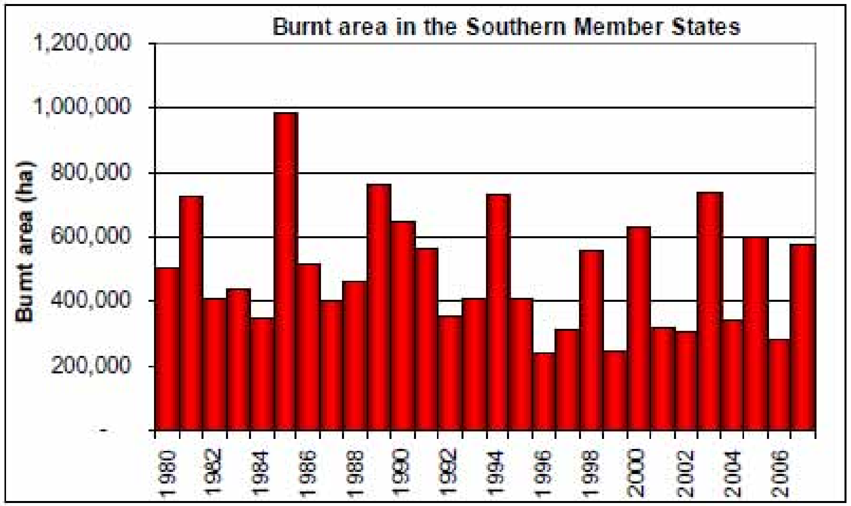
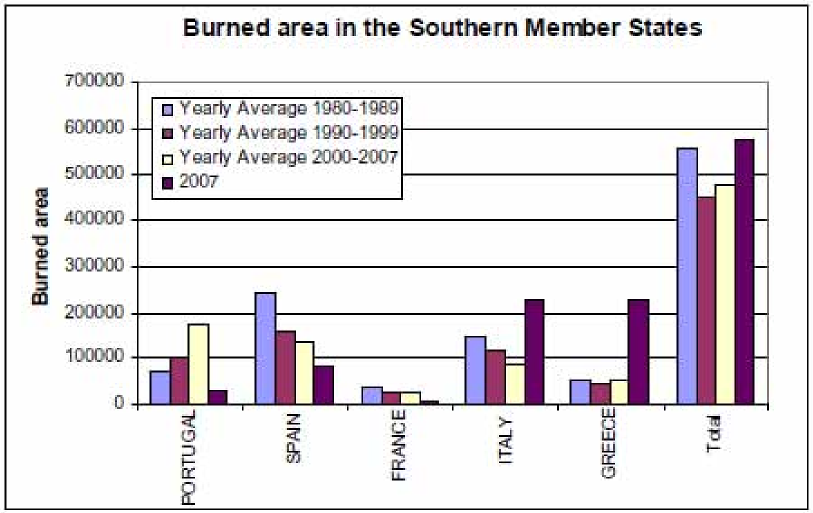
Forest planning dealing with fire risk

Dr José Ramón González Olabarria

CENTRE TECNOLÒGIC FORESTAL DE CATALUNYA

- Fire is the most important hazard in southern Europe
  - It affects an average of 500.000 ha per year.
  - Fire has an impact on several aspects other than timber lost.
    - Human lives
    - Properties
    - Non-timber values from forest (recreational, soil protection etc…)





Source: Joint Research Center
http://effis.jrc.ec.europa.eu/

Forest management and fire risk in Northern Mediterranean Basin: a vicious circle

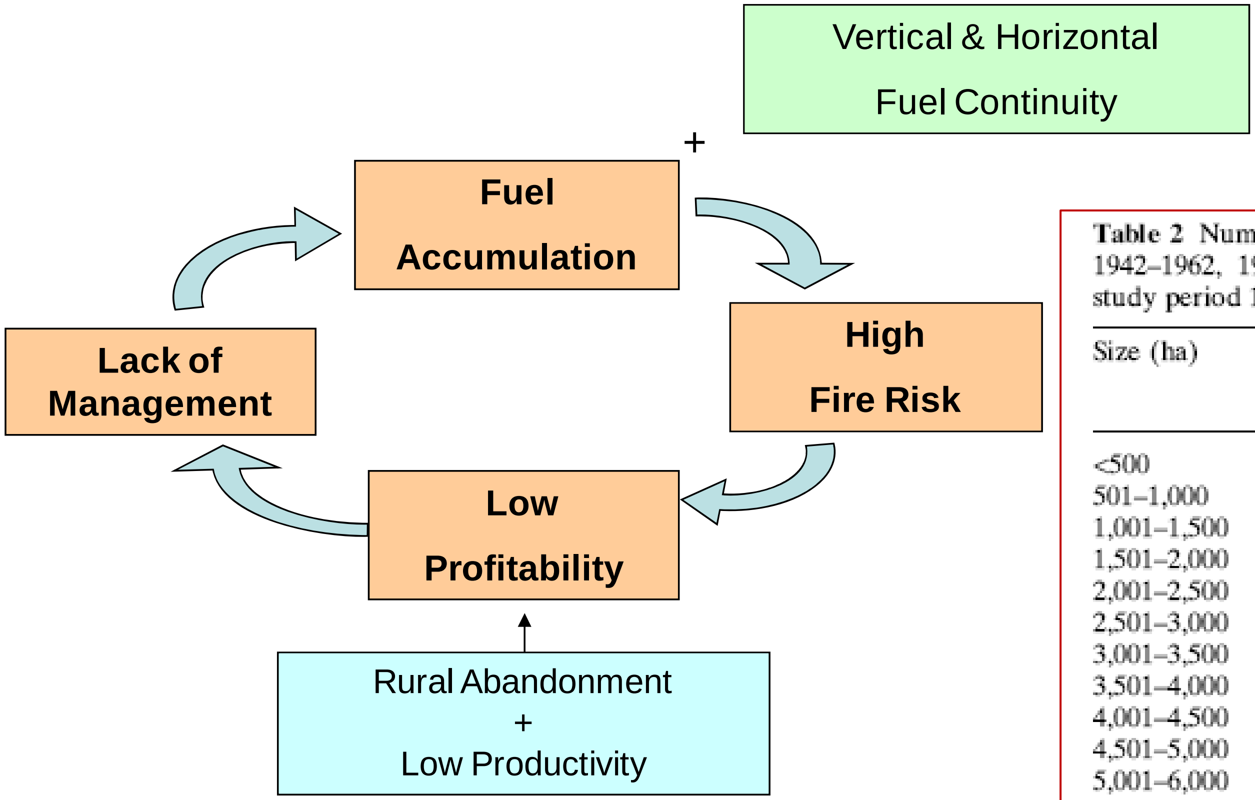


Table 2 Number of fire events recorded during sub-periods 1942–1962, 1963–1982 and 1983–2002, and during the whole study period 1942–2002

Size (ha)	Period			
	1942–1962	1963–1982	1983–2002	1942–2002
<500	141	4,182	3,646	7,969
501–1,000	5	36	30	71
1,001–1,500	0	10	13	23
1,501–2,000	0	8	5	13
2,001–2,500	0	6	4	10
2,501–3,000	0	5	3	8
3,001–3,500	0	1	1	2
3,501–4,000	0	0	3	3
4,001–4,500	0	0	3	3
4,501–5,000	0	2	3	5
5,001–6,000	0	4	3	7
6,001–7,000	0	1	0	1
7,001–8,000	0	1	0	1
8,001–13,000	0	0	1	1
13,001–14,000	0	0	1	1
14,001–15,000	0	0	1	1
15,001–17,000	0	0	2	2
Total	146	4,256	3,719	8,121

Effect of fuel on fire behaviour

- Fuel on fire effect depends on type, amount, allocation
  - Type (composition, dead/alive, size)
  - Allocation (vertical and horizontal continuity)

- Fire behaviour models have been traditionally focused on surface fires. (Rothermel Fuel Types)

