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ECOSYSTEM DEGRADATION IN THE BAHUAJA SONENE NATIONAL PARK: A MULTI-TEMPORAL ANALYSIS

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SUMMARY

In recent years, terrestrial ecosystems have suffered transformations as a result of anthropogenic activities, leading to the loss of natural heritage. Therefore, the objective of the study was to identify ecosystem degradation through a multi-temporal analysis of vegetation cover and land use change in the Bahuaja Sonene National Park (BSNP) and its Buffer Zone (BA) during the period 1984 - 2018. For the development of the research, multispectral satellite images Landsat 4, 5, 7 and 8 were used, which were processed in the ENVI 5.0.0 software, and then analysed through the following indices: Normalised Difference Vegetation Index (NDVI), Normalised Difference Water Index (NDWI), Enhanced Vegetation Index (EVI2), and Cellulose Absorption Index (CAI). The results show that 1.45% of the total territory showed changes due to vegetation cover dynamics, of which 0.32% showed changes due to vegetation succession. The extension of agricultural land in the southern part has a growth rate of 13 ha/year. As for the buffer zone, agricultural soils show a considerable growth, determining that the territory presented a change in soil use due to the expansion of agricultural activities.

Keywords: Multitemporal Analysis, Vegetation Cover, Land Use, Landsat, Environmental Studies.

INTRODUCTION

In recent years, terrestrial ecosystems have undergone major transformations (Budiharta, et al., 2014) and "deforestation and forest degradation are among the main drivers of biodiversity loss" (p 1), researchers such as (Aguayo, Pauchard, Azócar, & Parra 2009) mention that since the industrial revolution, the world's population has grown rapidly, increasing the need for food supply.

Under the capitalist development approach, ecosystems have been among the most affected by this situation, which is why, in recent years, development management has had the need to protect areas of great biodiversity, scientific and cultural importance, which represent only 1.4% of the planet's land surface and are home to approximately 60% of all terrestrial species diversity (Najera, 2010), one of the most emblematic cases being the Peruvian Amazon.

Peru has 73 million hectares of forests that are characterised by a wide diversity, of which according to information, satellite maps and quantitative data collected over the last decade show an increasing rate of deforestation, which on average reached 113,000 hectares per year (Servicio Nacional Forestal y de Fauna Silvestre [SERFOR], 2015).

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One of the emblematic parks of the Peruvian Amazon is the Bahuaja Sonene National Park (PNBS), which is a natural area protected by the Peruvian government and is located in the provinces of Tambopata (Department of Madre de Dios), Carabaya and Sandia (Department of Puno). This area has a considerable wealth of biodiversity, and is considered one of the seven Natural Sanctuaries on the planet (INRENA, 2006). It is important to highlight that in this park there are natural ecosystems such as the savannahs of Beni, and it is also home to endemic species such as the maned wolf and the marsh deer.

The diversity of natural and biological conditions has made the PNBS aim to protect representative ecosystems of the Subtropical Amazon and Subtropical Yunga Biogeographical Provinces, of high biological diversity and extraordinary scenic beauty. (Tambopata National Reserve - Legislation, n.d.) In this sense, the percentage of coverage in each one of them and the degree of affectation of the Natural Protected Area (NPA) is presented as an indicator to see how it varies over time. (SERNANP, 2015)

Despite its great biodiversity and great importance for conservation in the country and the world, the PNBS and its buffer zone are facing a progressive change in vegetation cover and land use, due to the dynamics of the rivers, the plant succession that develops in the natural ecosystem of the Sabanas del Beni and the expansion of agricultural land, which is why special treatment is required to ensure the conservation of the NPA.

Given the presence of these negative impacts in the PNBS, the need arises to observe the conservation of biodiversity over time. Therefore, the identification of the degradation of the ecosystem was carried out through a multi-temporal analysis taking different years from 1984 to 2018, analysing the data separately for the PNBS and its buffer zone, with the aim of revealing the changes in vegetation cover and land use.

