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Article

The multifaceted importance of mediterranean pine-tree forests to social cohesion. Energy, resin, grazing, and wildfire management in North Euboea, Greece

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Abstract: Forests are essential not only for their ecological roles but also as invaluable natural resources supporting biodiversity, climate regulation, and human livelihoods. In Mediterranean regions, pine-tree forests are particularly susceptible to intense wildfires, which pose significant challenges to containment and long-term forest health. This study focuses on the pine-tree forests of North Euboea, examining their embedded energy, natural regenerative capacity, and sustainable management approaches. Key aspects investigated include the forest's contributions to biomass and resin productivity, the social and economic impacts of wildfire events, and the role of managed grazing as a proactive tool in fire prevention and forest stewardship. Our analysis highlights the potential benefits of grazing as a strategic measure to manage forest biomass levels, thereby reducing the fuel load and lowering the intensity of possible future fires. Grazing is also shown to support broader access across the forest landscape, allowing firefighting forces to respond more effectively in case of a fire outbreak. By utilizing grazing to maintain forest ecosystems beyond just the periphery, this approach can enhance both ecological resilience and community cohesion in regions vulnerable to forest fires. The study underscores the need for integrated management practices that balance forest use with conservation, leveraging grazing as a means to sustain the health and accessibility of Mediterranean pine-tree forests.

Keywords: pine-tree forest resilience; wildfire mitigation; forest grazing; biomass energy potential; community fire protection strategies; energy self-sufficiency; human progress

1. Introduction

From prehistorical times, humans sought available energy. The first use of energy by humans was biomass, while gradually solar and wind energy sources were incorporated during antiquity. After 1800, various other energy sources were introduced into the energy mix. Although other sources are more systematically utilized in modern societies, biomass still contributes around 6% to the energy mix [1].

In North Euboea, the frequency of natural disasters—such as wildfires, storms, and disease outbreaks of plane trees—poses significant threats to forest ecosystems and the communities that rely on them. These events not only impact forest biomass and biodiversity but also disrupt local livelihoods dependent on forest resources, such as resin production, the use of the forest's biomass, and grazing of the livestock. Considering these challenges, this study aims to explore sustainable forest management strategies, focusing on managed grazing as a means to reduce fire fuel loads, support ecosystem resilience, and enhance social cohesion within communities in fire-prone areas.

In the developed world, the forest is considered a valuable natural resource that is protected due to its ecological value, its ecosystems, and its aesthetics [2,3]. Biomass is not the first choice for energy utilization because forests' exploitation involves intervention, and there is a fear of causing problems in the stability of the complex ecosystem's functioning [4].

However, even though pine-tree forests (typically Aleppo pine in the Mediterranean region) are protected and undergo minimal interventions, they inherently contain the potential for self-destruction. The biomass from pine trees contains 18–20 MJ/kg [5], and each hectare of pine-tree forest (over 40 years old) contains 100–200 t/ha, 1800–3600 GJ/ha, depending on environmental and soil conditions. Due to its high energy density, under specific conditions, the magnificent pine tree forest can be transformed into a threat to itself and to the communities at its borders through wildfires.

In order to reduce the threat of wildfires, it is crucial to decrease the fire's potential, which can be achieved by reducing the forest's energy density and empowering forest accessibility. A natural and effective method is through livestock farming and grazing in the forests.

To understand the impact of grazing on forests, the region of North Euboea was selected, specifically the Municipality of Mandoudi-Limni-Agia Anna, an area covered by a large expanse of (grazed and non-grazed) forests and which, in recent years, has suffered a series of natural disasters.