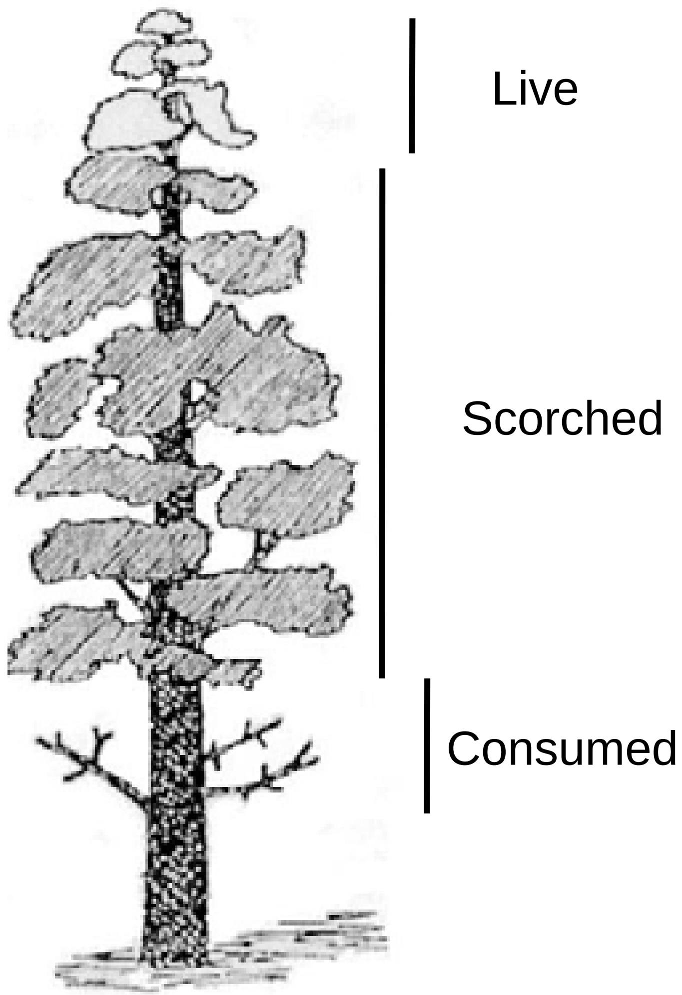
Advantages and disadvantages of traditional approaches

- Fire behaviour models are able to predict the extent and effect of fire if the initial ignition point, the weather conditions, and the surface fuels are known.
- Some models even predict the possibility of canopy fires (surface fire intensity + canopy characteristics).
- Are useful to plan fuel management (analysis of fuel treatments)

- Limitations
  - Data demanding
  - Should consider specific characteristics for 1 fire event (historic conditions?)
  - Inaccurate for long term predictions

- Mortality models
    - Tree size
    - Fire intensity or severity
        - % scorched canopy
        - Deep consumed bark
        - Consumed litter etc…

- Difficult to predict in the future, depend on behaviour of specific event



Source: Fowler and Sieg. 2004
USDA Report RMRS-GTR-132, Rocky Mountain Research Station
http://www.rmrs.nau.edu/lab/people/jfowler/

Fire risk and forest management planning

- Forest structure and composition is closely related with fire behaviour and effect
  - Horizontal and vertical continuity of living fuels
  - Surface fuels are related with forest management (bushes, slash)

- This relation is not so easy to measure but:
  - Forest structure and composition can be predicted and simulated over long-periods
  - It can be used to estimate potential losses and benefits of fire
  - Through forest planning it can be integrated into a productive process (obtain more realistic predictions, reduce fire risk)

Use of the models in forest planning

- Already applied in: from 80s
  - Finding optimal forest stand management schedules
  - Forest and landscape level forest management planning applications
  - Scenario analysis

- Can consider as objectives:
  - Reduction of economic losses
  - Reduction of fire hazard

How to integrate the risk of forest fires in planning problems

- Need to develop models that estimate **probability of fire occurrence** and **damage** depending on the **stand characteristics** (basic management unit).

- ...which should be defined from **variables easily measurable** in forest inventories, or **predicted** from existing simulation models.

- If the stand characteristics used to predict the risk of fire are under the control of the manager, the risk of fire can be modified.

- Fire occurrence not only depends on stand characteristics but strongly on spatial characteristics and fire spread (more easy and reliable to consider it as exogenous at landscape scale)

- Potential damage more sound if considering its endogenous nature.
  – Damage → fire severity + forest resistance & resilience

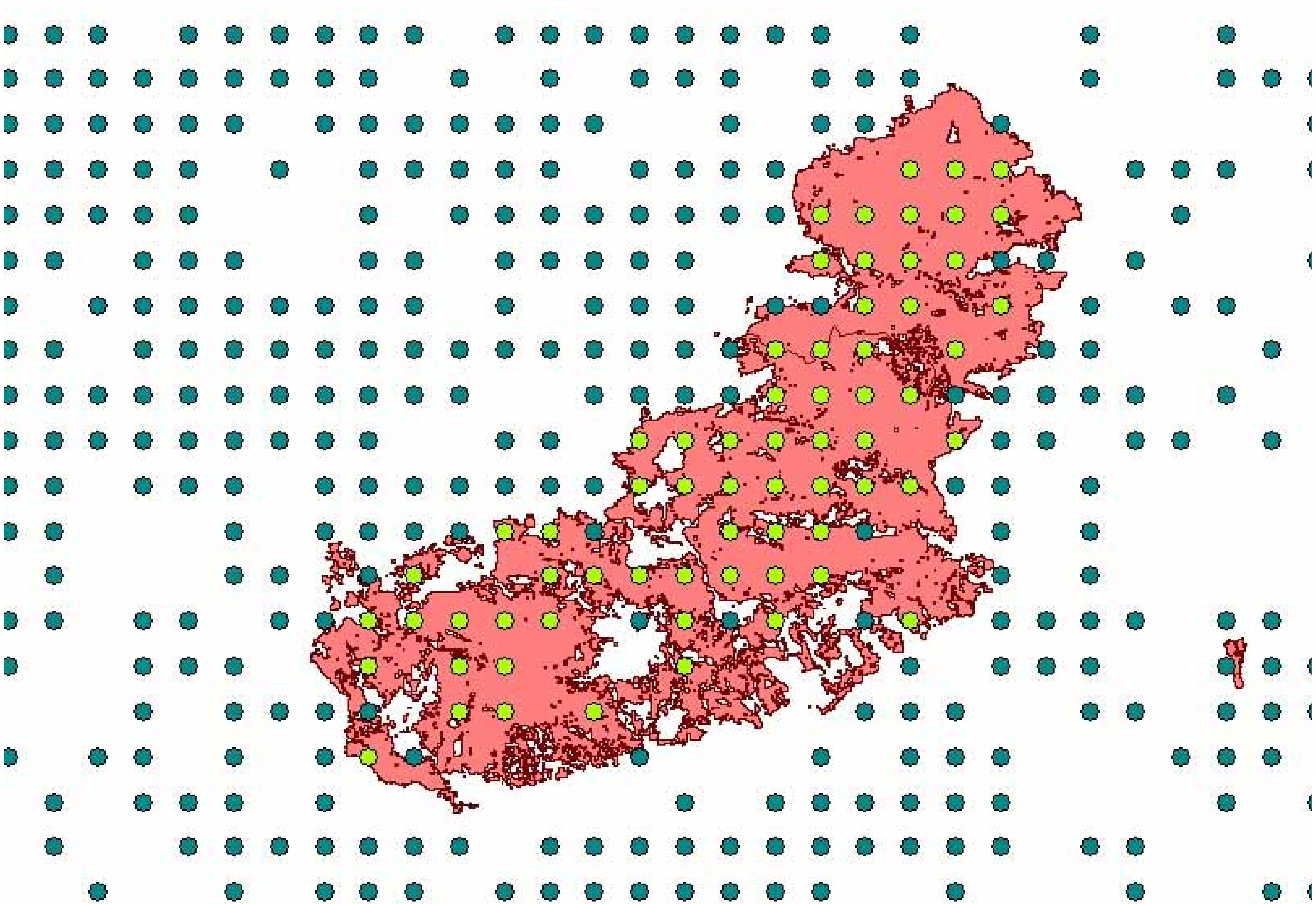
↓

(stand characteristics: species, tree sizes, amount of fuel)

Both occurrence and damage should be quantify for planning purposes

Occurrence * damage = expected losses

Modelling the risk of forest fires for forest planning



Fire occurrence

Photo: José Ramón González

$$P_{fire} = \left(1 + e^{-\left(b_0 + b_1 ELE + b_2 Dg + b_3 G + b_4 P_{hard} + b_5 \left(\frac{s_d}{Dg + 0.01}\right)\right)}\right)^{-1}$$

- Dg, G and (SD/Dg+0.01); **stand structure**
- P_{hard} the proportion of hardwoods; **composition**
- ELE = transformed elevation

Source: Gonzalez et al., 2006
Annals of Forest Science 63: 169-176
http://www.afs-journal.org/

Stand damage and
Tree survival

Photo: José Ramón González

$$y = b_0 + b_1 G + b_2 Slope + b_3 Pine + b_4 \left(\frac{G}{D_q + 0.01} \right) + b_5 \left(\frac{s_d}{D_q + 0.01} \right) + e$$