MATERIALS AND METHODS

This is analytical-correlational research between the independent variables which is the time period from 1984 to 2018 and the dependent variable which is the 5 types of vegetation cover; forest, water bodies, bare soils, Beni savannahs, agricultural soils; agricultural soils qualify as land use change.

In addition, this is longitudinal research because of the multi-temporal analysis of the extent of the five types of vegetation cover and land use of the PNBS and its ZA within the period 1984 - 2018.

Study area

The PNBS (Figure 1) is located in the departments of Madre de Dios and Puno, and covers an area of 1,091,416 hectares, distributed approximately 70% in the Puno region and 30% in the Madre de Dios region. Furthermore, it is located at an altitude ranging from 200 to 2450 m.a.s.l. geographically, the area is located within the UTM coordinates (WGS84) 8'600,317- 8'458,421 S and 354,794 - 531,238 W.

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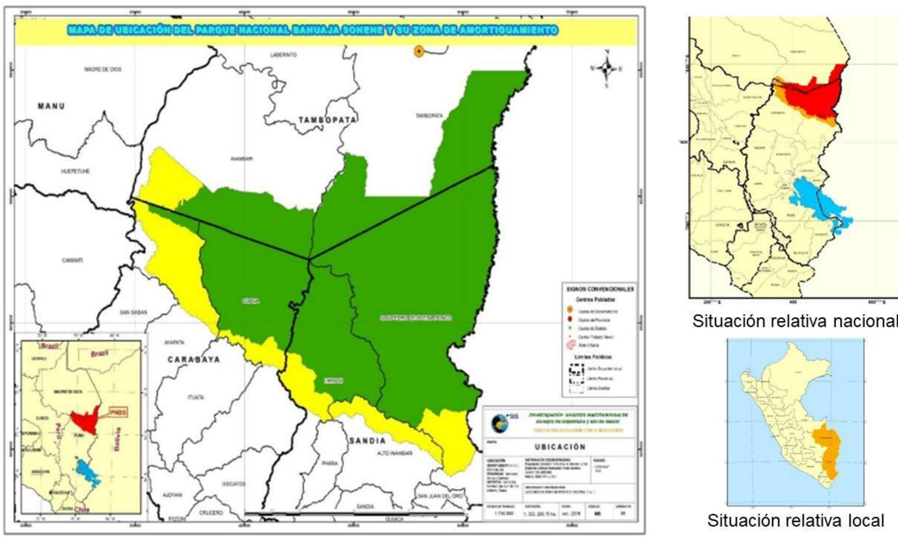
Figure 1: Map of the political location of research



Source: Own elaboration

In terms of the ecosystems found within the PNBS, there are five types of vegetation cover: forest, water bodies, Beni savannahs, areas without vegetation, and agricultural soils. The forest that has a minimum soil surface between 0.5 and 1 ha with a canopy cover; the water bodies that are made up of rivers, lagoons, among others; the Beni savannas that are the herbaceous formations that highlight the river beaches; the areas without vegetation are areas that are occupied by landslides; and finally the agricultural soils that are used for food production such as crops, pastures and fibres (James, Anderson, Hardy, & Roach, 1976), the latter being of special interest because they have been most affected by agricultural expansion.

MATERIALS

For the development of the work an Intel(R) Corel (TM) i7 - 3770 CPU computer was used, whose operating system is 64 bits, allowing the use of ENVI 5.0.0 software capable of reading RASTER and Vector files (Envi Guide for geomorphology). It performs orthorectification, segmentation and algorithms for the classification of vegetation cover that act on deforestation and land use change.

The Code Editor which is based on Earth Engine's JavaScript application programming interface (API); as well as USGS Landsat 8 Surface Reflectance Tier 1 images containing 5 visible and near infrared (VNIR) bands and 2 shortwave infrared (SWIR) bands processed for orthorectified surface reflectance, and two thermal infrared (TIR) bands processed for orthorectified brightness temperature. (Google Earth Engine).

