

Fire influence on forest cover in the Caparaó microregion, state of Espírito Santo, Brazil

Denyse Cássia de Maria Sales,
Gabrielli Machado Bindeli,
Nívea Maria Mafra Rodrigues,
Elaine Cordeiro dos Santos,
Carem Cristina Araujo Valente,
Joana Scheidegger Marinato,
Thaís Arão Feletti

Forests play a crucial role in biodiversity conservation, climate regulation, and the provision of essential ecosystem services. However, their resilience has been compromised by disturbances such as wildfires, which cause vegetation loss, habitat fragmentation, and disruptions of ecological cycles. Understanding the relationship between fire and forest cover is crucial for guiding conservation strategies, especially in biodiversity-rich regions like the Caparaó microregion in the state of Espírito Santo (Brazil). This study examined the impact of wildfires on forest cover between 2012 and 2021, integrating remote sensing data, meteorological information, and geoprocessing tools. The results indicated that approximately 43.92 km² were affected by fire, with 1.78% (0.78 km²) of the impacted areas covered by forests. A strong positive correlation ($r = 0.837$) was found between fire occurrence and forest cover loss, indicating that increased fire activity is associated with a reduction in forest area. A moderate positive correlation ($r = 0.422$) was observed between maximum temperature and burned area, which may indicate a trend of increasing fire risk as temperatures rise. It is important to note that the increase in forest cover observed during the study period primarily occurred in areas distinct from those affected by fire, suggesting natural regeneration or reforestation processes in other parts of the landscape. This scenario highlights the importance of public policies that prioritize continuous monitoring and fire prevention, especially given the projected increase in extreme climatic events, such as severe droughts, expected over the coming decades. The results of this study provide useful insights for land-use planning and the development of restoration and conservation strategies for the Atlantic Forest and similar ecosystems.

Keywords: Burn Analysis, Ecosystem Dynamics, Conservation Strategies, Remote Sensing, Atlantic Forest, Wildfire, Forest Degradation, Reforestation.

Introduction

The degradation and fragmentation of Brazilian forest ecosystems, driven by increasing population demands and economic pressures, have led to a scarcity of primary forests over time (Gomes et al. 2021), with the Atlantic Forest being the most affected biome. The Atlantic Forest biome is a global biodiversity hotspot, spanning 17 states and currently housing 72% of Brazil's population (Rezende et al. 2018, SOS Mata Atlântica/INPE 2021).

The expected fire regime in the Atlantic Forest is minimal or nonexistent, as fire is

neither a natural nor adaptive factor within this biome. Fire occurrences are generally linked to human activities, such as land clearing for agriculture, and act as external disturbances that degrade the ecosystem rather than promoting evolutionary adaptations of species to fire (Baião et al. 2023).

Between 2019 and 2020, ten states within the Atlantic Forest region experienced a decline in forest cover, attributed to factors such as natural resource exploitation, urbanization, and wildfires (SOS Mata Atlântica/INPE 2021). Despite these challenges, some well-preserved forest remnants remain, such as the Caparaó National Park (PARNA Caparaó), which contains highly preserved areas and a notable number of endemic species from representative families of the Brazilian flora (Camelo et al. 2020).

The Caparaó region is an area of great environmental relevance, rich in biodiversity and extensive forest cover. The occurrence of wildfires can significantly impact both vegetation cover and biodiversity in this region, directly affecting the integrity of ecosystems. Understanding these impacts is essential for evaluating the current and future responses of tropical forests to fire (Dutra 2019).

The intense fragmentation of the Atlantic Forest has increased the biome's vulnerability to wildfires (Singh & Huang 2022). The reduction in vegetation cover, the increase in fragment edges, and the proximity to anthropic areas favor fire spread, intensifying the frequency and severity of wildfires (Guedes et al. 2020). These processes, driven by human activities, compromise natural regeneration and may accelerate the transition of the forest into more open systems, such as savanna-like formations (Santos et al. 2019).

□ Department of Forestry and Wood Sciences, Universidade Federal do Espírito Santo, rua Conceição Augusta de Souza 13, Jerônimo Monteiro (Brazil)

@ Denyse Cássia de Maria Sales (denysecmariasales@gmail.com)

Received: Mar 22, 2024 - Accepted: May 04, 2025

Citation: Sales DCM, Bindeli GM, Rodrigues NMM, dos Santos EC, Valente CCA, Marinato JS, Feletti TA (2025). Fire influence on forest cover in the Caparaó microregion, state of Espírito Santo, Brazil. *iForest* 18: 267-272. - doi: [10.3832/ifor4608-018](https://doi.org/10.3832/ifor4608-018) [online 2025-10-14]