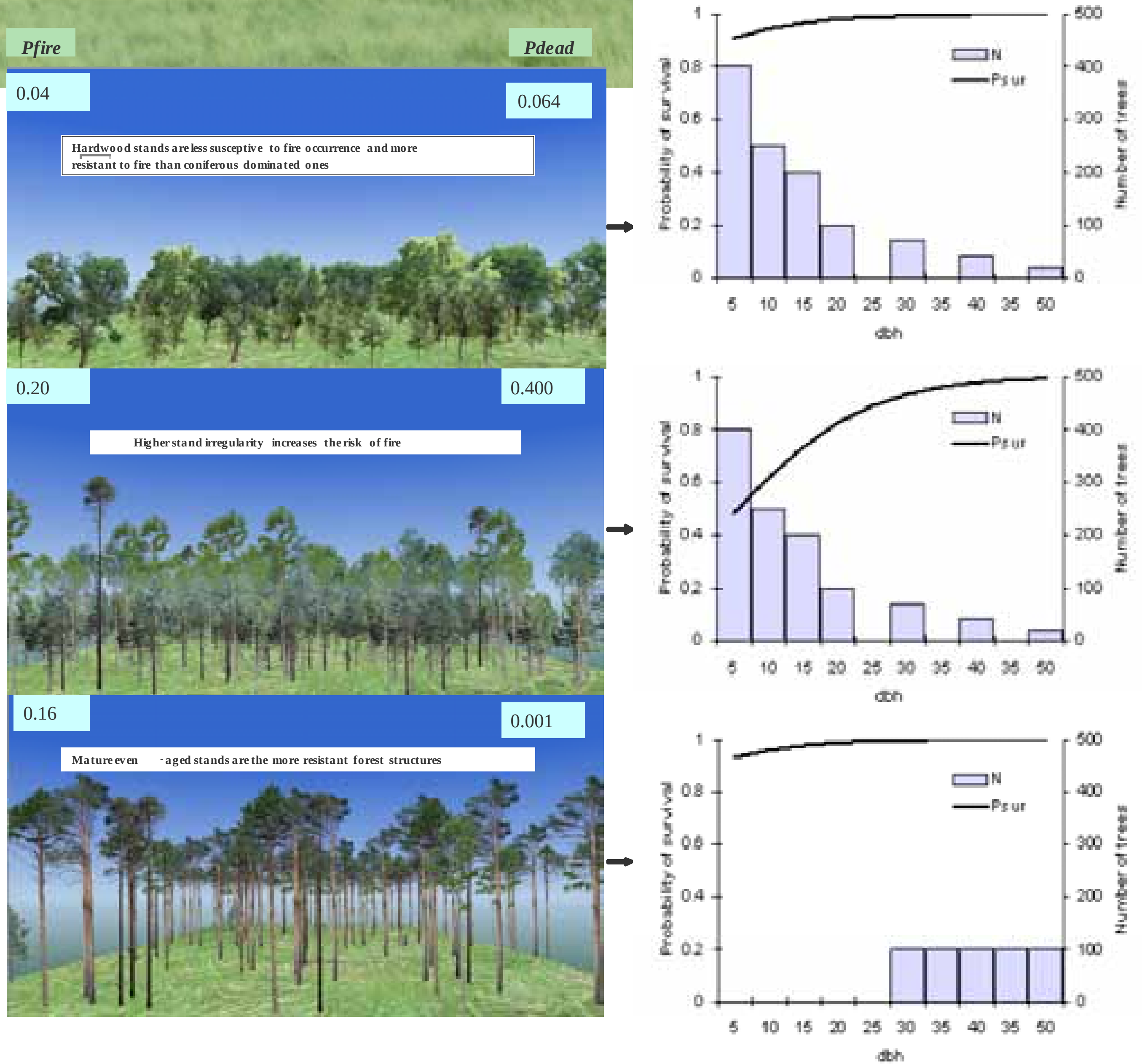
y= transformation of the proportion of dead trees Pdead

again management related variables or fixed ones (Slope)

$$P_{sur} = \left(1 + e^{-(b_0 + b_1 d + b_2 P_{dead})} \right)^{-1}$$

Source: Gonzalez et al., 2007
Annals of Forest Science. 64: 733-742.
http://www.afs-journal.org/

Fire risk depends on forest structure and composition



Source: Gonzalez et al., 2007
EFI Proceedings: 56:85-91.
http://www.efi.int/portal/virtual_library/publications/proceedings/

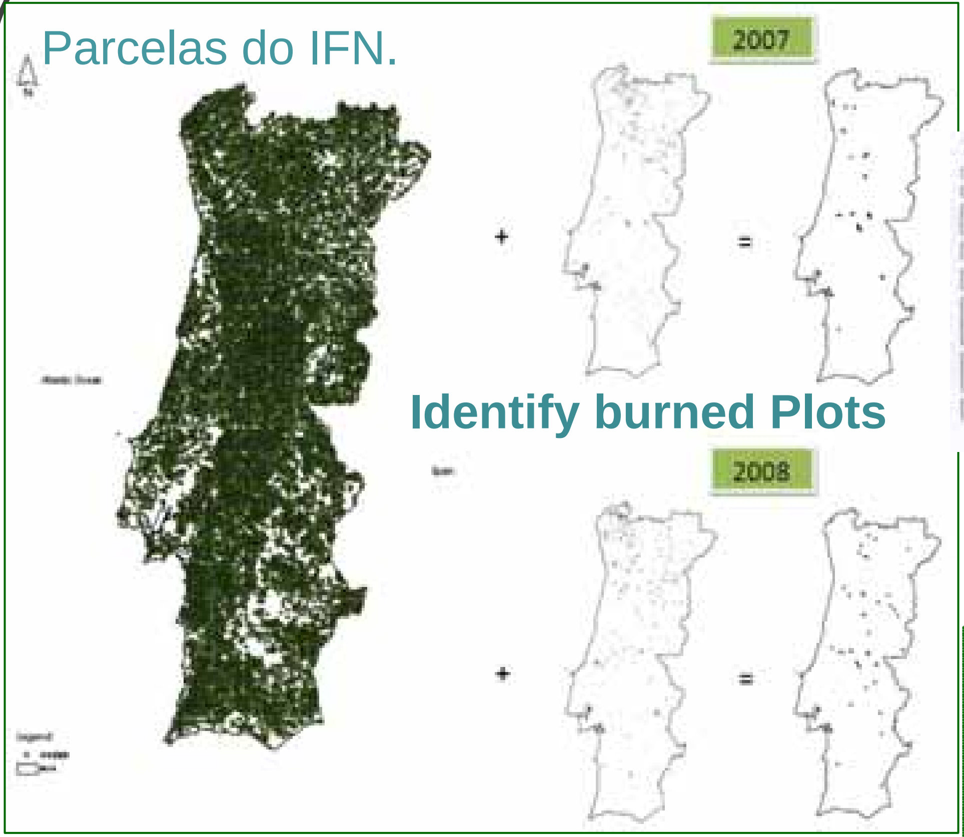
From Jordi Garcia-Gonzalo, José G. Borges

Simillar approach in Portugal

Instituto Superior de Agronomia
Universidade Técnica de Lisboa

“Instrumento s de aopio ao desenho de paisagens florestais resistentes ao fogo”

- Fire perimeters > 5 ha during two periods (1997 – 2004 and 2005 – 2007)



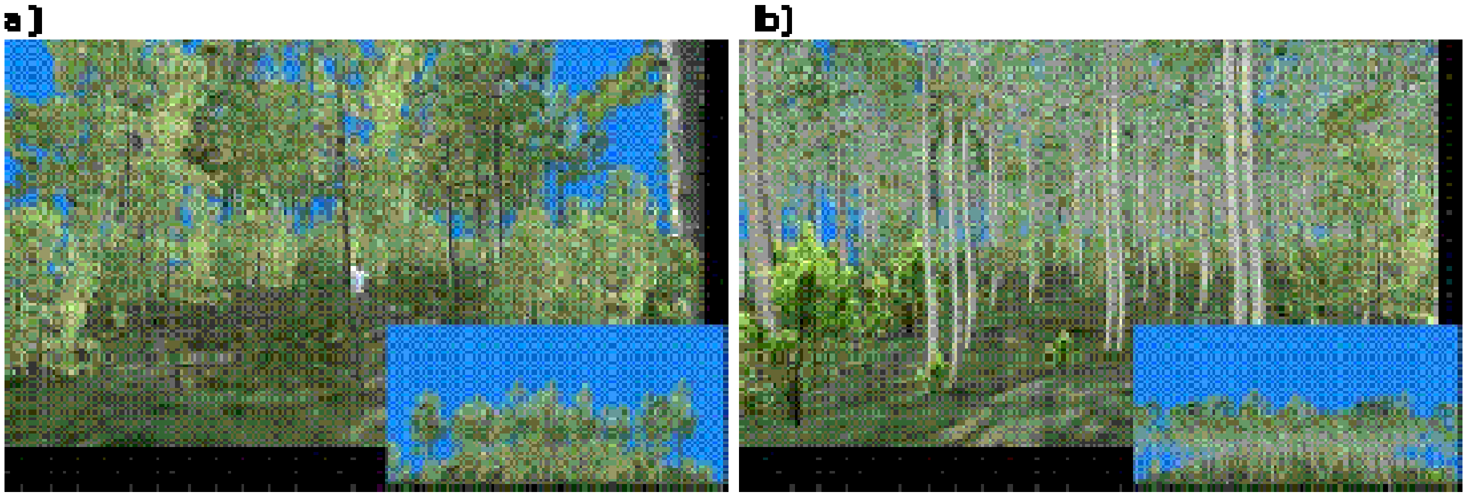
Inventorying burned plots

What if data not good enough?

