COMPLEX ENGINEERING SYSTEMS INSTITUTE

SCIENCE FOR FOREST MANAGEMENT, BIODIVERSITY & BIOECONOMY
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Fire management and Advanced Analytics group

Risk-averse optimization for tactical forest planning:

chance constraint by a simulation-based approximation approach.

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DecisionES 2025
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Symposium on Ecosystem Services, Forest Management and Decision Making

For forestry companies:

i. Tactical planning aims to define scheduling silviculture and harvesting decisions over mid-term (e.g., from 5 to 20 years).
ii. Uncertainties related to tree growth and potential losses from wildfires are significant (Alonso-Ayuso et al., 2020).

Some facts:

i. Plantation forests are established for productive purposes, intensively managed, monospecific, regular spacing, becoming very fire-prone.
ii. The fire risk to an individual management unit is determined by the overall condition of the entire landscape (Lauer et al., 2017).
iii. In Chile, forest sector is the third most important economic activity, largely due to the proliferation of commercial plantation forest (Jélvez et al., 1990).

Objective:

Determine the optimal tactical management plan that maximize the NPV considering the inherent risks of wildfires and the dynamic growth of forests over time.

methodology

Baseline management plan

Extended Johnson & Scheurman, (1977) LP model to set P_0 MILP formulation: a deterministic and risk-neutral forest management plan.

Forest growth & yield simulator

to project a_{ijt} the amount of biomass [tons] in each stand i when managed with each feasible policy j in each period t.

$$x_{ij} = \begin{cases} 1 & \text{if for stand } i \text{ the management policy } j \text{ is selected.} \\ 0 & \text{otherwise.} \end{cases}$$

v_t: total biomass collected in each period t.

$$\max\,(x^*) = \sum_{i \in I} \sum_{j \in J} \sum_{t \in T} \frac{1}{(1+\tau)^t} r^t a_{ijt} x_{ij}$$