Communicated by: Davide Ascoli

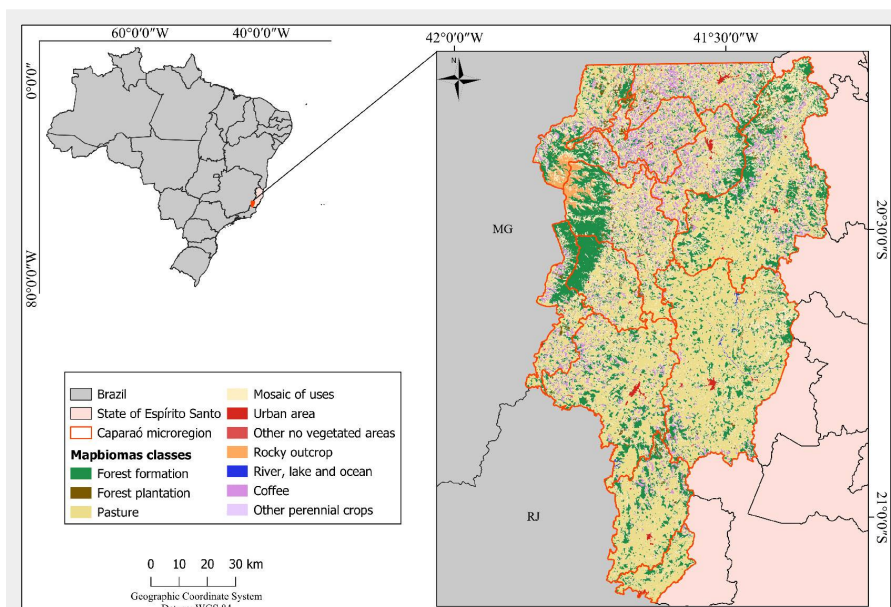


Fig. 1 - The study area, Caparaó microregion, state of Espírito Santo (Brazil).

In this context, wildfires have become a major driver of forest fragment degradation, causing direct destruction and disrupting the ecological dynamics of affected areas (Gobbo et al. 2016). Although the use of fire is associated with traditional anthropogenic practices, previous studies indicate that climate change has also contributed to the increasing frequency and intensity of wildfires through the extension of dry periods and rising temperatures (Aragão et al. 2018, Jones et al. 2024). Therefore, both anthropogenic pressures and climatic conditions must be considered when assessing fire regimes and their effects on the Atlantic Forest.

Recent extreme climatic events, such as intense heatwaves, prolonged droughts, and record-breaking temperatures, have contributed to increasing the vulnerability of forest ecosystems (Libonati et al. 2022, Oliveira et al. 2024, Mello et al. 2025). Such events, associated with unpredictable rainfall patterns, are creating conditions that foster increasingly severe wildfires (Flannigan et al. 2013). This underscores the relevance of the climate crisis for decision-makers, as some climate impacts are now considered irreversible (IPCC 2023).

Forests in the state of Espírito Santo are particularly susceptible to these extreme events, as evidenced by the high percentage of areas classified as high to extreme fire risk (over 78%) due to climatic factors (Eugenio et al. 2016). Rising temperatures and altered precipitation patterns increase the risk of wildfires, requiring proactive conservation efforts to maintain ecosystem balance (Firmansyah et al. 2024).

In this scenario, analyzing temperature trends and burned areas becomes essential to understand how climate variations have influenced the severity and extent of fires in the region. Furthermore, recognizing these climatic pressure factors helps in un-

derstanding and anticipating future risks in climate change scenarios (Jones et al. 2022), and contributes to assessing the vulnerability of local forests, thereby supporting the development of more effective management strategies in the face of climate change.

This study aims to analyze the relationship between fire occurrence and forest cover in the South Caparaó region of Espírito Santo by mapping and quantifying burned areas from 2012 to 2021, along with their overlap with forest cover. To this end, Pearson's correlation was applied to evaluate the relationships between wildfires and forest cover loss, as well as between maximum temperature and burned area. This coefficient helps in identifying the positive or negative relationship between two linear variables. In addition, this study aims to investigate how climatic variables, particularly temperature, affect fire patterns in the region and assess their impact on wildfire patterns.

Materials and methods

Given the significant increase in extreme weather events and the intensification of the climate crisis over the past decade (Karki et al. 2020, Zhang et al. 2020), the period from 2012 to 2021 was selected for analysis. This timeframe represents a critical period during which climate change has had a direct and escalating impact on wildfires (Ault 2020), underscoring the need for a detailed study of this period.

Study area

The state of Espírito Santo (ES), located in southeastern Brazil, spans an area of 46,074,448 km² and has a population of 4,108,508 inhabitants (IBGE 2022). The Espírito Santo State is divided into ten microregions (Geobases 2017); in this study, we focus on the Caparaó microregion, lo-

cated in the southern portion of Espírito Santo. This area is characterized by mountainous terrain and includes the Caparaó Mountain Range, a critical zone for preserving the Atlantic Forest in Espírito Santo (ICMBIO 2025).

The Caparaó microregion comprises the municipalities of Alegre, Bom Jesus do Norte, Dolores do Rio Preto, Divino de São Lourenço, Guaçuí, Ibatiba, Ibitirama, Irupi, Iúna, Muniz Freire, and São José do Calçado (Fig. 1). The microregion covers an area of approximately 3,987,88 km², which corresponds to 8.31% of the state's territory, and about 50% of the population lives in rural areas (Lima & Oliveira 2022).

The average annual temperature in this region ranges from 16 °C to 22 °C, with peak temperatures between 24 °C and 29 °C during the hottest seasons. The area features a varied altitude, ranging from 300 to 2900 m a.s.l., and receives an average annual precipitation of 1200 to 1500 mm (Lima & Oliveira 2022). Vegetation in the region is part of the Atlantic Tropical Domain, characterized by semideciduous seasonal forests (Garbin et al. 2017).

Acquisition data

Territorial limits data

Data for national, state, and municipal borders were obtained from the database provided by the Brazilian Institute of Geography and Statistics (IBGE 2022). The delimitation of the Caparaó region followed the classification from the State Institute of Environment and Water Resources (IEMA), specifically Class 6 in Geobases (2017). The municipalities within the Caparaó microregion were extracted from the IBGE vector file. Data processing was conducted using QGIS v. 3.28.4, a free and open-source software (QGIS Development Team 2023).

Burned coverage data

Data on burned areas were acquired from the MapBiomas Fire product, Collection 2.0 (Mapbiomas 2022a), which maps fire scars across Brazil. The area corresponding to Espírito Santo was selected, using Annual Burned Coverage data. Images from 2012 to 2021 were downloaded for subsequent data processing.