- You may try to extrapolate and adjust existing models
- Expert knowledge can be a cheap and easy to obtain source of information
  - Take into consideration that experts are persons and may have different perceptions even wrong ones
  - Different methodologies exist to quantify subjective opinions
    - Direct rating (give an scaled value to an object or opinion)
    - AHP (Analityc Hierarchy Process) relative priorities of an object respect o another
      - Be sure what you want to compare and that the experts undertand it

Example used to model vulnerability of a stand to fire.

Photos are more commonly used but you have to be careful that are representative of the stand



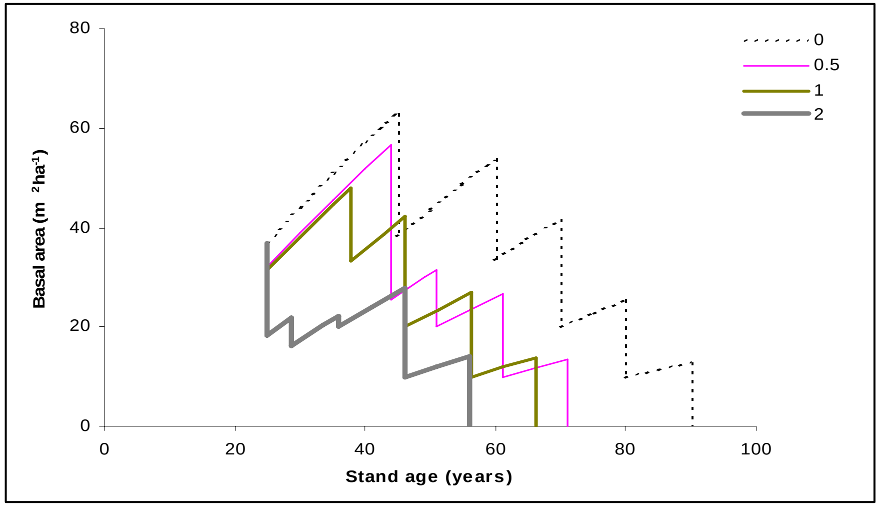
Superiority of a over b — Superiority of b over a

Absolutely Superior	Extremely Superior	Very Superior	Superior	Equal	Superior	Very Superior	Extremely Superior	Absolutely Superior
9/1	7/1	5/1	3/1	1	1/3	1/5	1/7	1/9

González , Kolehmainen and Pukkala. 2007. Using expert knowledge to model forest stands vulnerability. Computers and electronics in agriculture 55: 107-114

Stand-level management

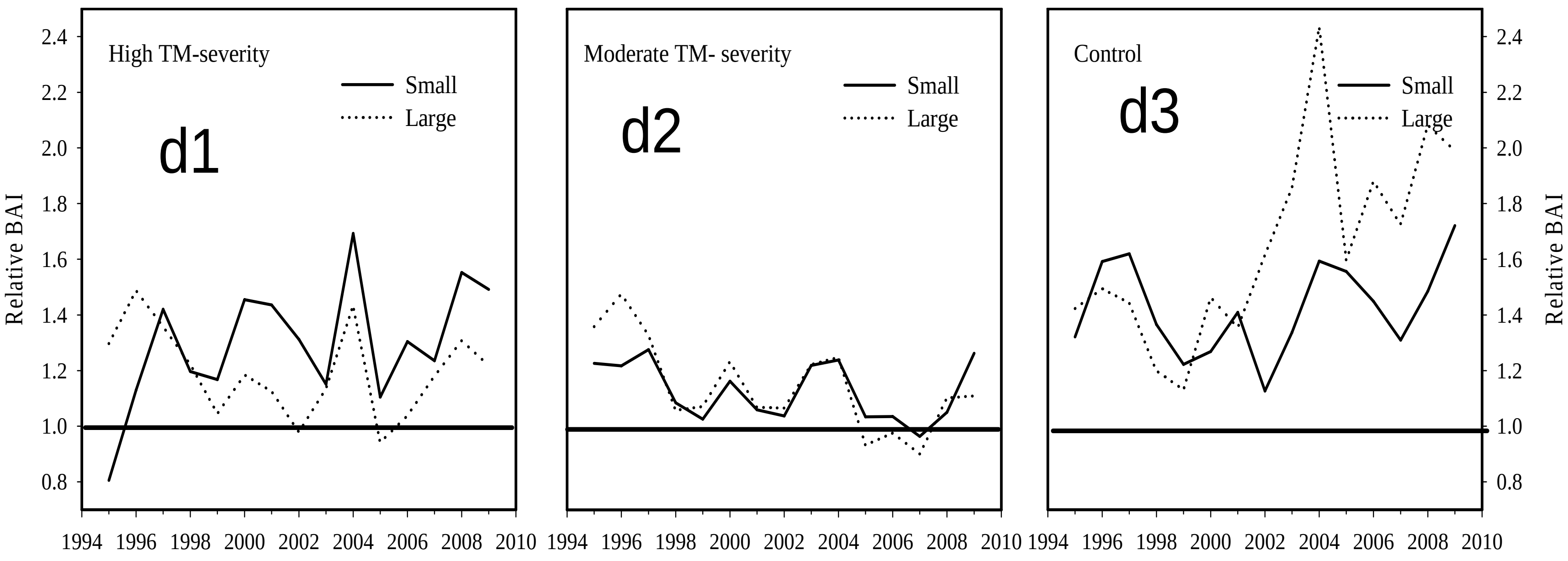
- By optimizing different objective at stand level (under risk of fire) is possible to generate management prescriptions.
- If fire is considered endogenous (management dependent), minimize the risk can be one objective
- Still the effect of adjacent stands is not fully addressed (end vs exo).



Source: Gonzalez et al.,2005
Annals of Forest Science 62: 493-501
http://www.afs-journal.org/

new possibilities

- Include post-fire evolution (regeneration success, effect of fire on surviving trees even positive effects)
- Or prescribed burning as a management tool (cheap??, close to nature??)



From Valor et al. 2012 manuscript

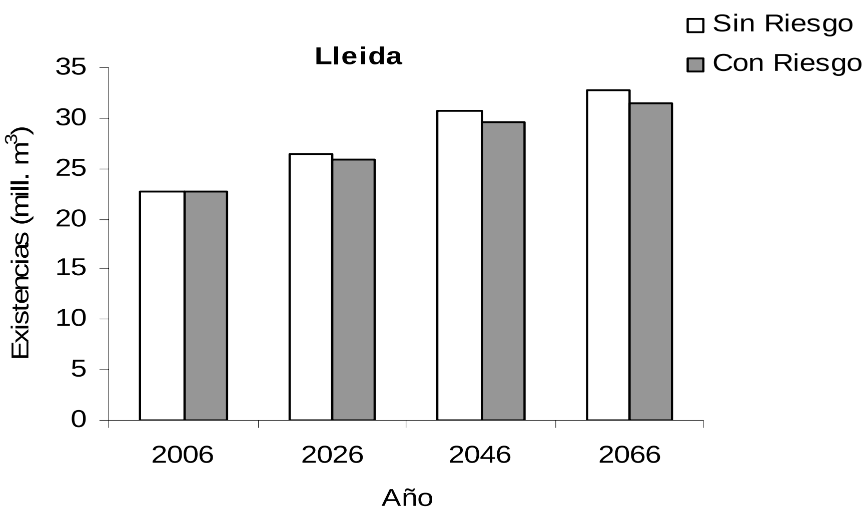
Fire in forest planning
forest level

- Started in the beginning of the 1980´s in North America.
- Forest level problems can be divided in 2 by 2 classes
  - Depending the “goal”
    - **economic approach planning**
    - **ecological approach planning (emulate fires through cuttings)**
  - Depending on the way of consider the nature of fire risk
    - **spatially explicit**
    - **non-spatially explicit**

