frax for future

Ash Dieback Disease

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FNR
Fachagentur Nachwachsende Rohstoffe e.V.

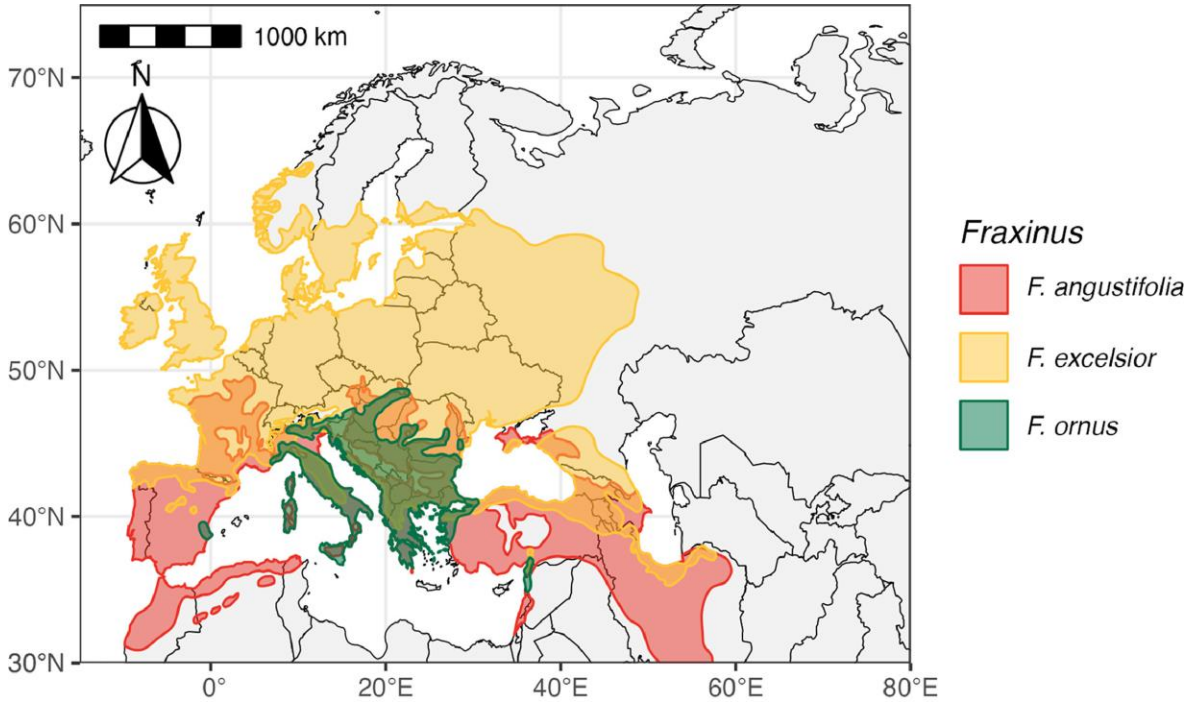
Waldklimafonds

Major ash species in Europe

- **European Ash (*F. excelsior*)**
- Narrow-leaved ash (*F. angustifolia*)
- Manna/ flowering ash (*F. ornus*)