$s.t.:$

$$\sum_{j \in J} x_{ij} = 1 \qquad \forall\, i \in I$$

$$\sum_{i \in I} \sum_{j \in J} a_{ijt} x_{ij} = v_t \qquad \forall\, t \in T$$

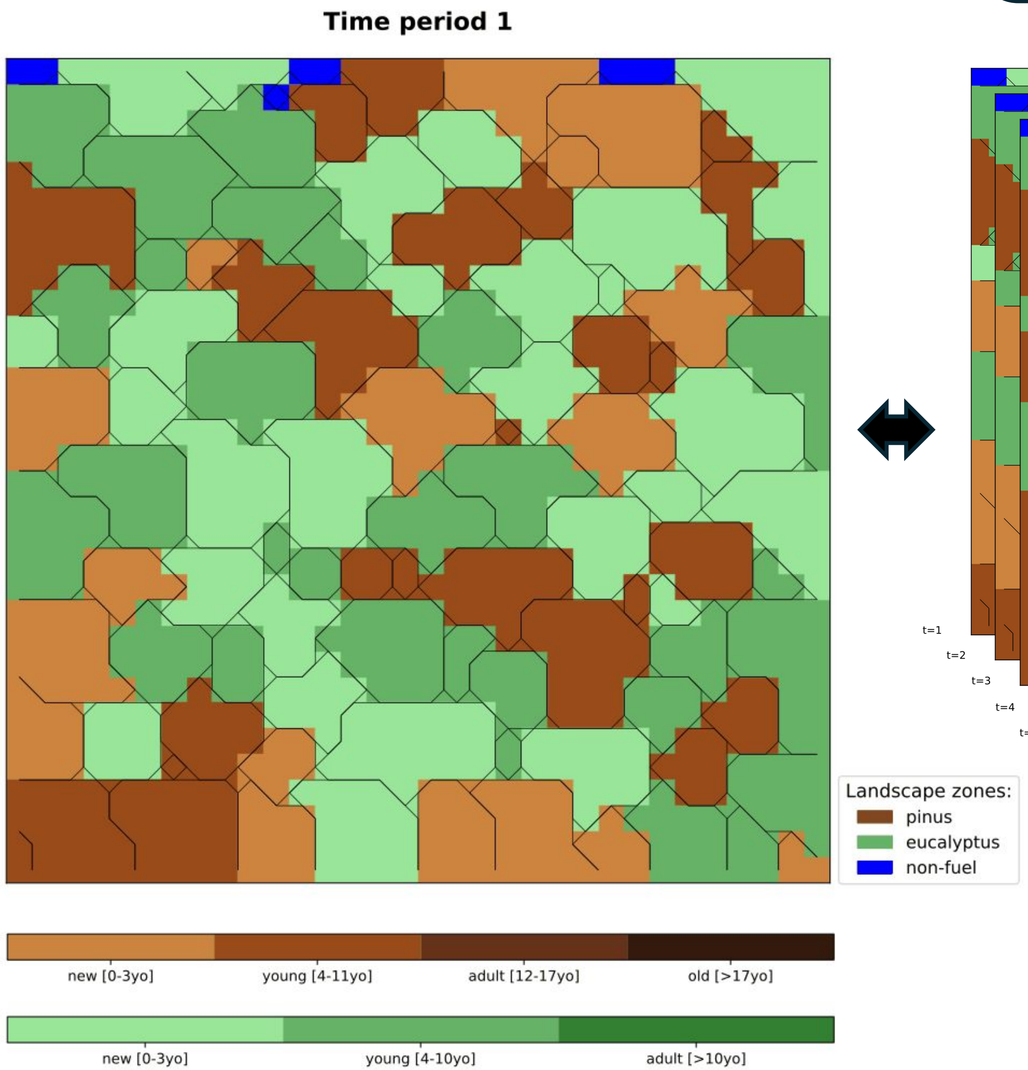
$$v_{t+1} \geq v_t$$

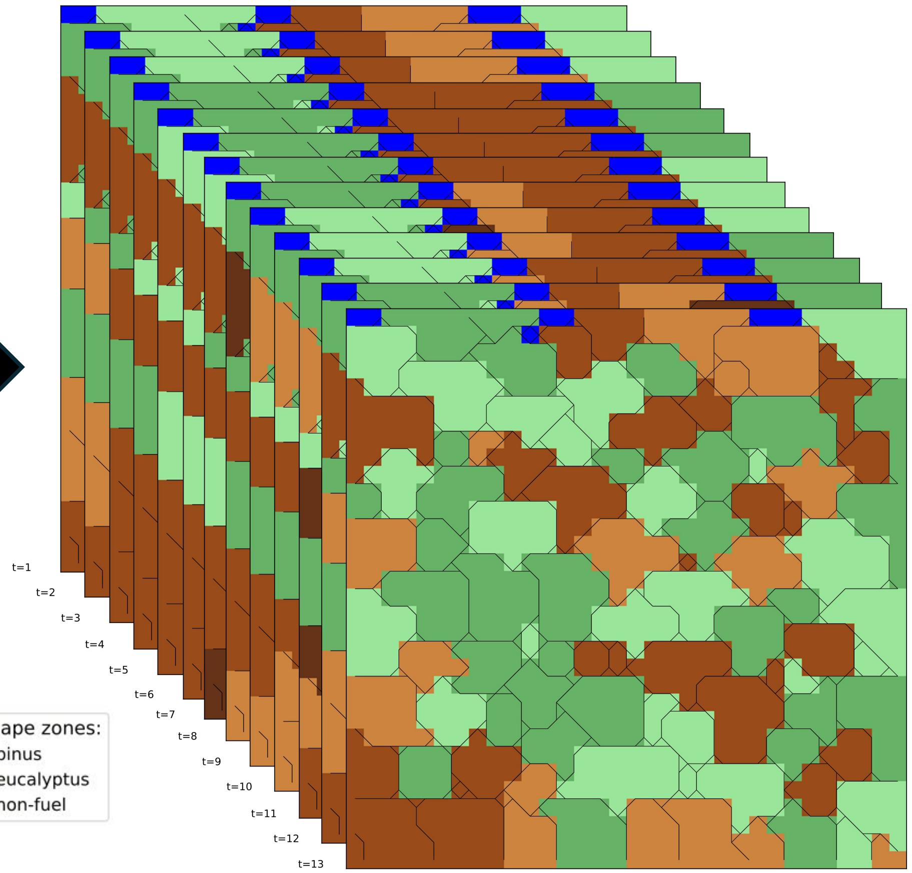
$$\sum_{i \in I} \sum_{j \in J} a_{ij|T|} x_{ij} \geq B \qquad \forall\, t \in T \setminus \{max(T)\}$$

