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ORIGINAL RESEARCH ARTICLE

Deterioration and conservation of the Nevado de Toluca forests and the role of local stakeholders

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ABSTRACT

The Nevado de Toluca Flora and Fauna Protection Area presents a constant fragmentation of its forests. The objective of the research was to identify the processes of forest deterioration and the role of local stakeholders in its conservation. Geographic information systems were used as a basis for the generation of thematic maps, in addition to the application of a flow diagram that defines the problems of the forest and another that describes and analyzes them for the search of solutions. The results show that the main factors affecting deterioration are forest fires, immoderate logging, pests and diseases. Finally, strategies and scenarios for forest management are proposed based on the articulation of local stakeholders.

Keywords: Nevado de Toluca, Forest Deterioration, Local Stakeholders, Conservation Strategies

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1. Introduction

The Nevado de Toluca Flora and Fauna Protection Area (APFFNT) is an important natural protected area in the State of Mexico and has suffered a considerable decrease in tree density (pine forests account for 40%), attributed to the extraction of forest resources for commercial purposes[1], affecting *Pinus hartwegii* populations[2].

The highland pine *(Pinus h*artwegii) is so named because it is the only pine in Mexico that lives at the limits of the arboreal vegetation and grows up to 4,200 meters above sea level[3]. It is a fire-adapted species and it is estimated that the average occurrence of natural fires in these forests is every five years[4], which are caused by lightning and volcanic activity. However, induced fires (of human origin) outnumber natural fires[5].

The decrease in forest cover, grazing and forest fires in pine forests[1] and excessive logging in the fir forest[6] provide necessary information for the analysis and the relationship with the role of local actors in the conservation or deterioration of these resources.

The forest ecosystems of the Nevado de Toluca are constantly subjected to anthropic pressure that affects their surfaces and reduces their densities, which is why it is imperative to involve local stakeholders (ejidatarios, community members, government authorities, etc.) in the design of conservation practices and direct participation in the sustainable management of their forest resources. Therefore, we intend to identify the deterioration processes of the Nevado de Toluca forests based on the analysis of satellite images, interpretation of thematic maps (considering its 54,000 hectare as the object of study) and the role

of local stakeholders that influence the conservation or deterioration of its forest resources.

Local stakeholders are the people living in the study site and their natural resource extraction practices are regulated through laws such as the General Law of Ecological Equilibrium and Environmental Protection, the General Law of Sustainable Forestry Development and the Presidential Decree of October 1, 2013. This legal framework, among other legal provisions, regulates whether or not local stakeholders can harvest timber resources in the context of the Nevado de Toluca Flora and Fauna Protected Natural Area.

Therefore, in the territorial context in which the ANPFFNT is located, the following is fundamental: (1) the actions of the local inhabitants are considered to be a negative anthropic factor, in case there is no sustainability scheme (extraction-restitution) and their activities can encourage disturbance in terms of excessive logging and deterioration of the forests due to damage to the wood by the use of saws and axes, which serves as a vehicle of entry of pathogens; (2) local stakeholders are a decisive factor in the conservation and sustainable management of the territory, and their participation will determine to a great extent the future of the conservation of the Nevado de Toluca forests.

The structure of this article presents a first part based on the geographic evidence of the deterioration of the forest ecosystems of the ANPFFNT. Then a diagram (problem tree) and a diagram of solutions are presented as tools for analyzing the current situation of forest deterioration. The third part proposes the establishment of general lines of action or management and conservation strategies, with the voluntary and responsible participation of local stakeholders convinced by their knowledge of the problem and their desire to get involved in the maintenance of the forest resource and the environmental balance of the study area. Finally, the article proposes desirable scenarios for the forest and a prospective approach for the sustainability of the Nevado de Toluca Flora and Fauna Protected Natural Area.

2. Current status of the forest and problems

A temporal analysis of the ANPFFNT forest maps shows a reduction in pine forest cover densities (**Figure 1**); this implies the extraction of adult trees with the best phenotypic characteristics, resulting in a residual ecosystem with diseased or decrepit trees, which are now the seed support for future forest stands. The above implies the loss of just over 40% of dense pine forests[1], which has led to an increase in areas infested by pests and parasitic plants; the latter has come to parasitize up to 60% of pine trees in fragmented or open forests[7,8].

