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Original article

Socioeconomic and environmental analysis of restored forest ecosystems in the Nazas River basin, Mexico

Análisis socioeconómico y ambiental de ecosistemas forestales restaurados en la cuenca del río Nazas, México

Análise socioeconômica e ambiental de ecossistemas florestais restaurados na bacia do rio Nazas, México

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ABSTRACT

The social, economic, and environmental impact of soil restoration and conservation activities implemented in forests of the upper Nazas River basin in Durango, Mexico, was evaluated. To analyze the economic and social aspects, a survey was done or performed to the population over 15 years of age, which included general population information, knowledge about conservation and restoration, social perceptions, and economic perceptions. Through a multi-temporal analysis of satellite images (2009, 2016, and 2023), changes in land use and vegetation were examined, estimating rates of change for the periods 2009–2016, 2016–2023, and 2009–2023. Additionally, the Normalized Difference Vegetation Index (NDVI), the Soil-Adjusted Vegetation Index (SAVI), and the Normalized Difference Moisture Index (NDMI) were calculated. The results indicate that the population possesses knowledge about forest conservation and restoration, and that their participation is focused on project implementation activities. Furthermore, there is a perception of economic benefit derived from the projects. The pine forest registered the largest area in the three years analyzed, while the oak forest showed the highest levels of degradation. Bare soil decreased. Vegetation indices reflected low vegetation cover and water stress. This study contributes to the understanding of the impact of conservation and restoration projects on temperate forest soils in Mexico.

Keywords: temperate forests, conservation, degradation, soil conservation and restoration projects, economic perception, social perception.

RESUMEN

Se evaluó el impacto social, económico y ambiental de las actividades de restauración y conservación de suelos implementadas en bosques de la cuenca alta del río Nazas en Durango, México. Para analizar los aspectos económico y social, se aplicó una encuesta a la población mayor de 15 años, que incluyó información general de la población, conocimientos sobre conservación y restauración, percepción social y percepción económica. Mediante un análisis multitemporal de imágenes satelitales (2009, 2016 y 2023), se examinaron los cambios en el uso de suelo y vegetación, estimando tasas de cambio para los periodos 2009-2016, 2016-2023 y 2009-2023. Adicionalmente, se

calcularon el índice de vegetación de diferencia normalizada (*NDVI*), el índice de vegetación ajustado al suelo (*SAVI*) y el índice de diferencia normalizada de humedad (*NDMI*). Los resultados indican que la población posee conocimientos sobre conservación y restauración de bosques, y que su participación se enfoca en las actividades de implementación de los proyectos; asimismo, existe una percepción de beneficio económico derivado de los proyectos. El bosque de pino registró la mayor superficie en los tres años analizados, mientras que el bosque de encino presentó los mayores niveles de degradación. El suelo desnudo disminuyó. Los índices de vegetación reflejaron baja cobertura vegetal y estrés hídrico. El presente estudio contribuye al entendimiento del impacto de obras de conservación y restauración en suelos de bosques templados de México.

Palabras clave: bosques templados, conservación, degradación, obras de conservación y restauración de suelo, percepción económica, percepción social.

RESUMO

O impacto social, econômico e ambiental das atividades de restauração e conservação do solo implementadas nas florestas da bacia hidrográfica do alto rio Nazas, em Durango, México, foi avaliado. Para analisar os aspectos econômicos e sociais, foi aplicado um questionário à população com mais de 15 anos de idade, que incluiu informações gerais sobre a população, conhecimento sobre conservação e restauração, percepções sociais e percepções econômicas. Por meio de uma análise multitemporal de imagens de satélite (2009, 2016 e 2023), foram examinadas as mudanças no uso da terra e na vegetação, estimando-se as taxas de mudança para os períodos de 2009–2016, 2016–2023 e 2009–2023. Adicionalmente, foram calculados o Índice de Vegetação por Diferença Normalizada (NDVI), o Índice de Vegetação Ajustado ao Solo (SAVI) e o Índice de Umidade por Diferença Normalizada (NDMI). Os resultados indicam que a população possui conhecimento sobre conservação e restauração florestal e que sua participação está voltada para as atividades de implementação dos projetos. Além disso, há uma percepção de benefício econômico derivado dos projetos. A floresta de pinheiros registrou a maior área nos três anos analisados, enquanto a floresta de carvalhos apresentou os maiores níveis de degradação. A área de solo exposto diminuiu. Os

índices de vegetação refletiram baixa cobertura vegetal e estresse hídrico. Este estudo contribui para a compreensão do impacto de projetos de conservação e restauração em solos de florestas temperadas no México.

Palavras-chave: florestas temperadas, conservação, degradação, projetos de conservação e restauração do solo, percepção econômica, percepção social.