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Satellite images such as USGS Landsat 7 Surface Reflectance Tier 1, USGS Landsat 5 Surface Reflectance Tier 1, and USGS Landsat 4 Surface Reflectance Tier 1 were processed with the above software.

Procedure

For land cover discrimination, a combination of Green, NIR and SWIR2 bands was used to observe the spectral signature of the 5 types of vegetation cover and land use.

With this, more than 10 regions of interest were established for each type of vegetation cover and land use in different zones of the Bahuaja Sonene National Park and the buffer zone, obtaining the spectral signature of each one of them with the values of their averages.

The Degree of Spectral Signature Separability was used to calculate the spectral separability between selected ROI pairs for an input file, with values ranging from 0 to 2.0 with values of 1.9 indicating that the ROI pairs have good vegetation cover. For the band indices, the values were extracted from Landsat 8 satellite imagery from June, July and August 2018, taken in dry seasons because they contain a lower percentage of cloud cover.

The satellite images were filtered by year, choosing the dry months to obtain clean images of cloudiness, then banding mathematics with vegetation and water indices, putting their respective formulas. For the research the indices used were Normalized Difference Vegetation Index (NDVI) ranging between -1 to 1 (Carlson & Ripley, 1997, p.1), Normalised Difference Water Index (NDWI) describe the reflectance properties of green vegetation, dry vegetation and soils (Gao. 1966, p. 257), Enhanced Vegetation Index (EVI2) improves the vegetation signal with improved sensitivity in regions of high biomass and better vegetation monitoring. (Farrel & Raul, 2011, p. 103), Cellulose Called Absorption Index (CAI) describes the depth of the lignocellulose absorption feature in the shortwave infrared region (2.0-2.2 μm) (Nagler, Inoue, Glenn, Russ, & Daughtry, 2003, p. 312).

Having visualised the satellite image, training areas were created for each type of land cover and land use, which are: Forest, water bodies, Beni savannah, bare soils and agricultural soils respectively. This procedure was carried out for each region. Taking the various training areas as collection folder and coding them for classification, it was carried out in different years between the period 1984 - 2018.

For the classification by sectors of the Bahuaja Sonene National Park, the classification is made in 4 sectors A, B, C1 and C2, making training areas for each type of classification, differentiating into forest, bare soils, water bodies, agricultural soils and Beni savannah.

Statistical analysis

To find the correlation that the Beni sheets present in relation to time, the Pearson correlation was used, which has an interval of 1 to -1 indicating a perfect direct or inversely proportional correlation, while the value is close to 0 its correlation is not significant, after

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which the variance was calculated with ANOVA. To determine the sample size, the Ministry of the Environment (MINAM, 2014) established as a reference the following: "The calculation of random sampling points must be verified in high resolution images and is obtained according to the formula established by Cochran-1977" (p 16)".