Considering the four main forest species of the APFFNT, pine (*Pinus hartwegii*), fir (*Abies religiosa*), oak (*Quercus laurina*) and aile (*Alnus jorullensis*), the disturbance dynamics in the pine forest is given by the occurrence of induced fires to favor the germination of forage as food for sheep and cattle[1,6,7].

Logging in the forests of fir (*Abies religiosa*) and oak (*Quercus laurina*), as well as induced fires in pine, may cause a long-term cut in future generations, scilicet, areas dominated by adult and senile individuals, on the contrary, other areas where only juvenile individuals prevail, making the forest a fragile ecosystem to attacks by pests (exfoliating insect), diseases (mainly fungi) and parasitic plants (*Arceuthobium globosum*, *A. vaginatum*). On the contrary, aile forests seem to increase due to the constant fragmentation of pine and oak forests and the abandonment of farmland, since a large part is a product of the natural succession of ecosystems and, being a pioneer and nitrogen-fixing species, it helps to restore the original vegetation through the gradual regeneration of these forests. Therefore, its knowledge is important as a functional part of the activities planned for the rehabilitation of degraded ecological communities (ecosystems)[7].

Continuous extraction becomes an important factor in the reduction of the forest mass of Nevado de Toluca, mainly in activities for self-consumption such as firewood, although this does not represent a threat to the conservation of the forest; however, it does when it is commercialized, since large vol-

umes are extracted for massive exploitation. The extraction of timber for the market does not follow a controlled management system, which has been corroborated in the field when stumps of different diameters are found in the same area and under no criteria of directed cuts. In other words, without any sustainable forest management measures[9].

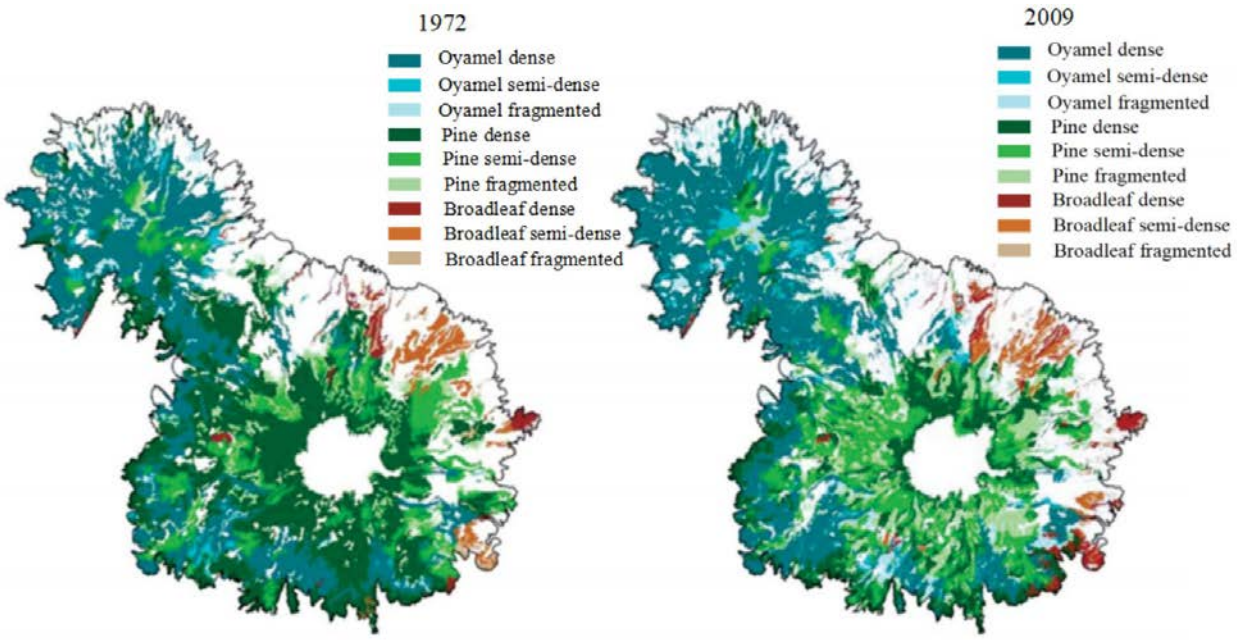

Figure 1. Comparison of land use in 1972 and 2009.
Source: Regil García, 2013.