Depending on nature of fire

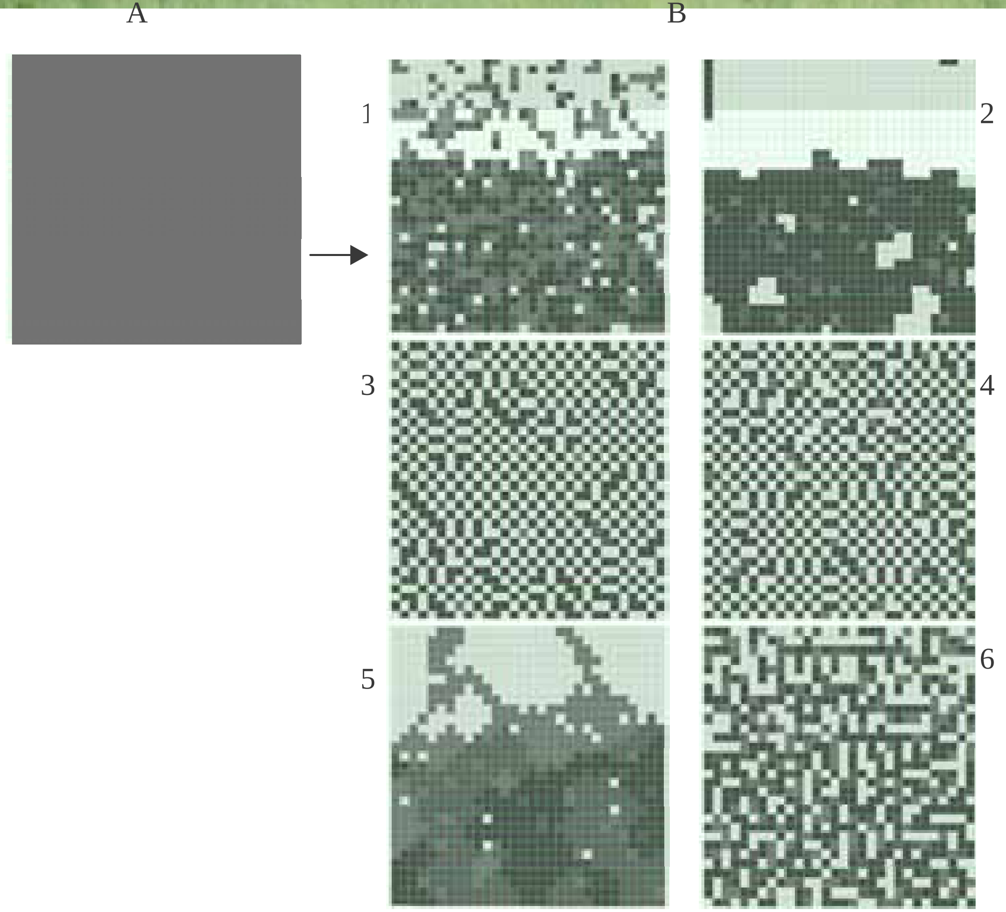
SPATIALLY NON-EXPLICIT

- In some cases spatial objectives were considered as means to reduce risk, but the risk itself is not considered spatially explicit.



If not spatial objective is included, only losses are considered and works simillar to an scenario analysis.

Ok for regional analysis and strategic planning (long periods)



It is possible to allocate management operation in a way that a desired landscape configuration is attained using spatial optimisation

Even if the risk has not a spatial component, principals of landscape fragmentation can be applied to reduce the risk at landscape level

Landscape metrics

To measure the sizes, shapes and connectivity of forest patches, (can be used to modify the landscape configuration respect to a certain variable)

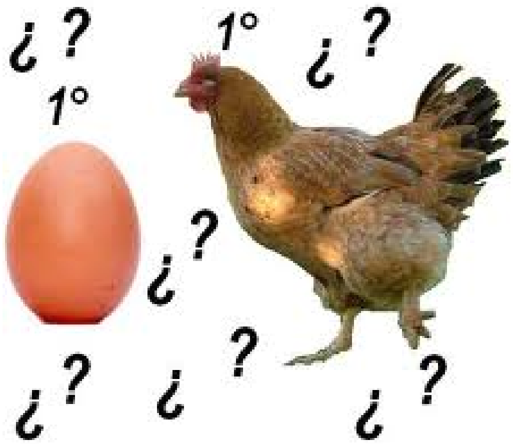
Source: Gonzalez et al., 2005
Landscape Ecology 20 (8): 957- 970.
http://www.springerlink.com/content/103025/

SPATIALLY EXPLICIT

- More recently some studies have **incorporate fire simulators** (spread, damage) to asses the impacts of fire during the planning period

Depending on the initial state of the forest and evolution of the forest without management, the fire risk is estimated and included in the planning problem.

- New family of studies are trying to not only asses the effect of planning on fire risk and risk on planning (more adaptive approach?)



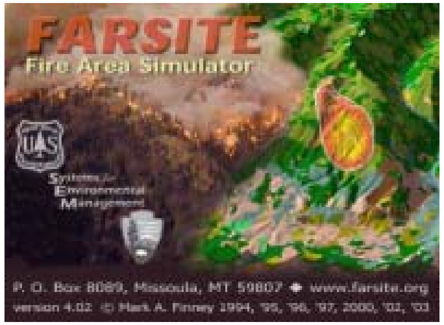
New approach on landscape planning
Spatially explicit and adaptive

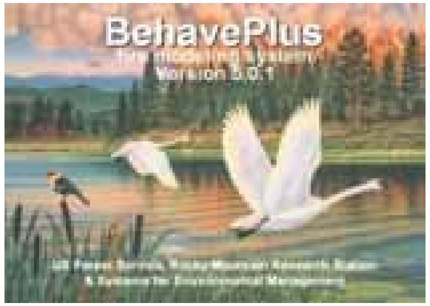
Konishima., 2008
Bettinger, 2009
Kim et al., 2009
Gonzalez-Olabarria and Pukkala 2011

Principle to solve the problem

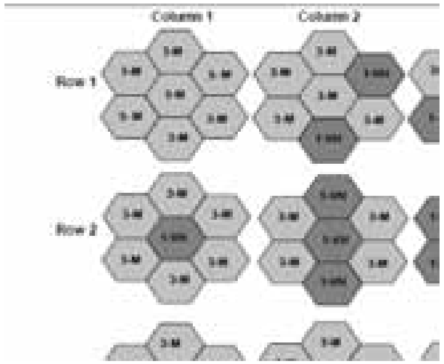
1-Fire risk being estimated through the planning period (with or without management)
2- Get an optimal forest plan with the predefined risk
3- Recalculate risk with selected management plan
4- Obtain new optimal plan with adjusted risk
5- New risk
6- New plan
7- etc……..

Variation in new approaches at landcape level





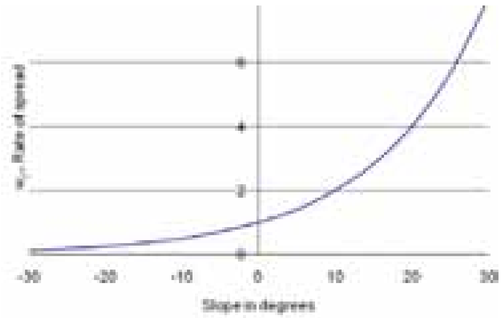
- Use of well known simulators
  - Advantages
    - Based on proved simulators (realistic)
  - Problems
    - Data demanding (some difficult to obtain, or predict over long periods)
    - Slow for planning (few fire scenarios)
  - Applications
- Konishima., 2008 (all fire scenarios on simple landscape 7 stands)
- Bettinger, 2009 ; Kim et al., 2009 (complex landscape, but limited fire simulations)
  - Have to be based on historic fires or worst conditions



More simple simulators

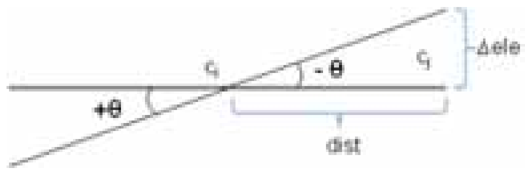
Gonzalez-olabarria and pukkala 2011 Forest ecology and management 261: 278-297

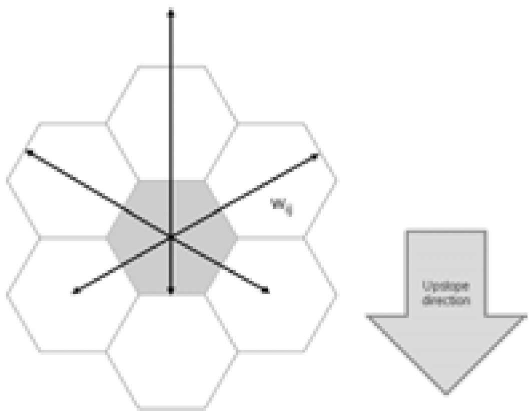
- Fire occurrence was estimated using the outcomes from multiple fire spread simulations for different sub-periods of the planning period
  - The fire spread simulator was based on a cellular automaton where the probability of a fire to move from one stand (hexagon) to an adjacent one, depended on the fire resistance of the stands (from Pdead) and their relative position (Topography)



