Impacts of forest fires on hydrological processes: ongoing research in northwestern Iberia

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CIRCLE2 SHARE workshop
Climate Change Adaptation & Ecosystem Services
Teruel, 2013
Global wildfire occurrence
(Goldammer and Mutch, 2001 – FAO)

- Where do forest fires occur?

- Interface between humid and dry climates:
  - Climatic regimes with wet and dry seasons
  - Subtropical Africa
  - Subtropical Australia
  - Subtropical South America
  - Mediterranean Europe

- Allow for both vegetation growth and fire weather

Global dryland areas
(Millennium ecosystem assessment 2005)
Climate change and fire regime

- Climate change: expansion of drier climates from subtropical to temperate regions
- Fire-prone climates will follow this expansion (?)
- Afforestation under climate change could bring an added risk of forest fires (?)
- Forest fires have their own hydrological impacts

Average annual global burnt areas 2001/2004 (Giglio et al., 2006 – Atmos Chem Phys 6)
Forests in NW Iberia

- Important forest cover
  - (semi-)natural oak forests
  - Commercial forestry: fast-growing eucalypts and maritime pines
  - Fire-prone commercial species
  - **Recent afforestation** (XX\textsuperscript{th} cent.)

- Some ecosystem services:
  - Flood regulation
  - Maintenance of downstream water quality
  - Soil protection
  - Biomass production, etc.

(Pereira et al., 2004 – Portugal Millennium Ecosystem Assessment)
Wildfires in NW Iberia

Hydrological Impacts

- Loss of vegetation cover
- Changes to soil properties

Hydrological processes in Humid Mediterranean or Atlantic climate:

- Fire-prone trees
- Disturbance
- Slow recovery

Fire season

Caramulo (PP = 2337 mm/y)

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Why do forest fire research?

- Fires are a **recurring feature** of NW Iberia.
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Research in NW Iberia

Águeda river (~350 Km²) 20% burned (+ subcatchments)

Albergaria (hillslopes)

Esteiro river (~5 Km² per catchment) 58% burned

Colmeal headwater catchment (~0.1 Km²) 95% burned

1986 wildfire

2007 wildfire

2008 wildfire

Study catchment

WATERSHED

HILLSLOPE

WATERSHED

WATERSHED

WATERSHED

HILLSLOPE

HILLSLOPE
Hydrological impacts of forest fires

(Fire induced hydrological impacts)

(Shakesby and Doerr, 2006 – Earth-Science Reviews 74)

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Vegetation and soil disturbance

Albergaria (hillslope)
Wildfire in July 2005

Vegetation cover (satellite imagery: NDVI)

Ground cover (measured)

Vegetation and soil disturbance

Albergaria (hillslope)
Wildfire in July 2005

Vegetation cover (satellite imagery: NDVI)

Ground cover (measured)
Impacts on evapotranspiration

- Loss of (tree) potential evapotranspiration:
  - Smaller interception storage capacity: lower evaporation
  - Leaf loss, tree death: lower transpiration
  - Albergaria: loss of 45%, 30% and 20% in the 1st, 2nd and 3rd years after fire

- Systems are strongly water limited in summer – decreases to actual evapotranspiration is probably much smaller
Impacts on soil properties

- Burning of the litter layer -> topsoil covered with ash
- Ashes can clog the soil pores and prevent infiltration
- Fire can vaporise and alter OM -> condensation of OM in the soil profile can create hydrophobic conditions
  - Many soils in eucalypt and pine forests are naturally hydrophobic
- Hydrophobicity limits wetting of the soil matrix when soils are dry

(Larsen et al., 2009 – Soil Sci Soc Am J 75)
(see Keizer et al., 2008 – Catena 74)
Consequences for hillslope hydrology

- The wildfire disturbance can greatly increase surface runoff generation in burnt areas
  - Vegetation destruction + ash layer + soil water repellency

