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Development and Implementation of a Protocol for the Prevention of Forest Fires for the Conservation of Biodiversity in the Protected Forest La Prosperina - ESPOL"

Desarrollo e Implementación de un Protocolo de Prevención de Incendios Forestales para la Conservación de la Biodiversidad en el Bosque Protector La Prosperina - ESPOL"

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Abstract: Forest fires have emerged as an environmental problem of growing relevance on a global scale, with projections indicating an exacerbation in their frequency and intensity due to climate change. The incidence of these pyrogenic events is predominantly concentrated during dry periods, when environmental conditions favor a reduction in the ignition point of plant material, increasing its susceptibility to combustion.

Keywords: forestry, biodiversity, forests

Resumen: Los incendios forestales han emergido como una problemática ambiental de creciente relevancia a escala global, con proyecciones que indican una exacerbación en su frecuencia e intensidad debido al cambio climático. La incidencia de estos eventos pirogénicos se concentra predominantemente durante los períodos de estiaje, cuando las condiciones ambientales propician una reducción en el punto de ignición del material vegetal, incrementando su susceptibilidad a la combustión.

Palabras clave: forestal, biodiversidad, bosques

Introduction

The phenomenology of wildfires involves a multiplicity of ecosystem and socioeconomic impacts. These include edaphic alterations, atmospheric disturbances, modifications in the composition and structure of flora and fauna, as well as visual and socioeconomic repercussions in the affected environment (Pausas & Keeley, 2019; Turner, 2010). The magnitude and complexity of these impacts underscore the imperative need to develop comprehensive studies that establish protocols and methodologies for the prevention and mitigation of these events, with particular emphasis on protected areas characterized by their high ecological vulnerability (Moritz et al., 2014).

The identification and precise quantification of damage caused by wildfires is a fundamental step in the formulation of effective prevention and mitigation strategies. This analytical approach allows the implementation of more effective preventive and control measures, adapted to the specific characteristics of the ecosystem at risk (Calkin et al., 2014). In the particular context of La Prosperina Protected Forest - ESPOL, a comprehensive analysis of these measures is proposed, with the objective of developing a common frame of reference for forest emergency response entities, including both ESPOL forest firefighters and the Forestry and Environmental Technical Division.

Standardization of terminology and techniques for forest fire prevention and firefighting among these key actors is essential to optimize the effectiveness of interventions (Agee & Skinner, 2005). In addition, quantitative damage assessment will facilitate the determination of specific restoration strategies, addressing critical aspects such as the recovery of biological diversity, mitigation of soil erosion and reduction of post-fire atmospheric pollution (Bond & Keeley, 2005).

This holistic approach to the study of wildland fires requires the application of multidisciplinary methodologies ranging from fire ecology to climate modeling and natural resource management (Keeley et al., 2011). The implementation of advanced remote sensing techniques and geographic information systems can provide crucial data on fire extent and severity, while detailed field studies are essential to assess specific impacts on biodiversity and ecosystem processes (Chuvieco et al., 2019).

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The proposed research will not only contribute to scientific knowledge on the dynamics of forest fires in specific ecosystems, but will also provide practical tools for the management and conservation of protected areas. Dissemination of the results and recommendations derived from this study through scientific publications and training workshops for environmental managers and emergency response personnel will facilitate knowledge transfer and the improvement of fire management practices at the regional level (Gedalof, 2011).

This study seeks to address the problem of forest fires in a holistic manner, from prevention to post-fire restoration, with a particular focus on the protection of vulnerable ecosystems and the optimization of emergency response resources.

La Prosperina Protected Forest, located in the province of Guayas, Ecuador, covers approximately 570 hectares of the Gustavo Galindo campus of the Escuela Superior Politécnica del Litoral. Declared a protected area in 1994, this ecosystem exemplifies the transition between Evergreen Montane Foothill Evergreen Forest, Semideciduous Lowland Forest and Semideciduous Piedmont Forest (Espinoza et al., 2019).

The topography of the area ranges from regular to very irregular, with steep slopes. The forest has five main watersheds, oriented south-north, with headwaters above 100 m above sea level, which, together with associated micro-watersheds, form a drainage system that covers approximately 1000 hectares (Molina et al., 2020).

Climatologically, the area is classified as AW Tropical Savanna according to Köppen, influenced by the Chongón-Colonche mountain range. Rainfall, concentrated between January and April, reaches an annual average of 1,135 mm, with torrential characteristics that promote erosive phenomena, especially in steep and deforested areas (Sierra et al., 2021).

Vegetation cover is composed of 38.3% lowland deciduous Ecuadorian forest and 61.7% deciduous Ecuadorian forest on limestone outcrops (Vallejo et al., 2017). Biodiversity is remarkable, with approximately 18 species of mammals, 10 species of reptiles and amphibians, and 100 species of birds documented (Torres et al., 2018). The flora presents a significant taxonomic variety, classified into arboreal, shrub, herbaceous and lianoid strata (Jiménez & Alvarado, 2016).

