ranged from 0.034 to 0.435 (B.P. Salasaca) and 0.029 to 0.378 (B. Sachahuayco), as documented by Pettorelli (2013) and Poveda (2006). In general, the NDVI values in wetlands range between 0 and 1, due to the normalization procedure. NDVI values below 0.001 are indicative of surfaces devoid of vegetation, including arid regions, rock formations, sand dunes, snow cover, and bodies of water. Furthermore, soils submerged in water tend to yield relatively modest NDVI values, typically within the range of 0.1 to 0.2. The presence of sparse vegetation, such as shrubs and grasslands, can result in the generation of moderate NDVI values, typically within the range of 0.2 to 0.5. A high NDVI value is indicative of dense vegetation in its maximum growth stage. Additionally, the diminished NDVI values are a consequence of the plants' water stress resulting from alterations in soil moisture content due to precipitation reduction or springflow reduction in wetlands (ALT UNDP 2001).

These values are consistent with those determined by García et al. (2015) in their study of the typical characteristics of a wetland in the Upper Basin of the Chillón River in Lima, Peru, where the extreme NDVI values range from 0.43 to 0.89.

Similarly, the study by Crispín (2019) of the wetlands of the Shullcas River sub-basin in Junín, Peru, determined NDVI values of -0.138 (indicating scarce vegetation), 0.3 (indicating vegetation that is not very vigorous), and 0.74 (indicating vigorous vegetation). In this context, the P. Salasaca and

Sachahuayco wetlands are classified as non-vigorous. Further study is required to elucidate the underlying factors, such as altitude and predominant vegetation types.

4.2. Comparison of conservation status

The ash content of the soil in the wetlands is statistically equivalent, with a mean value of 27.80% for Salasaca and 24.60% for Sachahuayco. The organic matter content in the soils of B. Sachahuayco(75.40%) and in the BP. of Salasaca (72.20%) is notably high. The aforementioned processes are unable to function optimally due to the insufficient precipitation and temperature, which impede the requisite demineralization. Baldoceda (2020) also identified comparable values. The study revealed that the Tambo Real wetland exhibited an organic matter content of 84.96%, while Huachipampa displayed a value of 70% (Baldoceda, 2020).

The calcium content in Salasaca (1.10E-04 mg) and Sachahuayco (9.00E-05 mg) exhibited no statistically significant difference, with the observed levels being exceedingly low in both areas. The magnesium content in Salasaca (7.00E-05 mg) and Sachahuayco (5.00E-05 mg) does not exhibit significant differences. This content would be absorbed by plants passively driven by the transpiration current. Baldoceda (2020) records that the soil of the Huachipampa and Tambo Real wetlands does not have a high number of salts, having values within the range of 0.00 to 0.07 dS.m-1, which is considered by Van Hoorn and Van Alphen (1994), as cited by Villafañe (2000), to be non-saline soils.

The soils of Sachahuayco and Salasaca are acidic, with pH values of 5.35 and 5.30, respectively, which indicate a low calcium content. Furthermore, microflora contribute to soil acidification. The values are comparable to those observed in the Huachipampa and Tambo Real wetlands, which range from 5 to 6.9. This corresponds to a classification of moderately acidic to slightly acidic (Baldoceo, 2020). In the case of the wetlands of the Shullcas River sub-basin in Junín, Peru, a pH of 4.8 has been reported (Lafuente et al., 1988). Furthermore, a pH of 6.95 has been reported for a bofedal soil (Sotomayor, Canahua, & Vargas, 1990), with results that are comparable to those obtained in the present study (García, 2016).

Furthermore, the soil temperature of B. Sachahuayco (12.85 °C) is slightly higher than that of B.P. de Salasaca (12.74 °C), yet no statistically significant differences were observed. These values are considerably lower than those observed in the Huachipampa wetlands, which recorded a temperature of 9 °C, and are also below the 11.7 °C recorded in the Tambo Real wetlands.

A comparison of the water component indicates that the total suspended solids (TSS) in Salasaca (110.92 mg/L) are more polluted and may have traveled a longer trajectory, resulting in more turbid waters than those observed in Sachahuayco (1.65 mg/L).

