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Effects of air pollution on Scots pine stands in industrial areas in Poland on the basis dendrochronological analysis

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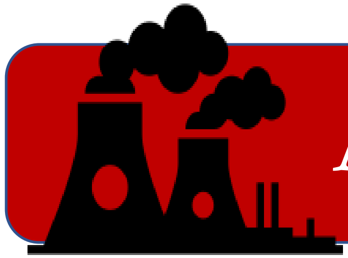
Introduction/research problem



AIR POLLUTION CONSEQUNCES

Substances emitted into the atmosphere by human activity

GLOBAL WARMING

HEALTH PROBLEMS

5.5 million premature deaths globally in 2015.

25% Forest area in Europe

FOREST PROBLEMS

SMOG

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Introduction/research problem

Climate change

increase of global temperature, increase of extreme weather events: droughts, hurricane, frost

+

Air pollution

mainly:

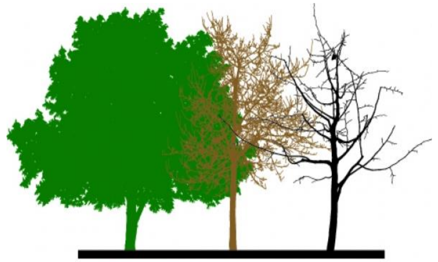
SO_2

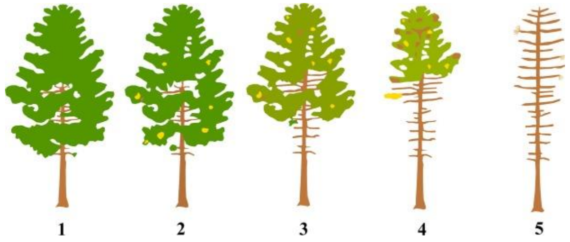
NO_x

→

Air pollution and climate change - two key factors comprising the global change threat to forest health and sustainability

forest health, structure, functioning and sustainability





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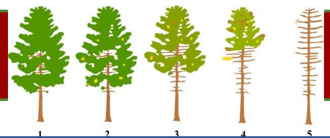
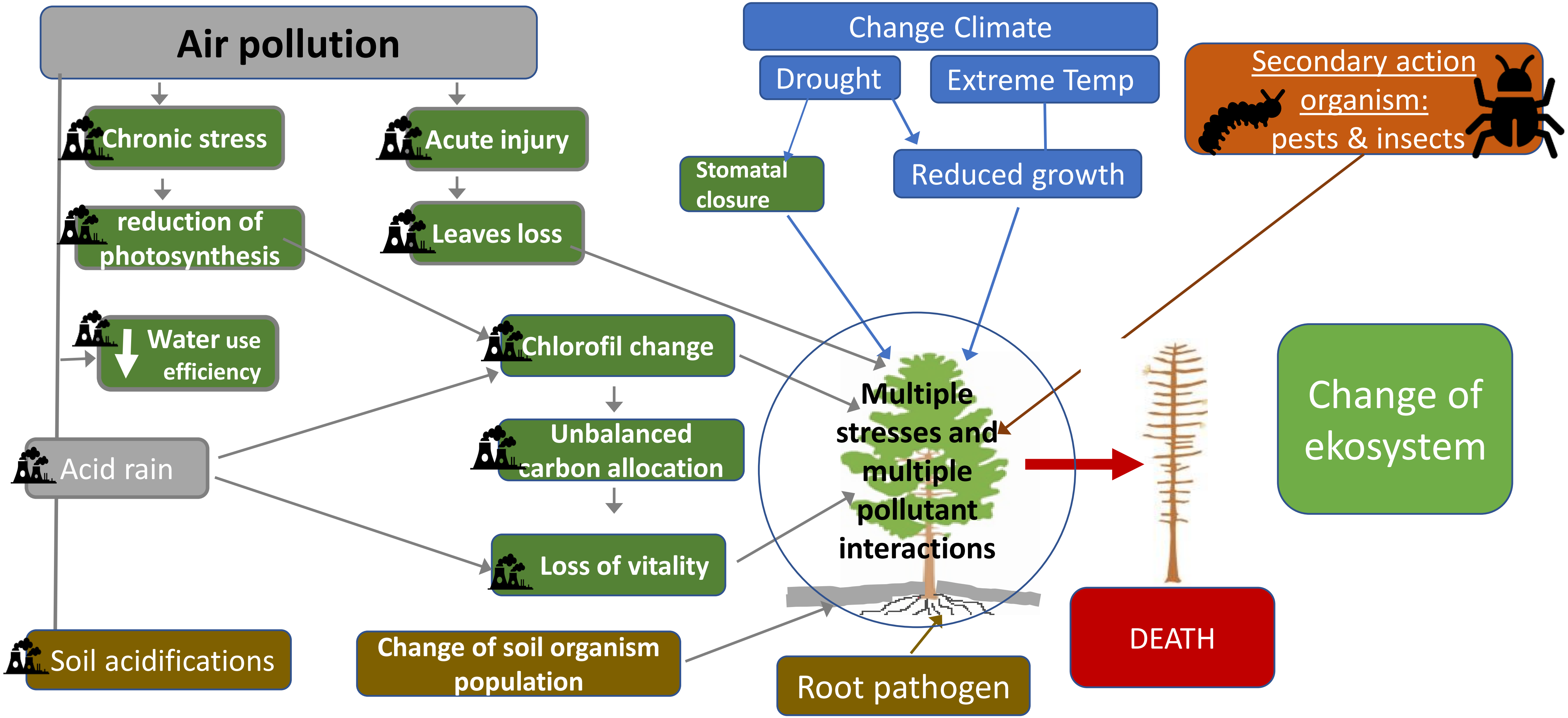
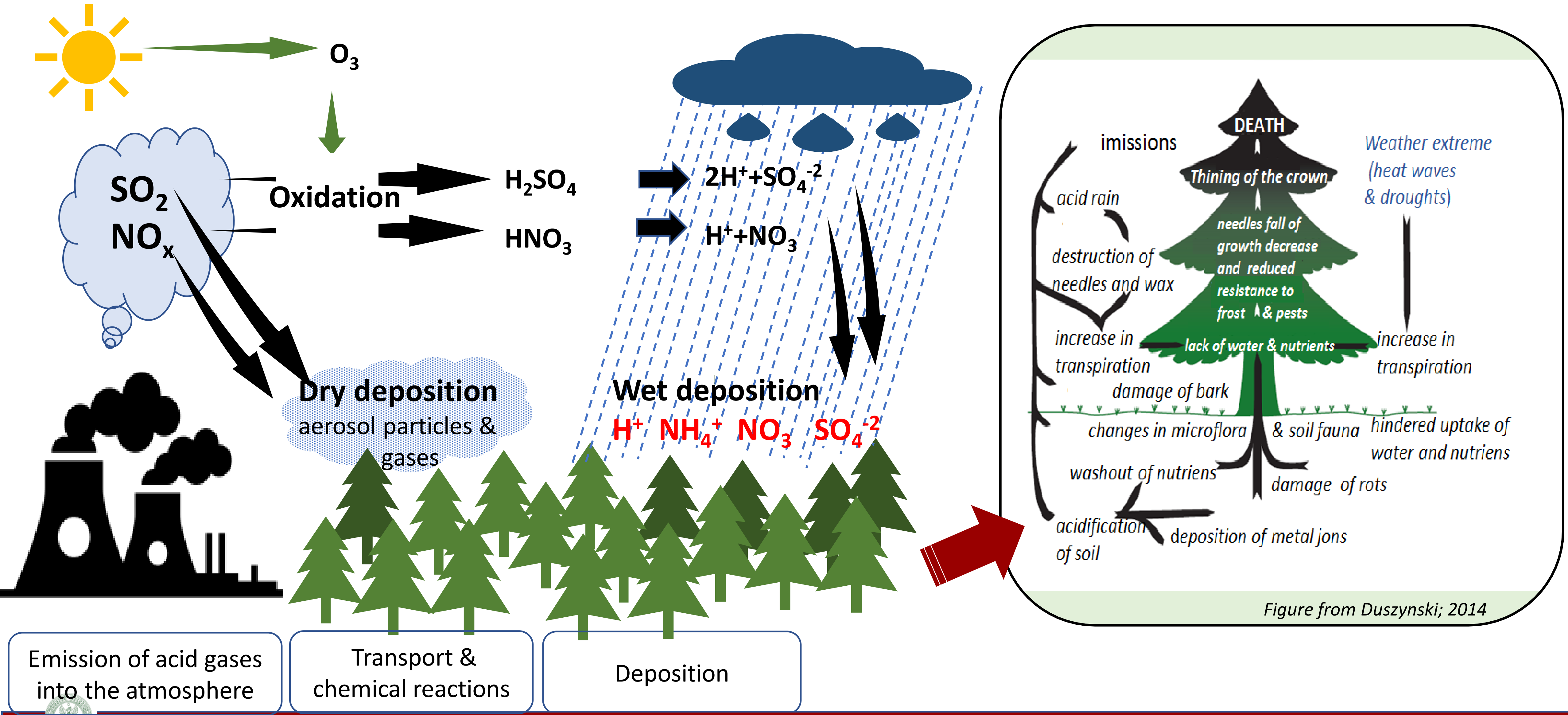