INTRODUCTION

The decline in forest cover is linked to soil loss and degradation, and a decrease in ecosystem services. The level of soil degradation is associated with disturbance and environmental factors; for example, soil type, topography, climate, deforestation, overgrazing, population density, vegetation type, and the state of the vegetation cover (Montero-Torres 2023). Currently, one of the most serious problems worldwide is soil erosion, caused by the movement of particles, resulting in the progressive loss of soil and nutrients (Castelán-Vega *et al.*, 2019). This degradation contributes to deforestation, leading to desertification processes and disruption of hydrological cycles, resulting in a decrease in the productive capacity of ecosystems worldwide (Meaza-Rodríguez and Laguna-Lumbreras 2022).

In Mexico's river basins, the loss and transformation of original land cover are persistent problems that affect the hydrological cycle, promote deforestation, and increase the incidence of forest fires. These changes lead to a significant replacement of vegetation cover. The combination of anthropogenic and natural factors intensifies these negative impacts, threatening biodiversity and the sustainability of communities (Gándara *et al.*, 2021). In Durango, Mexico, lies the Nazas River basin, an endorheic basin in the north of the country that originates in the Sierra Madre Occidental, an important biological corridor for boreal species and one of the regions with the greatest coverage of temperate forests. This basin provides multiple environmental services essential for human well-being. In particular, its upper reaches contribute 89% of the total water volume that supplies the Comarca Lagunera region, meeting the water needs of the metropolitan area of Torreón, Mexico (Revenga and Nilsson 2000).

Historically, forestry, mining, and agricultural activities have been carried out in the upper part of the basin, generating significant environmental impacts on the ecosystem (Cabral-Alemán *et al.,* 2021). To mitigate environmental degradation, various soil and water conservation and restoration programs have been implemented on agricultural, livestock, and forest lands, promoted by the National Forestry Commission through the Payment for Hydrological Environmental Services Program (PSAH) and the La Laguna Metropolitan Fund (Peláez-Mora *et al.* , 2022). In this context, the objective of this study was to evaluate, from a socioeconomic and environmental perspective, the soil conservation and restoration projects carried out in the temperate forests of the Upper Nazas River Basin, Durango, Mexico.

MATERIALS AND METHODS

Study area

The study was conducted in the area known as Mi Patria es Primero (My Homeland Comes First), which covers 5,696.46 hectares, comprised of the ejido (communal land) of the same name (4,877.74 hectares) and the private property Laguna (818.72 hectares). It is located in the southwest of the state of Durango, in the Sierra Madre Occidental mountain range, in northwestern Mexico. Its location within the Nazas River basin is strategic, as the Santiago River originates there, later joining the Sextín River to form the Nazas River downstream.

Mi Patria es Primero is located between 24° 05' 45" north latitude and 105° 08' 26" west longitude (Figure 1), with an average elevation of 2,500 m above sea level. The predominant soil types in the area are Cambisol, Lithosol, and Regosol, while the predominant rock is of acidic extrusive igneous origin. The climate is temperate-cold, with an average annual rainfall of 1,200 mm and an average annual temperature of 18 °C (INEGI 2009). The vegetation consists mainly of natural pine and pine-oak forest formations.