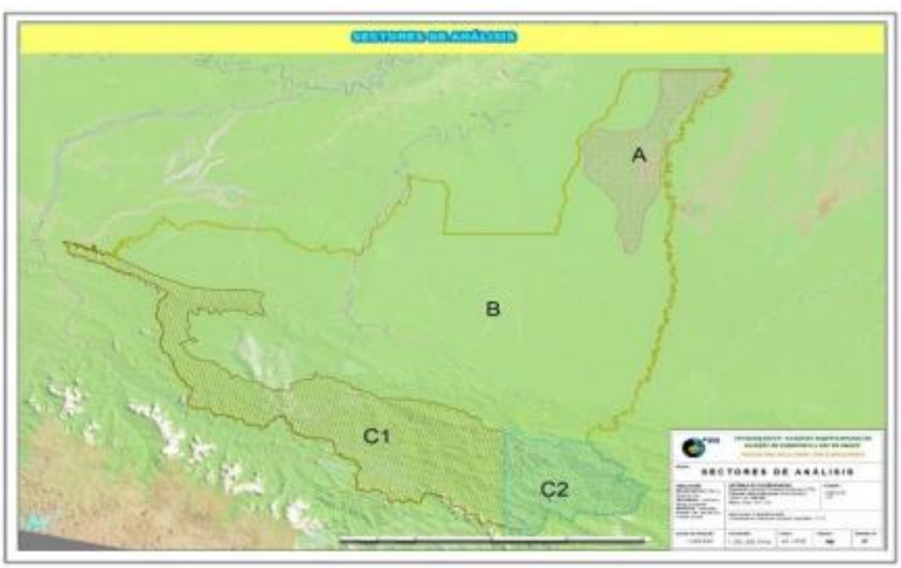
For data validation, the protocol for evaluating the thematic accuracy of the deforestation map carried out by MINAM (MINAM, 2014) was used as a guide, taking 12,706 random sampling points, using the Arcmap Random Point creation tool, distributed uniformly throughout the study area, increasing it by 43 points due to validation in the field, thus having a total of 12,749 validation points. For the analysis of the data was evaluated through a confusion matrix that determined the reliability of the map taking into account the metric to evaluate the Kappa Index map which is a measure of the difference between the accuracy achieved in the classification with a software and the accuracy of achieving a correct classification with a visual classification in the field or image of better resolution (MINAM, 2014).

The final result indicates which areas show changes through a pyramid operation process, and a mosaic of the overlapping map was made, where the areas that showed changes during that period could be observed. This procedure was carried out separately for Bahuaja Sonene National Park and its buffer zone.

RESULTS

The 5 analysis sector of the Bahuaja Sonene National Park are shown (Figure 2).

Figure 2: Sectorization in the PNBS



Source: (Own elaboration). Within the sectorisation, altitude and unique ecosystems were taken as criteria. The image belongs to the mosaic made in 2018.

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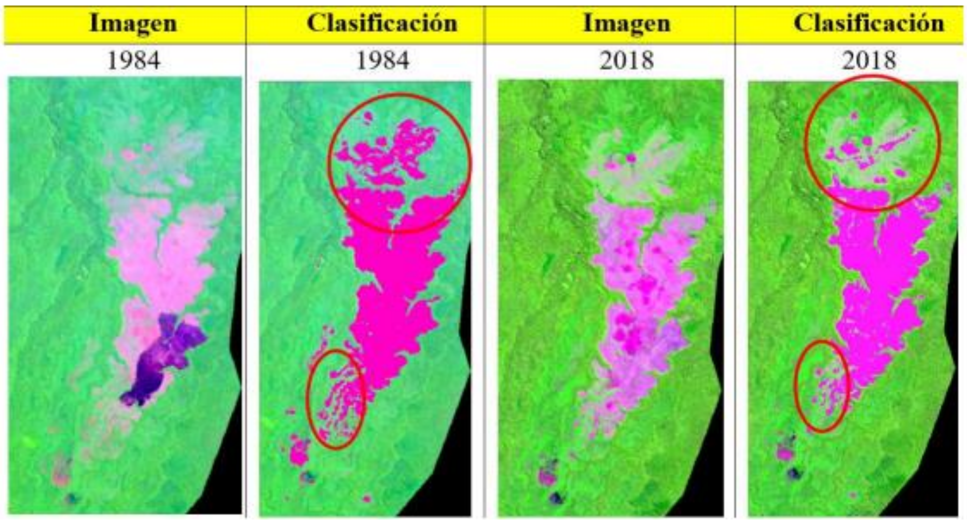
Figure 3 shows the Sabanas Del Beni Classification, the extreme areas show a more significant decrease based on the concept of habitat fragmentation, for the years 1984 and 2018.