The integrative effects



IECF 2020 Introduction/research problem

A complex mechanism of the influence of sulphur dioxide & nitrogen oxide on trees



Effects of air pollution on forests

The direct effects of pollution

The indirect effects of pollution

LONG-TERM chronic exposure to air pollution
CHRONIC STRESS
→ **Decreasing biomass growth**

RAPIDLY high concentration of air pollution
DRASTIC STRESS
→ **Acute Damage**
DEATH of trees (1-2 yr)

- **Reducing forests resistance to biotic and abiotic stress**
- **Possibility decline of certain tree species**
- **Change in forest ecosystem**
- **Global Change**

Research problem

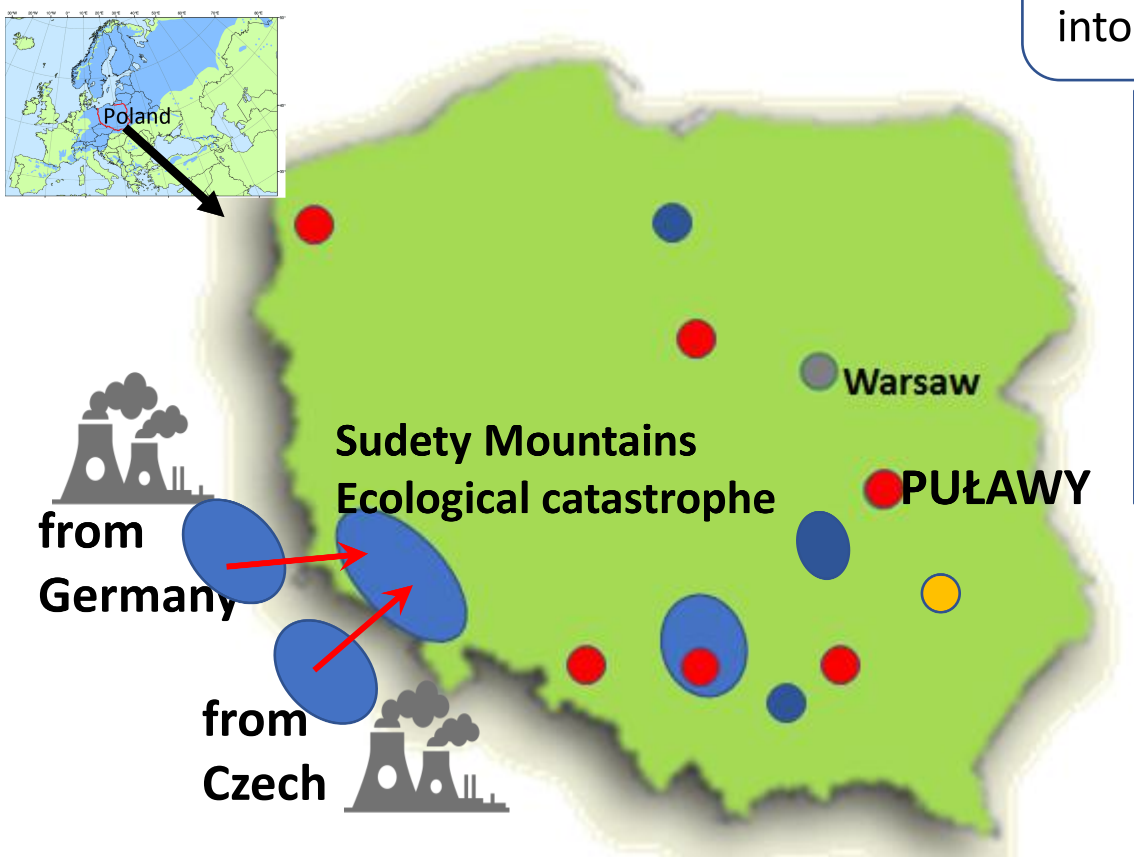
Air pollution and forest health in Poland

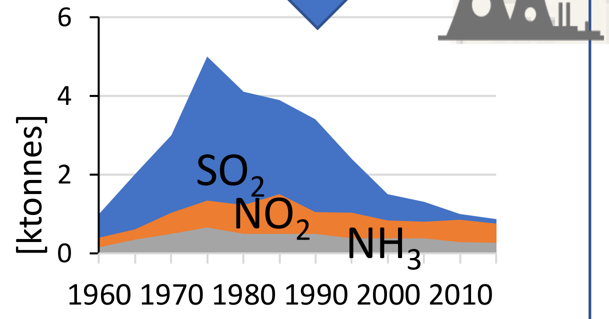
Intensive development of industry in the second half of the 20th century

Significant increase of the level of pollutants emitted into the atmosphere

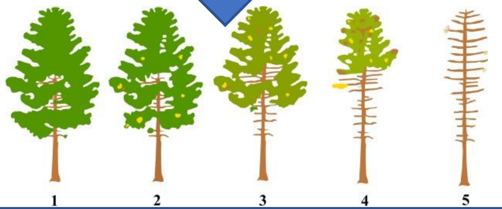
Toxic pollutants

SO_2; NO_x, NH_3





Emissions of air pollutants in Poland



Over 40 years - serious damage to forest stands.

The location of industrial plants emitting toxic pollution causing damage of forests.
Red circles – nitrogen plants,
Blue signs- other plants or industrial region

PROCES TIME

Most forest areas that were exposed to pollution pressure:

LONG-TERM weakening of the tree vitality

gradual general deterioration, sometimes ending in death of trees.

Puławy - RAPID DEATH (1-2 years) many hectares of forests

Research goals

Evaluation of Scots pine stands degradation caused by the pollutants emitted from the Nitrogen Fertilizer Factory in Puławy

1. What are the direct and indirect effects of air pollution on the forest growing in the vicinity of factory?

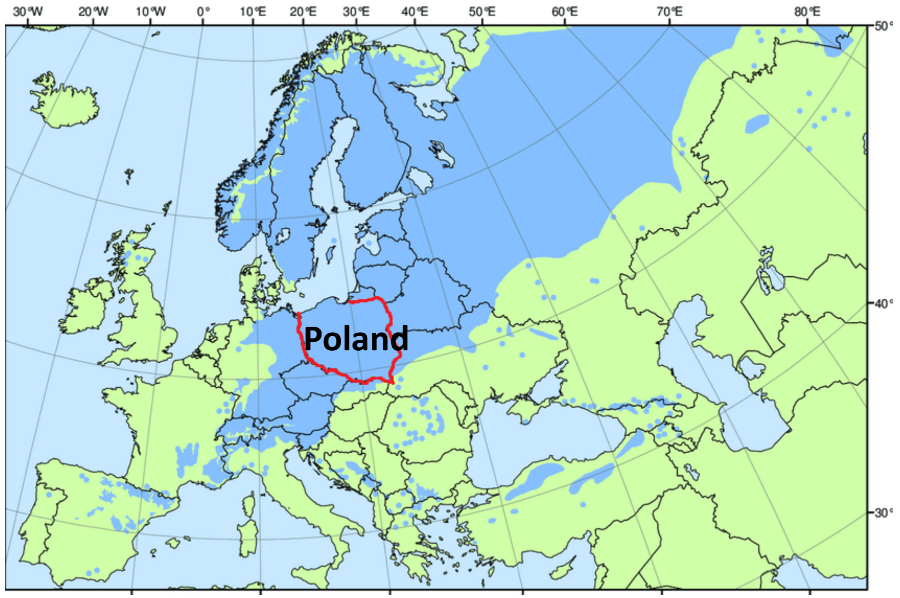
2. What is the spatio & temporal distribution of forest damage caused by the pollutants?

3. What factors, besides air pollution, contributed to such a large forest damage?

Research Goals

Why Scots pine stand were investigated?

Scots pine grow all over Poland



Distribution map of Scots pine [www.Euforgen 2009]

In Poland

58%

of forests are pine

In Puławy Forest District

71%

of forest are pine

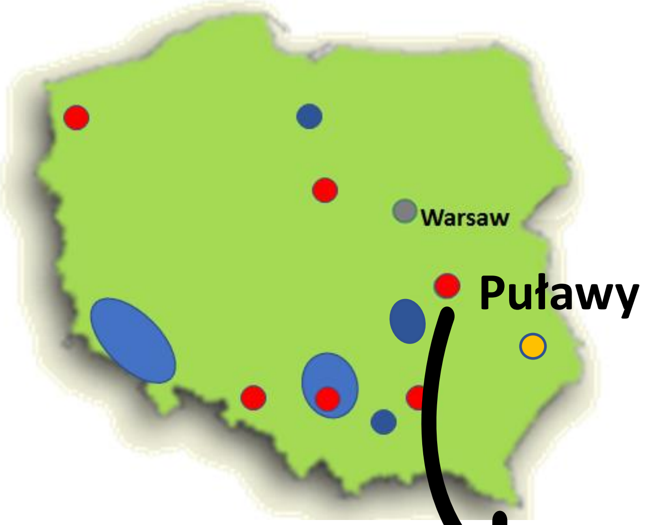
Scots pine:

very sensitive species to air pollution

Exposure of needles on direct contact with pollution may lead to decline of trees