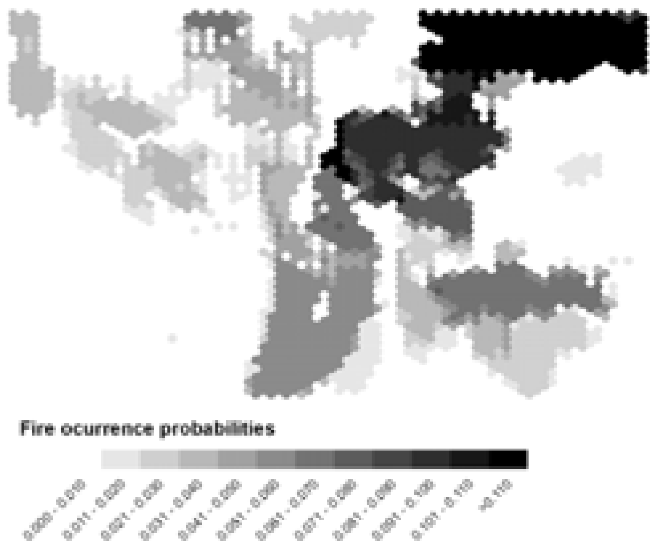
$$w_{ij} = Exp(0.693 \cdot \theta_{ij})$$

$$\pm\theta_{ij} = \arctan\left(\frac{|\Delta ele|}{dist}\right)$$





Plan 5



How fire was considered

- For economic purposes
  - Damage as endogenous f (stand's characteristics)

$$y = \ln(Pdead / (Pdead - 1))$$

$$EI_T = \underbrace{\prod_{t=0}^{T} (1 - p_t)}_{\text{P (not burned)}} \cdot \underbrace{R_T}_{\text{Net revenue}} + \underbrace{\left[1 - \prod_{t=0}^{T} (1 - p_t)\right]}_{\text{P (burned)}} \cdot \underbrace{\frac{1}{T} \sum_{t=0}^{T} (1 - P_{dead\ t})}_{\text{Average salvage rate}} \cdot \underbrace{R_T}_{\text{Net revenue}}$$

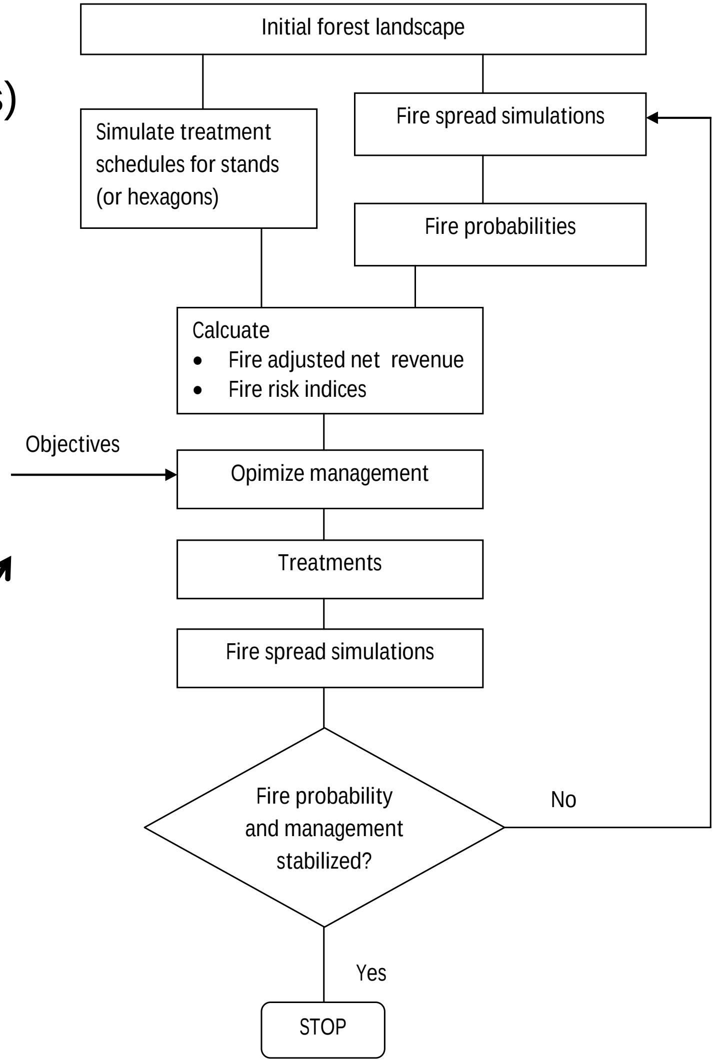
Plan 1 $U = 1/2u_h (H) + 1/2u_{ni0} (N)$

Plan 2 $U = 1/2u_h (H) + 1/2u_{ni} (N^{adj})$

Plan 3 $U = 1/3u_h (H) + 1/3u_{wr} (F^{saf}) + 1/3u_{wr} (F^{res})$

Plan 4 $U = 1/3u_h (H) + 1/3u_{ni} (N^{adj}) + 1/3u_{wr} (F^{saf})$

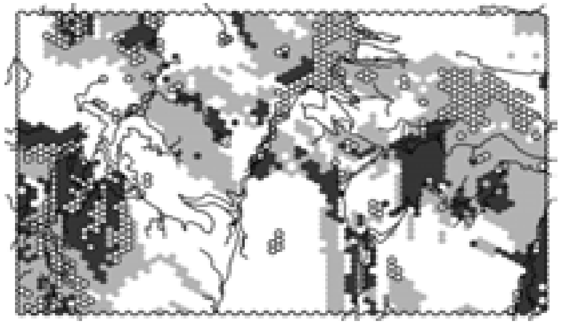
Plan 5 $U = 1/6u_h (H) + 1/6u_{ni} (N^{adj}) + 1/6u_{wr} (F^{saf}) + 3/6u_{fb} (FB\text{-}FB)$



Results: Allocation of treatments

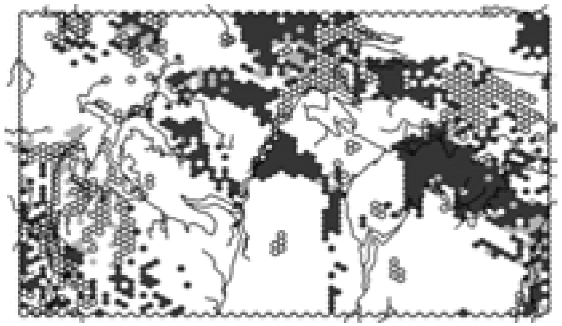
Road network defines management location if economic objective applied

Plan 1 (No Risk)