This ecosystem faces conservation challenges due to its proximity to urban areas and its history of anthropogenic exploitation, including activities such as grazing, limestone extraction and deforestation (Martínez et al., 2020). Current management focuses on the preservation of biodiversity and the ecological integrity of the forest, allowing controlled activities such as scientific research, sustainable tourism, and phytosanitary control measures, in accordance with current forest legislation (Ecuador Ministry of Environment, 2018).

Forest pyrology focuses on the study of forest fires, analyzing their patterns, characteristics and the factors that influence their occurrence. Forest fires are adverse phenomena, without human control, that affect vegetation areas (Rodríguez et al., 2019).

They are classified into five states: out of control, contained, circumscribed, controlled and extinguished, and their spread depends on variables such as topography, meteorological conditions and types of fuels involved (FAO, 2017). Fires present different parts such as head, tail, flanks and perimeter, and their combustion involves the rapid oxidation of plant materials, releasing stored energy (García et al., 2021).

The combustion process in forest fires includes phases such as preheating, gas combustion and solid phase, with heat being transferred by conduction, radiation and convection (Silva et al., 2022). Fire spread varies according to the nature of the combustible material and environmental conditions, such as humidity and wind (Fernandez et al., 2020).

There are three main types of forest fires: surface, crown and understory, each with specific characteristics and challenges in their combat (FAO, 2017). In La Prosperina Protected Forest, surface fires predominate, often triggering crown fires under the influence of wind (Martínez et al., 2020).

Forest fires in La Prosperina Protected Forest are predominantly anthropogenic in origin, driven by negligent human activities and exacerbated by environmental factors such as high temperatures and waste accumulation (Rodríguez et al., 2019). Uncontrolled burning of brush and debris, as well as mishandling of cigarettes and campfires, are common causes. Naturally, high temperatures and the flammability

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of vegetation also contribute to these fires, influencing both their initiation and spread (FAO, 2017).

From a legal approach, Ecuador adheres to international frameworks such as FAO, which facilitates cooperation and technical assistance in fire prevention (Ministry of Environment of Ecuador, 2018). At the national level, the Constitution and laws such as the Forestry Law establish responsibilities and sanctions to prevent and control fires, imposing penalties ranging from minor to extraordinary major confinement, depending on the damage caused (Constitution of Ecuador, 2008).

International standards, such as those of the NFPA, regulate the qualifications and procedures for preventing and fighting wildland fires, ensuring that the equipment and methods used are effective (NFPA, 2016).

In terms of prevention, the importance of environmental education and awareness is emphasized, along with the implementation of strategies such as deterrent surveillance, controlled burns and control of access to forested areas (García et al., 2021). Modifying human behavior is key, and awareness campaigns play a crucial role. These campaigns must be continuous, didactic, and stratified to be effective in different social groups, ensuring that preventive measures are widely adopted and understood (FAO, 2017).

Methodology

In order to prevent forest fires in La Prosperina Protected Forest, it is essential to implement an action protocol that involves both continuous monitoring and community education. The creation of awareness campaigns for the local population and visitors is essential because forest fires are often caused by human activities, such as poorly extinguished campfires or uncontrolled burning of agricultural waste. In addition, it is suggested that surveillance towers and smoke sensors be installed to allow rapid identification of fires in their early stages, which would facilitate the immediate response of specialized personnel (Rojas & Fernández, 2021).

On the other hand, it is essential to establish brigades specialized in extinguishing forest fires, made up of personnel trained in firefighting techniques. These brigades should be equipped with tools such as water backpacks, chainsaws and light machinery to facilitate the creation of

control lines and firebreaks. In addition, the implementation of periodic drills is vital to ensure that, in the event of an emergency, action is taken quickly and efficiently. In addition, there is a need to coordinate efforts with local and regional authorities to ensure access to resources and logistical support in critical situations (González et al., 2020).

The determination of the impacts of forest fires in La Prosperina Protected Forest reveals varied effects on vegetation, fauna, soil, water, atmosphere, landscape, and social and economic aspects. In terms of vegetation, fires affect species differently according to their ecological maturity. Young species are more susceptible to fire, while mature species are more resistant. Ecosystem regeneration depends on factors such as species adaptability and post-fire environmental conditions. Pyrophytic species, adapted to fire, tend to dominate after recurrent fires (Rodríguez et al., 2020).

Wildlife faces serious consequences from fire, such as loss of habitat, trophic resources and nesting sites. Less mobile species, such as soil invertebrates, are the most affected. Although some species can recolonize regenerated areas, the imbalance in the food chain hinders recovery (Pérez & Gómez, 2018).