The current phytosanitary status is a reflection of immoderate harvesting in past years, as well as strong pressure from agricultural activities, especially in the pine forest. In addition, the biology of the mountain pine bark stripper (Dentroctonus adjunctus) seems to have undergone important changes, such as the apparent overlapping of its generations, due to the fact that nowadays buds are observed throughout the year, in addition to finding the insect in the same tree in all its stages of development[8]. In relation to the incidence of parasitic plants, such as dwarf mistletoes (Arceuthobium globosum and A. vaginatum), they undoubtedly cause greater damage in the APFFNT, because they reach 60% of affectation in the pine forest (**Figure 2**). This leads to an urgent rethinking of the approval of sanitation programs and projects aimed at the felling of trees parasitized by mistletoe, where the following are considered to be the most important threats to the APFFNT. The procedures for this purpose should be specified and research on the pharmacological knowledge of mistletoe should continue, which is currently under investigation, as well as the evaluation of its nutritional properties[8].

3. Analysis of the problems

Under the scheme of a strong incidence of pests and parasitic plants in these forests, it is important to analyze the possible alternatives to counteract this problem, which implies the search for healthy trees in infested areas, in theory, have some resistance to these pathogens, so that the collection of seed, soil removal and controlled fires could induce the natural renewal of this species, as well as the beginning of the processes of adaptation to the new climate conditions. Likewise, it is necessary to resume research in integrated pest management, where one of the main components is biological control, which in the case of the forests of Nevado de Toluca has not yet been addressed, at least for the management of its forests.

However, forest resource extraction is due to people's need to access the resource through anti-hunting[10]. Extraction obeys two important factors: first, the social component, which is related to the proximity to the resource, fundamental for the

inhabitants because extraction implies less energy, time and sometimes even money, and promotes greater pressure on the oyamel because of its proximity to most of the populations in this Natural Protected Area. The second factor is undoubtedly the quality of the wood from the pine (*Pinus hartwegii*) and oak (*Quercus laurina*) forests, which are the most affected because they have several uses: wood for furniture, firewood and charcoal.

In this regard, this work suggests that it is possible to carry out a project on the integral analysis of forest dynamics, in which the local population participates as an agent of control, deterioration or conservation of the forest (**Figures 3** and **4**). In this sense, and based on the results obtained, it is necessary to educate the local population about the necessary basic knowledge of ecology, the meaning of the forest continuum, about the balance of biological interactions and then make them participate in decision making, and also provide them with legal resources so that they are able to decide what to do with their own natural resources, since many of their limitations are due to the legal restrictions that they are unaware of in the area and fundamentally the lack of access to information.