$$x_{ij} \in \{0,1\}^{|I| \times |J|} \qquad \forall\, i \in I, \forall\, j \in J$$

$$v_t \in \mathbb{R}_+^{|T|} \qquad \forall\, t \in T$$

P_0 solution allow us to mapping the evolution of each stand i in each period t.





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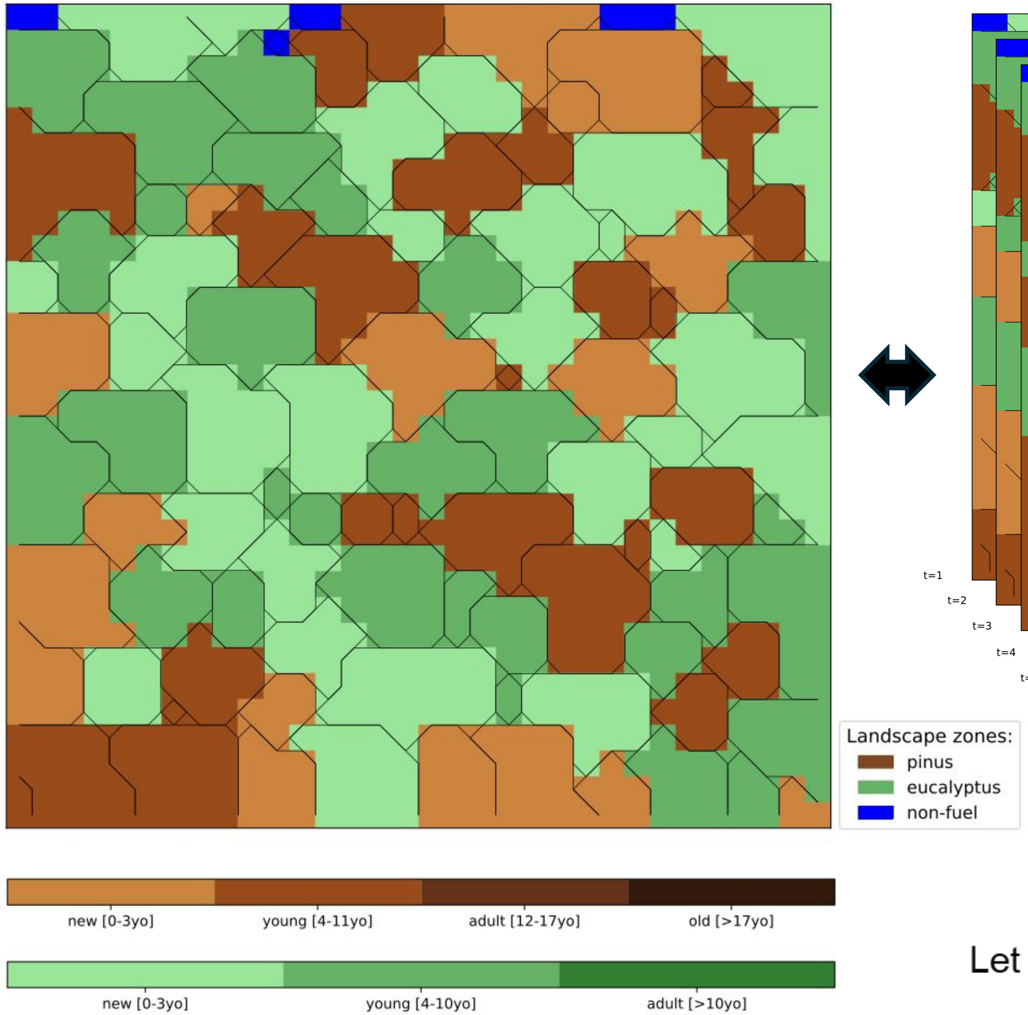
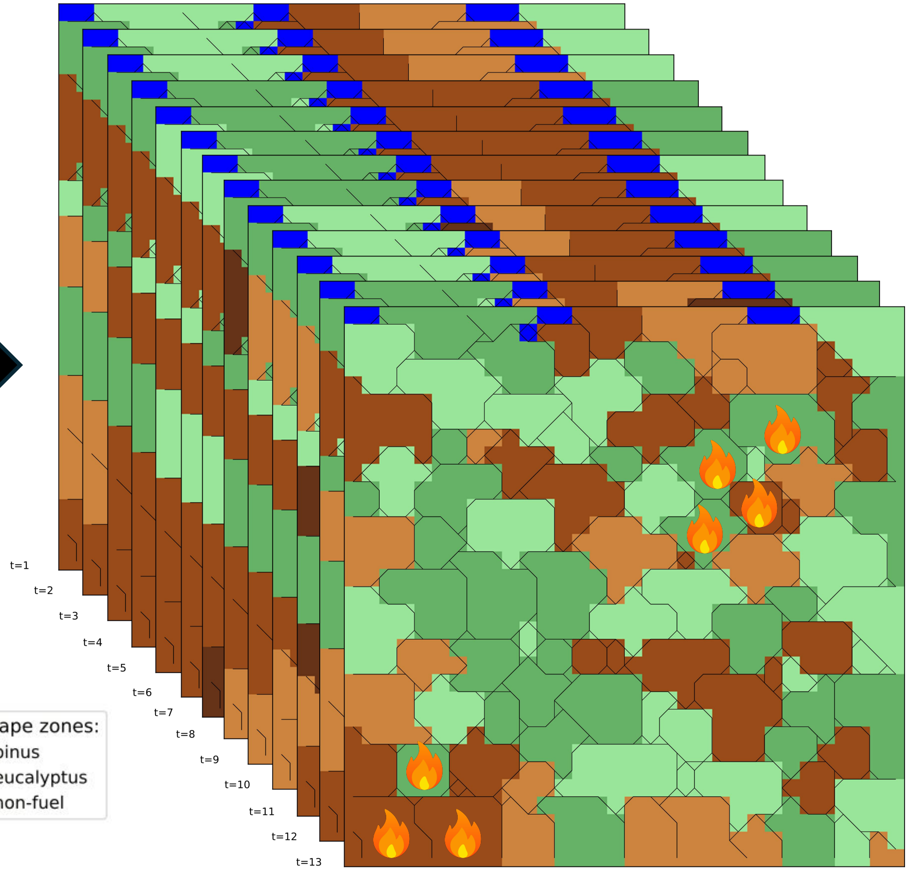
Time period 1