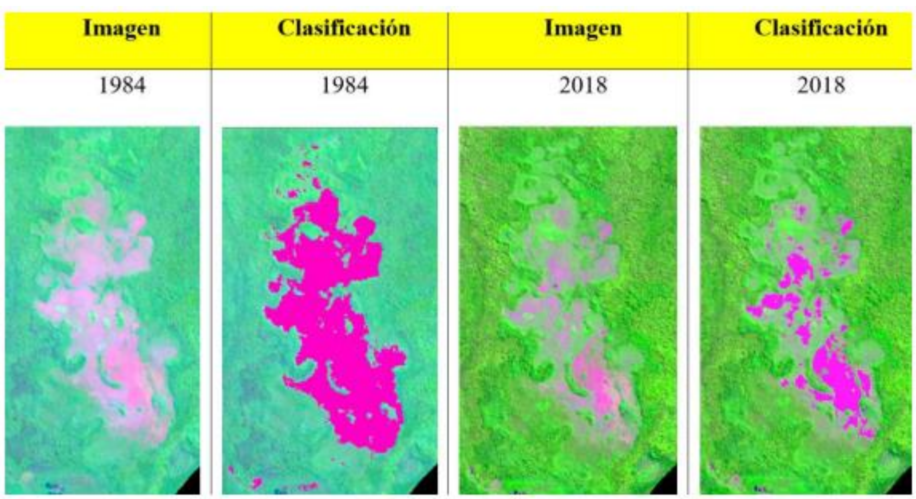
Figure 3: Classification Sabanas del Beni zona SB-A



Source: (Own elaboration) the image and classification of the years 1984 and 2018 for Sabanas Del Beni zona SB-A was established

Figure 4 shows the classification of the savannahs of Beni zone SB-B, this zone presents a more irregular and elongated shape, which contributes to its disappearance as shown in the years 1984 and 2018.

Figure 4: Classification Sabanas Del Beni zona SB-B



*Source: (Own elaboration)**.** The image and classification of the years 1984 and 2018 was established for Sabanas del Beni SB-B zone.*

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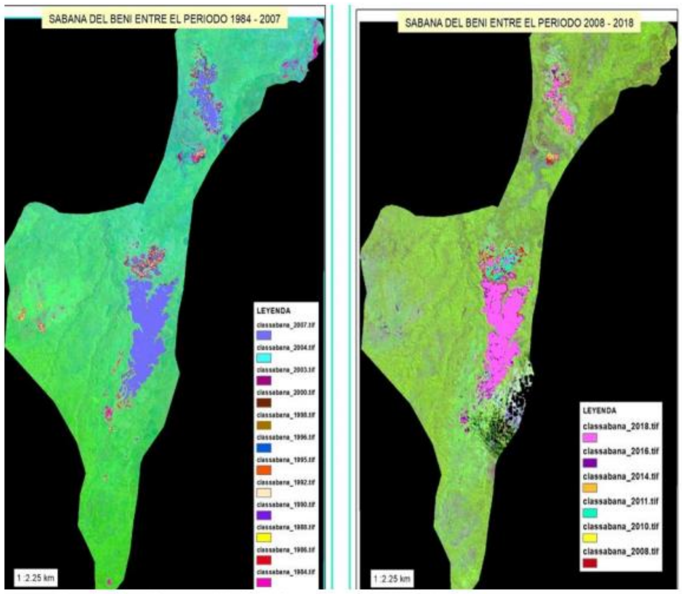
Figure 5 shows the general classification of the Sabanas Del Beni, comparing two time periods, the first between 1984 - 2007 and the second between 2008 - 2018.

Figure 5: Classification Sabanas Del Beni



Source: (Own elaboration)**.**

The results for the Beni Savannah indicate that the 0.6% of area representation that the Beni savannahs had in front of the Bahuaja Sonene National Park in 1984 became 0.4% of representation, which indicates that it lost a large amount of extension of 2,193 ha between the period 1984 - 2018, the Beni savannahs present a negative growth rate of -44 ha/year.