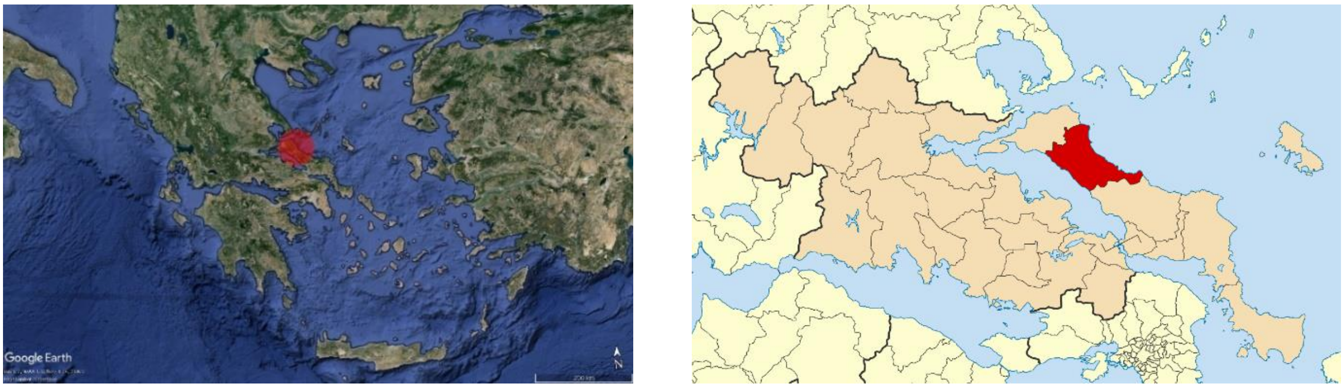
The study examines the available biomass in the area, its regenerative capacity, and its management. Data were collected from local residents engaged in forestry and livestock farming, verified through international literature, on-site measurements, and aerial surveillance of the area using drones. It's worth noting that the data contain uncertainties related to soil quality, forest orientation, and other environmental parameters. However, given the highly fertile soils in the study area, substantial annual rainfall [6], and observations exceeding average values reported in literature, conservative estimates will be based on the mid-range values provided.

While literature often emphasizes forest protection through the prohibition of grazing by goats and sheep [7,8] an alternative hypothesis favors human-managed grazing and cultivation of forests [9–16]. An introduction to this recovery process is given by Savory and his method, "Managing the complexities of land & livestock" [17]. Through on-site measurements and visual evidence, in this study we verify Savory's method, which assumes that forest grazing benefits growth, naturally thins the forest, makes it accessible and exploitable by humans, and provides protection against wildfires. Additionally, it highlights that a rational use of forest could become a sustainable energy source, which can empower the energy self-sufficiency of the area [18,19].

These issues can stabilize the social cohesion, which is broadly defined as the capacity of a society to ensure the prosperity of all its members [20]. Social cohesion was jeopardized in 2021, when a wildfire burned a major part of the forest, which was vital to the inhabitants [21]. It is noted that approximately 800 people (almost 7% of the inhabitants of the area) were employed in collective resin by pine trees of the forest and found themselves unemployed after the destructive wildfire. In the context of fire-prone Mediterranean regions, social cohesion is not only essential for recovery and resilience but also for the proactive engagement of communities in sustainable forest management practices. Therefore, we present examines how managed grazing contributes to social cohesion by creating employment opportunities, preserving traditional practices, and enhancing the accessibility and resilience of forest ecosystems.

2. Case study area

The study area is the Municipality of Mantoudi-Limni-Agia Anna in North Euboea. It was chosen because in recent years, it has experienced successive natural disasters such as plane tree disease (2017-present), storm Zorbas (2018), wildfire (2021) [21], and storms Daniel-Elias [22]. The municipality consists of 48 settlements, and according to the 2021 census, it has a population of 12,235 residents. It is a typical rural area with the highest land coverage being pine-tree forest (**Figure 1**).



(a) **(b)**

Figure 1. (a) North Euboea [23]; **(b)** municipality of mantoudi-limni-agia Anna.

3. Methodology

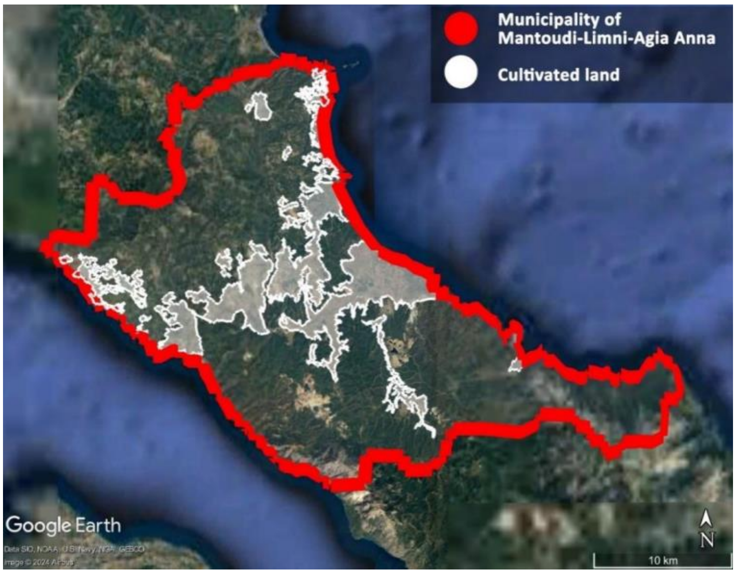


Figure 2. Municipality of Mantoudi-Limni-Agia Anna and cultivated land [23].