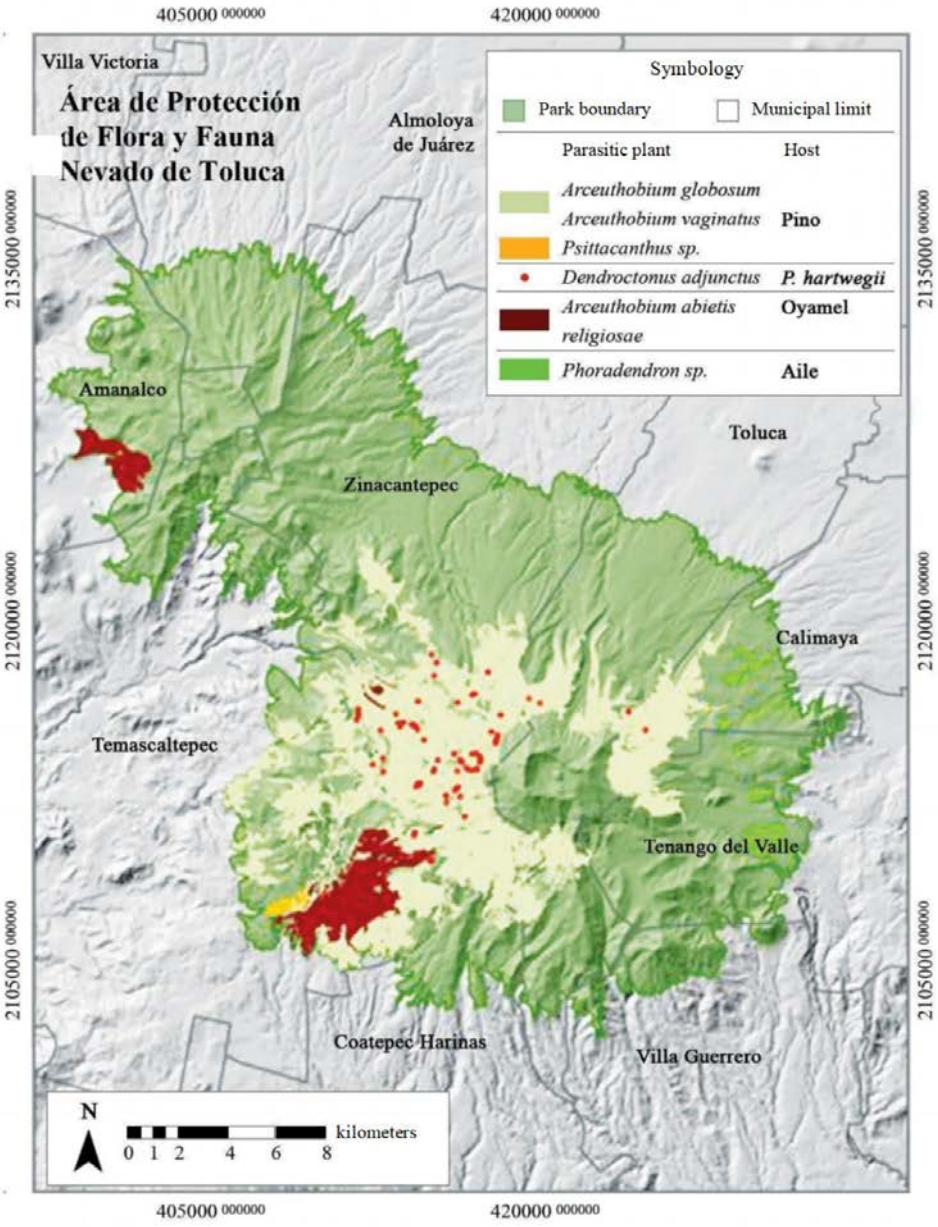

Figure 2. Phytosanitary status of the Nevado de Toluca forest.
Source: Prepared by the company.