Let ω be a realisation of uncertainty due to fire 🔥 .

$a_{ijt}(\omega)$: amount of biomass [ton] in stand i when is managed by policy j in period t, for a realisation $\omega \in \Omega$.

$$x_{ij} = \begin{cases} 1 & \text{if for stand } i \text{ the management policy } j \text{ is selected.} \\ 0 & \text{otherwise.} \end{cases}$$

v_t: total biomass collected in each period t.

P_α model:

$$\max\ (x^*) = \sum_{i\in I}\sum_{j\in J}\sum_{t\in T}\frac{1}{(1+\tau)^t} r^t a_{ijt}(\omega) x_{ij}$$

subject to:

$$\sum_{j\in J} x_{ij} = 1 \qquad \forall\, i \in I$$

$$\sum_{i\in I}\sum_{j\in J} a_{ijt}(\omega) x_{ij} = v_t \qquad \forall\, t \in T$$

$$\mathbb{P}[v_{t+1} \geq v_t] \geq \alpha \qquad \forall\, t \in T \setminus \{max(T)\}$$

$$\mathbb{P}\left[\sum_{i\in I}\sum_{j\in J} a_{ij|T|}(\omega) x_{ij} \geq B\right] \geq \alpha$$

$$x_{ij} \in \{0,1\}^{|I|\times|J|} \qquad \forall\, i \in I, \forall\, j \in J$$

$$v_t \in \mathbb{R}_+^{|T|} \qquad \forall\, t \in T$$

$$x_{ij} = \begin{cases} 1 & \text{if for stand } i \text{ the management policy } j \text{ is selected.} \\ 0 & \text{otherwise.} \end{cases}$$

v_t^s: total biomass collected in each period t, for the scenario s.

