Resilience & Resistance of Ecosystems: The role of Disturbance

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Content

The role of disturbance in resistance/resilience thinking

The concept of disturbance across different sciences
- Definition
  - Disturbance descriptors
  - Examples
- Ecosystem response
  - Different Aspects

Disturbances in European forests:
- Changes over time: exercise
- Disturbance changes under climate change:
  - Findings within the Research program „Wald und Klimawandel”
  - Disturbance interactions
  - „Megadisturbances”

Conclusion
Disturbance as motor

Gradually changing conditions: rapid changes in ecosystems if threshold is reached

+ Disturbance

Disturbance theory in social sciences

Political sciences

Interest groups form primarily in opposition to other interest groups so as to counteract influence in their respective political domains. Interest groups also form and grow in response to threats.

David Truman (June 1, 1913 – August 28, 2003)

Civil disorder a delicate balance of power – riot or oppression being the result of an unbalance. Participant in a civil disorder are not in agreement about appropriate behaviour, with a highly visible minority being responsible for most of the damage. Not involved citizens may have their lives significantly disrupted.

- Rebellion, Revolution, Economic collapse, etc.
Definition

“Any relatively discrete event in time and space that disrupts ecosystem, community or population structure, and/or changes resources, substrate availability or the physical environment.”


Disturbance descriptors

- **Scale**: spatial extent \([m^2, ha, km^2]\)
- **Intensity**: the energy per area and time \([1, 2, 3, 4, 5]\)
- **Severity**: biological impact and change \([<10\%, 30\%, 60\%, >90\%]\)
- **Frequency**: number of events per unit time \([h, d, w, y, dec]\)
- ...

![Disturbance Example 1](image1.jpg)
![Disturbance Example 2](image2.jpg)
**Lightning Strike**

Scale: $m^2$
Intensity: 5
Severity: <10%
Frequency: w

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**Fire**

Scale: ha–km$^2$
Intensity: 2-5
Severity: <10 - 100%
Frequency: dec
Global warming

- Scale
- Intensity
- Severity
- Frequency

- abiotic vs. biotic
- natural vs. anthropogenic
- historical vs. novel

- individuals, populations, ecosystems, landscape
- structure, processes and functions
Effects of disturbances

“Any relatively discrete event in time and space that disrupts ecosystem, community or population structure, and/or changes resources, substrate availability or the physical environment."


Ecosystem response (i)

Energetics
Due to disturbance:
- Production/respiration becomes unbalanced
- Production/biomass and respiration/biomass ratios increase
- Exported or unused primary production increases

Nutrient flow
Due to disturbance:
- Disruption of nutrient cycles
- Nutrient turnover increases
- Vertical cycling of nutrients decreases
- Nutrient loss increases
**Ecosystem response (ii)**

**Water use**
Due to disturbance:
- Different ecosystem states need different amounts of water.

**Example:**
Water use in uniform forests of different ages
(*Eucalyptus regnans*, builds uniform stands after forest fires)

**Light conditions**
Due to disturbance:
- Drastic changes in light conditions in gaps

**Ecosystem response (iii)**

**Species interactions**
Due to disturbance:
- Changing competition
- Competitive exclusion vs. coexistence

➢ **Frequency of reduction determines coexistence**

**Intermediate disturbance hypothesis**
- Evidence from ecological succession.
- But not in all ecosystems confirmed.


- Frequency of reduction determines coexistence
Ecosystem response (iv)

Community structure
- Species composition
- Proportion of r-strategists increases
- Food chains shorten
- Species diversity changes

General system level trends
- Ecosystem becomes more open
- Succession reverts to earlier stages
- Efficiency of resource use decreases
- Negative interactions (e.g. parasitism) increase and positive interactions (e.g. mutualism) decrease
- Loss of ecosystem services
Ecosystem response (v)

Cascading effects
Due to disturbance:
- Habitat changes
- Indirect effects on other species

Example:
Effects of disturbance on spatial & temporal population dynamics – a modelling study

Eucalyptus regnans,
Gymnobelideus laedbeateri

Habitat suitability given by:
TSF: time since fire
IFI: most recent interfire interval

Large: 50 x 50 cells
Small: 5 x 5 cells

- Frequent fires reduce landscape-wide distribution of Eucalyptus with follow on effects on the Possum

Positive effects of disturbances?!?

- Natural and ubiquitous process, shaping ecosystem structure and function
- Broad variety of temporal and spatial scales, intensities and severities
- Promotes diversity
- Renews processes

Anthropogenic view
- Effect on ecosystem services
  - Ecological (e.g. protection of natural hazard)
  - Economic (e.g. production of wood)
  - Welfare (e.g. recreation)
Disturbances in forest ecosystems in Europe

Historical trends & future expectations
In the past...