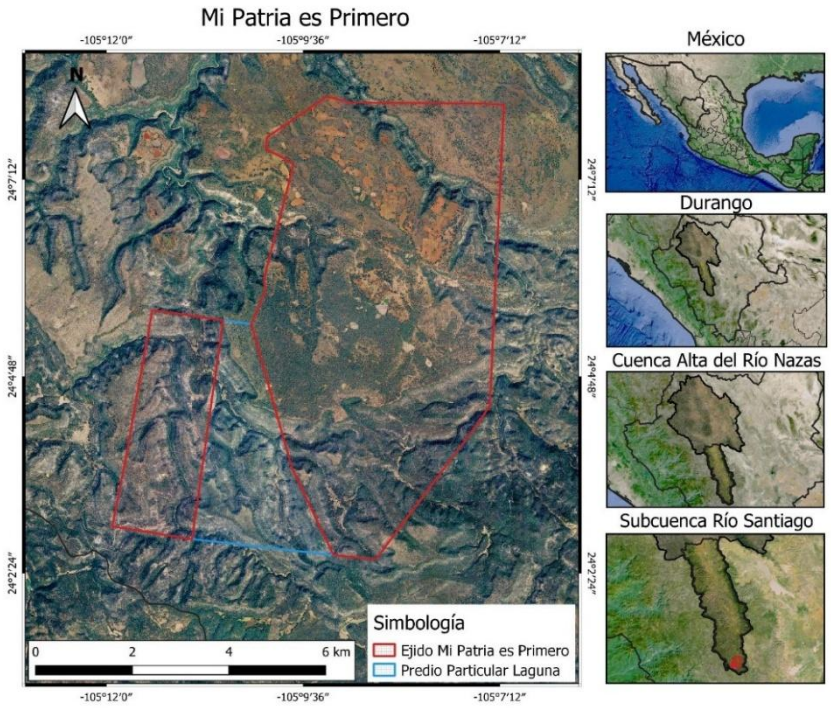


Figure 1.- *Location of the study area*

The current population in the communities of the study area is 51 inhabitants, of whom 30 are men and 21 are women. The main economic activities in the area include agriculture, livestock farming, and forestry (INEGI 2020). There are records of soil conservation and restoration work in the area. Although exact data on the surface areas and quantities of work carried out are not available, documentary evidence indicates that the main conservation and restoration works included stone barriers along contour lines, filter dams, reforestation, forest fire prevention activities, and the creation of barriers around dead vegetation (Peláez-Mora *et al.*, 2022).

Socioeconomic analysis

The social and economic analysis was descriptive with a mixed-methods approach, as the variables studied included both quantitative and qualitative data. Fieldwork was conducted using a structured interview based on a mixed-methods questionnaire, that is, closed-ended questions to obtain quantitative information and open-ended questions to assess qualitative aspects. The target population consisted of residents over 15 years of age living in the study area. Since the entire population was accessible, 30 people were

surveyed (17 ejido members and 13 residents), thus obtaining data without the need for a sampling process.

Initially, a preliminary survey was conducted through visits to the study area to establish contact with key informants, such as local authorities and individuals involved in soil conservation and restoration efforts. This process facilitated the collection of primary data and allowed for a pilot test with five interviews, enabling adjustments to questions as needed and identification of the interviewees' profiles. The final mixed-methods questionnaire was structured in four sections: general information about the interviewees, knowledge of soil conservation and restoration, social aspects, and economic aspects. The collected data was coded and systematized for analysis using descriptive statistics in SPSS. For the execution of the fieldwork, authorization was obtained from community representatives (the president of the ejido council and the local community leader), as well as the prior and informed consent of each interviewee.

Environmental analysis

This analysis was developed using Google Earth Engine. (GEE 2024) . Three satellite images of the study area were used, corresponding to the years 2009, 2016 and 2023, belonging to the dry season and with cloud cover of less than 5% (Table 1). The images were obtained from the website of the United States Geological Survey (USGS 2024).

Table 1.- *Landsat satellite images from the years 2009, 2016 and 2023*

Image identifier	Date	Satellite
LT5_L1T/LT50310432009068EDC00	09/03/2009	LANDSAT 5
LC8_L1T/LC80310432016072LGN00	12/03/2016	LANDSAT 8
LANDSAT/LC08/ CO2 /T1_L2/LC08_031043_20230417	17/04/2023	LANDSAT 8

Each image underwent atmospheric correction and was cropped using the polygon of the study area as a reference. Subsequently, supervised classification was performed using the Random Forest (RF) algorithm, selecting representative pixels as training samples for each of the ten predefined land use and vegetation classes: agriculture, human settlements, oak forest, oak-pine forest, pine forest, pine-oak forest, scrubland, grassland, water bodies, and bare soil. The RF algorithm, based on machine learning, combines the results of multiple decision trees to arrive at a single result and improve

classification accuracy (Breiman 2001). The number and size of the training samples were determined based on the availability of pixels for each class.

The accuracy of the classification was assessed using the overall accuracy index and Kappa (Cohen 1960). Values close to one in the overall accuracy index indicate greater classification accuracy. For the Kappa index, which measures the agreement between the classification and the terrain, accuracy is classified into three levels: strong (0.80–1.0), moderate (0.40–0.80), and poor (0.0–0.40).

δ_n), expressed as a percentage of coverage, was determined for each coverage class in the periods 2009-2016, 2016-2023 and 2009-2023, for which Equation 1, modified by (Palacio-Prieto *et al.*, 2004), was used.

$$\delta_n = \left(\left[\frac{S_2}{S_1} \right]^{\frac{1}{n}} - 1 \right) * 100 (1)$$

Where: *S1* is the surface area on date 1, *S2* is the surface area on date 2 and n is the number of years between the two dates.

Three vegetation indices were calculated To analyze the spectral properties of vegetation and the functional dynamics of ecosystems (Bora and Bora 2023): the normalized difference vegetation index (*NDVI*), the soil-adjusted vegetation index (*SAVI*), and the normalized difference moisture index (*NDMI*). The *NDVI* has values ranging from -1 to 1, where values close to 1 indicate high photosynthetic activity, while negative values reflect low photosynthetic activity and little or no vegetation cover (Equation 2).

$$NDVI = \frac{NIR - R}{NIR + R} (2)$$

Where: *NIR* is the near infrared spectrum and *R* is the red spectrum.