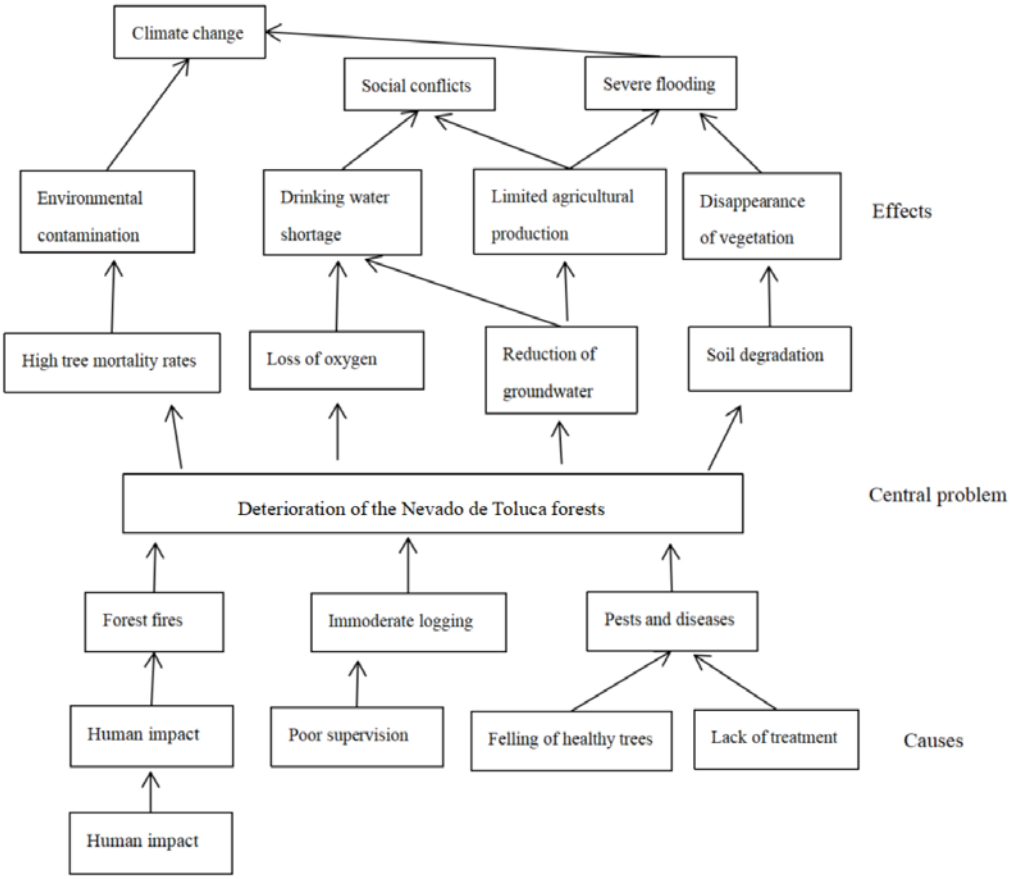

Figure 3. problems of the Nevado de Toluca forests.
Source: Own elaboration based on field data.

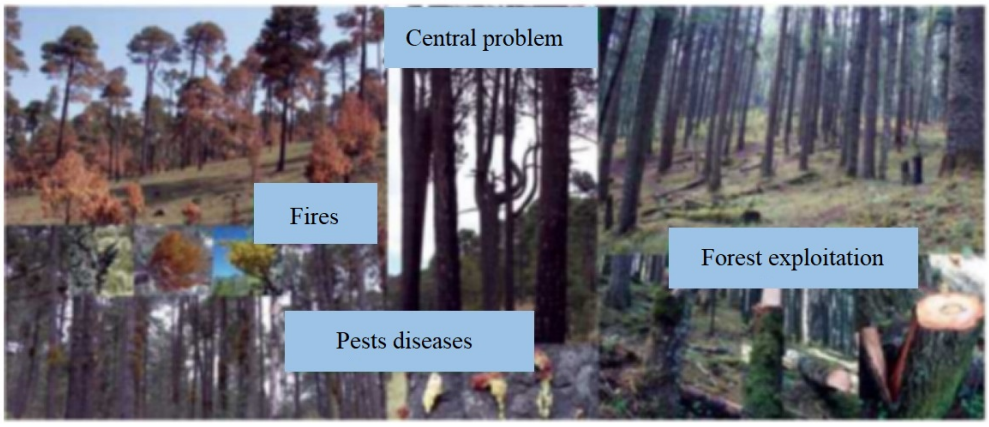

Figure 4. Illustration of the Nevado de Toluca problem.
Source: Own elaboration based on field photographs.

It is likely that the local population does not see the conservation of the forest as their own. In the medium term, deterioration will continue and the forest will disappear. There is a need for a project to raise community awareness so that they understand what they stand to gain from a healthy forest and what they stand to lose from a diseased and overexploited forest. This situation was the main limitation to working in many of the localities located within the park, due to the people's distrust in dealing with issues related to the use of firewood or timber.