For the study of the area, available spatial data from Corine Land Cover (CLC) [24] were initially used. For a more recent and detailed analysis of land uses in the Municipality of Mantoudi-Limni-Agia Anna, land use was quantified into the following categories: high-intensity agriculture, low-intensity agriculture, tree crops (such as olives), forests, and other uses by detailed observations using Google Earth imagery (**Figure 2**).

Land use within the Municipality of Mantoudi-Limni-Agia Anna predominantly consists of pine-tree forests, which cover approximately 83.9% of the area, with smaller portions dedicated to high- and low-intensity agriculture (4.6% and 6.6%, respectively) and tree crops such as olives (5%). This distribution highlights the region's significant forest coverage, underscoring the importance of effective forest management strategies to mitigate wildfire risks and support the local economy. The total cultivated area today is estimated at 9341.5 hectares, and the area of forests is estimated at 48,510 ha.

In order to study the dynamics of forest management, interviews were conducted with professionals in the area who are involved in logging, forest cultivation, and livestock. These interviews aimed to determine the forest biomass and livestock grazing dynamics in the region. It's important to note that the data contain significant uncertainty, as forest development depends on soil quality, orientation, and environmental conditions. Therefore, the results are presented in order of magnitude.

From the collected data, values were verified using expected values from international literature. Field visits and measurements were conducted in forests within the area, including drone surveys. Quantities calculated for the entire forest in the region allowed estimation of the forest's energy content before the 2021 wildfire and its current state. Additionally, an approximation of the forest's energy efficiency was made, considering a dynamic approach to good management practices.

Furthermore, through visual imagery obtained from drone surveys, we draw conclusions about the impact of goat and sheep grazing on forests and explore how grazing could benefit their rational management. Furthermore, we analyze how an optimized management practice of the forest could add a positive mark to social cohesion [25].

4. The forest biomass

4.1. Distribution and biomass growth

The pine tree forests in the area provide firewood and resin. Few private and cooperative forests are used for grazing.

The growth of a pine tree [26–29] can be categorized into the following stages:

- Establishment Phase (0–5 years): Slow growth as the tree focuses on root development and adaptation to its environment. Growth Rate: Relatively slow in height and diameter.
- Youth Growth Phase (5–20 years): Rapid growth as the tree enters a period of vertical growth, with significant increases in height and diameter. Growth Rate: Exponential or nearly exponential, especially in height.
- Maturity Phase (20–50 years): Growth slows down as the tree approaches its maximum height. Diameter growth may continue at a steady rate, but height

growth decelerates. Growth Rate: Linear, gradually slowing down.

- Senescence Phase (50+ years): Minimal growth. Height increase largely stops, but diameter growth may continue at a very slow pace. Growth Rate: Slow; height stabilizes, and diameter growth is minimal.

The biomass in a Mediterranean pine-tree forest can vary significantly based on factors such as species, soil quality, climate, and forest management practices.

A general analysis of biomass accumulation over time for a typical Mediterranean pine-tree forest [30–32], dominated by species like Aleppo Pine, is as follows:

- 0–10 years: Relatively low. Young pines focus on root establishment and have small trunks and branches, yielding around 1-10 tons per hectare.
- 10–20 years: Rapid growth as trees enter the youth development phase, yielding approximately 10–40 tons per hectare.
- 20–40 years: Trees mature, with significant increases in trunk diameter and crown size, yielding around 40-100 tons per hectare.
- 40–60 years: Growth slows down as the forest reaches maturity. Diameter continues to increase, but height growth decelerates, yielding approximately 100–200 tons per hectare.

In the region, forests fall into three categories, marked in red in the image:

- Category 1: Young forest burned in 2021 (3 years old).
- Category 2: Developing forest burned in 2006 (18 years old).
- Category 3: Mature forests over 60 years old (no recorded fire in collective memory).