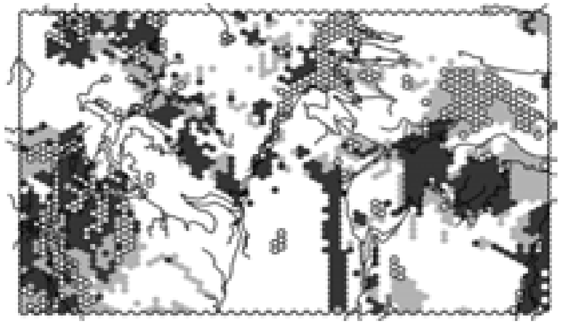
Plan 2

Plan 3



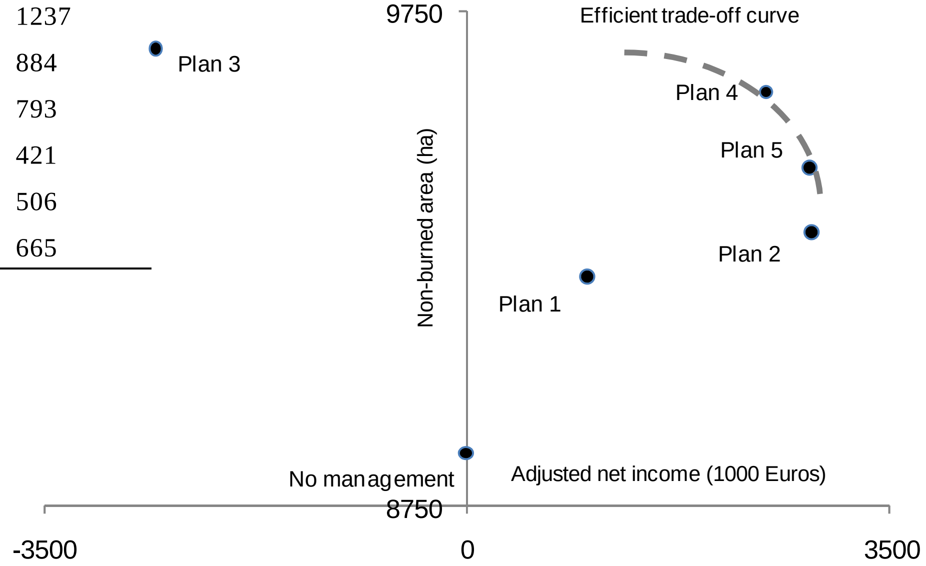
Plan 4

Plan 5



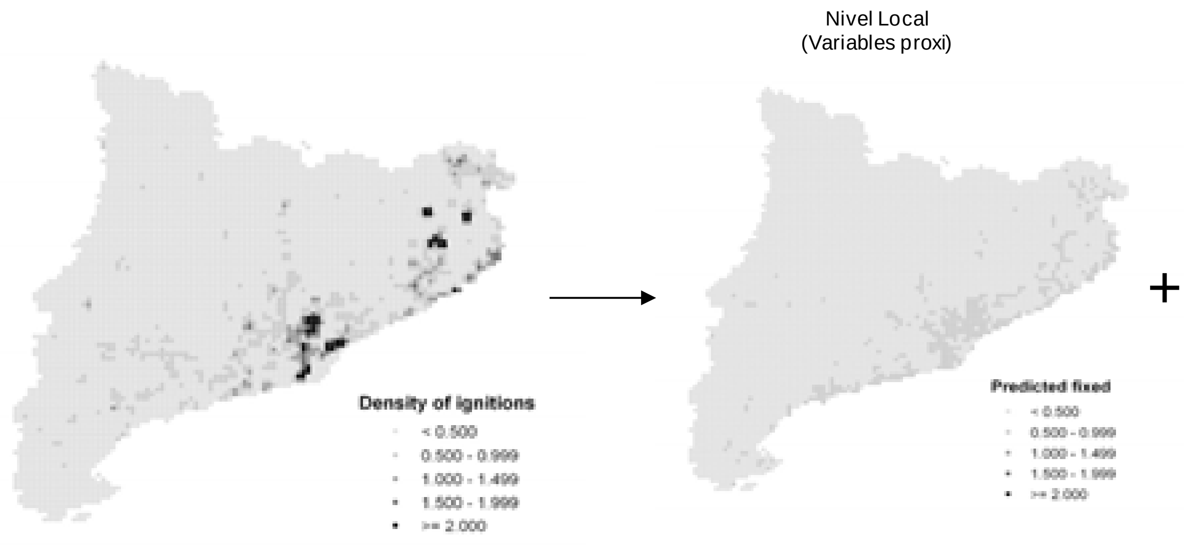
Chosing the plans

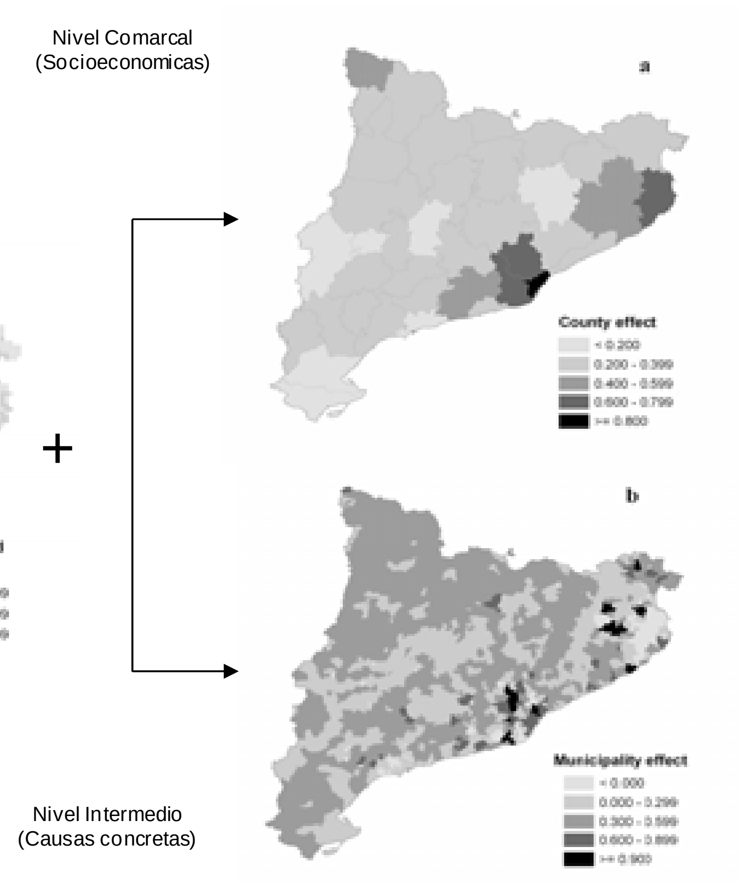
	Average fire occurrence probability				Burned area	
	Period 1	Period 2	Period 3	Post-plan	Plan period	Post-plan
	2010–2020	2020–2030	2030–2040	2040–2050	2010–2040	2040–2050
No management	0.054	0.042	0.038	0.056	2996	1237
Plan 1	0.054	0.041	0.035	0.039	2901	884
Plan 2	0.054	0.036	0.031	0.035	2685	793
Plan 3	0.054	0.032	0.024	0.019	2445	421
Plan 4	0.054	0.033	0.026	0.023	2508	506
Plan 5	0.054	0.037	0.030	0.029	2690	665



- Those plans combining economic and fire resistance objectives are the most efficient ones

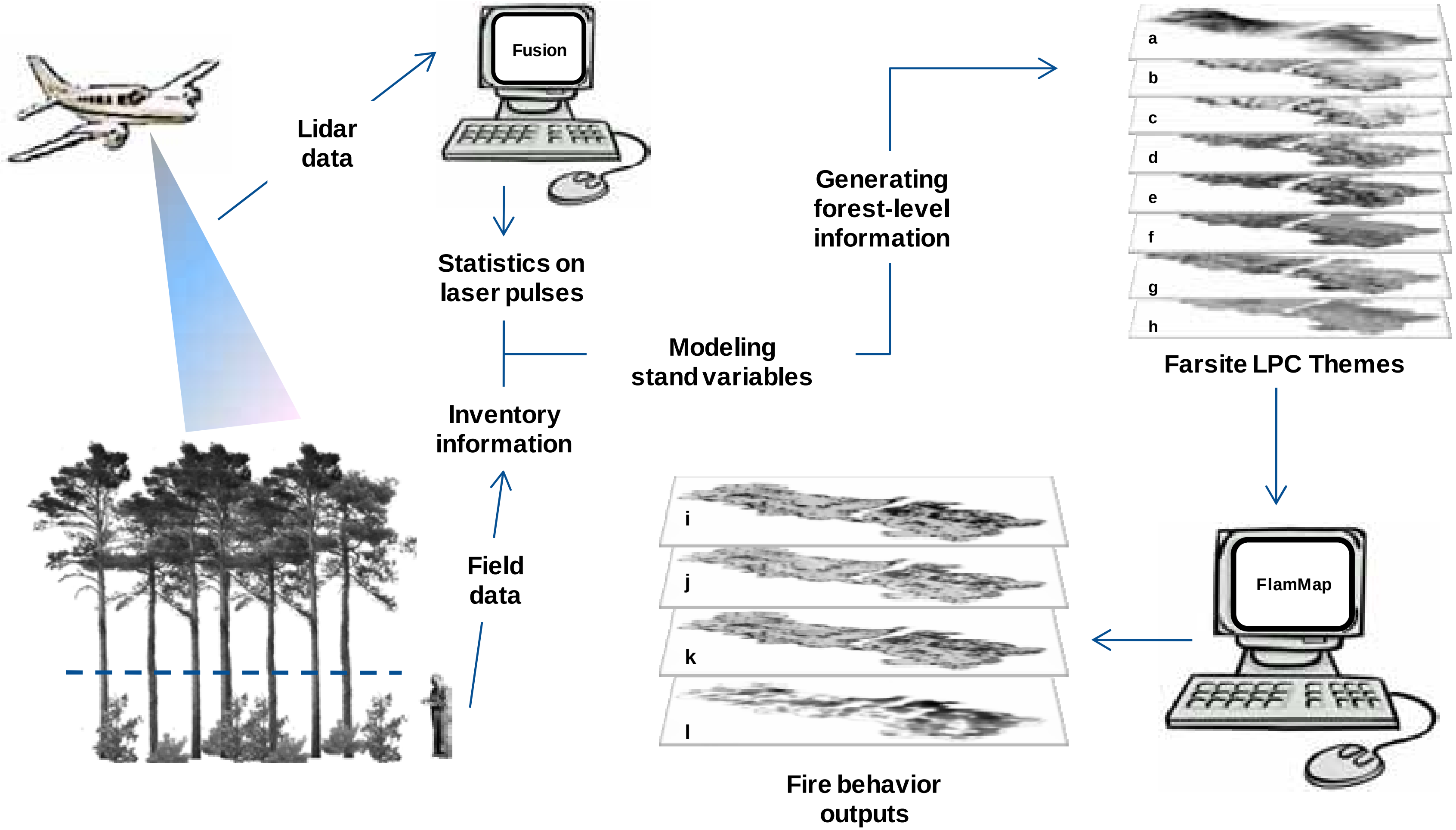
- Make ignitions not fully random (based on probabilities occurrence)
  - More realistic, for very large areas