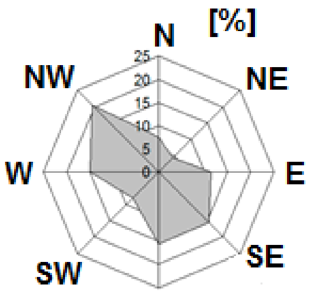
Study site

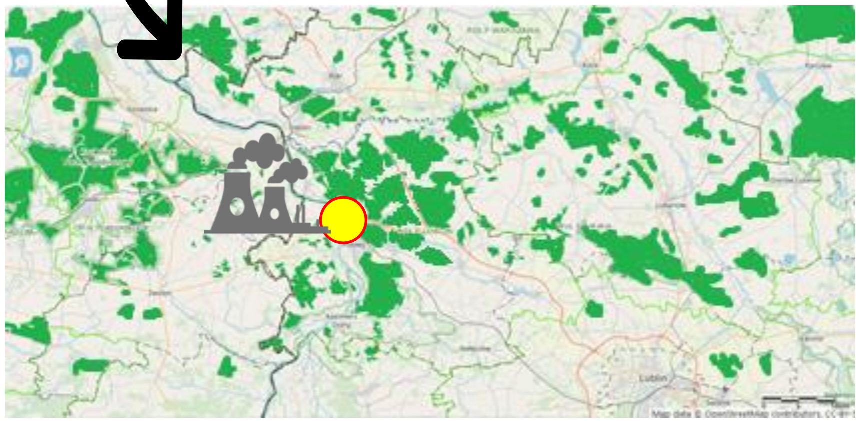
Forests growing in the vicinity of the Nitrogen Fertilizer Factory in Puławy



Location of factory

- **western part of a large forest complex**
- **the prevailing wind direction – sector W**





Lull – 21%,
The average wind speed -2,1m/s

The nitrogen fertilizer factory in Puławy - the one of biggest polluters of the environment in Poland for over 25 years (1966-1990).

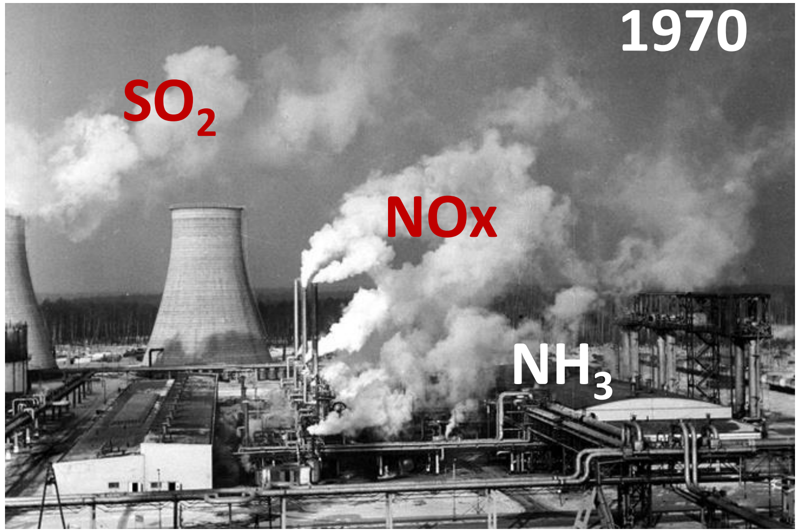
1966 – Start of factory's activity – [autumn 1966]
start of destructive impact on natural environment

1967 [spring] - the death of Scots pine trees -70 ha
1967 – 1970 "biological death zone" (all the trees were died)- 500ha
Since 1970- the zones spread outwards from the fertilizer plant as the devastation of the environment progressed
1975 - the zone of strong destruction - about 1200 ha

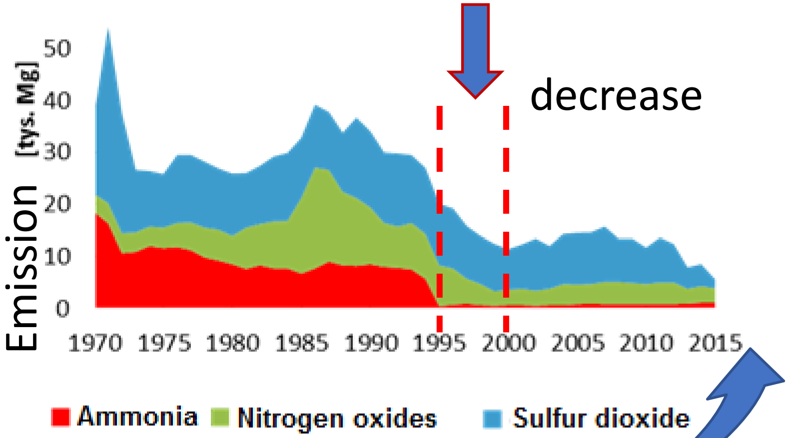
1975-2015

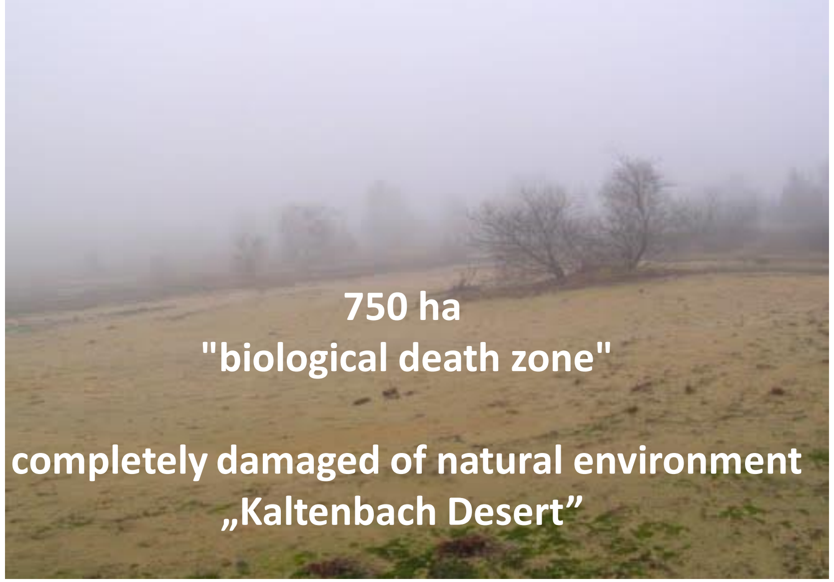
Severe destruction (>75% trees) 1200 ha	**Medium destruction (31-75% trees) 5000 ha**	**Lower destruction (5-30% trees) 7000 ha**
Since 1975 **stable area**	**Increase in the area until 1990,** then stable	**Increase in the area until 1998,** then stable

Study site



Changes in pollutant emissions





Methods

Trees that survived

Long-term stress → **Decreasing tree vitality** → **Growth reduction** → It is noted in the tree-ring width

Trunk curvature and crown & needle deformation

The best method to determine the effect of pollution on tree growth - dendrochronological analysis

- a retrospective analysis of the variation of tree-ring widths
- the estimation of the direct and indirect effects of pollution

it has been used in our research.

The period before serious air pollution

The period of immensely serious air pollution

The period of gradually improving air quality

Relatively wide tree-rings

Reduced tree-rings

Relatively wide tree-rings

Bark

Research Materials

Scots pine trees (100-120 years old) growing at different distances of factory and in different geographical directions

7 research plots located in different damage zones
Reference plot (no. 8) - stand without damage
All plots: the same habitat, similar age (100-120 years old)