Figure 3 shows the growth rate of a pine tree (the orange line represents height, the blue dashed line represents diameter, and the green area indicates biomass range).

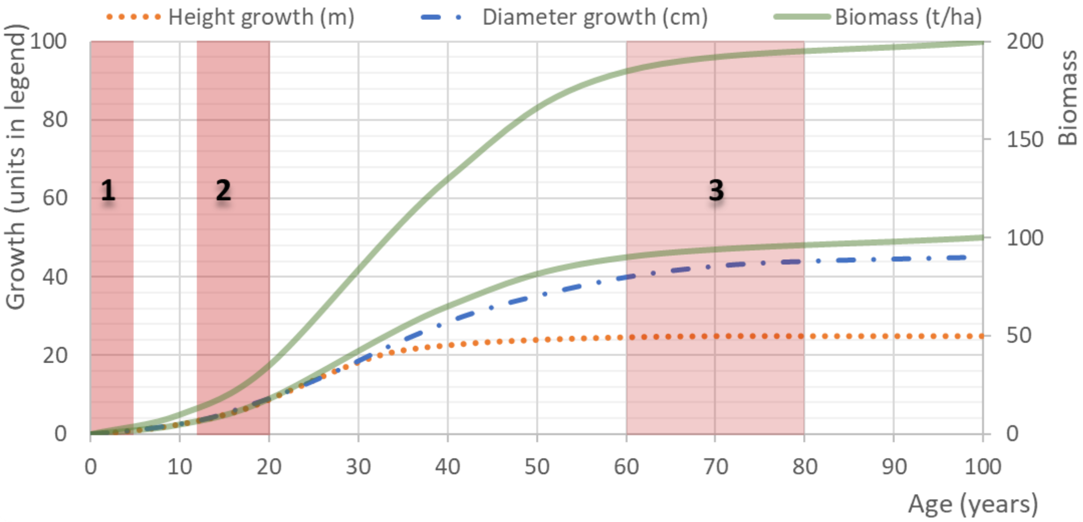


Figure 3. Indicative growth rate of a pine tree and biomass accumulation of a one-hectare pine-tree forest.

In the study area, forests can be categorized into three types, highlighted in red in **Figure 3**:

- Category 1: Young forests that were burned in 2021 (3 years old) (**Figure 4** and **Figure 5**).
- Category 2: Developing forests that were burned in 2006 (18 years old) (**Figure 6**).

- Category 3: Mature forests older than 60 years (no recorded fire in the collective memory of residents) (**Figures 7** and **8**).

Figure 4. Category 1 (young forest) of diagram in **Figure 3**. No grazing occurs. Coordinates 38°49′5.19″ N; 23°26′40.75″ E.

Figure 5. Category 1 (young forest) of diagram in **Figure 3**. Grazing occurs. Coordinates 38°49′41.01″ N; 23°26′17.19″ E.

Figure 6. Category 2 (developing forests) of diagram in **Figure 3**. No grazing occurs. Coordinates 38°46′26.19″ N; 23°28′17.71″ E.

Figure 7. Category 3 (mature forests) of diagram in **Figure 3**. No grazing occurs. Coordinates 38°46′34.48″ N, 23°28′33.43″ E.

Figure 8. Category 3 (mature forest) of diagram in **Figure 3**. Grazing occurs. Coordinates 38°47′51.97″ N; 23°29′15.11″ E.

The biomass in a pine-tree forest increases with the age of the trees (**Figure 9**). The biomass in a forest can be divided into three main categories: stems, branches, and shrubs. Generally, the distribution of biomass in a pine-tree forest is as follows:

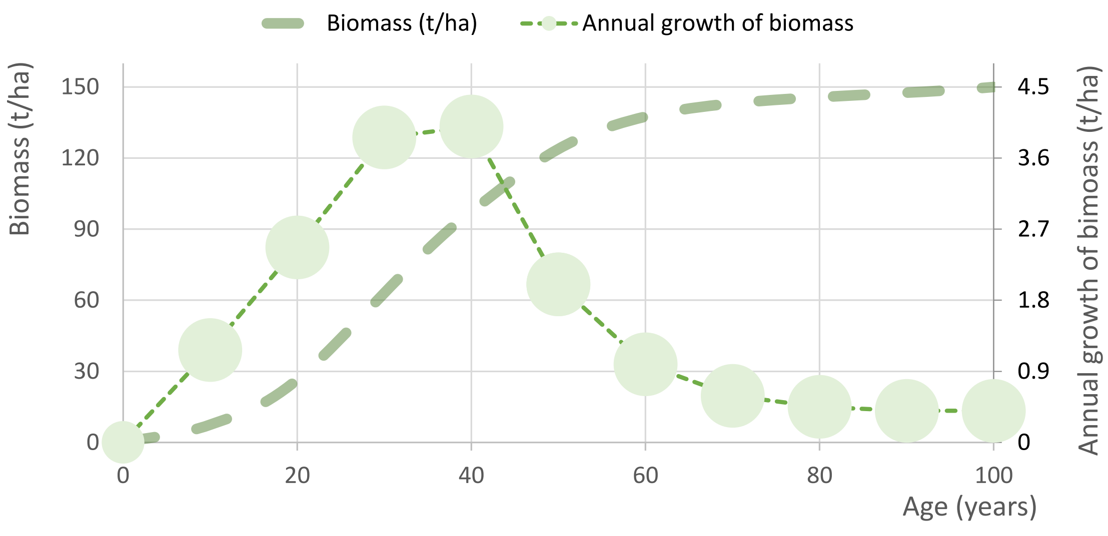


Figure 9. Growth rate of total and annual biomass in a pine-tree forest per hectare.

- Stems: Represent approximately 50%–70% of the total biomass (commonly around 60%).
- Branches: Contribute about 15%–30% of the biomass (typically 30%).
- Shrubs: Account for roughly 5%–20% of the biomass (commonly 10%).

For a one-hectare study area with mature pines (20–40 years old), based on on-site research and interviews with individuals involved in logging and forest cultivation, it is estimated to contain approximately:

- 50 tons of firewood (stem biomass).
- 20 tons of branches.
- 10 tons of shrubby vegetation.

These estimates, extracted from interviews with local forestry and agricultural workers and supplementary data from drone surveys, align with expected values in literature [30–32]. The fastest growth stage of the forest occurs between ages 20–40 years, during which biomass increases from around 25 tons per hectare to approximately 100 tons per hectare.

4.2. Energy calculations

The energy content of one ton of pine-tree forest biomass can vary depending on its moisture content and composition (**Figure 10**). Assuming that the dry wood biomass contains 18–20 MJ/kg (equivalent to 4300–4780 kcal/kg) [5], a 20-40-year-old forest contains 97.5 t/ha, which can yield 1755 GJ/ha (42 toe/ha). Before the 2021 wildfire, the study area's forests contained a total of 85,135,928 GJ (2,034,311 toe).

Figure 10. Biomass. Trunks from recent forest logging.

The 20-40-year-old forest grows annually at a rate of approximately 3.5–4 tons per hectare, contributing 63–72 GJ/ha per year. With proper management, the 20-40-year-old forest in the study area is estimated to yield 3,056,162–3,492,756 GJ per year.

However, it's important to note that approximately 72% of the study area's forest was burned in the 2021 wildfire [21]. The red-shaded area in **Figure 11** indicates the burned regions.