The results of the analysis of the water bodies show a Pearson correlation of 0.328, it is inferred that the relationship is not significant and the linear regression does not adequately adjust to the data; on the other hand, the results of the analysis of the bare soils show a Pearson correlation value of 0.075, which means that the relationship between the two variables is not significant; finally, the results analysed for the forests mean that for every year that passes, an increase of 38,236 ha of forests is expected.

However, as for the northern zone, the results show that the buffer zone had a loss of 4,876 ha. of forest during the period from 1984 to 2018, while in the period from 2011 - 2018 there was an increase in bare soils and water bodies, which are scattered in the area affected by mining activities, on the other hand, the agrarian soils show an aggressive advance since 2016 (Figure 6).

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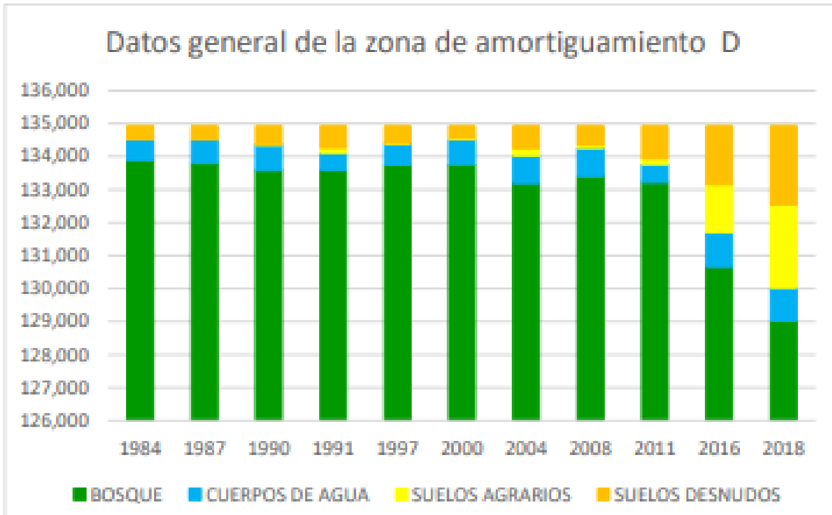
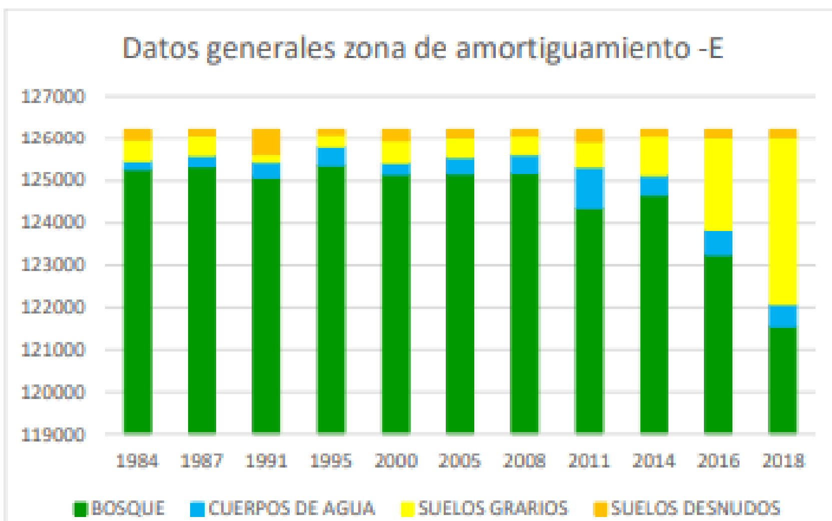
Figure 6. Land cover and land use graph for the northern side of the A.A.



Source: (Own elaboration) Representation of buffer zone D from 1984 to 2018.

Meanwhile, the southern sector of the buffer zone shows changes in land use due to agricultural extension and change of vegetation cover due to landslides that occur in the upper parts of the A.Z. (Figure 7).

Figure 7: Land cover and land use graph of the south side of the A.A.