Core samples
at breast height
one core per tree

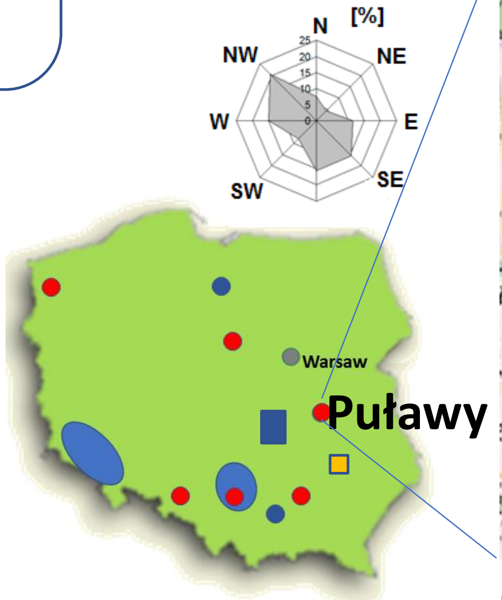
October 2017

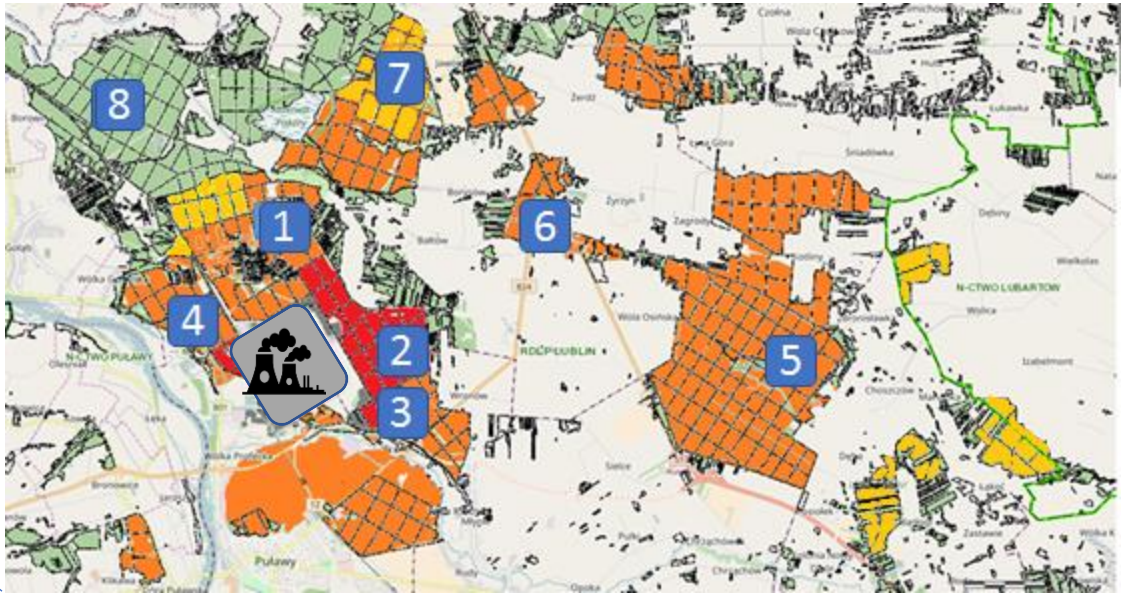
20 samples in each of plots

In total - 160 samples

1,3m

Tree-ring sampling





Damage zone

- Severe damage >75% trees
- Medium damage 31-75% trees
- Minor damage 5-30% trees
- Without damage

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Methods: Standard dendrochronological techniques

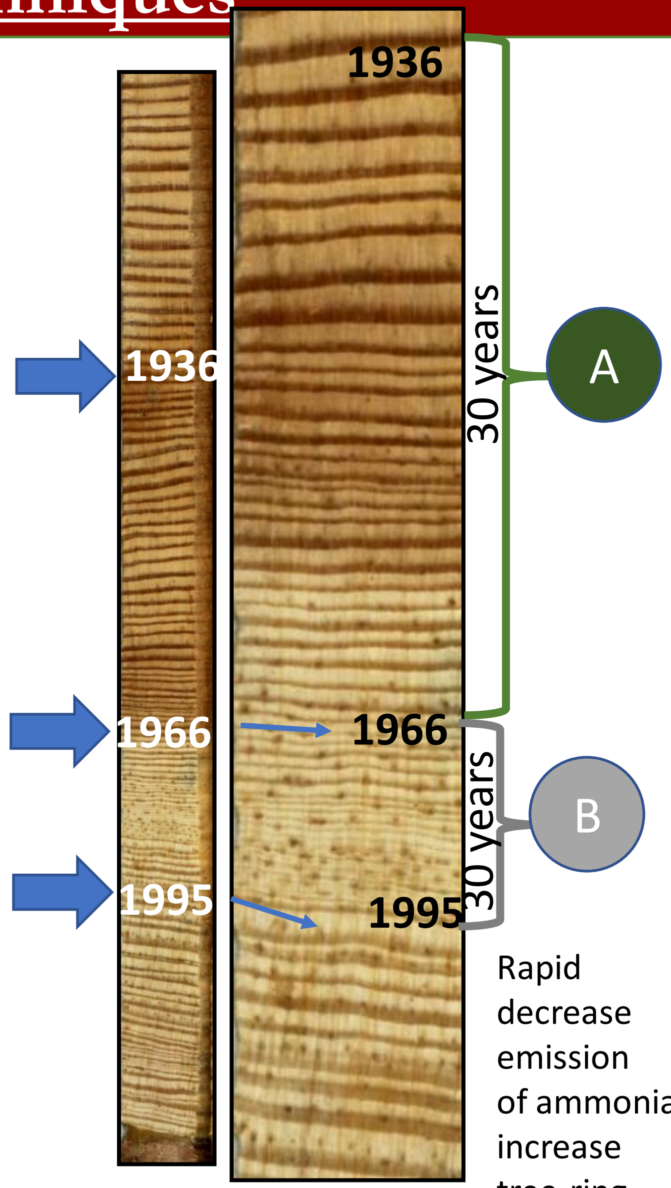
1. **Measurements of tree-ring widths TRW (0,01mm)**
   [software Coo-Recoder 7.8]

2. **Crossdating tree-ring series: visual & statistical**
   [software: CDendro 7.8, COFECHA]

3. **Chronology construction & basic statistic (**chronologies for each plot**)**
   [software DPL, ARSTAN]

4. **The reduction [R] of tree-ring widths** (for each measuredTRW series, into three ranges: low 30%R<50%, high 50%<R<70%, very high >70%)
   [according Schweingruber 1985, software Tree-Ring]

5. **Climate–growth relations: response function & pointer years**
   [software DendroClim2002, Weiser]



Rapid decrease emission of ammonia, increase tree-ring widths

<u>Analysis was carried out for three periods:</u>

(A) 1936-1965 (period of 30 years before start of factory)

(B) 1966-1995 (the period of 30 years of extremely high air pollution)

(C) 1996-2017 (1995 - decrease emission of ammonia, gradually decrease air pollution

RESULTS

Results

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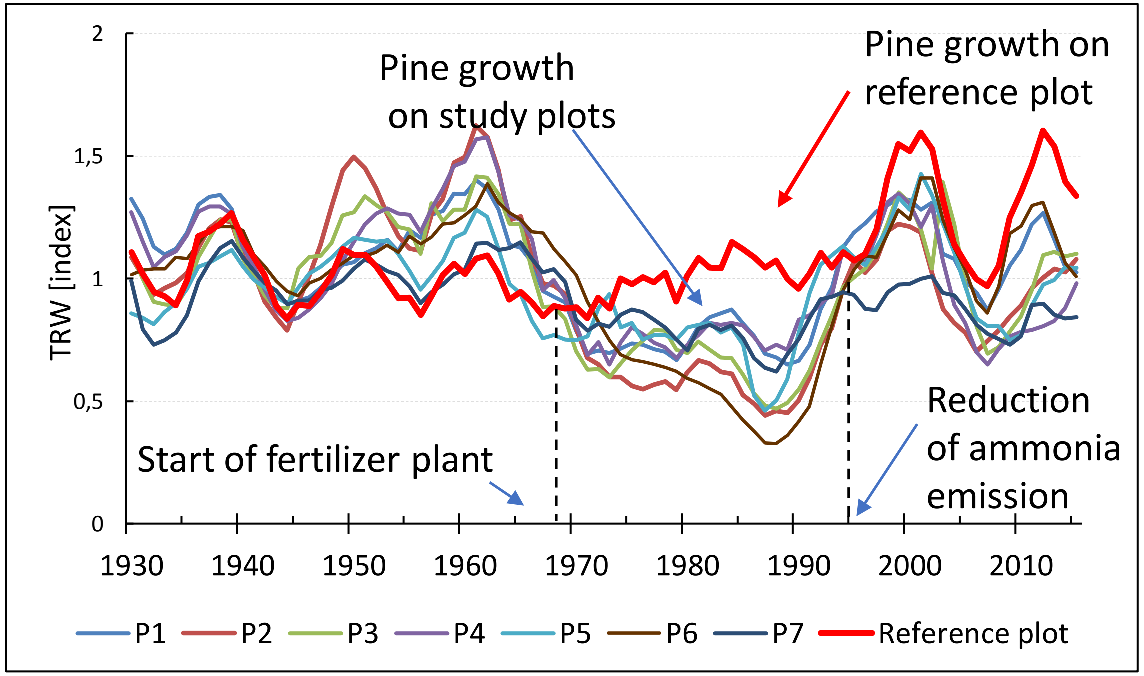
EMISSIONS of POLLUTIONS from the NITROGEN FERTILIZER PLANT in PUŁAWY