In sum, the illegal extraction of timber and firewood for commercial purposes is causing a gradual deterioration of the forest due to the fragmentation of pine, fir, and oak forests (**Table 1**).

This stems from a lack of control mechanisms for accessing and harvesting forest resources. Therefore, without an orderly harvesting system, as well as coordination between government agencies and the local population, pine and oak forests will tend to be displaced, if conditions permit, or in the worst case scenario, they will end up as pasture or bare soil; in addition, the possibility of seeing fragmentation in fir forests is becoming increasingly close.

Table 1. Timber extraction in the forests of Nevado de Toluca[11]

Forest Type	Diameter class (cm)	Standing trees (/ha)	Trees extracted (/ha)	Percentage of trees removed	Volume of standing trees ($m^3 ha^{-1}$)	Volume of trees harvested ($m^3 ha^{-1}$)	Percentage of volume extracted
Pine	5–30	246	22	8	22.31	5.58	20.01
	>35	90	21	19	231.99	95.43	29.15
Fir	5–30	418	256	38	78.31	53.53	40.60
	>35	219	15	6	963.25	75.62	7.28
Aile	5–30	496	24	5	32.94	2.84	7.94
	>35	76	4	3	74.80	2.38	3.08
Encino	5–30	702	288	29	68.96	40.32	36.90
	>35	56	26	31	48.50	26.20	35.07

4. The role of local actors in the processes of forest deterioration and conservation

In reviewing the situation and the diagram of problems presented, and assuming that it is possible to carry out an integral analysis of the forest dynamics, we consider that the local population is the main agent of control, deterioration or conservation, since human beings are intrinsically attached to ecosystems. They have proven throughout history that their role within natural spaces can be beneficial to conserve their resources, but can also affect the ecological balance in the absence or recurrent violation of social or institutional rules that regulate activities according to the disposition and management of timber and non-timber resources.

In this sense, we define local stakeholders as those inhabitants and external agents with decision-making power and individual or collective action on the control, dominion and opinion on natural resources in a territorial context of micro-regional character, whose functionality is also regulated by various governmental institutions and laws such as those already mentioned.

Some of the local actors that have an interest in the Nevado de Toluca are the social groups that are settled in some part of the area, such as the communities of Raíces, Agua Blanca and La Peñuela, as well as the public and private actors that in one way or another have an interest in the environmental services provided by the Nevado de Toluca, are determinants of the future of these high mountain forests; for example, the ejidatarios, lumber dealers, stone material traders, farmers in the lower basins of the Nevado, non-governmental organizations, etc. Likewise, the three levels of government: municipalities, the State and the Federation are the ones who regulate the institutional life of the Nevado de Toluca from their sphere of action.

In this context, the network of local stakeholders generates relationships that may or may not favor timely forest management; therefore, it is necessary to create participatory spaces such as ejidatarios assemblies, citizen and rural development councils, as well as those spaces determined by the legal framework or social management forums that present the different projects aimed at conservation and management of natural resources with concurrent participation.

5. Forest ecosystem management strategies

In view of the problems raised, we can point out that it is necessary to put into perspective and balance some basic criteria on their viability: cost, time, concentration on local actors, social risks and environmental impact, among others. In this sense, we develop some strategic lines to achieve

the recovery and sustainable management of forests.

(1) Strengthen local social participation and organization schemes and incorporate participatory forest management modalities with communities and local institutions.

(2) Expand the offer of comprehensive professional services linked to the conservation and sustainability of these high mountain forests.

(3) Develop interdisciplinary scientific projects for the monitoring and evaluation of environmental, social and economic impact in terms of the conservation and use of timber and non-timber resources, soils, watersheds, tourism and productive activities that currently exist in the Nevado de Toluca.

(4) Implement cultural campaigns to sensitize, educate and raise awareness among the public and local inhabitants about the importance of forests.

It is also suggested to address the development of capacities and strategies for citizen participation, which should be transversal throughout all activities for the integrated management of the forest. It is therefore a matter of generating natural resource projects, Sepúlveda[12] points out, their purpose is to promote environmentally friendly production and to protect, conserve and recover the natural resource base.