Source: (Own elaboration) Representation of buffer zone E from 1984 to 2018.

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Given this reality, it can be said that both on the north and south side of the buffer zone there is a continuous growth of agricultural land, with an accelerated increase in agricultural land between 2016 and 2018, resulting in an agricultural land growth rate of 117,478 ha/year.

The PNBS results after summing the 5 bands within the period 1984 - 2018 are shown in table 1.

Table 1: Sum of bands 1984-2018

Description	Area (has.)	%
Area with no changes	1,075,323	98.53
Area showing change due to vegetation succession	3,478	0.32
Area that showed change due to natural origin	12,329	1.13
Area that presented changes due to land use	285	0.02
Total	1,091,416	100.00

Note: Data are based on the mosaic representing the changes made in the PNBS between 1984 – 2018 (Own elaboration).

The spatial distribution of the areas that presented a change in vegetation cover as land use can be observed. It can be seen that the area that presented a change of cover is 1.45 % of its total area, which represents 15,807 ha.

The overlapping of classification images was carried out by sectors using the Band Math tool of the ENVI programme, carrying out 4 consecutive operations in which band 1 - band 2 are subtracted, where the areas that underwent changes during short periods can be observed, subsequently the sum of the areas that presented changes for different causes is carried out, obtaining table 2.

Table 2: Areas with multi-causal changes

Period	Areas of change (has.)		Unchanged areas (has.)
	For agricultural use	By dinamics: forest, bare soil and water bodies	
1984 - 1987	876	1,361	258,891
1991 - 2000	778	2,121	258,228
2008 - 2011	1,061	2,399	257,668
2016 - 2018	7,710	4,765	248,65

Note: Data were extrated from overlapping classification images using ENVI software (own source).

Table 2 also shows that the dynamics of the spatial distribution of agricultural soils increased significantly in the period from 2008 to 2018, and from 2011 onwards, the accelerated change of land use can be observed.

A general mosaic of land cover and land use change for the period 1984 - 2018 was obtained by summing the bands 4 of the short time periods, performing simple band mathematics using the Band Math tool of the ENVI program.

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It was thus determined that the extension of the areas that presented land use changes due to the expansion of agricultural land in the buffer zone of the Bahuaja Sonene National Park between 1984 and 2018 represents 2.95% of its territory. Therefore, the extent of areas with land use changes in the buffer zone of Bahuaja Sonene National Park between 1984-2018 is greater than 1% of its territory (Table 3).

Table 3: Changes in land use

Description	Area (has.)	%
Area with no changes	248,338	95.77
Area showing changes due to agricultural use	7,710	2.95
Area showing changes between land cover: forest, bare soil and wáter bodies	5,079	1.95
Total	**261,127**	**100**

Note: The data is base don the mosaic representing the changes made in the ZA between 1984 – 2018 (own source).

The progress of land use change in the buffer zone of the Bahuaja Sonene National Park between 1984 and 2018 saw an increase of 5,956 ha of agricultural land, with the greatest growth being observed in sectors D1, D2 and E1, which are located at the northern and southern ends of the ZA respectively.

DISCUSSION

Within the PNBS the extension of 5 types of vegetation cover and land use were analysed, identifying the degradation of the ecosystem through the spatial multitemporal analysis of these, in which it was found that the Sabanas del Beni presented a decrease of 2,786 ha between the period 1984-2018, presenting a negative growth rate of -44.10 ha/year. /Year, observing that it has an inversely proportional relationship with forests because this type of coverage presents a process called vegetation succession which means that much of its coverage has been replaced by the convergence of communities towards a state of equilibrium (Clements 1904), due to this much of the extent of savannas of Beni were occupied by forests over the years.