Land use and occupation data

Land Use and Land Cover data were sourced from Collection 7.1 of Mapbiomas (2022b). The state of Espírito Santo was selected, and images with "coverage" data for the years 2012 to 2021 were downloaded for further processing.

Meteorological data

Meteorological data were obtained from the Brazilian Daily Weather Gridded Data collection (Xavier et al. 2022) via Google Earth Engine™, and processed in QGIS v. 3.28.4. Average values were extracted for precipitation, maximum and minimum temperatures, solar radiation, and relative hu-

midity in the study area. Values for 2021 were estimated by averaging data from 2012 to 2020 to compensate for limitations in the data series.

Data processing

Burned coverage data

The previously downloaded raster scenes were imported into QGIS and clipped to the Caparaó microregion study area shapefile. Layers were then vectorized, converting them from raster to vector format, and classes were dissolved. An attribute named “year” was assigned to all vector layers, which were subsequently merged based on this attribute, creating a single shapefile containing burned coverage (BC) data for each year.

Land use and occupation data

Raster scenes representing land use and land cover (LUC) were imported into QGIS and clipped to the study area shapefile, generating raster images for the Caparaó microregion. Layers were vectorized, and polygons with the same LUC class were merged. Forest classes were then isolated for the specified years. A symmetric difference operation compared forest area between 2012 and 2021 to assess changes (losses and gains) in forest cover over the period (QGIS Project 2023a). This method identifies and quantifies areas of change in forest cover, excluding areas that remained constant.

Land use vs. burned coverage

Following the identification of changes in forest cover and the mapping of burned areas, an “intersection” operation was performed in QGIS. This step aimed to evaluate areas of forest gain or loss that over-

lapped with burned areas, comparing data on forest cover loss or gain with burned coverage.

The “intersection” tool extracts overlapping features from the input and overlay layers (QGIS Project 2023b). The input layer utilized was the burned area data for a period of 10 years. As the overlay layer, data on forest losses during the specified period were used. The output layer at this stage allows for the identification of areas where forest losses or gains overlap with fire-affected areas, facilitating the identification of forested areas impacted by fire.

Statistical analysis

A Pearson's correlation analysis was conducted to assess the relationships between wildfires and forest cover loss, as well as between maximum temperature and burned area. Pearson's correlation coefficient measures the linear relationship between two variables. A value close to +1 indicates a strong positive correlation, meaning that a one-unit change in variable X results in a similar change in variable Y (Moore & Notz 2021, Figueiredo Filho et al. 2014). In this study, the correlation between the wildfire-affected area and forest cover loss was examined to identify potential associations between the extent of burned areas and the reduction in forest cover. Similarly, the correlation between maximum temperature and burned area allowed for the examination of the influence of extreme temperatures on the extent of areas affected by fire.

In addition to the correlation analysis, a scatter plot was generated to illustrate the relationships between wildfires and forest cover loss, as well as between maximum temperature and burned area, providing a clear visualization of observed patterns

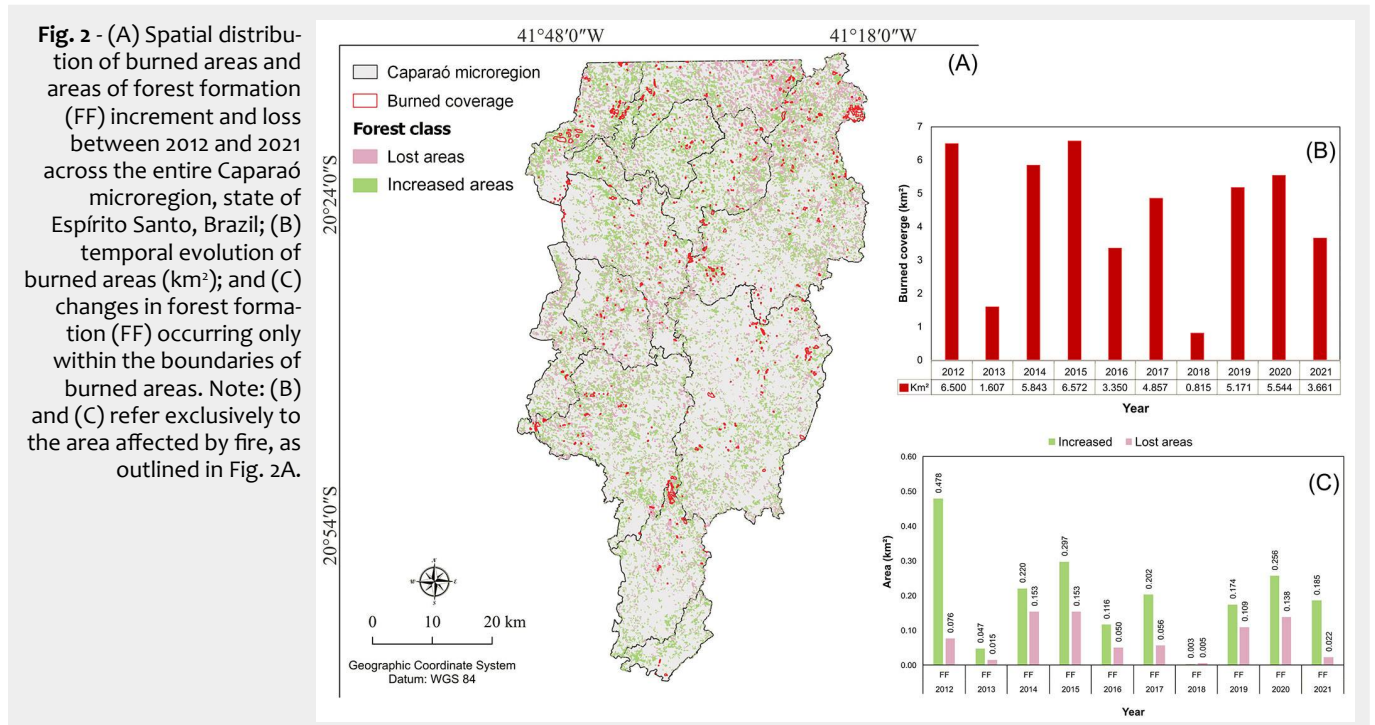
and trends. This analysis was conducted using the R language within the RStudio software (R Core Team 2023).