$$z^s = \begin{cases} 1 & \text{if all chance constraints are satisfied simultaneously in the scenario } s. \\ 0 & \text{otherwise.} \end{cases}$$

$P_{S,\alpha}$ model:

$$\max\ (x^*, z^*) = \sum_{i\in I}\sum_{j\in J}\sum_{t\in T}\sum_{s\in S}\frac{1}{(1+\tau)^t} r^t a_{ijt}^s x_{ij} \varphi^s$$

subject to:

$$\sum_{j\in J} x_{ij} = 1 \qquad \forall\, i \in I$$

$$\sum_{i\in I}\sum_{j\in J} a_{ijt}^s x_{ij} = v_t^s \qquad \forall\, t \in T, \forall\, s \in S$$

$$v_{t+1}^s - v_t^s \geq M(z^s - 1) \qquad \forall\, t \in T \setminus \{max(T)\}, \forall\, s \in S$$

$$\sum_{i\in I}\sum_{j\in J} a_{ij|T|}^s x_{ij} - B \geq M(z^s - 1) \qquad \forall\, s \in S$$

$$\sum_{s\in S} z^s \varphi^s \geq \alpha$$

$$x_{ij} \in \{0,1\}^{|I|\times|J|} \qquad \forall\, i \in I, \forall\, j \in J$$

$$z^s \in \{0,1\}^{|S|} \qquad \forall\, s \in S$$

$$v_t^s \in \mathbb{R}_+^{|S|\times|T|} \qquad \forall\, t \in T, \forall\, s \in S$$

study area & main results

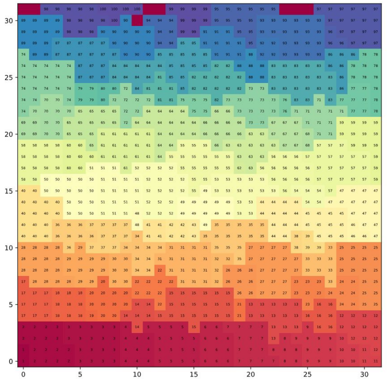
100 productive stands (pine & eucalyptus) ~ 1000 has.

20 management policy (16 for pinus, 4 for eucalyptus)

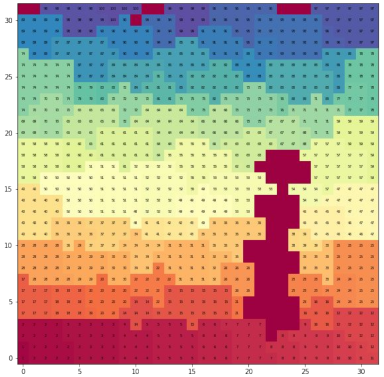
Planning horizon:13 years

~~to get a_{ijt}~~ we use 3mun (unpublished) a plantation forest growth & yield simulator.

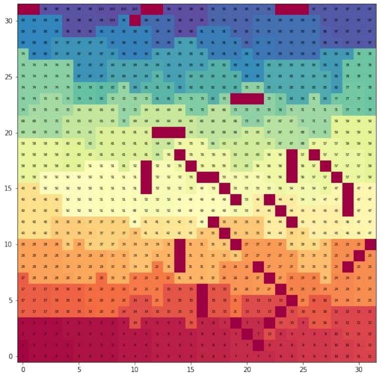
100 scenarios built using C2F+K (Carrasco et al., 2023) to get a_{ijt}^{s}