LONG LASTING, STRONG GROWTH REDUCTION OF SCOTS PINE LIVING IN THE REGION

LONG-TERM CHRONIC DECLINE OF SCOTS PINE VITALITY



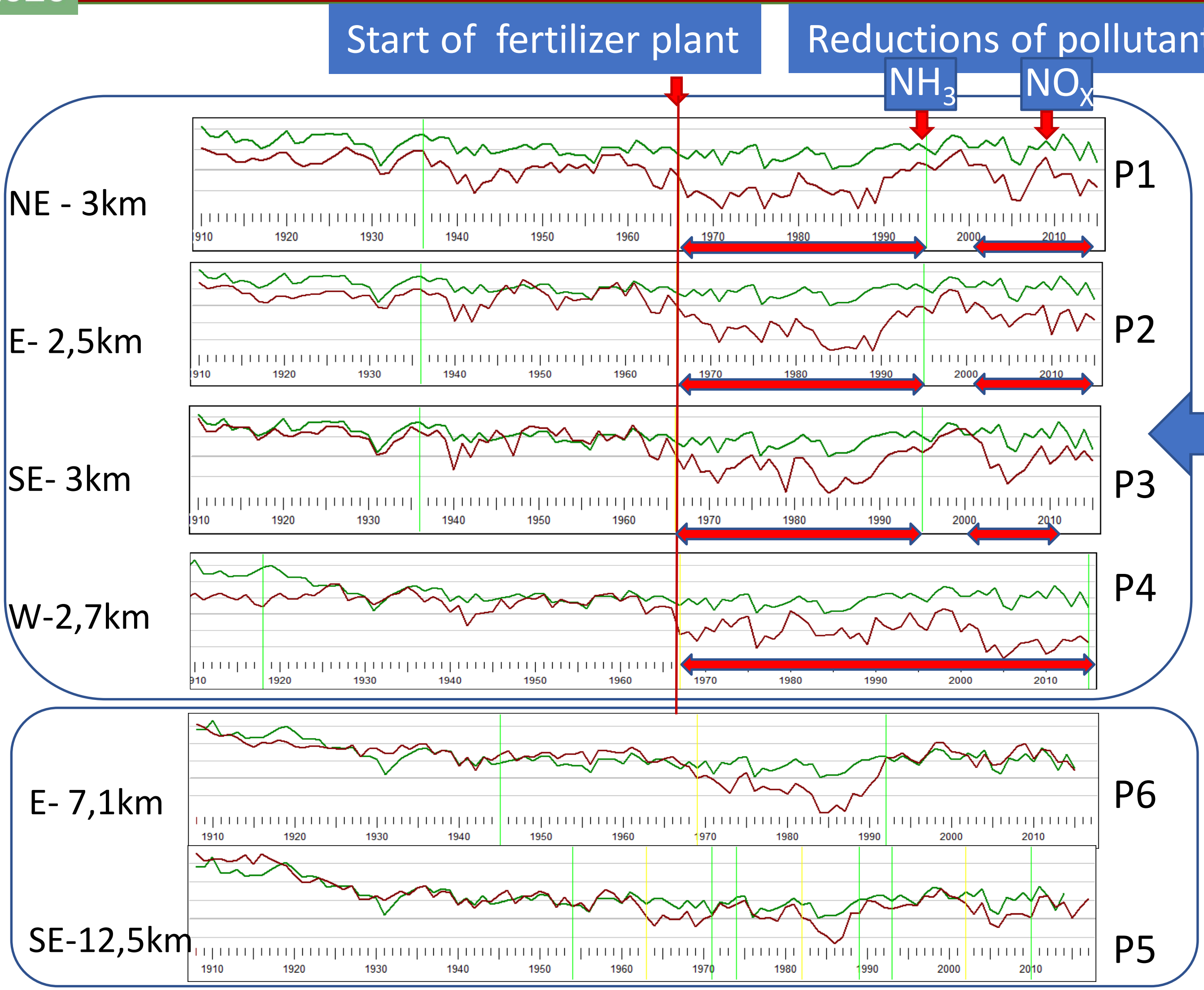
Growth reductions - the majority of the examined trees

Percentage of pine trees affected by reductions >30%

Plot	P1	P2	P3	P4	P5	P6	p7	P8-Ref
%	66,7	89,7	76,9	88,1	62,5	66,5	41,2	0

Growth reductions - spatially and temporally different

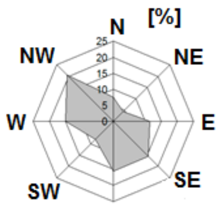
Results Time - duration of decline of growth/vitality

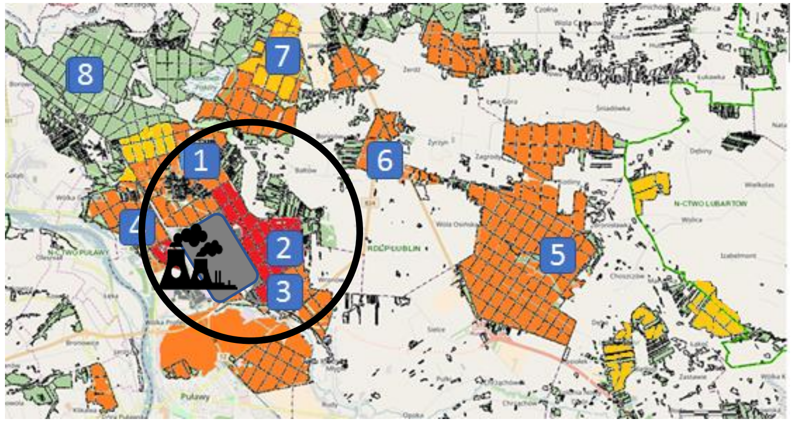


Significant decline of tree vitality

Scots pine growing in the vicinity of the factory (zone to 3 km from factory):

- a dramatic growth reduction after 1966, following the start of factory and beginning pollution emission;
- growth reductions was not directly connected with prevailing wind directions;
- growth reductions - long-term, over 30 years long,
- Plots 1,2,3 – after 1995 increase of growth, but after 2003 – another growth reductions;
- Plot 4 - reduction of growth occurs until the present.





Green line – chronology for pine on reference plot;
Vertical lines- yellow - start of reduction; green on the right- finish of reduction; green on the left – beginning of comparing period;

Results Time - duration of decline of growth/vitality

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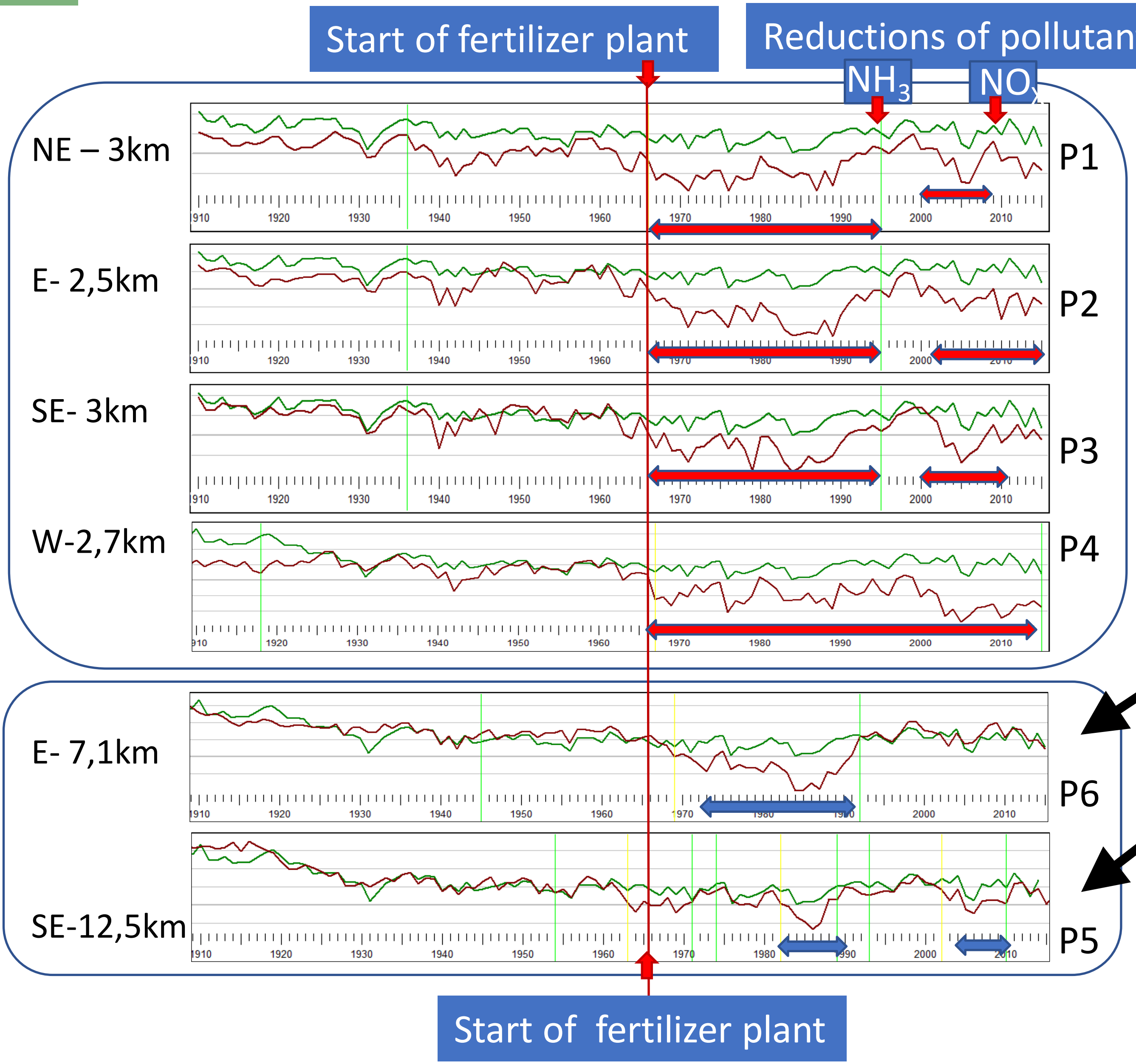
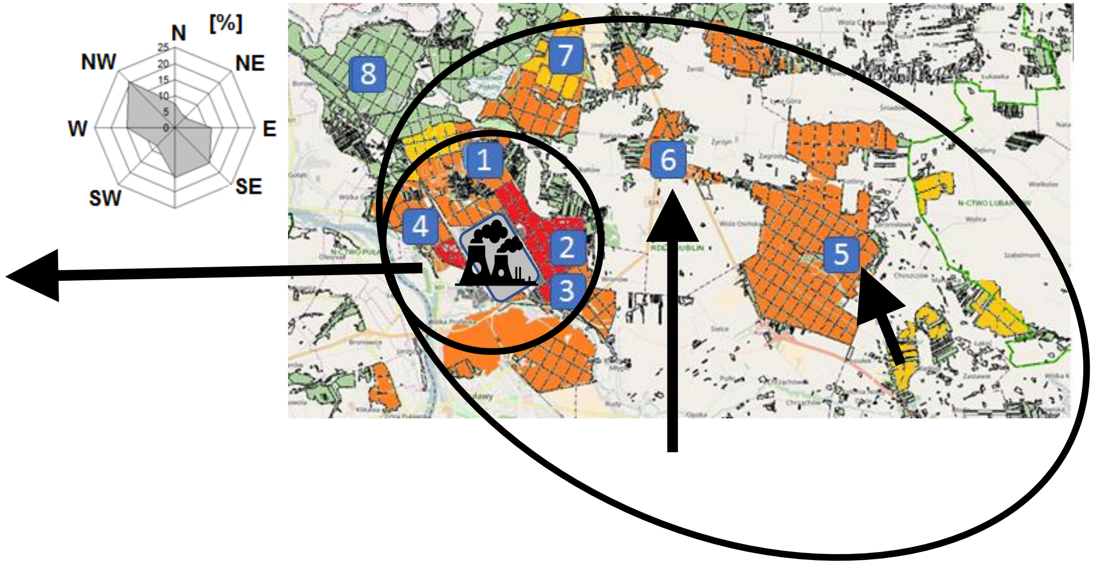