Results and discussion

The Caparaó microregion encompasses a total area of 3,987.89 km², of which approximately 43.92 km² (1.10%) was affected by fire between 2012 and 2021. Of the burned areas, only 0.78 km² (1.78%) overlapped with regions classified as forest cover (Fig. 2A), indicating that most fire events occurred in non-forested landscapes, such as pastures or agricultural lands. Although the proportion of forested areas affected by fire was relatively low, this value becomes significant when analyzed in the context of land-use and land-cover dynamics. During this period, forest cover in the microregion increased substantially from 894,659 km² in 2012 to 983,328 km² in 2021, according to Mapbiomas data (Mapbiomas 2022a). Therefore, even small-scale disturbances in forested areas may compromise the progress achieved in ecological restoration and native vegetation conservation efforts in the region.

This suggests that even small burned areas can represent a significant portion of the remaining forest fragments. Notably, the year 2015 recorded the largest burned area per km² in Espírito Santo (Fig. 2B), coinciding with the largest forest loss observed during the study period (Fig. 2C). Despite these localized losses, an overall increase in forest cover was observed in areas unaffected by fire, possibly due to natural regeneration or changes in land use elsewhere in the landscape.

It is worth noting that the areas affected by fires and those showing forest cover expansion do not necessarily overlap.



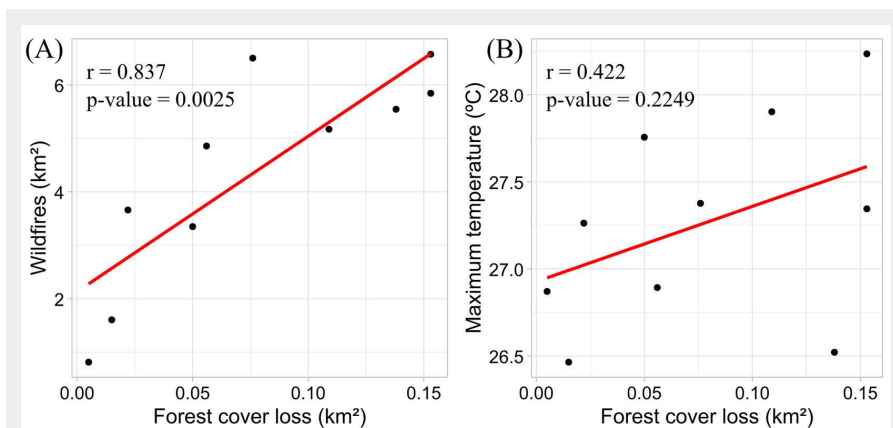


Fig. 3 - Correlation between forest loss (km²) and (A) forest fires (km²) and (B) maximum temperature (°C) in the Caparaó microregion, state of Espírito Santo, Brazil.

Through the intersection analysis between burned area data and changes in forest cover, it was possible to identify that, while some regions in the Caparaó microregion experienced vegetation loss due to fire, forest cover gains predominantly occurred in other areas that were not affected by fires, likely driven by natural regeneration processes and restoration programs such as Reflorestar (SEAMA 2023). This result highlights the spatially distinct dynamics of forest loss and gain, indicating that the observed forest increase was not a direct response to fire events, but rather the outcome of other initiatives and favorable local conditions for recovery.

According to data from the National Institute for Space Research (INPE), 940 active fire detections were recorded in Espírito Santo in 2015, the highest number in the 2014-2019 period. These detections refer to satellite-identified thermal anomalies associated with active fires (Queimadas Program – INPE). This peak coincided with a period of significantly reduced precipitation in the state (IDAF 2023), particularly affecting the dry season months. This correlation suggests that prolonged drought conditions may have contributed to the increased fire activity observed that year.

Fire risk is closely linked to rainfall patterns (Fiorese et al. 2018). Drought was further intensified by the 2015 El Niño phenomenon, which raised temperatures in Brazil, thereby increasing thermal stress and amplifying fire severity in certain regions. This event also heightened concerns and discussions on deforestation and tropical forest protection (Aragão et al. 2007, Marenco & Souza Junior 2018).

Restoration efforts have helped to counterbalance some of these adverse effects. The increase in forest areas (Fig. 2C) is primarily due to the Reflorestar Program, which has played a crucial role in restoring forest cover in the Caparaó microregion, where 2879.13 ha have been included in recovery initiatives (SEAMA 2023). Beyond financial support, the program provides technical assistance and promotes sustainable practices, benefitting rural producers and encouraging responsible land use (SEAG 2017, Viana 2020, SEAMA 2023).