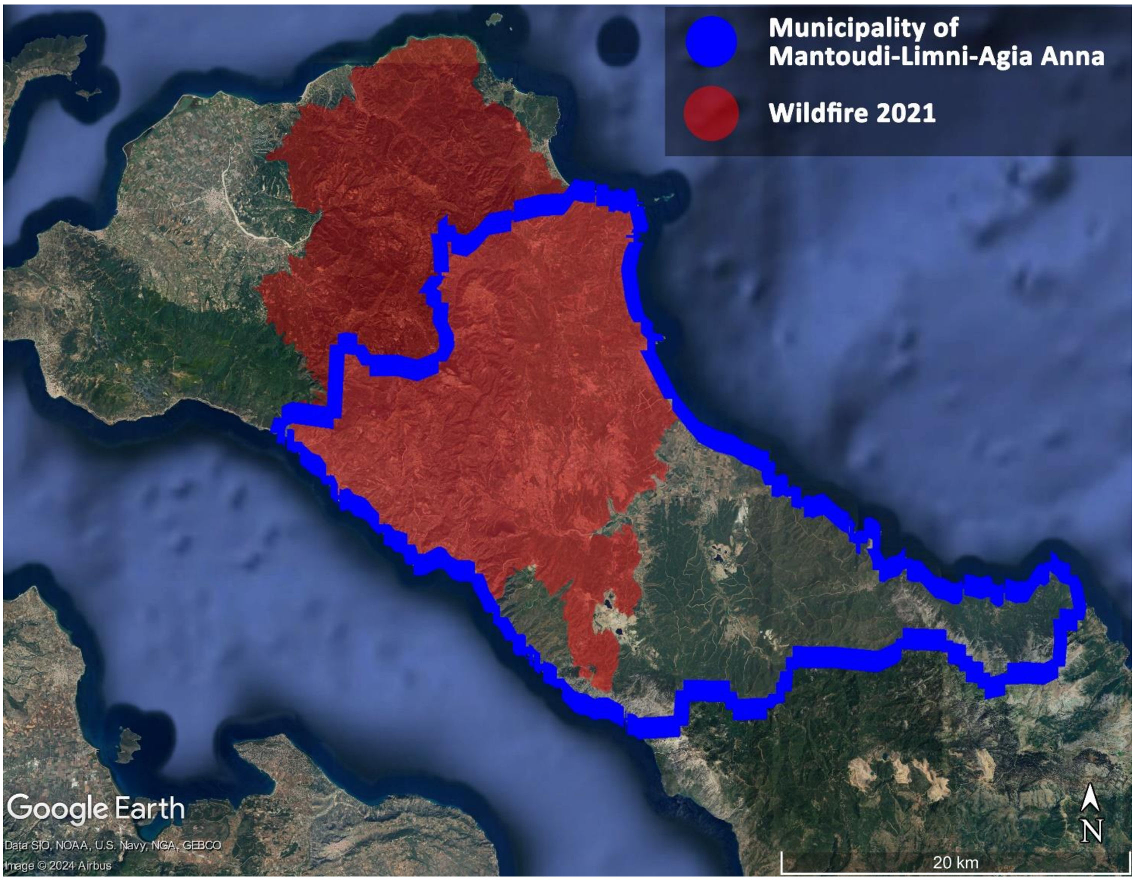


Figure 11. Municipality of Mandudi-Limni-Agia Anna and the area of wildfire (2021) [21].

The study area's forests, after the 2021 fire, contained only burned tree stems, which account for 50% of the total pine-tree forest biomass. After the wildfire, the available biomass in the burned forest area is estimated at 0.5×97.5 t/ha or 877 GJ/ha. Therefore, post-wildfire, the biomass contained in the forest was:

$$30{,}648{,}934 \text{ GJ/ha } (burned\ forest) + 23{,}838{,}060 \text{ GJ/ha } (non\ burned) = 54{,}486{,}994 \text{ GJ/ha}$$

Today, the available annual biomass in forests older than 20 years is estimated solely from the non-burned forest and ranges from 855,000 to 977,000 GJ/year (20,430–23,350 toe/year).

As a reference, an average Greek individual consumes 30,000 kWh/year of primary energy (equivalent to 108 GJ/year) across various forms of energy [33,34]. If we consider an efficiency rate of 30% [35], the available electrical energy that biomass could provide would be 256,500–293,100 GJ/year. Given that the average Greek consumes 5020 kWh/year (18 GJ), this conversion could cover the electricity needs of 15,250 residents [36], which are more than the area's residence (12,235 people) [37].

5. The management of forest

There is a vigorous debate about what constitutes optimal forest management and how proper forest regeneration occurs. In literature [7,8] and Greek legislation, grazing is considered a threat to the regeneration of a pine-tree forest. For this reason, regulatory frameworks have been incorporated into the Greek Constitution [38] (articles 24, 117), the legislative decree of 86/1969 [39] (articles 66, 105, 107, 113, 114), which are replaced by article 60 of Law 4264/2014 [40] that mentions:"An order forbidding grazing, issued ex officio by the forest service, prohibits the grazing of any animal in an area that has been declared reforestable."

European Union, emphasize the role of grazing as a wildfire prevention tool [41]. Although the EU encourages grazing as a protection measure for wildfires, it does not distinguish the importance of supporting livestock that feeds on forest. It is noted that even inhabitants who, in the present, feed their livestock in the forest want to abandon this activity. However, this activity provides an additional employment perspective in a region plagued by unemployment and offers higher quality livestock products compared to those produced in livestock units.

