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Evaluation method for selecting the most suitable intensity of silvicultural intervention in relation with the estimated reduction in combustion energy load within a forest ecosystem

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INTRODUCTION & AIM

Wildfires represent an increasing threat to forest ecosystems, particularly exacerbated by climate change, which intensifies conditions of aridity and flammability. This study examines a *Pinus pinea* forest stand in the Mediterranean area, where managing fuel loads is crucial for wildfire prevention and risk reduction. Effective management of fuel loads is one of the few modifiable factors available to reduce both the intensity and hazard of wildfires. The research proposes a quantitative methodology to assess the effectiveness of silvicultural interventions in reducing combustion energy. This approach provides a robust tool for forest managers. Furthermore, by reducing potential combustion energy, the method also contributes to significant water conservation, which is essential for combating large-scale fires. Integrating the resultant data with Q-GIS software enhances the visualization and planning of intervention strategies, supporting more sustainable and effective forest management practices.

The aim of this study is to develop a forest management methodology that enables the selection of the optimal intensity of silvicultural interventions to minimize combustion energy load within a forest ecosystem. This method is designed not only to prevent or mitigate wildfires by providing a scientific basis for determining thinning intensity but also to conserve water resources that would otherwise be required for fire suppression. By achieving a balance between ecological health, wildfire prevention, and water resource efficiency, the proposed methodology seeks to enhance overall forest management practices.

METHOD

The methodology consists of measuring the tree volume within a designated sample area, assessing the volumetric difference per square meter before and after the intervention, and calculating the volume of aboveground biomass removed based on the specific wood density of the target species. The higher heating value of the species is determined and multiplied by the volume of removed biomass and its specific weight. By applying Byram's equation to compare pre- and post-intervention values, the variation in flame front intensity can also be evaluated. Additionally, the study calculates the kilograms per square meter of water saved post-intervention compared to what would be needed to extinguish a full-scale forest fire.

Sum Volumes (m^3)	
908,948406	
Sum Volumes m^3 * 1 hectare	
9089484,06	
Sum Volumes (m^3 * 1ha) / Survey Area (m^2)	
151,491401	m^3/ha
Specific weight *Pinus pinea* t/m^3	
0,62	t/m^3
Specific weight *Pinus pinea* t/m^3*1kg	
620	kg/m^3
Aboveground biomass potentially susceptible to wildfire = Sum Volumes (m^3) * Spec. weight *Pinus pinea* (kg/m^3)	
93924,66862	kg/ha
Aboveground biomass potentially susceptible to wildfire = Sum Volumes (m^3) * Spec. weight Pinus pinea (kg/m^2) / 1m^2	
9,392466862	kg/m^2
Higher calorific value *Pinus pinea* kcal/kg	
4252,5	kcal/kg
Higher calorific value *Pinus pinea* kcal/kg *1 kJ	
17800,965	kJ/kg
Calorific energy NOT subtracted from the forest ecosystem = Be (kg/m^2) * PcalS (kJ/kg)	
167194,9739	kJ/m^2
Fire Extinguishing Formula (Marotta & Mossa Verre 1998):	
Previous water contribution NOT saved before the silvicultural intervention to extinguish the potential fire affecting the entire pine forest	
AH2O = Ecal/βΔhw	
171,3063257	kg/m^2
171306,3257	g/m^3

Sum Volumes post-silvicultural intervention (m^3)	
832,7727011	
Sum Volumes m^3 * 1 hectare	
8327727,011	
Sum Volumes (m^3 * 1ha) / Survey Area (m^2)	Post-silvicultural intervention of interlayer thinning at T=10 years with chopping intensity of 20% = (60/20*100) = 12 thinned out plants
138,7954502	m^3/ha
Volume difference removed after silvicultural intervention	
12,69595081	m^3/ha
Specific weight Pinus pinea t/m^3	
0,62	t/m^3
Specific weight Pinus pinea t/m^3*1kg	
620	kg/m^3
Aboveground biomass removed post-silvicultural intervention (m^3/ha) * Peso spec.Spec. weight Pinus pinea (kg/m^3)	
7871,4895	kg/ha
Aboveground biomass removed post-silvicultural intervention (m^3/ha) * Peso spec.Spec. weight Pinus pinea (kg/m^3) / 1 m^2	
0,78714895	kg/m^2
Higher calorific value Pinus pinea kcal/kg	
4252,5	kcal/kg
Higher calorific value Pinus pinea kcal/kg *1 kJ	
17800,965	kJ/kg
Removed Calorifc Energy from the forest ecosystem = Be (kg/m^2) * PcalS (kJ/kg)	
14012,01091	kJ/m^2
Fire Extinguishing Formula (Marotta & Mossa Verre 1998):	$AH_2O = \frac{E_{cal}}{\beta \Delta h_w}$
Water Contribution Saved after-silvicultural intervention	AH2O = Quantity of water needed to absorb the heat energy produced during combustion; Ecal = Calorific energy (kJ/m^2); β = efficency coefficient = 0,4 (*Delle Chiaie, 1979*); Δhw = latent heat of evaporation of water 100°C = 2440 kJ/kg
AH2O = Ecal/βΔhw	
14,35656855	kg/m^2
14356,56855	kg/m^3