A broader vision is therefore required that recognizes that timber production is no longer the sole or even the primary objective; on the contrary, other environmental services are fundamental: forest-dependent lifestyles, biodiversity conservation and carbon storage[13].

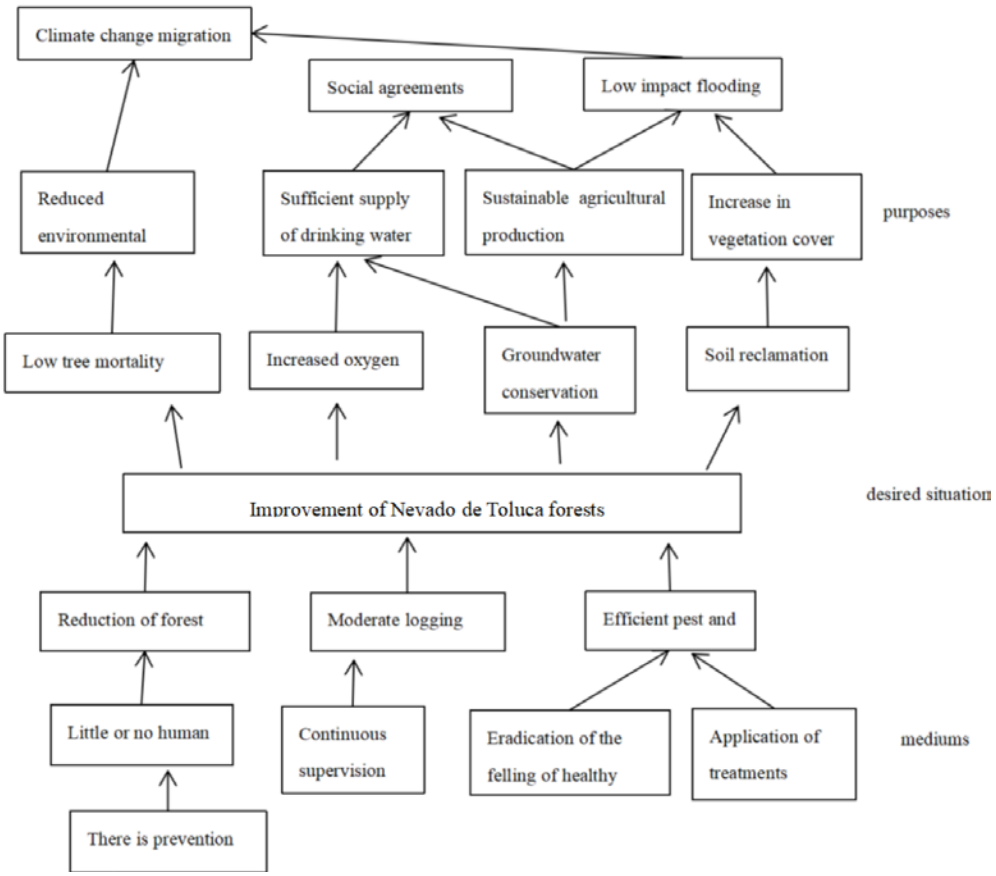

Figure 5. Diagram of objectives for the improvement of the Nevado de Toluca forests.
Source: Own elaboration based on field data.

6. Prospective analysis and desirable scenarios

In this sense, it is suggested that the recovery of the forest should incorporate local actors, especially the rural communities that have greater territorial proximity to the forest areas; management activities should be possible to be integrated into a dynamic of sustainability, according to pertinent studies, which should be subject to the legal

framework and land uses that are officially established for this purpose in the context of an integral ecological planning of the territory. In a future scenario, a desired situation oriented to the environmental balance of the Nevado de Toluca forest is sought, as can be seen in **Figures 5** and **6**.