The Pearson's correlation (r) between wildfires and forest cover loss was 0.837 ($p\text{-value} = 0.0025$), indicating a strong positive relationship as commonly interpreted for correlation coefficients above 0.7, where variables increase together in a consistent linear pattern (Cohen 1988, Bos-

laugh 2013), with forest cover loss increasing in tandem with the extent of wildfire-affected area (Fig. 3A). This significant correlation highlights the considerable impact of wildfires on forest cover loss in the Caparaó microregion. Furthermore, the correlation between maximum temperature and burned area yielded an r -value of 0.422 ($p\text{-value} = 0.2249$ – Fig. 3B). This suggests a moderate positive relationship, typically applied to coefficients between 0.3 and 0.49 (Cohen 1988), indicating that while temperature may influence forest cover loss, other factors might be more directly associated with the forest loss observed in the region.

The strong correlation between wildfires and forest cover loss ($r = 0.837$) underscores the importance of integrating fire prevention into conservation strategies. Educational campaigns and community-based initiatives, particularly in schools and communities near Caparaó National Park, can be highly effective in mitigating fire impacts (Gobbo et al. 2016, Neves et al. 2021).

While the correlation between maximum temperature and forest cover loss was moderate and not statistically significant ($r = 0.422$, $p = 0.2249$), the results suggest that drier and warmer conditions increase fire risk, particularly during events such as the 2015 El Niño, which heightened fire susceptibility in southeastern Brazil (Silva et al. 2022, Clemente et al. 2017). Overall, proactive prevention and robust forest monitoring are crucial for mitigating wildfires and conserving forest cover in the Caparaó microregion.

The historical data from 2012 to 2021 shows that maximum temperatures remained relatively stable through time, averaging around 40 °C and showing a peak in 2015 (Fig. 4). Annual precipitation, however, fluctuated more significantly, with the lowest rainfall recorded in 2015, the same year that experienced the highest maximum temperature. This combination of high temperature and low rainfall in 2015 led to extremely arid conditions, increasing the fire risk in the region.

High maximum temperatures, particularly in combination with low rainfall, amplify fire risk by reducing relative humidity and drying vegetation, making it more combustible (Silva et al. 2022). Analysis of precipitation from 2012 to 2021 reveals that 2015 was an unusually arid year, with only 876.66 mm of rainfall, exacerbated by high temperatures associated with a strong El Niño event. These conditions intensified fire risks in southeastern Brazil, stressing the importance of climate monitoring in fire prevention efforts (Clemente et al. 2017).

In response to recurring fire risks, national policies, such as the Brazilian Forest Code, mandate responsible fire management and wildfire prevention, which are crucial to protecting forest ecosystems. Local programs, such as PRAVALER and the Municipal Atlantic Forest Plans, focus on

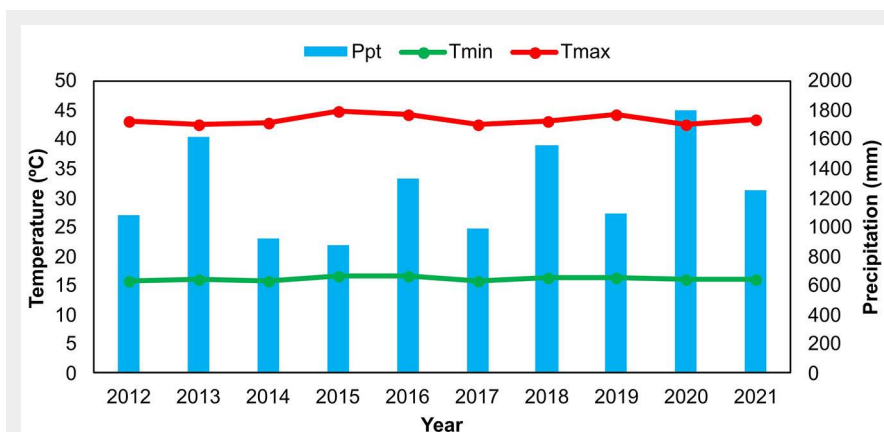


Fig. 4 – Trends in precipitation (ppt) and maximum (Tmax) and minimum (Tmin) temperature in the Caparaó microregion, state of Espírito Santo, Brazil, during the study period.

restoring native forest cover and enforcing the Atlantic Forest Law at the municipal level (Santos et al. 2019).

These strategies, supported by environmental laws and proactive restoration efforts, are crucial for enhancing forest resilience and mitigating fire impacts, which will be increasingly vital as climate change intensifies.

Conclusion

Despite the area affected by fires, an overall increase in forest cover was observed over the study period. These findings indicate that, despite the damage caused by fires, recovery and reforestation efforts have positively impacted forest ecosystems, highlighting the vital role of conservation and restoration initiatives in enhancing the resilience of forest ecosystems. This reinforces the value of projects aimed at restoring the Atlantic Forest in Espírito Santo, such as the Reflorestar Program. However, it is essential to maintain consistent monitoring and implement measures to prevent and combat wildfires, thereby protecting forest areas and reducing future risks. As climate conditions become increasingly extreme, ecosystems become more vulnerable and fragile, stressing the need for proactive management and protection strategies.

Acknowledgments

DS conceived the idea, drafted and revised the manuscript, GB processed the data and helped draft the manuscript, NM processed the data and helped draft the manuscript, ES helped process the data, CV helped draft the manuscript, JM helped draft the manuscript, TF helped draft the manuscript.

The authors thank the Federal University of Espírito Santo for its support.

This research did not receive any specific subsidies from funding agencies in the public, commercial, or non-profit sectors.