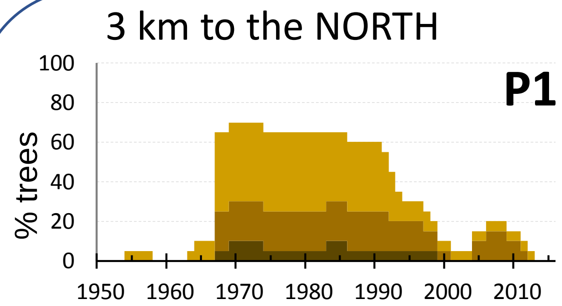
In the stands growing a little further away (3-10 km) growth reduction occurred a little later (in the early 1970s) and lasted about 20 years (1970-1990).

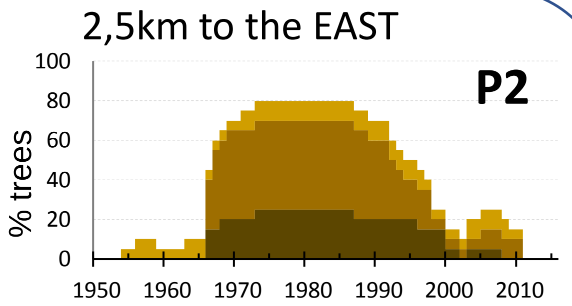
In the stands growing further (over 10km) decline of growth lasted even shorter and occurred twice: in the 1980-1990 and 2003-2010

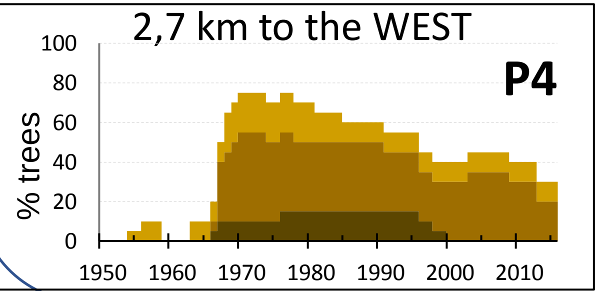
The duration and values of growth reduction in stands growing further from the factory (>3km) depended on the wind direction.

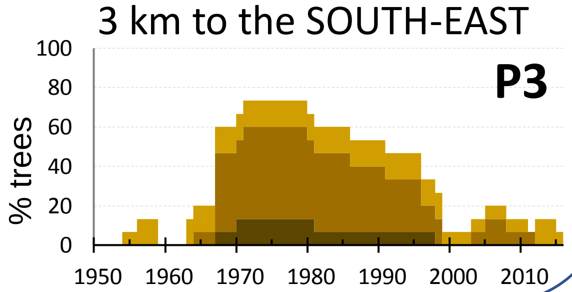
Results — Degree of damage / decline of trees vitality

Spatial & temporal distribution of the growth reductions [R]









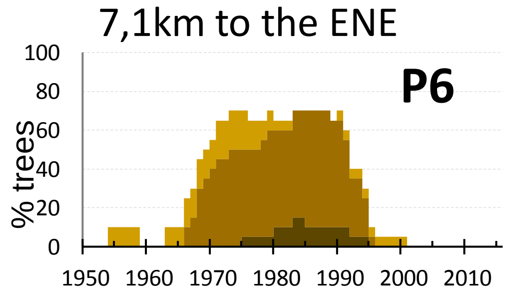
REDUCTION: Average R< 50% | Strong 50%<R<70% | Very strong R>70%

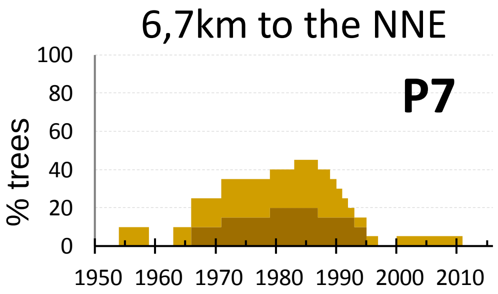
Forests in the zone up to 3 km from emitter:

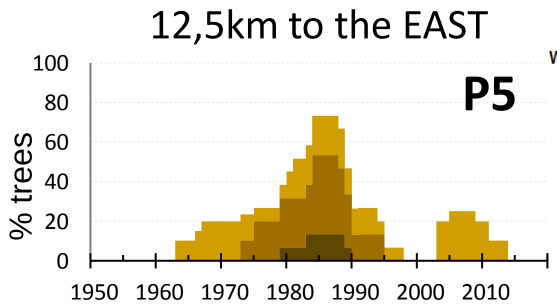
Almost all trees (80%) - considerable damage.
Most trees - long-term, strong & very strong growth reductions.
Pines growing in N part of this zone - lower reduction

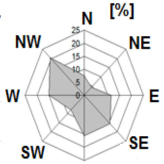
Forests growing further away from the emitter:

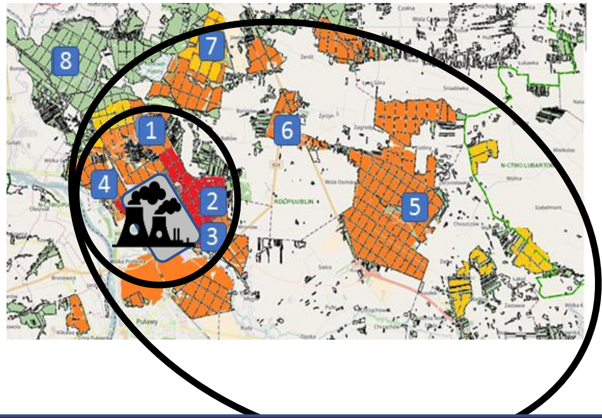
Generally, the degree of damage to trees decreased with increasing distance from the emitter.
However, trees growing in sites situated in prevailing wind direction suffered more then trees growing at similar distance from the factory but in northerly direction.