SAVI is interpreted similarly to *NDVI,* but It incorporates a correction factor "L" to minimize the influence of soil brightness. This factor generally takes a value of 0.5, which is the soil brightness component and allows the index to be adjusted for different types of vegetation cover (Equation 3).

$$SAVI = \frac{NIR - R}{(NIR + R + L)(L + 1)} (3)$$

Where *L* is the adjustment factor, *NIR* is the near infrared and *R* is the red spectrum.

The *NDMI* ranges from -1 to 1 and complements the *NDVI*, as it is primarily related to the moisture present in plant tissues. Higher values indicate greater water availability in the vegetation, while lower values reflect water stress or reduced moisture in the vegetation cover (Equation 4).

$$NDMI = \frac{NIR-SWIR\ 1}{NIR+SWIR\ 1} (4)$$

Where *NIR* is the near infrared spectrum and *SWIR* 1 is the far infrared.

RESULTS AND DISCUSSION

Population overview

Of the surveyed population, 65% were male and 35% female, with an average age of 50 years (±14.4 standard deviation). The age distribution was as follows: 5% between 18 and 30 years, 24% between 31 and 50 years, 62% between 51 and 70 years, and 10% over 71 years. In terms of education, 43% of respondents had completed primary school, 26% secondary school, 13% high school, 9% a bachelor's degree, and another 9% had no formal education. The low level of education recorded reflects the scarcity of educational institutions in the region, limited to preschool and primary levels, and is similar to that reported in other rural areas of Mexico (INEGI 2020).

Regarding economic activities, 52% of the population is engaged in agriculture, 10% in livestock farming, 19% in forestry, and another 19% in housework. Although each person reported one of these activities as their primary occupation, many diversify their work. For example, because agriculture is rain-fed, farmers often supplement their income by raising livestock, although on a smaller scale than ranchers, who also engage in agricultural activities. This diversification reflects the capacity of the inhabitants in the study area, who, as in much of rural Mexico, seek to innovate and combine different economic activities to meet their basic needs (Román-Montes de Oca *et al.*, 2020). Despite

these community efforts, access to basic services in homes remains limited, particularly electricity, drinking water, and drainage.

Knowledge about conservation

The forests of the upper Nazas River basin have been historically overexploited, according to documentary records and local testimonies. As a result, the population has identified various processes of soil degradation: 48% of respondents associate soil degradation with the loss of vegetation cover, 42% with erosion, and 10% are unaware of the issue. Respondents attribute this phenomenon primarily to anthropogenic activities such as livestock farming, agriculture, logging, and pollution. These findings are consistent with those reported by Delgado *et al.* (2024), who indicate that the loss of soil quality and fertility is due to multiple factors, including erosion, pollution, nutrient depletion, and compaction.

All respondents recognized the importance of the forest, primarily for the resources it provides, such as water and timber, which are the most valued. Although they acknowledged the importance of conservation and restoration, their understanding of these concepts focused on specific actions for the recovery of forest soils. Forty-eight percent of the population associated soil conservation and restoration with the implementation of retention structures, such as levees and seepage dams; 24% linked it to preventing overexploitation of the forest; and 19% to the establishment of forest plantations (Figure 2). Furthermore, all agreed that these actions generate key benefits, such as soil improvement, increased vegetation, the availability of clean water, increased vegetation cover, job creation, and the recovery of wildlife. These results reflect a widespread understanding of the relevance of these soil conservation and restoration projects and their contribution to the improvement of the forest ecosystem (Chavarría-Aráuz. *et al*., 2020).

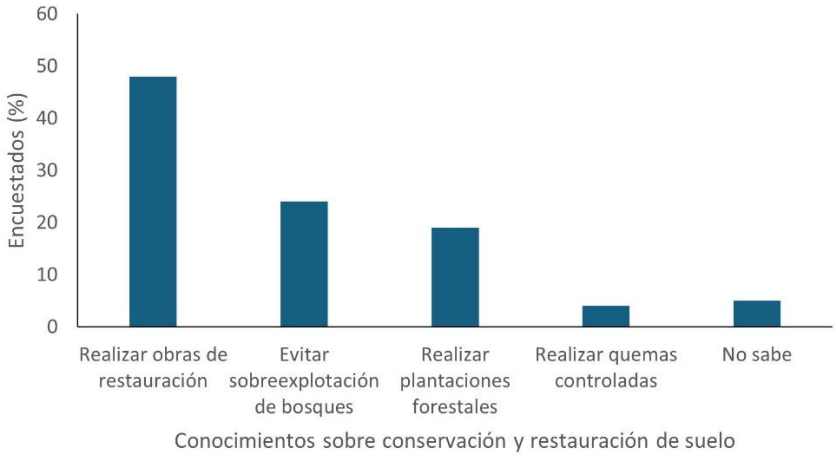


Figure 2.- *Knowledge of the population of Mi Patria es Primero about soil conservation and restoration*

Social perception

For the entire population, the objectives of conservation and restoration efforts in the watershed are to retain soil, maintain moisture and water production, contribute to increased vegetation cover (trees, shrubs, and herbaceous plants), and improve the environment and the community's quality of life. All respondents have participated in conservation and restoration activities at some point; all have carried out reforestation, but only 52% have dedicated themselves exclusively to this activity, as 33% have also participated in sheet erosion control activities and 14% in gully erosion control. This is not surprising, since in this region, conservation and restoration projects are often combined with reforestation (CONAFOR 2023).