- These effects wear out as time passes; weather during the disturbance period is critical for impacts

Surface runoff in an eucalypt burnt area – Australia

Swansea Univ:
http://geography.swan.ac.uk/hydrophobicity/soil_hydrophobicity.htm
Consequences for hillslope soil loss

- Loss of topsoil until reaching a stone lag
  - Supply-limited erosion
  - Lower erosion than other landcovers
  - About 1/3 is Organic Matter

- Important loss of fines and OM in already degraded soils

<table>
<thead>
<tr>
<th>Cover type</th>
<th>Erosion (ton/ha.y)</th>
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</thead>
<tbody>
<tr>
<td>Vineyards</td>
<td>13.5</td>
</tr>
<tr>
<td>Wheat croplands</td>
<td>3.6</td>
</tr>
<tr>
<td>Burnt forest: Albergaria</td>
<td>0.5</td>
</tr>
<tr>
<td>Unburnt forests</td>
<td>~0</td>
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</tbody>
</table>

Wildfire in July 2005
Albergaria (hillslope)
Impacts of post-fire management

Macieira: Águeda watershed

1. Fire
   Aug 2011

2. Plowing & planting oaks
   May 2012

3. Severe erosion: 200 tons/ha
   Mar 2013

Post-fire terracing
Links between hillslope and watershed

Colmeal headwater watershed (0.1 km²)

Low connectivity

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Streamflow in headwater watersheds

Esteiro river (~5 Km² per watershed)

![Graph showing streamflow and rainfall for unburnt and burnt areas](image)

<table>
<thead>
<tr>
<th></th>
<th>Unburnt</th>
<th>Burnt</th>
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</thead>
<tbody>
<tr>
<td>Flow (mm/y)</td>
<td>2321</td>
<td>2346</td>
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<tr>
<td>Stormflow fraction</td>
<td>28%</td>
<td>36%</td>
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</tbody>
</table>

Unburnt (58%)

Rainfall (mm)

- Streamflow (mm)
- Unburnt
- Burnt

2007 wildfire

Unburnt
Burnt

Flow (mm/y)

35%

Stormflow fraction
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Impacts in headwater catchments

Oliveira do Hospital, Portugal (1986)

Road Cut

(Lourenço, 1992 – Est. Cin. 50)

Buffalo Creek, US (1996)

Reservoir silting and contamination

Debris flow

US Geological Survey
Impacts in large-scale watersheds

Águeda watershed (350 Km²)

- Typical fire size: ~1-10 Km²; 1986: 20% burnt area is very high!
  (Blöschl et al., 2007 – Hydrol. Process. 21)

- Large-scale: weather more important than land use
  – Modelling impacts of this fire: difference in peak flow rates <5%

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Rainfall / Streamflow (mm)

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall</th>
<th>Streamflow (Pte. Redonda)</th>
<th>Streamflow (Ribeiro)</th>
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<tbody>
<tr>
<td>1982/1983</td>
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Water quality

• Increased exports to runoff
  – sediments, OM, ashes, nutrients…
  – Ongoing research: ecotoxicology of ashes

• Contamination of large-scale watersheds?
  – Impacts on water quality can occur at a larger scale than impacts on quantity?

(Blöschl et al., 2007 – Hydrol. Process 21)

Tests of eco-toxicological effects of runoff from burnt areas

Preliminary results with *L minor* (macrophyta): 60% growth inhibition with unfiltered runoff sample
Large-scale potential for disaster

- Riadas event: Galicia, 2006
  - Forest fires in 2006
  - Storms in October 2006 lead to flash floods and high suspended sediments
  - Water and sediment reach estuaries ("Rias")
  - Excess mud and freshwater in the estuaries lead to widespread destruction of aquaculture

- Large-scale impacts of fire on water quality
Fire impact control

Before the fire

- Prescribed burning
  - Less destruction of vegetation and trees
  - Less impacts on soils
  - Easier to control post-fire hazards

After the fire

- Runoff and erosion control measures
  - US Burnt Area Emergency Response teams
  - Response time: 3 weeks after fire

Valetorto, Portugal

http://www.fireparadox.org
http://www.desire-project.eu

U.S. Forest Service
Moscow Forestry Sciences Laboratory
http://forest.moscowfsl.wsu.edu/BAERTOOLS/
Conclusions

- Afforestation in boundary dry regions: is fire to be expected?