Management over the last centuries

*Management European scale*
- Long period of deforestation and forest exploitation: clearcutting
- Start of reforestation
- Changing tree composition from broadleaved species to conifers

*Role of natural disturbances*
- In European forests natural disturbance dynamics have been largely eliminated

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In the past...

Management over the last centuries

*Management in Switzerland*
- Ca. 300 to 100 y ago: culmination of anthropogenic disturbances
- Artificial regeneration became more common around 1800
- After 1845: ca. 1’200’000 saplings planted per year
- Beginning 20th century: ‘close to nature silviculture’
Learning from the past...

Understand past disturbance patterns to model the future

Focus of this review:

• A quantitative historical overview
  – a basis for modelling impacts of climate change
  – and development of new management guidelines

• Estimate the total damage to European forests from natural disturbances

• Discuss possible causes of observed trends

Changes since 1948

Forest area and growing stock

Across 19 European countries:

• 1948 to 1995, area of conifers increased by 16%, while the total conifer growing stock increased by 275%
Excercise

Evaluate main disturbance in European forests

a) Describe the damage trend you observe in your charts.

b) Try to explain your observations (there may be several reasons).

c) How could management respond in order to minimize crop failure?

Schelhaas et al. 2003
Natural disturbances in the European forests in the 19th and 20th century

Abiotic disturbance
Storm damage

Fig. 5 Volumes of wood damaged by storms as reported in European countries for 1850–2000 and as scaled up for total Europe for 1950–2000.
Abiotic disturbance

Storm damage

- Reported damage has increased since 1850, both in frequency and magnitude
- Annual damage: 18.7 million m³ (1950-2000 average)
- Occasional very large events (1990, 1999)
- Bayern (Germany) and in Czech Republic: sharp increase in sanitation felling since 1950
- Switzerland: increase in storm damage since 1868

Abiotic disturbance

Snow damage

Fig. 6 Volumes of wood damaged by snow, as reported in European countries for 1850-2000 and as scaled up for total Europe for 1950-2000.
**Abiotic disturbance**

**Snow damage**

- Trend for increasing damage
- ca. 1 million m$^3$ yr$^{-1}$: small loss compared to most other disturbances
- Most reported snow damage in Germany, Austria, Czech Republic and Slovak Republic

![Graph showing snow damage](graph.png)

**Fig. 6** Volumes of wood damaged by snow, as reported in European countries for 1850-2000 and as scaled up for total Europe for 1950-2000.

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**Abiotic disturbance**

**Climate extremes:** drought, waterlogging of the soil and frost

![Graph showing climate extremes](graph.png)

**Fig. 7** Volumes of wood damaged by other abiotic causes, as reported in European countries for 1900–2000 and as scaled up for total Europe for 1950–2000.
**Abiotic disturbance**

**Climate extremes:** drought, waterlogging of the soil and frost

- Annual damage: 0.4 million m³
- Waterlogged soils give less support to roots and increase susceptibility to windthrow
- Future climatic change could enhance synergies

![Fig. 7](image1.png) Volumes of wood damaged by other abiotic causes, as reported in European countries for 1900-2000 and as scaled up for total Europe for 1950-2000.

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**Abiotic disturbance**

**Fire**

![Fig. 3](image2.png) Annual number of forest fires as reported in European countries and as scaled up for total Europe for 1970-2000.

![Fig. 4](image3.png) Volumes of wood damaged by fire for total Europe (1961-2000) as estimated from the total upscaled forest fire area and average wood volume damaged by fire, per country.

![Fig. 2](image4.png) Annual burned forest area as reported in European countries for 1960-2000, and as scaled up for total Europe for 1961-2000.
Abiotic disturbance

Fire

- Forest fire area and frequency have increased over time
- From 1961–2000, on average 213,000 ha (about 0.15% of Europe’s forest area) affected by fire
- Mediterranean area accounts for 88% of fires (94% if France is included)

Biotic disturbance

Bark beetle

Fig. 8 Volumes of wood damaged by bark beetles, as reported in European countries for 1850–2000 and as scaled up for total Europe for 1950–2000.
Biotic disturbance

Bark beetle

- Annual damage: 2.9 million m$^3$
- Highly correlated with storm damage.
- Severe outbreaks known from historical records:
  - Sumava Mountains and surroundings (Czech Republic) after the storms of 1868 and 1870
  - Central Europe after the Second World War

Fig. 8  Volumes of wood damaged by bark beetles, as reported in European countries for 1850-2000 and as scaled up for total Europe for 1950-2000.