The soil suffers erosion and nutrient loss after fires. Although fire heat mainly affects the surface layer of the soil, its impact is significant. The initial increased fertility is rapidly lost with erosion (Torres et al., 2017). Soil microorganisms are also affected, with a reduction in the surface layers, although some, such as nitrogen fixers, subsequently proliferate (López & Vargas, 2019).

In terms of water, sediment runoff increases turbidity, affecting nearby water bodies (Mendoza et al., 2021). The landscape changes drastically, impacting not only the visual environment, but also ecological and cultural values (Fernández & Ortiz, 2016). In addition, the atmosphere is affected by the emission of polluting gases (Ramírez & Santos, 2020).

Wildfires have social impacts, including fatal accidents during extinction and economic effects due to the loss of natural resources and mobilization costs to fight them (Garcia et al., 2019).

Firebreak strips are essential tools in forest fire prevention, especially in vulnerable areas such as La Prosperina Protected Forest. These strips

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can be located in various positions, such as perimeters or areas near buildings, and their function is to stop the spread of fire by reducing flammable vegetation. Factors such as wind direction, terrain slope and vegetation cover are considered for their implementation (Silva et al., 2020).

In the case of La Prosperina Protected Forest, the use of manual clearing is recommended due to the irregularity of the terrain, which limits the use of heavy machinery. This technique, along with others such as mechanical clearing, manual pruning or prescribed fire, seeks to reduce the vegetation mass and prevent the rapid spread of fire (Gómez et al., 2020). In addition, the need for a forest emergency plan that contemplates the construction of firebreak strips in recreational areas, buildings and areas with high vegetation density is highlighted. The continuous training of personnel, the acquisition of specialized equipment, and the establishment of evacuation and extinction routes are crucial elements for the effectiveness of the plan (Martínez & Vega, 2018). It is also vital to analyze the costs associated with fire suppression, considering both unit costs per mission and average costs per hectare affected (Reyes, 2019).

In this context, the implementation of efficient monitoring and communication systems is fundamental to minimize response times in case of emergency, thus increasing the probability of controlling the fire quickly and effectively (Hernández & Morales, 2021).

Results

In the context of the emergency reported by the Corporation for Citizen Security of Guayaquil, the reports received indicated the presence of smoke and fire in the surroundings of the Escuela Superior Politécnica del Litoral (ESPOL) (Ramos, 2019). These reports were corroborated by the ESPOL Forest Firefighters Group, who confirmed the magnitude of the fire in the Bosque Protector La Prosperina, an area adjacent to the institution (Gómez et al., 2020). In response to this situation, the forest emergency response protocol was immediately activated, mobilizing different responsible entities (Torres & Rodríguez, 2021).

The Guayaquil Fire Department was the first to respond, sending units to the site of the incident. In addition, there was support from the Guayaquil Transit Commission, which facilitated traffic management on nearby roads, and from the Ministry of the Environment, whose task was to assess the environmental impact and coordinate actions with the

ESPOL Forest Firefighters (Pérez & Sánchez, 2022). This collaborative approach reflected the importance of structured planning to deal with this type of situation (López & Ortega, 2020).

The firefighting operation was carried out by both the Forestry Division of the Guayaquil Fire Department and the ESPOL Forestry Firefighters Group. Both institutions worked under a unified command, which included the Ministry of Environment and the National Secretariat of Risk Management, with the objective of maximizing the effectiveness of the intervention (García & Ramírez, 2018).

From a logistical perspective, each institution was responsible for managing the human resources, equipment and tools needed to deal with the emergency. This distribution of responsibilities allowed for a more efficient and organized response (Mendoza, 2021). In terms of funding, the institutions involved also managed their own resources, since large-scale wildfires usually require the acquisition of new supplies or collaboration with other entities to ensure the provision of what is needed (Vega & Pérez, 2019).

The response time of the first units of the Guayaquil Fire Department was 7 minutes. Subsequently, when reinforcements were requested, the additional units arrived in an average of between 8 and 12 minutes, which highlighted the speed with which the emergency forces were mobilized (Rojas & Vásquez, 2020). This response time is a crucial indicator in the evaluation of the effectiveness of the activated procedures (Santos et al., 2021).

Consequently, the effectiveness of the responders is measured by comparing the results before and after the implementation of the forest fire prevention protocol. These indicators allow evaluating the improvement in the coordination and execution of operations, reflecting the importance of having a structured protocol to mitigate the impacts of this type of emergency in the future (Torres & Rodríguez, 2021). In summary, coordination between institutions and detailed planning were key elements to face the fire efficiently and minimize damages (García & Ramírez, 2018).

Conclusions

As stated in the objectives of this research, the results confirm that:

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Forest fires in La Prosperina Protected Forest have profound effects on biodiversity, soil, and the ecosystem in general. The implementation of prevention and mitigation strategies should be a priority, with a focus on environmental education, sustainable forest management, and compliance with a solid legal framework.

Community involvement and the use of advanced technologies for early fire detection can significantly contribute to reducing the incidence of fires and mitigating their long-term effects.

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