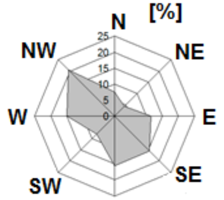




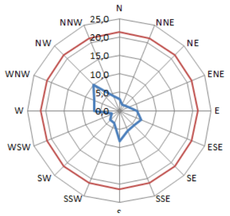


Results Spatial distribution of the damaged trees

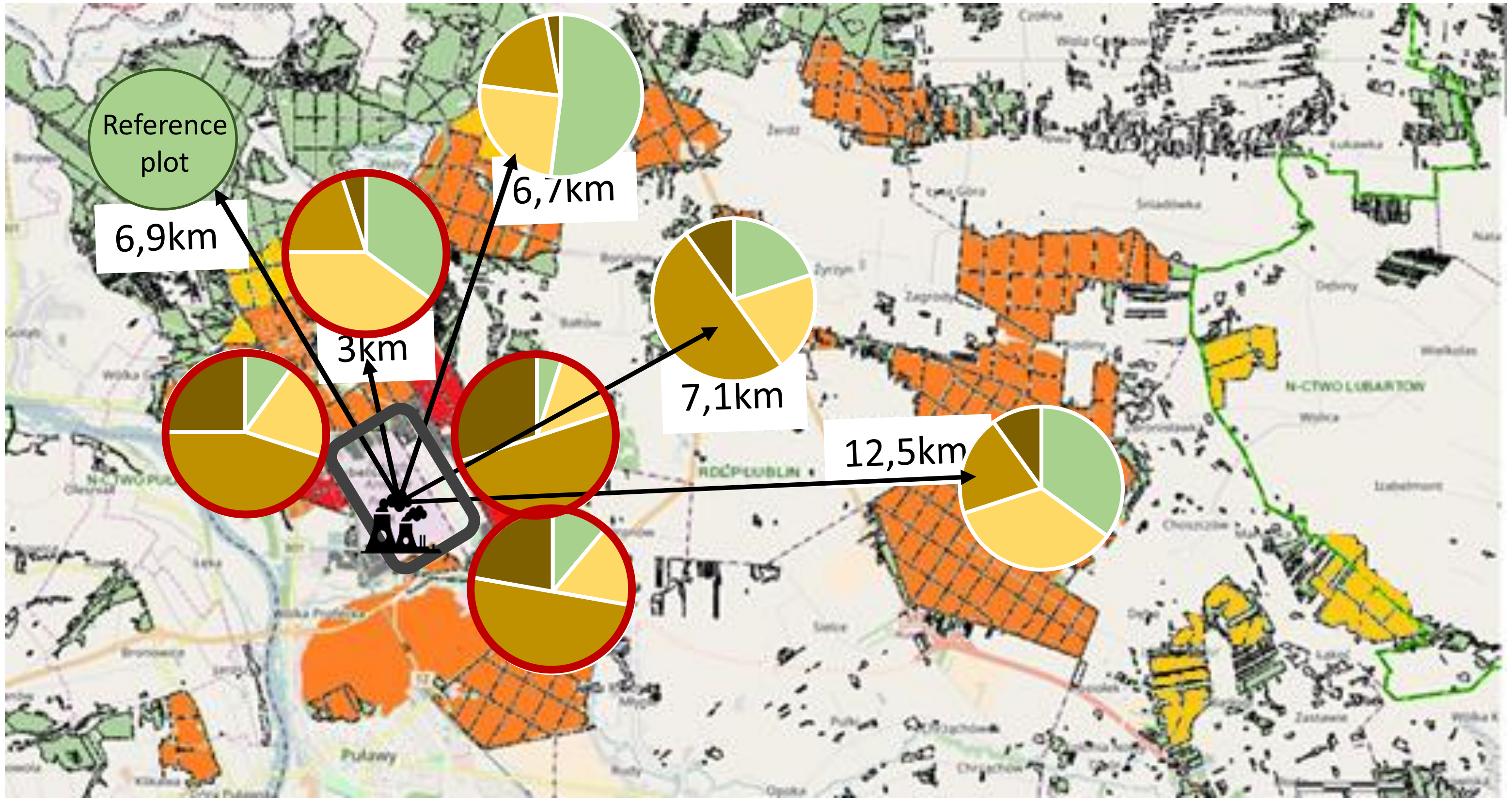
The distribution of growth reductions in particular sites indicates a clear relationships between the amount of reductions and DISTANCE FROM EMITTER & THE PREVAILING WIND DIRECTION



yearly frequencies of wind direction



summer frequencies of wind direction



Distribution of growth reduction on the research plots

R< 30% | 30%<R50% | 50%<R<70% | R>70%

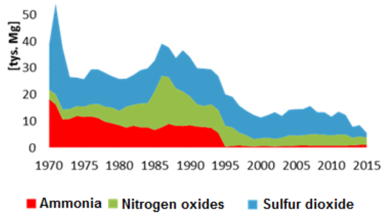
Results

what other factors could cause so large forest damage and their spatiotemporal distribution?

Results

what other factors could cause so large forest damage and their spatiotemporal distribution?

Excessive emission of toxic pollutants



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Uncontrolled emmisions, associated with equipment failures

Height of the chimneys emitting pollution

Relatively low chimneys emitting nitrogen compounds:

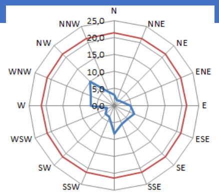
6 chimneys 47 m – NO_x

5 chimneys 30 m-NH_3

1chimney 160m –SO_2

Wind conditions in the region

High frequency of lull [21%]



which causes large deposition of pollution around the plant

Very high concentration of different pollution near the factory within radius 3km from the emitter - exceeding the norm

Tree stands situated in the closest proximity of factory, though not exposed to the action of wind from the prevailing directions, suffered the most damage due to emission.

Results

Air Pollution

Very high concentration of nitrogen compounds

Poor habitats with periodic water deficit

Increase deposition of toxic on needles

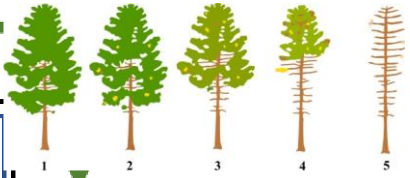
More penetrating of toxic pollutants

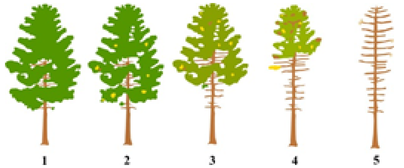
Dying of needles and shoots

Thinning of the crown

Death of part trees

Decrease in stand density





More sunlight penetrating to the bottom of the forest

microclimate change
increase difference between Tmin & Tmax
change in air humidity
extension of drought period

Soil desiccation
decrease of the amount of water available for plants

continuous deterioration of tree growth conditions

Long-term chronic STRESS

DECLINE OF VITALITY

REDUCE OF RESISTANCE to biotic & abiotic factors

Sudden enrichment of the soil and water with excess nitrogen

Transitory increase in soil fertility

Development of the undergrowth

Increase in the amount of water uptake by plants

Increase water deficit from periodic to continuous

An intensive transformation of the soil environment

Change in soil fauna & microbes

Reducing microbiological activity of the soil

Climate

whether damaged trees are more sensitive to climatic conditions?

whether damaged trees are more sensitive to pests?

Secondary action organism: insect pests

Since 1967, no outbreaks of the primary pine pests have been found

Threats to pine stands from pests - relatively low

impact could not be investigated

Were damaged trees not attractive to pests???

Results Climate-Growth Relationships

response function analysis: for the period spanning from June in the year preceding ring formation to September in the year of current increment (16 months in total)

Plots	Temperature*								Precipitation*				
	XI	I	II	III	IV	V	VI-X		V	VI	VII	VIII	IX
P1		+	+	+		-				+	+	+	
P2		+	+	+		-				+	+	+	
P3	+	+	+	+		-				+	+	+	
P4	+	+	+	+		-				+	+	+	
P5		+	+	+		-				+	+	+	
P6		+	+	+		-				+	+	+	
P7		+	+	+		-				+	+	+	
PR		+	+	+		-				+	+		

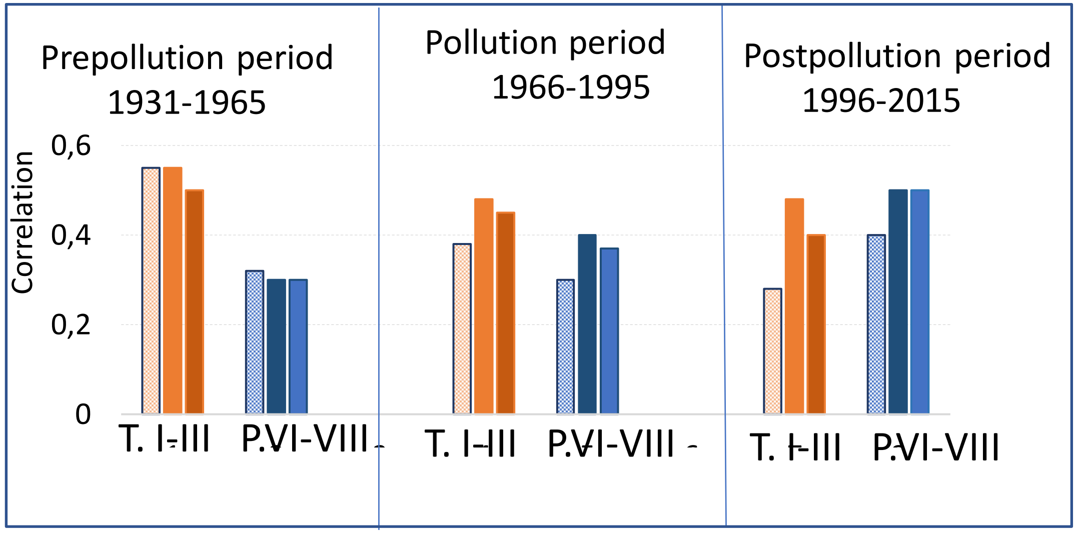
* Only significant

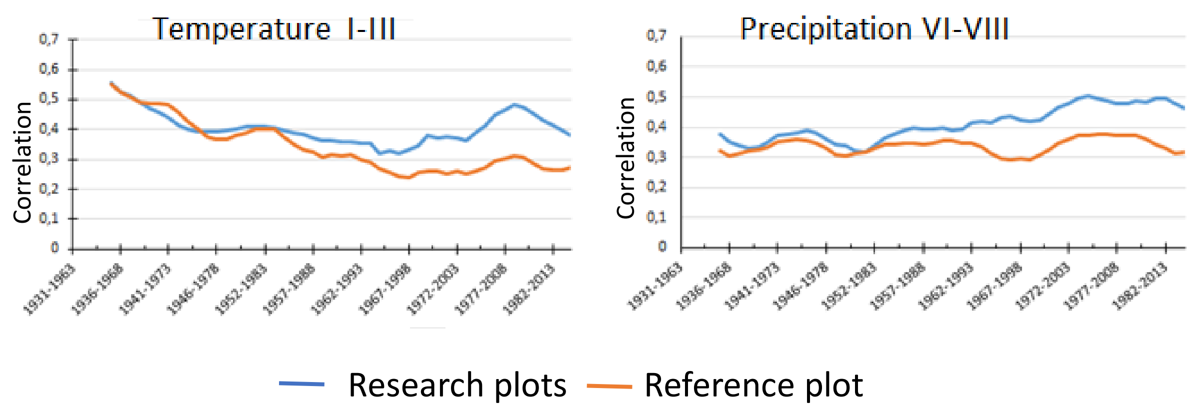
Main climatic determinants of the growth of studied pine stands:

- the thermal conditions in winter
- summer precipitation

- the frosty winter & summer drought - the strong negative impact on growth

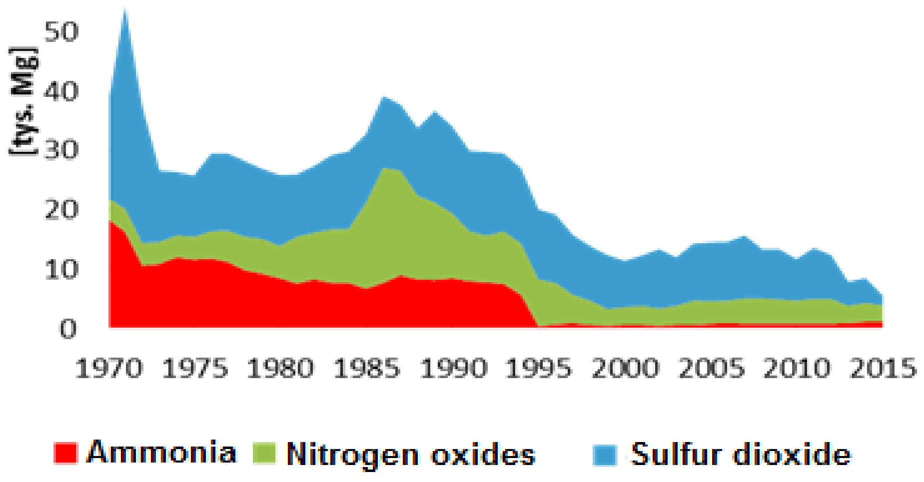
The effect of climatic conditions on pine growth on all plots - was similar in direction, but since 1966, it was different in strength of relationships. Pine trees exposed to toxic pollutions were more sensitive to cold winters and prolonged summer droughts.





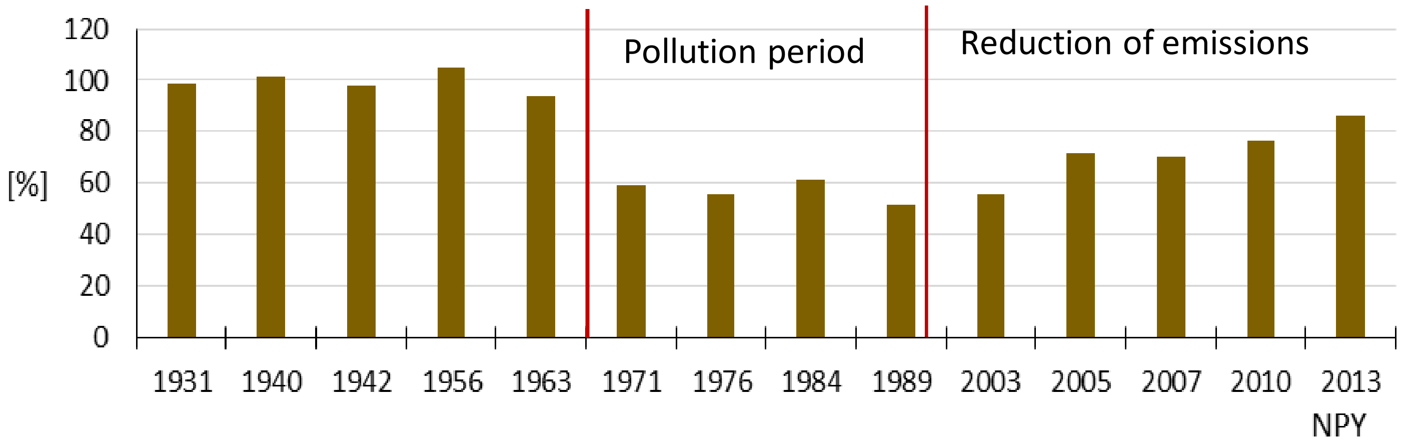
Change of climate-growth relationships over time

Results Drought and Growth Reduction



Reduction of emissions and improvement of environmental conditions in the last decade of the 20th century resulted in the formation of wider rings.

However, these trees are still weakened, have reduced resistance to climatic stress, are more sensitive to adverse weather conditions, especially summer drought.



TRW of pines growing on research plots in %TRW of pines growing on reference plot, in years with drought.

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Results

Air Pollution

Climate

Very high concentration of nitrogen compounds

Poor habitats with periodic water deficit

Increase deposition of toxic on needles

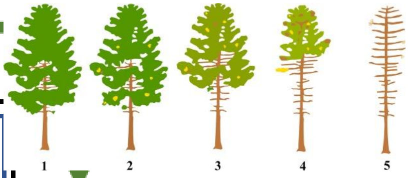
More penetrating of toxic pollutants

Dying of needles and shoots

Thinning of the crown

Death of part trees

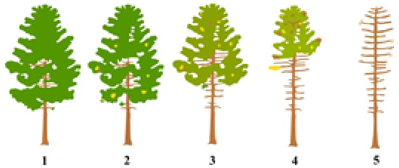
Decrease in stand density



More sunlight penetrating to the bottom of the forest

microclimate change
increase difference between Tmin & Tmax
change in air humidity
extension of drought period

Soil desiccation
decrease of the amount of water available for plants



continuous deterioration of tree growth conditions

Long-term chronic STRESS

DECLINE OF VITALITY

REDUCE OF RESISTANCE to biotic & abiotic factors

Pests

Sudden enrichment of the soil and water with excess nitrogen

Transitory increase in soil fertility

Development of the undergrowth

Increase in the amount of water uptake by plants

Increase water deficit from periodic to continuous

An intensive transformation of the soil environment

Change in soil fauna & microbes

Reducing microbiological activity of the soil

Damaged trees are more sensitive to climatic conditions

The reduction of resistance to stressful climatic factors is long-lasting and despite the reduction of emissions, it may last for many years.

Trees weakened by air pollution may be more sensitive to decline due to climate change

Secondary action organism: insect pests

Since 1967, no outbreaks of the primary pine pests have been found

Threats to pine stands from pests - relatively low

impact could not be investigated

Conclusion

Forest degradation in Puławy region was caused by the synergistic effect of the following factors:

The level and spatial extent of forest damage in the Puławy region was caused by both the amount and type of pollutions, and local factors, especially anemometric and habitat conditions and height of chimneys

CLIMATE CHANGE	• **Increase frequency, intensity, duration & timmimg DROUGHTS**
Species	• Scots pine - one of the most sensitive to air pollution
Distance from emitters	• **Damage zones up to 40 km to the east, associated with the prevailing wind directions**
Local conditions	• **High frequency lull & prevailing westerly winds** • **Poor habitat**
Technology	• **Relatively low chimneys emitting nitrogen compounds** • **Uncontrolled emissions associated with equipment failures.**
Air pollution	• **Amount, Type, Concentration**

Ammonia & nitrogen oxides .
Sulphur dioxide (SO_2)

Very high concentration
> 50 t/km2 within radius 3km

Conclusion

The level and spatial extent of forest ecosystem degradation in Puławy region was caused by both **the amount and type of pollutions, and local factors, especially anemometric and habitat conditions and high of chimneys**. A high frequency of lull combined with low chimneys emitting toxic pollutants multiplied the negative effects of pollutant emissions

The radical reduction of pollutant emissions improved the environmental conditions, and the trees began to grow, however, long-term strong anthropopressure caused a long-lasting reduction in the resistance of trees to abiotic factors.

Our research indicates that in areas where there has been a high concentration of pollution for a long time, THE ADVERSE IMPACT OF POLLUTION ON FORESTS PERSISTS FOR A VERY LONG TIME, EVEN TWENTY YEARS AFTER A RADICAL REDUCTION IN EMISSIONS. These forests have reduced resistance to abiotic stress related to climate change, especially drought.

Therefore, a greater impact of climate change, especially extreme events, on the process of dying trees growing in areas with strong anthropopressure can be expected.


Thank you very much
for you attention
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