- Fires can degrade forest ecosystem services:
  - flow regulation
  - soil protection
  - water quality

- Impacts are more visible at smaller scales – large-scale impacts should be on quality rather than quantity

- Afforestation to adapt to climate change: need also to adapt to forest fires?

More information: www.cesam.ua.pt/jpcn
Summary

1. Global wildfire occurrence
2. Climate change and fire regime
3. Hydrological consequences: window of exposure
4. This work: forests in NW Iberia: example of long-term afforestation
5. This work: forests in NW Iberia: they burn
6. Why our research?
7. Study areas and scales
8. Show impacts in NDVI
9. Impacts in vegetation evapotranspiration: potential and actual
10. Impacts on soils: ash layer, repellency
11. Consequence: enhanced runoff
12. Consequence: enhanced soil loss

1. Impacts of post-fire management
2. Catchment scale: hillslope and streams are not linked (Colmeal)
3. Catchment scale: Esteiro
4. Road cuts, debris flows, reservoir silting
5. Large catchment scale: importance of post-fire weather (Águeda)
6. Water quality impacts: sediments, nutrients, OM, toxic ashes
7. When fire and weather combine: Riadas, Galicia 2006
8. Adaptation: prescribed fires and BAER
9. Adaptation: policy challenges
10. Conclusions & Outlook
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Keizer et al, 2008 (Catena 74)

Hillslope runoff generation

Albergaria

Soil Water Repellency

Runoff (mm)

Rainfall (mm)

Soil Water (mm)

Ceira

Soil Water Repellency

Runoff (mm)

Rainfall (mm)

Soil Water (mm)

Keizer et al, 2008 (Catena 74)
Long-term impacts: fire ecology

- Ecosystems in fire-prone regions are usually adapted to wildfires

- Fire-adapted tree species: eucalypt
  - Highly flammable oils
  - Burning leaves can detach and travel with the wind, igniting new fires (spot fires)
  - Fire burns competition; eucalypt regrows quickly, before other vegetation types.

- Areas with recurrent fires may promote the appearance of fire-prone species -> higher fire frequency preventing ecosystem recovery

Eucalypt resprouting (Portugal): 4 months after fire
Policy challenges

• Workshops between Portuguese and Spanish researchers and forest managers in Aveiro, 2010:
  – “Forest fire research: beyond burnt area statistics”
  – “After the smoke clears: post-fire erosion and rehabilitation strategies”

• Some identified issues:
  – Need for locally-adapted, applied research on post-fire hydrological impacts and rehabilitation
  – Communication between researchers and forest managers
  – Include fire management – not only fire suppression – in regular forestry management
  – Coordinate and train post-fire emergency services to also help implement post-fire treatment
Prescribed burning

- Forests at risk can be burned in controlled ground fires
  - Less destruction of vegetation and trees
  - Less impacts on soils
  - Easier to control post-fire hazards

http://www.fireparadox.org
http://www.desire-project.eu

Valetorto, Portugal
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BAER: Burnt Area Emergency Response

1 week after fire
- Identify and map burn severity
- Identify soil and watershed issues
- Identify watershed vulnerabilities: threats to human life, property and resources

3 weeks after fire
- Produce and implement a treatment and stabilization plan

BAER teams across the US

USDA Forest Service – Moscow Forestry Sciences Laboratory
http://forest.moscowfsl.wsu.edu/BAERTOOLS/

Contour logging

Hydromulching

Debris rack