Excercise

Evaluate main disturbance in European forests

a) Describe the damage trend you observe in your charts.

b) Try to explain your observations (there may be several reasons).

c) How could management respond in order to minimize crop failure?

d) How do the different damages compare?

e) Challenges of inferences from historical records?

Schelhaas et al. 2003
Natural disturbances in the European forests in the 19th and 20th century.
### European scale

#### Damage by agent

<table>
<thead>
<tr>
<th>Agent</th>
<th>Damage (million m³ y⁻¹)</th>
<th>Europa</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td>Sturm</td>
<td>18.6</td>
<td>53</td>
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<tr>
<td>Feuer</td>
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<td>Schnee und weitere abiotische Faktoren</td>
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<tr>
<td>Hasen</td>
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<td>8</td>
<td></td>
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<tr>
<td>Einwohner</td>
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<td>8</td>
<td></td>
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<tr>
<td>Unbekannt und kombinierte Effekte</td>
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<tr>
<td>Total</td>
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<td></td>
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</tbody>
</table>

### Data recording

#### Challenges of historical records

*Records are patchy at the European scale*

- Numbers and detail of reports increased over time
  - Statistics for forest fires available only for the last 20–30 years
  - No statistics available on biotic damage
- More recent reports easier to access than older ones
- Some countries have detailed records, others have none
  - Upscaling sometimes based on only a few countries

*Ambiguous definitions*

- Definitions of ‘forest’ vary between countries and over time (crown cover exceeds 10-20%)
- Distinction between forest and other wooded land is difficult
Swiss scale

Damaged forests

LFI 3: Schweizerisches Landesforstinventar 2004 - 2006

- 56% of the forest is disturbed (increased from 53% during the last 11 y)
- 7% are a lot to highly disturbed
- Since mid 90ties: 4% of the total forest (ca. 49 000 ha) destroyed
  [Central Plateau: 7%, Pre-Alps 8%]

**European / Swiss scale**

Comparing damage

<table>
<thead>
<tr>
<th>Damage (million m³ y⁻¹)</th>
<th>CH: LFI 3</th>
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<tr>
<td>Storm</td>
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<td>Fire</td>
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<td>Snow and other biotic factors</td>
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<td>Insects</td>
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<tr>
<td>Others</td>
<td>0.1</td>
<td>2.4</td>
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<tr>
<td>Total</td>
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<td>100</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Damage (% of total forested area)</th>
<th>Europa</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm</td>
<td>18.6</td>
<td>53</td>
</tr>
<tr>
<td>Fire</td>
<td>5.6</td>
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<td>Snow and other abiotic factors</td>
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<td>Bark beetles</td>
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<tr>
<td>Other insects</td>
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<td>2.5</td>
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</table>
Climate change affects disturbances


Number of fires in 1990-2014

Climate change affects disturbances

Change in numbers of days with fire risk
Climate change affects disturbances

Wildland-Urban Interface (WUI): Management tool

Climate change and disturbance interactions


Barkbeetle live cycle:
Climate change and disturbance interactions

Bark beetle: Expected numbers of generations:

Climate change and disturbance interactions

Susceptibility of spruce trees:

- Interaction of abiotic and biotic disturbances is expected to result in larger damage.
From disturbances to «Megadisturbances»

Interaction of drought, temperature and management

Oak replacing pine

Pine dieback and establishment of oak
Climate change + Disturbances

Disturbance processes change with climate change. Severity of disturbances might increase.

➢ Manage ecosystem to increase its resistance and resilience!

Summary

Abrupt changes are called Disturbance

Disturbance...
- natural and ubiquitous process, shaping ecosystem structure and function
- encompass a broad variety of temporal and spatial scales, intensities and severities
- opens space and makes resources available
- does not affect biological systems uniformly
  - temporal and spatial variation of habitat suitability (patch dynamics)
  - influence on permeability of landscapes to dispersal
  - promotes habitat heterogeneity... and thereby species diversity
  - alters species interactions
Disturbance and society

Anthropogenic alteration of disturbance regimes:
- purposefully (e.g. fire suppression, flood control)
- inadvertently (e.g. land-use practices)

Disturbances can destroy life and property:
- Catastrophic events for development, but not necessarily for ecosystems.
- Built environment is often less resilient than the natural ecosystem.
- Restoration of natural disturbance regime may increase resilience of the system (e.g. prescribed burning, increasing wetland cover).
- Increase resilience in the social system

Conclusion

Climate change affects disturbance regimes

- Disturbance frequencies are expected to increase.
- Disturbance interactions are expected to result in increased loss of ecosystem services.
- Role of natural disturbances expected to increase in the future.
- Knowledge about the disturbance processes and effects provides the basis for ecosystem management.