On the other hand (Santos & Telleria 2006) tells us that one of the main factors that produces the reduction in certain areas in the savannahs of Beni is the fragmentation of ecosystems that are determinant in the acceleration, for this reason they have a plant succession that has been occurring in a regressive manner, which for the present investigation the data observed within the spatial distribution, also has two important zones which are SB-1 and SB-B; It also states that "the increase in the edge associated with the geometry of the fragmented landscapes favours the invasion of the fragments by many generalist species typical of the habitat matrices, or of sectors of the habitat itself subjected to some type of natural disturbance".

However, authors such as (Collinge, 1996; Wilcove, McLellan and Dobson, 1986) state that fragmentation is the main threat to biodiversity and that it is understood as the loss

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and isolation of species habitats that occurs through a process in which an entity is divided into small units called patches, tesserae, fragments, islets, etc., which will have characteristics very similar to each other (Forman, 1995) but also their own characteristics, due to their new frequency, size, shape, edge, etc. (Arroyo and Mandujano, 2009; Didham, 1997Rosselló and Lorenzo, 2017; Saunders, Hobbs and Margules, 1991; Wilcove et al., 1986), according to this, the extension of the Beni Savannah is dispersed and have elongated and deformed shapes, so that the zone SB - B, has a negative growth rate of -66 has/year, within the period 1984 - 2018 unlike the zone SB - A which has a negative growth rate of -30 has/year within the period 1984 - 2007, and on the other hand within the period 2008 - 2018 has a negative growth rate of -132 has/year.

So, according to the results of the change in land use in Bahuaja National Park, it began in 2004 and extended from 3 ha to 2018 with an extension of 241 ha, observing a growth rate of 13 ha/year. A growth rate of 13 ha/year was observed, for which the resolution and computing potential related to the size of the research area and the processing capacity of the computer equipment was considered (Hengl 2006), considering that the minimum size of representation can be reduced due to the fact that the Google Earth Engine geomatics platform has a large information processing engine at a global level and 1 pixel is taken as the unit of representation of the satellite image.

It should be noted that one of the problems in the measurement of extensions is the multispectral measurement, due to the fact that in the field of remote sensing a range of wavelengths is used, which are captured by the sensor and can be very dispersed, causing errors in the classification. Furthermore, remote sensors, especially the multispectral scanning radiometers of the LANDSAT series of satellites, provide a very particular perception of the environment and the landscape, characterised by a homogenisation of the image, which is a function of the level of resolution of the sensors or sensors. (Romero, 2006)

The variation in the characteristics of vegetation cover reveals the degradation and impoverishment of soils due to the exploitation of resources. The use of various definitions and tools found; Spatial Remote Sensing, the use of indicators to differentiate the variation of natural resources, its evaluation; employing techniques of using data from satellite images with different spectra and inserting algorithms of vegetation indices where you can discriminate the changes that have occurred in different periods. (Castillo Rojas, 2019).

CONCLUSIONS

According to the National Service of Natural Protected Areas (SERNANP, 2015) the PNBS presents an extension of 1,091,416 ha, but within the results of the present investigation the extension of the area presented changes in coverage between the period 1984-2018 is 15,807 ha. Which represents 1.45% of the total territory of the PNBS, within which 3,478 ha. 3,478 ha. Presented changes in cover due to vegetation

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succession, representing 0.32% and 12,329 ha. Which refers to the changes due to natural dynamics between the covers of forest, water and bare soils, which are found in greater proportion between the Tambopata River and the Heath River, therefore it can be deduced that the covers present a significant relationship with time, which are the forests and the Beni savannahs.

The change in land use in Bahuaja National Park began in 2004, when 3 hectares of agricultural land were identified, reaching an extension of 241 hectares in 2018, being the year with the greatest agricultural extension, and during the periods 1984 -2018 the percentage was 0.02% of the total area of the BSNP, showing a growth rate of 13 hectares/year.

According to SERNANP, the PNBS ZA has 261,127 hectares, so it can be concluded that the extension of the areas with changes in land use due to agricultural extension between 1984 and 2018 is 7,710 hectares, which represents 2.95% of its total area and has a growth rate of 117.47 hectares/year.

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