References

- Aragão L, Malhi Y, Roman-Cuesta RM, Saatchi S, Anderson LO, Shimabukuro YE (2007). Spatial patterns and fire response of recent Amazonian droughts. *Geophysical Research Letters* 34: 1-5. - doi: [10.1029/2006GL028946](https://doi.org/10.1029/2006GL028946)
- Aragão LEOC, Anderson LO, Fonseca MG, Rosan TM, Vedovato LB, Wagner FH, Silva CVJ, Silva Junior CHL, Arai E, Aguiar APD, Barlow J, Berenguer E (2018). 21st century drought-related fires counteract the decline of Amazon deforestation carbon emissions. *Nature Communications* 9: 536. - doi: [10.1038/s41467-017-02771-y](https://doi.org/10.1038/s41467-017-02771-y)
- Ault TR (2020). On the essentials of drought in a changing climate. *Science* 368: 256-260. - doi: [10.1126/science.aaz5492](https://doi.org/10.1126/science.aaz5492)
- Baião CFP, Santos FC, Ferreira MP, Bignotto RB, Silva RFG, Massi KG (2023). The relationship between forest fire and deforestation in the southeast Atlantic rainforest. *PLoS One* 18 (6): e0286754. - doi: [10.1371/journal.pone.0286754](https://doi.org/10.1371/journal.pone.0286754)
- Boslaugh S (2013). *Statistics in a nutshell: a desk-top quick reference* (2nd edn). O'Reilly, Beijing, China, pp. 569.
- Camelo MC, Coelho MAN, Leoni LS, Temponi LG (2020). *Araceae do Parque Nacional do Caparaó, MG-ES, Brasil* [Araceae from Caparaó National Park, MG-ES, Brazil]. *Rodriguésia* 71: e01742018. [in Portuguese] - doi: [10.1590/2175-7860202071065](https://doi.org/10.1590/2175-7860202071065)
- Clemente SS, Oliveira Júnior JF, Louzada MAP (2017). Fire focus in the Atlantic Forest of the State of Rio de Janeiro. *Revista Brasileira De Meteorologia* 32: 669-677. - doi: [10.1590/0102-7786324014](https://doi.org/10.1590/0102-7786324014)
- Cohen J (1988). *Statistical power analysis for the behavioral sciences* (2nd edn). Routledge, New York, USA, pp. 590.
- Dutra GJA (2019). A relação socioambiental no Alegre - microrregião do Caparaó a partir do século XIX e no projeto plantadores de água (2013-2015): uma análise de história ambiental [The socio-environmental relationship in Alegre - Caparaó micro-region from the 19th century and in the "Water Planters" project (2013-2015): an environmental history analysis]. MSc. thesis, Federal Institute of Espírito Santo, Alegre, ES, Brazil, pp. 120. [in Portuguese]
- Eugenio FC, Santos AR, Fiedler NC, Ribeiro GA, Silva AG, Santos AB, Paneto GG, Schettino VR (2016). Applying GIS to develop a model for forest fire risk: a case study in Espírito Santo, Brazil. *Journal of Environmental Management* 173: 65-71. - doi: [10.1016/j.jenvman.2016.02.021](https://doi.org/10.1016/j.jenvman.2016.02.021)
- Figueiredo Filho DB, Rocha EC, Silva Júnior JA, Paranhos R, Neves JAB, Silva MB (2014). Desvendando os mistérios do coeficiente de correlação de Pearson: o retorno [Unraveling the mysteries of Pearson's correlation coefficient: the return]. *Cadernos de Pesquisa Política* 8: 66-95. [in Portuguese]
- Fiores CHU, Silva IM, Valadão PC, Abreu RE, Torres H (2018). Estimativa de riscos de incêndio florestal em três municípios do Espírito Santo por dois métodos, em comparação com os índices de floresta nativa [Estimation of forest fire risks in three municipalities of Espírito Santo using two methods, in comparison with native forest indices]. *Cadernos Camilliani* 15: 636-653. [in Portuguese] [online] URL: <http://www.saocamilo-es.br/revista/index.php/cadernoscamiliani/article/view/348>
- Firmansyah IL, Wati AI, Sari IP, Syifa AM, Radianto DO (2024). Dampak perubahan iklim dapat meningkatnya kebakaran hutan dan upaya pelestarian lingkungan [The impact of climate change can increase forest fires and environmental conservation efforts.]. *Globe: Publikasi Ilmu Teknik, Teknologi Kebumihan, Ilmu Perkapalan* 2 (2): 88-100. [in Indonesian] - doi: [10.61132/globe.v2i2.251](https://doi.org/10.61132/globe.v2i2.251)