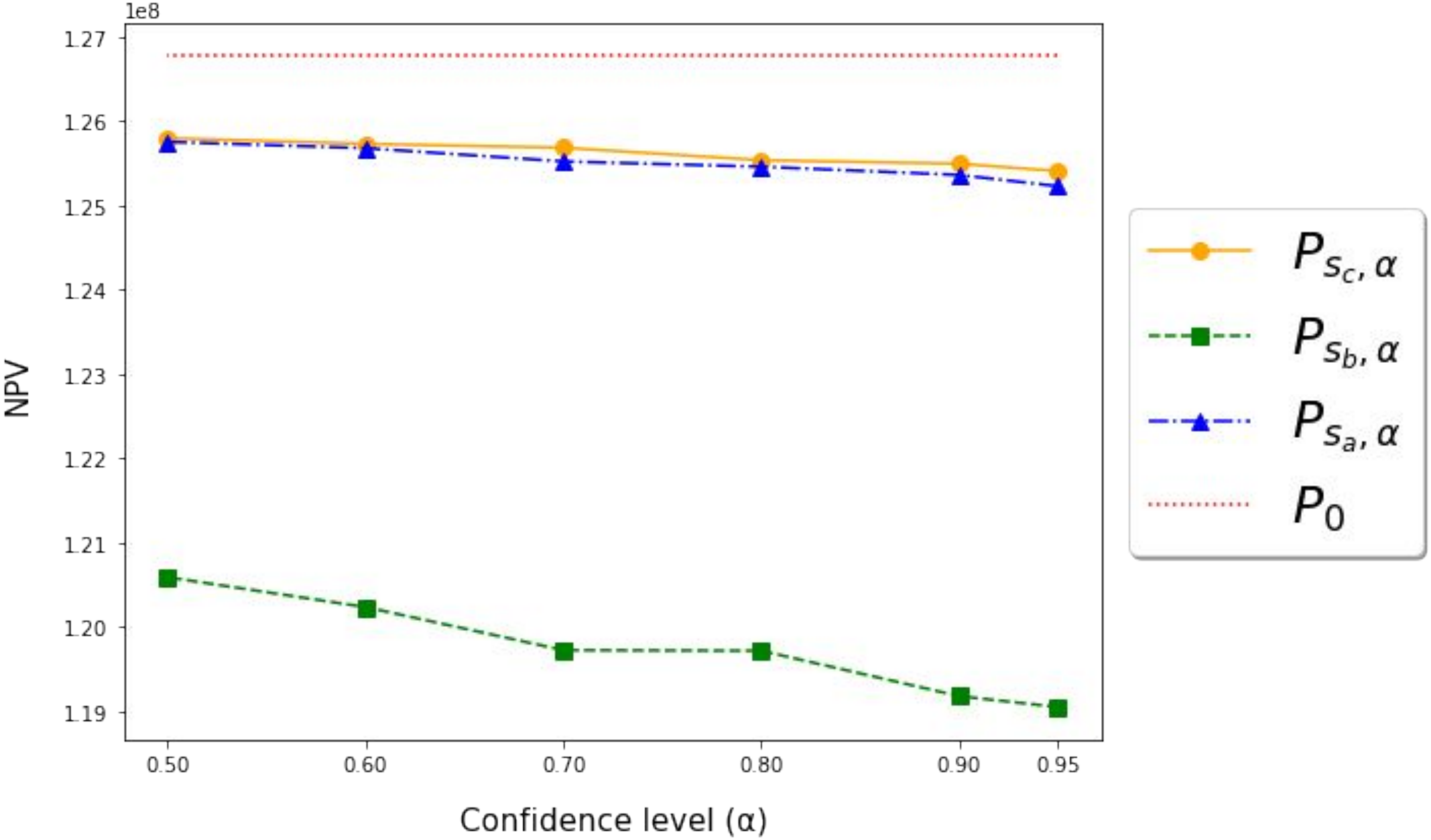
(a) unmanaged landscape



(b)*



(c)*



*strategic zones for fire prevention ~ 5.7% of landscape.

discussion & conclusion

We consider that the probability of wildfires is primarily driven by spatial characteristics like fuel continuity, weather, and topography, rather than specific management policies.

MILP model $P_{s,\alpha}$ remains deterministic, considering vegetation evolution over time but not accounting for actual fire occurrences, only their possibility, which simplifies the incorporation of parametric uncertainty.

Landscape partial fragmentation plans effectively mitigates risk while balancing fire prevention with economic value, proving superior to unmanaged landscape management plans.

This approach efficiently uses a chance constraint with a risk-level parameter to address uncertainty, offering a practical framework for optimization and reliable solutions.

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Thank you!
Obrigado!

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