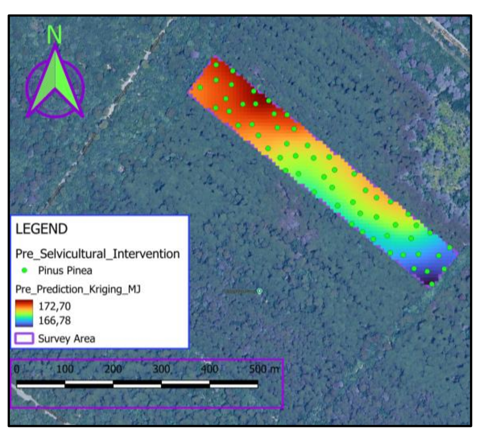

Fig.1 – Geospatial distribution of MegaJoules of thermal energy from sample trees in the study area. The map illustrates the spatial distribution of MegaJoules, calculated using Kriging interpolation, before the silvicultural intervention

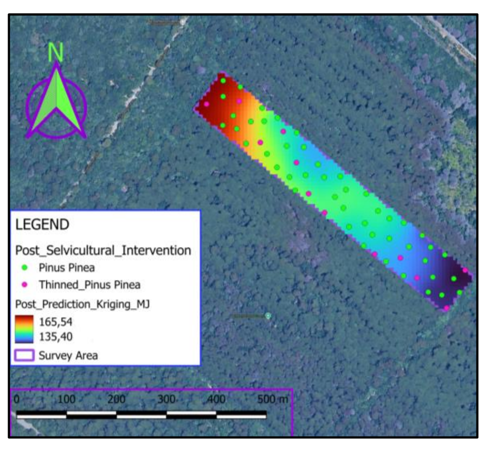

Fig.2 – Geospatial distribution of MegaJoules of thermal energy from sample trees in the study area. The map illustrates the spatial distribution of MegaJoules, calculated using Kriging interpolation, after the silvicultural intervention

RESULTS & DISCUSSION

Significant Results with Limited Intervention:

Reduction of Higher Calorific Potential: The research demonstrated that even with a cutting intensity limited to 20% in the study area, significant results were achieved in reducing the higher calorific potential and water savings. With just 20% cutting intensity, the higher calorific potential decreased by approximately 93400 kJ/m². This shows that even relatively modest interventions can have a substantial impact on reducing the combustible energy load, helping to mitigate the risk of wildfires.

Water Savings: The reduction in combustible load resulted in an estimated water savings of about 1.000 kg/m². This savings reflects the amount of water that would have been necessary to extinguish a fire in the area before the intervention, highlighting the effectiveness of the silvicultural operation in improving resource efficiency during fire emergencies.

Expansion to Larger Areas:
Creation of Firebreaks: The methodology, based on selective and calculated interventions, can be applied on a large scale for the creation of firebreaks. These corridors serve as physical barriers against the spread of wildfires, limiting the available fuel and thus reducing the intensity and speed of fire propagation.
Preventive Management: Expanding the methodology to larger areas would allow for the implementation of preventive and strategic forest management. This approach could be integrated into regional forest management plans, with targeted interventions in the most vulnerable areas to wildfires.

Adaptability to Different Environments:
Specific Weight and Calorific Value: To adapt this methodology to different forest environments, it is essential to have accurate data on the specific weight of the tree species present and their calorific value. These parameters are crucial for precisely calculating the reduction in combustible energy load and for assessing the effectiveness of silvicultural interventions in different ecological contexts.

Benefits of Expansion:
Reduction of Fire Risk: Extending the methodology to larger areas would increase the capacity for prevention, significantly reducing the risk of major wildfires. The large-scale reduction in fuel load would contribute to an overall decrease in the calorific potential within forests.
Conservation of Resources: The approach can optimize the use of water resources, limiting the need for large amounts of water to extinguish fires. Additionally, it could support more sustainable forest management planning, balancing fire prevention with the conservation of biodiversity and ecological health.

CONCLUSION

The proposed methodology optimizes silvicultural interventions to reduce fuel loads and enhance wildfire prevention. It can be applied on a large scale to create **firebreaks** and strategically plan forest management. Adaptable to various forest environments, it improves water resource efficiency. Integration with GIS technologies enhances the precision of operations. Overall, it offers an advanced approach for sustainable and targeted forest management.

FUTURE WORK / REFERENCES

Future Works and Perspectives:
Adaptation to Varied Forest Types: Future work could focus on refining the methodology for diverse forest ecosystems and climatic conditions. This would involve gathering data on the specific weight of different species and their calorific values to tailor forest management practices effectively for various contexts.
Integration with Advanced Technologies: Future research could explore the incorporation of advanced Q-GIS tools and plugins to enhance fire management capabilities. This includes:

- **Fire Risk Assessment Tools** for evaluating and modeling areas at risk of wildfires.
- **Fire Behavior Modeling** tools to simulate and predict the spread of fires.

References:

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