González-Olabarria, J.R., Mola, B. Pukkala, T, Palahí, M. 2011.
Using multi-scale spatial analysis to assess fire ignition density in Catalonia, Spain.
En prensa Annals of Forest Science

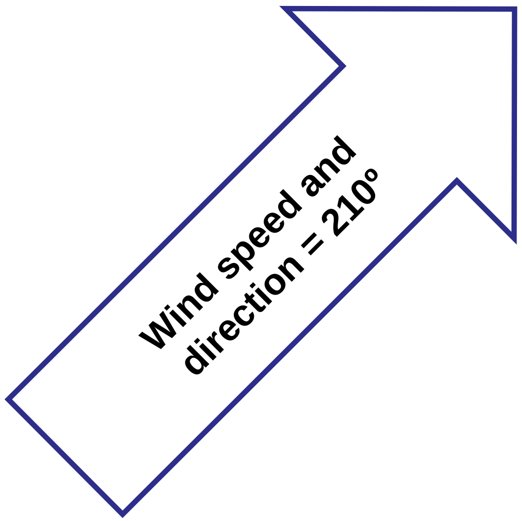
- New technologies as Airborne LiDAR can be used to provide better data on the spatial distribution of forest and fuels.
  - This can open a bridge with other simulation systems

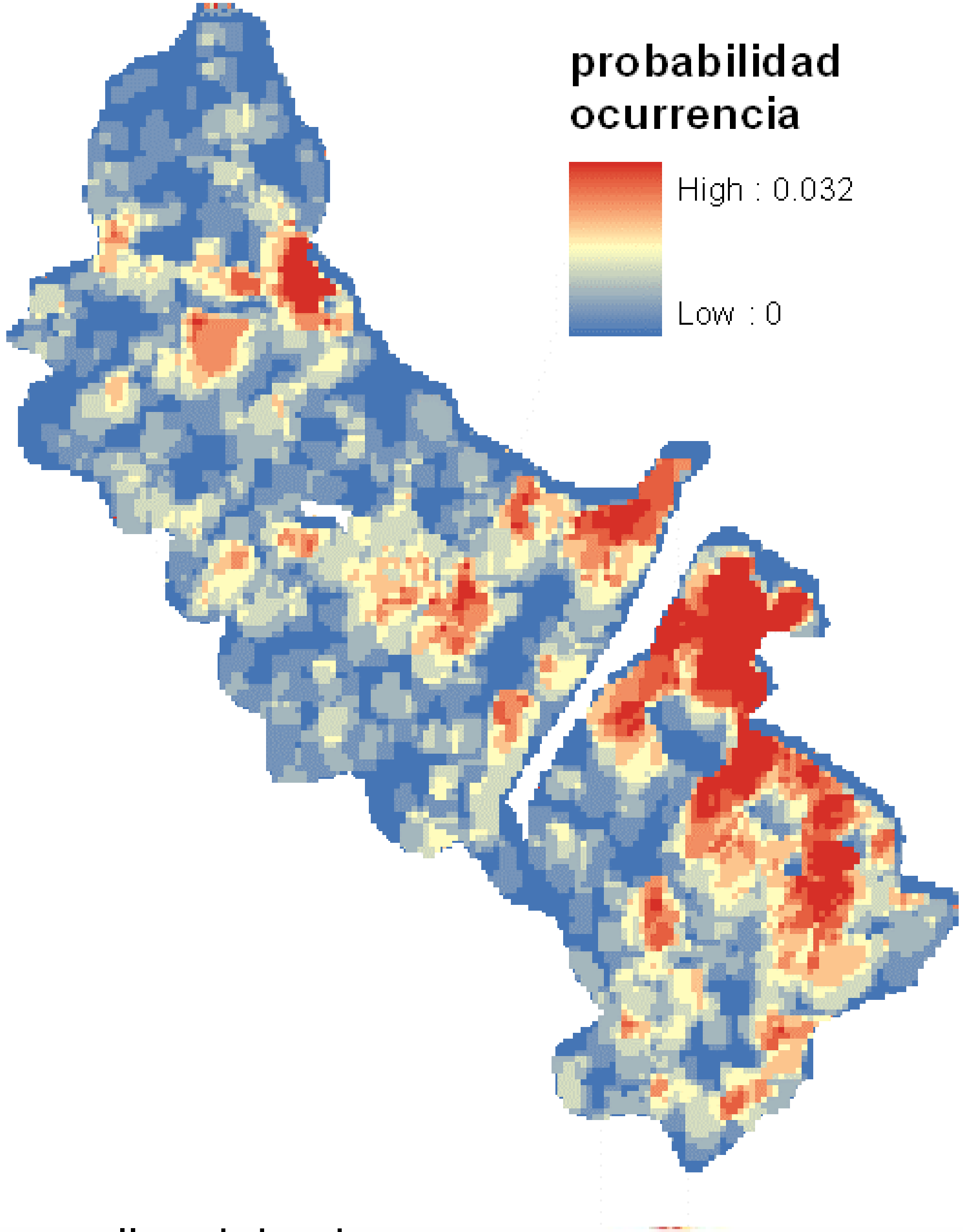


Gonzalez-Olabarria, J.R., Rodrigez, F., Fernandez-Landa, A., Mola-Yudego, B. (2012)
Mapping fire risk in the Model Forest of Urbión based on airborne LiDAR measurements.
Forest Ecology and Management. 282: 149-156

Results o

- Is possible to fairly predict fire behavior parameters in every place of the landscape for a given ignition allocation and weather conditions





Need to provide fuel moistures specially for small and dead ones

My point of view

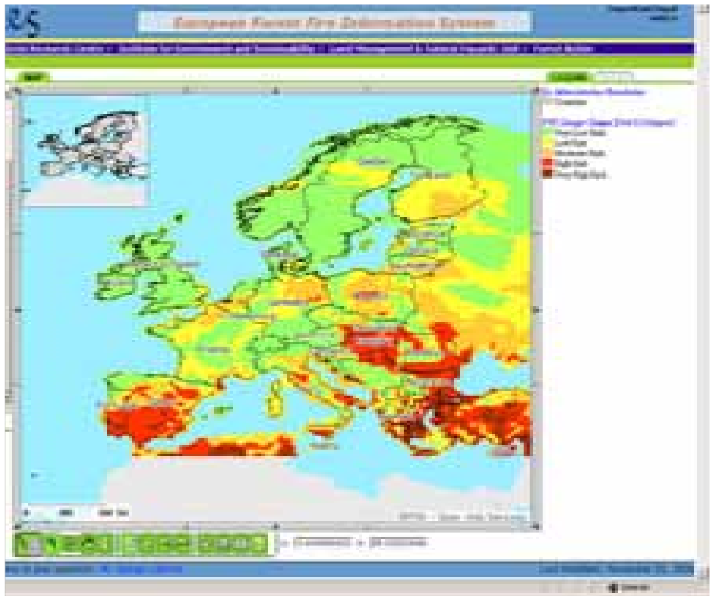
- Forest planning can be applied as the first step of an integrated fire prevention process.

- The risk of fire should be considered in ordinary silvicultural management and forest planning as a way to find efficient means to minimize fire damage cheaply.

- This step must be followed by other practices such as short term fuel management strategies in sensitive areas, and optimal allocation of the infrastructures supporting fire extinction efforts.

Adapting to Climate change **(my opinion)**

- Mediterranean areas
  - Conditions are bad enough (used to live with wildfires)
  - To many factors can affect fire risk
    - How fuel build-up will be affected (- risk) ?
    - More stress to trees (+risk) ? --- Other hazards?
    - Extreme fire weather will change? (Santa Ana, Mistral, Levante winds)
  - Improve forest management for current conditions is already a good approach and not only for fire
- Temperate areas
  - Extreme fire weather conditions will be more common
  - Are fire fighting resources ready?



Source: EFFIS Joint Research Center
http://effis.jrc.ec.europa.eu/

Thanks