The implementation of any soil conservation and restoration project involves various activities encompassing the planning, implementation, monitoring, and evaluation stages. Ninety-five percent of the population reported that their participation is limited to the implementation phase, while 5% have also been involved in planning and monitoring, particularly those who are part of the ejido council. This situation aligns with the findings of Ortega-López and Soares de Moraes (2022), who found that the rural population generally only participates in project implementation (labor) when analyzing social perceptions of participation in forest conservation activities in Michoacán, Mexico. Active community participation in all phases of conservation and restoration projects is

crucial, as it fosters a deeper understanding of the local context, promotes shared governance among stakeholders from different disciplines, such as the state and civil society, and generates a sense of ownership of the project, thus ensuring its continuity.

The most noticeable changes observed by the population after the implementation of conservation and restoration works include an increase in grass (45%) and shrubs (24%), although some also reported a decrease in grass cover (16%) (Figure 3). Furthermore, it is known that the oldest restoration or conservation project has been in place for over 30 years.

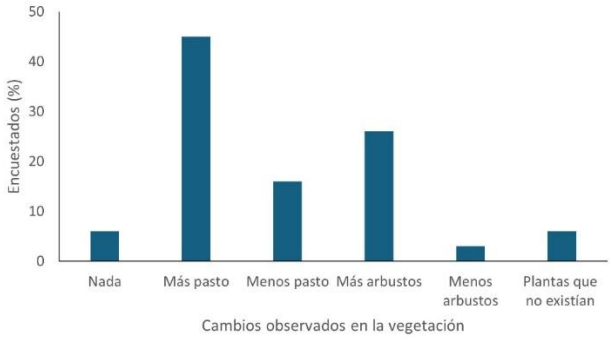


Figure 3.- *Perception of the population of Mi Patria es Primero on the observable changes in vegetation due to the soil conservation and restoration works*

Sixty-three percent of respondents indicated that the results of the projects were as expected, as an increase in vegetation cover, primarily grasslands, had been anticipated, which has improved soil retention. In contrast, 37% felt that the results were not as expected, as they had anticipated an increase in forested area. Regarding the perception of whether the project objectives had been met, 58% indicated that they had been achieved, highlighting the visible benefits, particularly in soil retention. However, they stressed the need to monitor the implemented projects. On the other hand, 42% felt that the objectives had not been met, as there are still areas with high sheet erosion and even gullies. Regarding project monitoring, 65% indicated that no monitoring is carried out, while 35% asserted that monitoring is indeed taking place and that the National Forestry Commission (CONAFOR) actively participates in this process (Figure 4).

All respondents agreed that the areas where gully headbreaking with stone, ditch embankments, filter dams, and reforestation have been carried out are the areas with the greatest change, as a greater amount of soil has been retained. However, the positive social perception regarding environmental recovery could be supported by measurements of runoff and sediment at the sub-basin outlet, which would allow verification of the decrease in sediment transport after the construction of the soil conservation works (Chanca-Flores *et al.*, 2020).

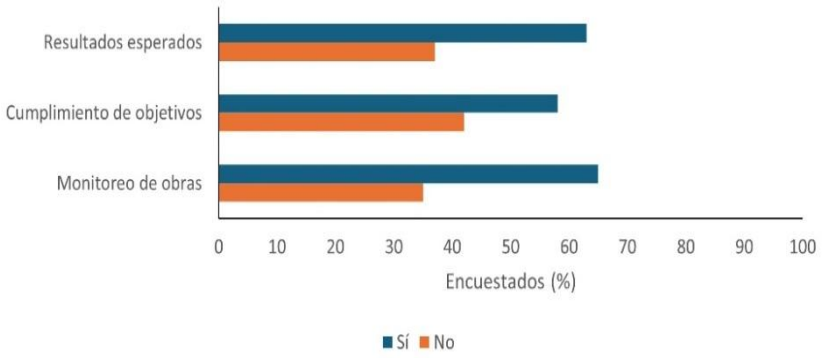


Figure 4. *- Perception of the population of Mi Patria es Primero regarding the expected results of soil conservation and restoration works*

Economic perception

The entire population agreed that conservation and reforestation programs help reduce labor migration, as they encourage residents to remain in the community and even attract new workers, which has significantly improved the local economy. However, this benefit is only temporary, preventing migration during the programs' implementation period, but causing it to resume once they conclude. Consequently, the region has experienced a population decline in recent years (INEGI 2020).