- Flannigan M, Cantin AS, De Groot WJ, Wotton M, Newbery A, Gowman LM (2013). Global wildland fire season severity in the 21st century. *Forest Ecology and Management* 294: 54-61. - doi: [10.1016/j.foreco.2012.10.022](https://doi.org/10.1016/j.foreco.2012.10.022)
- Garbin ML, Saiter FZ, Carrijo T, Peixoto AL (2017). Breve histórico e classificação da vegetação capixaba [Brief history and classification of vegetation in Espírito Santo]. *Rodriguésia* 68: 1883-1894. [in Portuguese] - doi: [10.1590/2175-7860201768521](https://doi.org/10.1590/2175-7860201768521)
- Geobases (2017). *Microrregiões do estado do Espírito Santo* [Microregions of the State of Espírito Santo]. Incaper, Vitória, Brazil, pp. 1. [online] URL: http://geobases.s3.es.gov.br/public/divisao_administrativa_es/microrregioes.pdf
- Gobbo SDA, Garcia RF, Amaral AA, Eugenio FC, Alvarez CRS, Luppi ASL (2016). Uso da terra no entorno do PARNA-Caparaó: preocupação com incêndios florestais [Land use around PARNACaparaó: concerns about forest fires]. *Floresta e Ambiente* 23: 350-361. [in Portuguese] - doi: [10.1590/2179-8087.110114](https://doi.org/10.1590/2179-8087.110114)
- Gomes JM, Carvalho JOP, Ruschel AR, Silva JNM, Ramos EMLS, Castro TC, Costa NSL (2021). Regeneração natural de espécies ameaçadas de extinção em áreas experimentais na Amazônia oriental [Natural regeneration of endangered species in experimental areas in Eastern Amazonia]. *Bio Brasil* 11: 1-11. [in Portuguese] - doi: [10.37002/biobrasil.v11i3.1658](https://doi.org/10.37002/biobrasil.v11i3.1658)
- Guedes BJ, Massi KG, Evers C, Nielsen-Pincus M (2020). Vulnerability of small forest patches to fire in the Paraíba do Sul River Valley, southeast Brazil: implications for restoration of the Atlantic Forest biome. *Forest Ecology and Management* 465 (16): 118095. - doi: [10.1016/j.for-eco.2020.118095](https://doi.org/10.1016/j.for-eco.2020.118095)
- IBGE (2022). *Cidades e estados: Espírito Santo*. [Cities and states: Espírito Santo]. Brazilian Institute of Geography and Statistics - IBGE, Brazil, website. [online] URL: <https://www.ibge.gov.br/en/cities-and-states/es.html>
- ICMBIO (2025). *Parque Nacional do Caparaó - História* [Caparaó National Park]. Website. [in Portuguese] [online] URL: <https://www.gov.br/icmbio/pt-br/assuntos/biodiversidade/unidade-de-conservacao/unidades-de-biomas/mata-atlantica/lista-de-ucs/parna-de-caparao/historia>
- IDAF (2023). *Forest fires and the situation in Espírito Santo*. IDAF, Vitória, Brazil, pp. 3. [in Portuguese] [online] URL: <http://idaf.es.gov.br/incendios-florestais-e-a-situacao-do-espirito-santo>
- IPCC (2023). *AR6 synthesis report: climate change 2023*. Website. [online] URL: http://report.ipcc.ch/ar6syrr/pdf/IPCC_AR6_SYR_LongerReport.pdf
- Jones MW, Abatzoglou JT, Veraverbeke S, Andela N, Lasslop G, Forkel M, Smith AJP, Burton C, Betts RA, Van Der Werf GR, Sitch S, Canadell JG, Santin C, Kolden C, Doerr SH, Le Quéré C (2022). Global and regional trends and drivers of fire under climate change. *Reviews of Geophysics* 60 (3): e2020RG000726. - doi: [10.1029/2020RG000726](https://doi.org/10.1029/2020RG000726)
- Jones MW, Kelley DI, Burton CA, Di Giuseppe F, Barbosa MLF, Brambleby E, Hartley AJ, Lombardi A, Mataveli G, McNorton JR, Spuler FR, Wessel JB, Abatzoglou JT, Anderson LO, Andela N, Archibald S, Armenteras D, Burke E, Carmenta R, Chuvieco E, Clarke H, Doerr SH, Fernandes PM, Giglio L, Hamilton DS, Hantson S, Harris S, Jain P, Kolden CA, Kurvits T, Lampe S, Meier S, New S, Parrington M, Perron MMG, Qu Y, Ribeiro NS, Saharjo BH, San-Miguel-Ayán J, Shuman JK, Tanpipat V, Van Der Werf GR, Veraverbeke S, Xanthopoulos G (2024). *State of wildfires 2023-2024*. *Earth System Science Data* 16: 3601-3685. - doi: [10.5194/essd-16-3601-2024](https://doi.org/10.5194/essd-16-3601-2024)
- Karki S, Burton P, Mackey B (2020). The experiences and perceptions of farmers about the impacts of climate change and variability on crop production: a review. *Climate and Development* 12: 80-95. - doi: [10.1080/17565529.2019.160](https://doi.org/10.1080/17565529.2019.160)