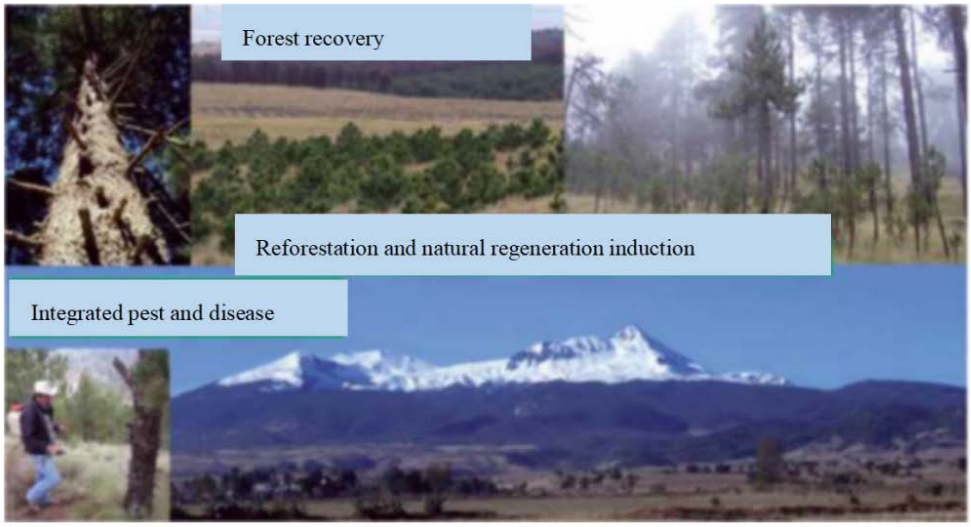

Figure 6. Illustration of forest recovery in the Nevado de Toluca.
Source: Own elaboration based on field data.

A systemic and territorial integration approach could be useful to strengthen the recovery strategies of the Nevado de Toluca forests, recognizing that the environmental balance depends on multiple biotic and abiotic factors that constitute and shape the ecological, social, economic and even cultural dynamics expressed in a territory. In this sense, the problems can be reversed to the extent that actions are generated by local actors aimed primarily at reducing forest fires, establishing strategies against immoderate logging and more efficient control of pests and diseases that afflict the trees of the Nevado de Toluca.

Likewise, we seek to coordinate with other territorial scales and institutions to configure a macro-regional territorial management strategy that will allow the inhabitants of the urban areas of the Toluca Valley and those parts of the Balsas basin to use resources in a more sustainable manner in an exercise of shared environmental responsibility.

In conclusion, the following are some of the substantive activities that could be developed in the future based on the strategies described as part of the projections for the improvement of forest management, and in general with a view to the ecological balance of the Nevado de Toluca:

(1) Restore biodiversity in the area through a comprehensive forest ecosystem restoration program (reforestation and natural regeneration of deteriorated forests).

(2) Program to control forest fires through prescribed burning and silvicultural actions, such as fire breaks.

(3) Combat pests and diseases of wild species through integrated management of pests and parasitic plants in coniferous and broadleaf forests.

(4) Control soil erosion and recover forest cover by developing a soil management and conservation program.

(5) Increase the availability of timber and non-timber forest resources to compensate for the use of local fuels such as firewood or mushrooms.

(6) Propose activities to improve the rural landscape, which involves soil recovery, reforestation and the promotion of environmental education activities.

(7) Make the prevention, surveillance and penalization of illegal acts related to forest protection more efficient.

This implies building a more comprehensive program of actions for the protection of the forest considering that it is necessary to create mecha-

nisms for transparency, citizen participation and a high institutional commitment in terms of regulations and sustainable planning practices, capable of sustaining an efficient ecological management of the forest. The sense of belonging to the place of individuals must also be incorporated, as this determines their behavior in terms of forest resource management aimed at the provision of environmental services[14]. In social terms, we observe that the transition to a better regime of protection, conservation and restoration of forests is desirable, which may be possible, as long as emphasis and care is placed on the design, implementation and monitoring of strategies, which should be harmonized in social, environmental, economic and cultural aspects to detonate in situ a perspective of sustainability and durability of the Nevado de Toluca and the territories over which it has some kind of ecological proximity.

Conflict of interest

The authors declare that they have no conflict of interest.

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