For 81% of those surveyed, their way of life and lifestyle have changed, mainly because they now engage in new activities. Many have moved to rural areas to work on various construction projects, and some indicated that these changes have improved their quality of life. In particular, the increase in their income has allowed them to improve their diet. However, they also pointed out that the jobs created are temporary, meaning that the improvements in their lifestyle are also likely to be transient.

Forest restoration efforts not only generate jobs and strengthen the local economy but also promote the recovery of the ecosystem and its environmental services. Furthermore, they contribute to a shift in perspective regarding the importance of forest cover and its impact on social well-being (CONAFOR 2023). For 90% of the population, the jobs resulting from these efforts have increased their income, albeit temporarily. However, they noted that promoting pasture cover has benefited livestock development, while increasing tree cover could boost forest productivity in the future.

In general, the entire population expects that the continuation of these projects will generate new jobs and greater economic benefits for the region. In particular, ranchers believe that increased pasture cover would improve livestock feed. Meanwhile, ejido members engaged in forestry expect an increase in tree cover, an objective that, according to 63% of those surveyed, has already been achieved to some extent. However, while they acknowledge the job creation, they emphasize that it has only been temporary and that they would like a project monitoring program in which they are involved at all stages (Figure 5).

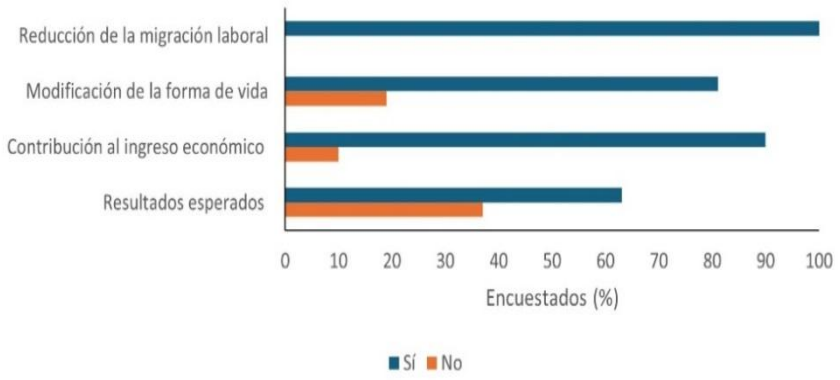


Figure 5.- *Perception of the population of Mi Patria es Primero on the economic impact of conservation and restoration works on the population*

Environmental analysis

The classification of land use and vegetation in the study area is presented in Figure 6; each color corresponds to a land use and vegetation type.

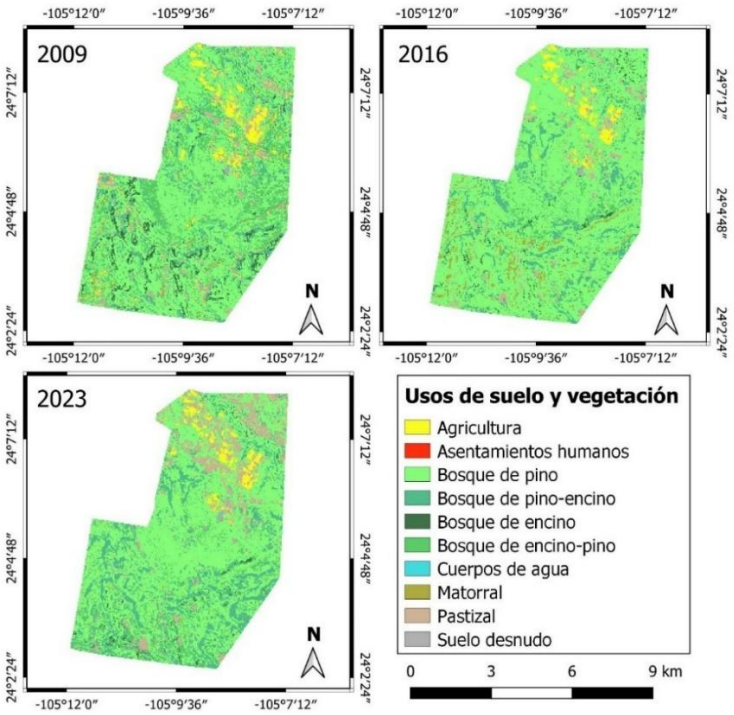


Figure 6. *- Land use and vegetation in Mi Patria es Primero for the years 2009, 2016 and 2023*

The overall accuracy of the supervised classification in each of the images (2009, 2016, and 2023) was greater than 0.8064, a value comparable to those reported in other classifications. For example, Ma *et al.* (2017) obtained values close to 0.8 when analyzing vegetation composition after the establishment of a protected natural area in northwestern Mexico. Furthermore, the Kappa index was greater than 0.7460 (Table 2), indicating acceptable classification, as values between 0.4 and 0.8 are considered moderate. Consequently, the generated maps accurately reflect the actual condition of the analyzed surface (Dennis-Pacheco *et al.*, 2023).