- Libonati R, Silva PMA, Peres LF, Silva Junior CHL, Carvalho LA, Rodrigues JA, Garcia LC, Morelli F, Anderson LO, Aragão LEOC (2022). Assessing the role of compound drought and heatwave events on unprecedented 2020 wildfires in the Pantanal. *Environmental Research Letters* 17 (1): 015005. - doi: [10.1088/1748-9326/ac43ab](https://doi.org/10.1088/1748-9326/ac43ab)
- Lima TLB, Oliveira MLR (2022). Dynamics of agrarian systems in Caparaó Capixaba. *Research, Society and Development* 11: e40011730 071. - doi: [10.33448/rsd-v11i7.30071](https://doi.org/10.33448/rsd-v11i7.30071)
- Mapbiomas (2022a). MapBiomas Collection no. 2.0. Web site. [online] URL: <http://mapbiomas.org/>
- Mapbiomas (2022b). MapBiomas Fire Collection no. 7.1. Website. [online] URL: <http://brasil.mapbiomas.org/en/>
- Marengo JA, Souza Junior C (2018). Mudanças climáticas: impactos e cenários para a Amazônia [Climate change: impacts and scenarios for the Amazon]. Alana, São Paulo, Brasil, pp. 33. [in Portuguese]
- Mello CR, Guzman JA, Vieira NP, Viola MR, Beskow S, Guo L, Alvarenga LA, Rodrigues AF (2025). Mitigating severe hydrological droughts in the Brazilian tropical high-land region: a novel land use strategy under climate change. *International Soil and Water Conservation Research* 13 (3): 627-643. - doi: [10.1016/j.iswcr.2025.03.005](https://doi.org/10.1016/j.iswcr.2025.03.005)
- Moore DS, Notz WI (2021). The basic practice of statistics (9th edn). Macmillan Learning, New York, USA, pp. 1889.
- Neves FP, Fiedler NC, Santos AR, Silva ECG, Canzian WP (2021). Incêndios florestais: educação ambiental em prol da prevenção [Forest fires: environmental education for prevention]. *Revista Multidisciplinar de Educação e Meio Ambiente* 2: 17-17. [in Portuguese] - doi: [10.51189/rema/1696](https://doi.org/10.51189/rema/1696)
- Oliveira MS, Ribeiro Neto A, Candido LA, Saemian P (2024). Assessing drought conditions in Northeast Brazil: a comparative analysis of soil moisture, groundwater, and total water storage. *Journal of Hydrology - Regional Studies* 56: 101983. - doi: [10.1016/j.ejrh.2023.101983](https://doi.org/10.1016/j.ejrh.2023.101983)
- QGIS Development Team (2023). QGIS geographic information system. Open Source Geospatial Foundation Project, website. [online] URL: http://docs.qgis.org/3.28/pt_BR/docs/user_manual/processing_algs/qgis/vectoroverlay.html#qgisintersection
- QGIS Project (2023a). Symmetric difference. QGIS documentation 28.1.23.9, website. [online] URL: http://docs.qgis.org/3.34/pt_BR/docs/user_manual/processing_algs/qgis/vectoroverlay.html#qgisymmetricaldifference
- QGIS Project (2023b). Intersection. QGIS Documentation 28.1.23.5, website. [online] URL: http://docs.qgis.org/3.22/pt_BR/docs/user_manual/processing_algs/qgis/vectoroverlay.html#intersection
- Rezende CL, Scarano FR, Assad ED, Joly CA, Metzger JP, Strassburg BBN, Mittermeier RA (2018). From hotspot to hopespot: an opportunity for the Brazilian Atlantic Forest. *Perspectives in Ecology and Conservation* 16: 208-214. - doi: [10.1016/j.pecon.2018.10.002](https://doi.org/10.1016/j.pecon.2018.10.002)
- R Core Team (2023). R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [online] URL: <http://www.r-project.org/>
- Santos JFC, Gleriani JM, Velloso SGS, Souza GSA, Amaral CH, Torres FTP, Reis M (2019). Wildfires as a major challenge for natural regeneration in Atlantic Forest. *Science of The Total Environment* 650: 809-821. - doi: [10.1016/j.scitotenv.2018.09.016](https://doi.org/10.1016/j.scitotenv.2018.09.016)
- SEAMA (2023). O que é o Reflorestar? [What is Reflorestar?]. Secretaria do Meio Ambiente e Recursos Hídricos - SEAMA, Governo do Estado do Espírito Santo, Brasil, Website. [in Portuguese] [online] URL: http://seama.es.gov.br/o_que_e_reflorestar
- SEAG (2017). 1º Encontro Estadual de Secretários Municipais de Agricultura e Meio Ambiente [1st State Meeting of Municipal Agriculture and Environment Secretaries]. Website. [in Portuguese] [online] URL: <https://seag.es.gov.br/Media/seag/Documentos/5>
- Silva EM, Vasconcelos FL, Costa AA (2022). Nexo entre a climatologia de precipitação e as ocorrências de incêndios em vegetação nos municípios ao longo da Rodovia CE-060 - Região de interesse econômico do Estado do Ceará [Link between precipitation climatology and occurrences of vegetation fires in municipalities along the CE-060 Highway - Region of economic interest in the State of Ceará]. *Revista Brasileira Meteorologia* 37: 467-475. [in Portuguese] - doi: [10.1590/0102-77863740080](https://doi.org/10.1590/0102-77863740080)
- Singh M, Huang Z (2022). Analysis of forest fire dynamics, distribution and main drivers in Atlantic Forest. *Sustainability* 14 (2): 992. - doi: [10.3390/su14020992](https://doi.org/10.3390/su14020992)
- SOS Mata Atlântica/INPE (2021). Atlas dos remanescentes florestais da Mata Atlântica: período 2018-2019: relatório técnico [Atlas of the Atlantic Forest remnants. 2018-2019 period: technical report]. SOS Mata Atlântica, São Paulo, SP, and Instituto Nacional de Pesquisas Espaciais - INPE, São José dos Campos, SP, Brazil, pp.39. [online] URL: http://cms.sosma.org.br/wp-content/uploads/2021/05/SOSMA_Atlas-da-Mata-Atlantica_2019-2020.pdf
- Viana AS (2020). Programa Reflorestar: uma alternativa de combate ao desmatamento através do desenvolvimento sustentável [Reflorestar Program: an alternative to combat deforestation through sustainable development]. *Revista Científica Multidisciplinar Núcleo do Conhecimento* 5: 83-94. [in Portuguese. [online] URL: <http://www.nucleodoconhecimento.com.br/meio-ambiente/programa-reflorestar>
- Xavier AC, Scanlon BR, King CW, Alves AI (2022). New improved Brazilian daily weather gridded data (1961-2020). *International Journal of Climatology* 42: 8390-8404. - doi: [10.1002/joc.7731](https://doi.org/10.1002/joc.7731)
- Zhang N, Wang H, Gallagher J, Song Q, Tam WWY, Duan H (2020). A dynamic analysis of the global warming potential associated with air conditioning at a city scale: an empirical study in Shenzhen, China. *Environmental Impact Assessment Review* 81: 106354. - doi: [10.1016/j.eiar.2019.106354](https://doi.org/10.1016/j.eiar.2019.106354)