The forests evaluated for the impact of grazing were aged 3 years (category 1 in the diagram of **Figure 3**) and older than 60 years (category 3 in the diagram of **Figure 3**).

Figure 12 depicts forests of category 1 where no grazing occurs, while **Figure 13** shows forests of category 1 where grazing takes place. We observe that in the grazed forest (**Figure 13**), there has been thinning, which happens as the livestock creates paths in the forest. In the non-grazed forest (**Figure 12**), there is no thinning. Based on on-site measurements, we see that in the young, grazed forest, the trees are more developed (approximately 1.5–2 m) compared to the forest where no grazing occurs. Tree height is approximately 0.5–1 m. Additionally, secondary pathways (created by livestock) are evident within the young forest, which will make the entire forest accessible when it matures.

(a)

(b)

Figure 12. Category 1 (young forest) in the diagram of **Figure 3**. No grazing occurs **(a)** General view; **(b)** Pine trees (height approximately 0.5–1 m). Coordinates 38°49′5.19″ N; 23°26′40.75″ E.

(a) (b)

Figure 13. Category 1 in the diagram of **Figure 3**. Grazing occurs **(a)** General view; **(b)** Pine trees (height approximately 1.5–2 m). Coordinates 38°49′41.01″ N; 23°26′17.19″ E.

Figure 7 depicts forests of category 3 where no grazing occurs, while **Figure 8** shows forests of category 3 where grazing takes place. It is noted that in the non-grazed forest of category 3, the ground biomass is at its maximum, and shrubs and low vegetation have created a barrier that restricts access.

6. Discussion—Conclusions

The forest's biomass content serves as a significant energy source with the potential to meet the energy needs of local residents.

Our findings highlight the innovation of managed grazing in forest management, where grazing not only naturally thins the forest to reduce fire fuel loads but also creates secondary pathways that act as natural firebreaks. This approach offers a proactive and sustainable alternative to traditional forest thinning techniques, enhancing both fire resilience and accessibility. In addition, the mature forest (20–40 years old) that existed before the wildfire of 2021 in North Euboea was a valuable economic resource for the broader area. It was cultivated for resin production, yielding 200–300 kg/ha annually. However, the forest's inaccessibility due to the absence of grazing led to cultivation primarily at the forest edges, rather than its entirety. Despite this, approximately 800 people (almost 7% of the inhabitants of the area) were employed in this sector. After the devastating 2021 wildfire, very few resin cultivators remain.

The forest wildfires not only destroyed valuable biomass but also hindered the forest's regeneration, as in the first years of establishment, the biomass of the forest increases very slowly. Additionally, wildfire-impacted resin collection (**Figure 14**), which relies on mature pine trees, and will take 20–40 years to recover.

Figure 14. Resin collection from pine trees in the study area.

In category 3 of **Figure 3**, forests where no grazing occurs (**Figure 7**), low vegetation acts as a barrier, limiting access during potential wildfires. Conversely, grazed forests in category 3 (**Figure 8**) maintain natural thinning, resulting in restricted biomass at the forest base (5–20% less), enhancing fire protection.

The forest destroyed by the 2021 wildfire was a valuable energy and economic resource for the local communities. Rational forest management, including secondary pathways created through grazing and natural thinning, could enhance fire protection and sustainable biomass utilization in the young forest. Such systematic management would also contribute to the region's energy self-sufficiency, providing the conservation of this valuable natural source, which has an important role in social cohesion.

As observed in this study, managed grazing serves not only as an ecological tool for reducing fire fuel loads but also as a socio-economic catalyst for enhancing social cohesion. Grazing creates secondary pathways that act as firebreaks and support access to remote forest areas, strengthening community engagement in wildfire prevention strategies. Furthermore, the employment opportunities generated by livestock farming and the production of higher-quality products reinforce the socio-economic fabric of rural areas.

However, the European Union's focus on grazing as a fire prevention measure overlooks its broader social implications. Policies that fail to account for the employment and traditional practices tied to forest grazing risk undercutting opportunities to enhance social cohesion. By integrating such dimensions, grazing policies could better align with the dual goals of ecological resilience and the prosperity of the community.

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