Table 2.- *Accuracy values in surface classification in Mi Patria es Primero*

Year	Overall accuracy index	Kappa Index
2009	0.8064	0.7460
2016	0.8441	0.7981
2023	0.8447	0.7968

Overall, forests (oak forest, oak-pine forest, pine forest, and pine-oak forest) represented the largest area in the three years analyzed. In 2009 and 2016, they covered more than 88% of the total area, while in 2023 their coverage decreased to 86%. Individually, pine forest had the greatest coverage, with 58% of the study area in 2009, increasing to 74%

in 2016 and decreasing to 60% in 2023. Pine-oak forest also occupied a significant area, increasing from 12% in 2009 to 11% in 2016 and 18% in 2023. In contrast, oak forest showed a progressive reduction, decreasing from 5% in 2009 to 1% in 2023 (Figure 7). It is worth noting that in the state of Durango, the main tree species harvested belong to the genus *Pinus*, while oak is less commonly used. This is relevant because, despite the economic and ecological importance of oak forests (Hernández-Ramos *et al.*, 2022), they are the ones that have shown the greatest degradation, which can be attributed to the fact that forest management and reforestation efforts have primarily favored pine species. On the other hand, non-forested areas showed variations in their extent. Pastureland remained at 4% in 2009 and 2016 but increased to 9% in 2023. The area under agriculture decreased, from 4% in 2009 to 3% in 2016 and 2023. In 2009, bare soil represented 2%, but its area was reduced to less than 1% in 2016 and 2023 (Figure 7).

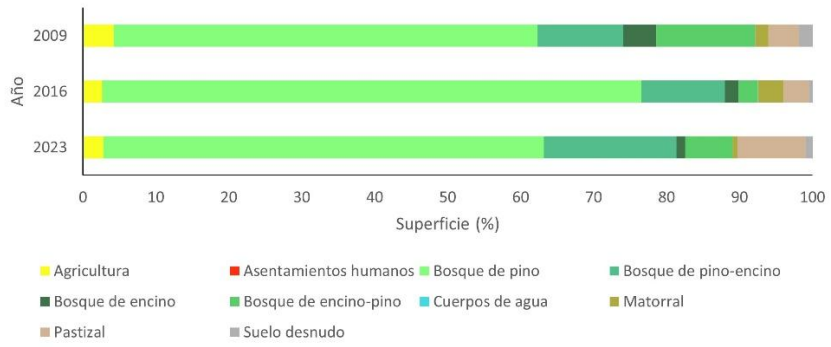


Figure 7.- *Surface area (%) of land use and vegetation of Mi Patria es Primero for the years 2009, 2016 and 2023*

Regarding the rate of land use and vegetation change, during the period 2009–2016, pine forest and scrubland registered positive values, with annual rates of change of 4% and 10%, respectively. In contrast, the other land use and vegetation classes showed negative rates during the same period. For example, agriculture showed an annual rate of change of -7%, oak forest -12%, oak-pine forest -21%, and bare soil -18% (Figure 8A).

During the period 2016-2023, the pine forest registered a negative annual rate of change of -3%, as did the scrubland, whose rate of change was -21%. The oak forest maintained negative values in its rate of change at -6%. However, some classes that previously

presented negative rates of change turned to positive values, such as the pine-oak forest with 7%, the oak-pine forest with 14%, and the grassland with 15% (Figure 8B).

Analyzing the entire period (2009–2023), six land cover classes showed negative annual rates of change. Agriculture and bare soil decreased by 3% and 5%, respectively. Similarly, some forested areas also showed reductions, such as oak forest (-9%) and oak-pine forest (-5%). On the other hand, pine forest and pine-oak forest showed positive rates of change of 1% and 3%, respectively (Figure 8C). These results suggest that vegetation cover has been slowly recovering. Some authors point out that soil recovery can be a slow process in restored areas; however, the accumulation of organic matter gradually promotes plant regeneration (Bonfil *et al.*, 2022).