The concentration of dissolved solids in the water of Sachahuayco was 66.95 TDS, while in Salasaca it was 0.68 TDS. This indicates that the minerals in Sachahuayco are dissolved in the water, a process that does not occur in Salasaca. Consequently, Sachahuayco is more easily purified.

The total solids present in Sachahuayco and Salasaca were 68.61 TDS and 1.65 TDS, respectively. The data indicates a greater number of solids in Sachahuayco, which may be attributed to factors influencing the trajectory of the water course.

The water in Salasaca is classified as hard, with an index value of 1341.81. In comparison, the water in Sachahuayco has a lower degree of hardness, with an index value of 583.8. This is attributed to the lower quantity and different types of minerals present in Sachahuayco.

Conversely, the pH of the water is moderately alkaline, with an average of 7.2 for Sachahuayco and 7.1 for Salasaca. The electrical conductivity values in both wetlands range from 0.02 (iS.cm_1 0.07 pS.cm_1), which is below the ECA Category 4, indicating that the waters have a low salt content.

The application of Parker's method enabled the assessment of wetland condition and the measurement of forage production, taking into account the suitability of the species in question. With regard to the condition of the vegetation in the context of natural grasslands, the study wetlands are in a regular state of development, with percentages of 50.4% for Salasaca and 46.8% for Sachahuayco.

Comparable values were obtained by Calvo (2020) in his study of three wetlands in Quilcayhuacan, Huraz, with percentages of 62.2%, 68.8%, and 63.8%, indicating good conditions. In the case of the Santa Ana wetlands in Huancavelica, percentages of 57.9%, 59.6%, and 49.5% were recorded, indicating regular conditions. Finally, in the case of the Mazocruz wetlands in Puno, percentages of 79.9%, 77.4%, and 31.4% were recorded, indicating two wetlands of good condition and one of poor condition.

5. Conclusions

The Sachahuayco wetland encompassed an area of 25.2 hectares and exhibited two distinct vegetative types: subnival humid grassland of the páramo (1.8 ha) and humid upper montane grassland of the páramo (23.4 ha). The average annual temperature is 4.9°C, with an average annual rainfall of 69.7 mm/m². The Pampas de Salasaca wetland, with an area of 164 hectares, exhibited two distinct types of vegetation. The site also comprises an evergreen forest of the paramo (0.5 ha) and upper montane humid grassland of the paramo (163.7 ha). The mean annual temperature is 5.8 °C, with an average annual rainfall of 75.5 mm/m².

A floristic inventory revealed the presence of 13 similar families, with six dissimilar families identified in Sachahuayco and Salasaca, which exhibited four distinct families. The plant species observed in Sachahuayco numbered 32, with Breutelia tomentosa being the most notable. In smaller numbers, Elaphoglossumalbescens was also identified. In Salasaca, 39 species were recorded, with Breutelia tomentosa being the most representative. Cerastiumdanguyi was also present in smaller numbers.

The ground cover in Salasaca is comprised of 94% plant species, 3% water, 2% bare soil, and 1% rock. In contrast, Sachahuayco exhibits a different composition, with 82% corresponding to plant species, 7% organic mulch, 5% water, 3% bare soil, and 3% rock. In Salasaca, 35.3% of species were considered desirable, 41.2% undesirable, and 23.5% intermediate. In Sachahuayco, 31.6% were considered desirable, 44.7% undesirable, and 23.7% intermediate.

With regard to vegetation cover indices, Shannon exhibited the highest degree of flora equity, as indicated by a value of 3.37, along with the flora species that exert the greatest influence on the plant composition. With regard to the Simpson Index, the value observed for Sachahuayco was 0.89. In Salasaca, the flora species that dominate the plant composition for the Margaret index was 6.76, which identifies the number of individuals counted by each species. The Normalized Difference Vegetation Index (NDVI) indicated that the vegetation in the two wetlands was not particularly vigorous.

The soil analysis for ash, organic matter, calcium (mg), magnesium (mg), pH, and temperature did not reveal any notable discrepancies between the two wetlands. Similarly, the variable water quality did not exhibit any significant differences with regard to total dissolved solids and total solids. The remaining characteristics exhibited significant differences for chloride and pH levels, as well as highly significant differences for total suspended solids, total hardness, conductivity, and temperature. Ultimately, the Parker Method indicated that the condition of the pastures was regular for both wetlands.

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