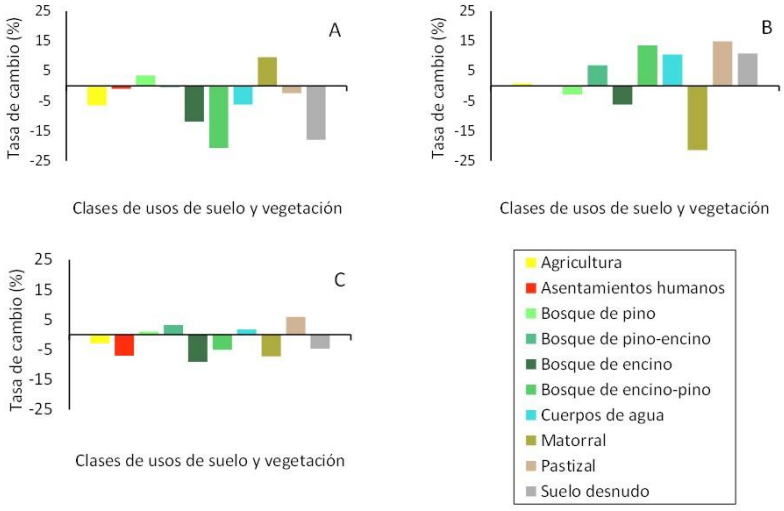


Figure 8.- *Annual rate of change of land use and vegetation classes of Mi Patria es Primero for the periods 2009-2016 (A), 2016-2023 (B) and 2009-2023 (C)*

The average values of the Normalized Difference Vegetation Index (NDVI) and the Soil-Adjusted Vegetation Index (*SAVI*) were positive, although below 0.4 in the three years analyzed (Figure 9). This suggests the presence of vegetation areas, but with low density, which, according to Ruan *et al.* (2022), may be associated with low photosynthetic activity or disturbed conditions. On the other hand, the Normalized Difference Moisture Index (*NDMI*) registered negative average values, with a higher frequency in the range of -0.2 to -0.1 (Figure 9), indicating a high level of water stress and medium to low canopy cover (Bora and Bora 2023). Therefore, although some soil and vegetation classes showed

recovery, water stress remains a limiting factor. Although the analysis was conducted using images from the dry season, the low vegetation index values can be partly attributed to the incidence of moderate to severe droughts recorded in the region in recent years (CONAGUA 2024). Furthermore, the survival of plants used in soil conservation and restoration efforts may be affected by these adverse climatic conditions, as well as by the poor quality of the plants.

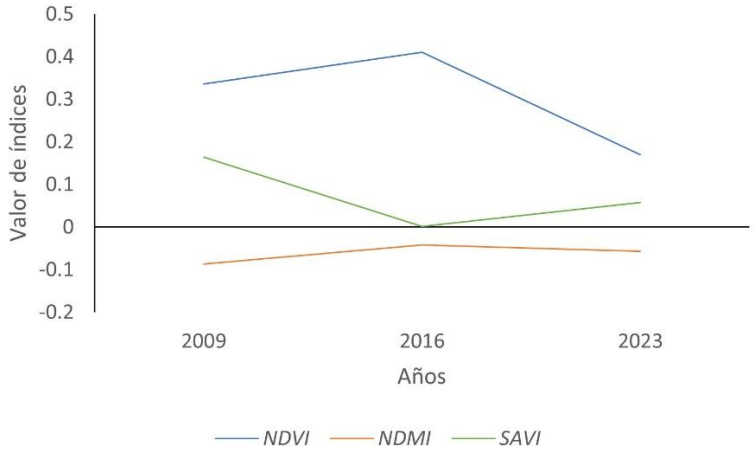


Figure 9.- *Values of the NDVI, SAVI and NDMI indices of Mi Patria es Primero for the years 2009, 2016 and 2023*

CONCLUSIONS

The inhabitants of the study area recognize the importance of conservation and restoration projects in forest ecosystems. Although community participation in these projects has been active, it has been primarily limited to implementation activities, without involvement in the planning, monitoring, and evaluation stages. This limitation reduces the social impact of the projects, as people participate only as laborers, hindering the strengthening of social capital. From the community's perspective, the projects have increased pasture cover, and it is perceived that their objectives have been met. Furthermore, their implementation has generated employment and promoted economic income, which has temporarily contributed to reducing labor migration. Regarding the multi-temporal analysis, pine forests were the most extensive in the three years evaluated, with an increasing trend reflected in positive annual rates of change. This

increase can be attributed to conservation, restoration, and reforestation projects carried out mainly with pine species. On the other hand, oak forests have been the most degraded, as they receive less attention in reforestation efforts. The reduction in bare soil area indicates a recovery of vegetation cover; however, the average values of the spectral indices show the persistence of water stress in the vegetation, which could limit the long-term success of soil conservation and restoration works.

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***Conflicts of interest*:**

The authors declare no conflicts of interest.

Authors' contribution:

The authors have participated in the writing of the work and analysis of the documents.

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