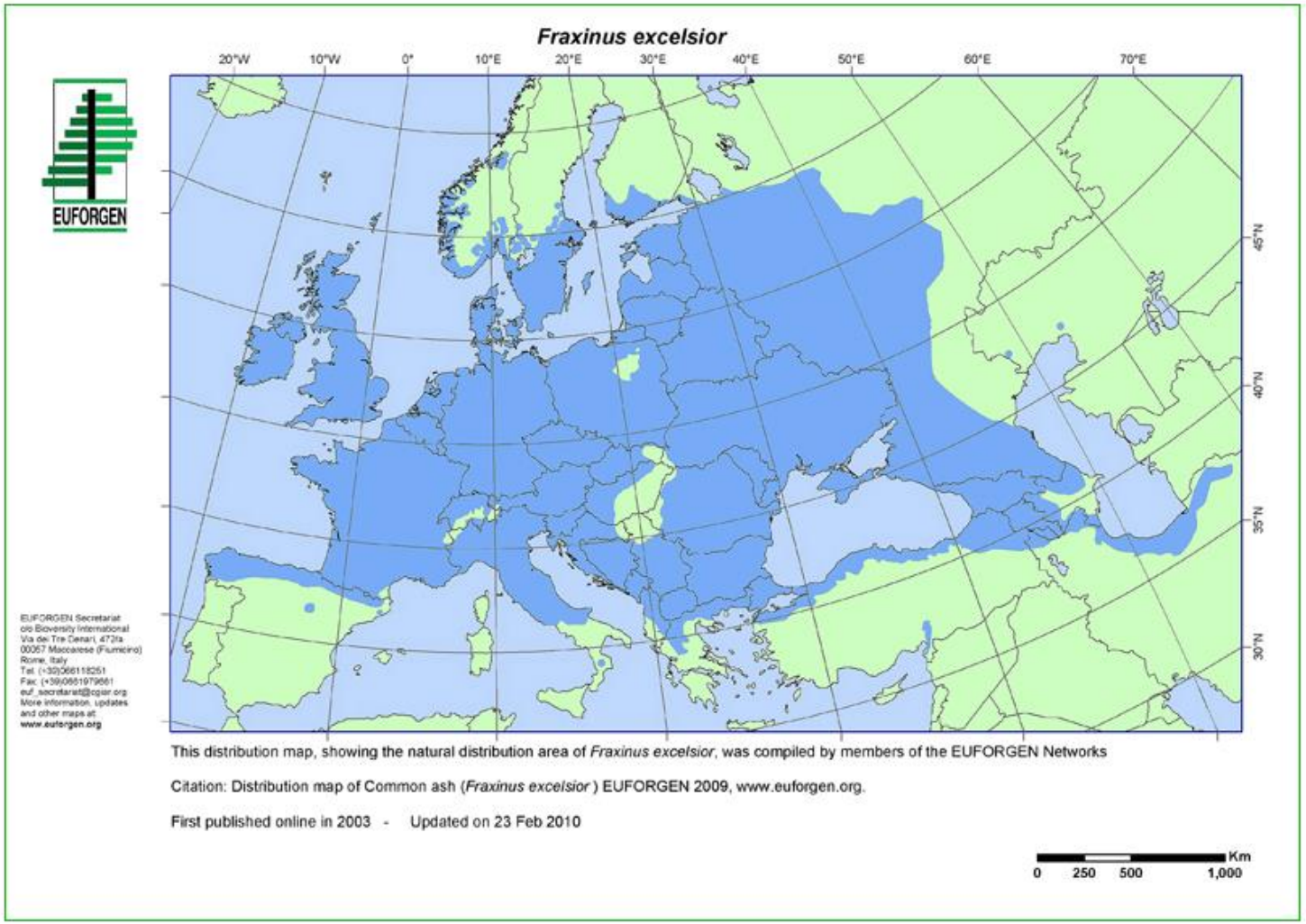
- Exotic green ash (*F. pennsylvanica*)

Caudullo *et al.* (2017)



While the ranges of ash species overlap in Europe, *F. excelsior* is dominant.

F. excelsior - an important tree in Europe



Source: Zelimir Borzan

F. excelsior - an important tree in Europe

Source: Wikipedia

The European ash (*Fraxinus excelsior*)

The European ash is an important tree in woodland, hedgerows, riverbanks, commercial forestry and urban areas.

It was the second or third most frequent deciduous tree species in Central Europe., accounting for approx. 1% of the forests

In Germany, it is estimated that it comprised 2.4% of forest area (250,000 ha), or 74.7 million solid cubic meters (2001/2002).

F. excelsior as a cultural legacy

Yggdrasil

In Norse mythology, ash was the ***tree of life,*** **Yggdrasil,** which harboured all the life in the universe. Moreover, the first human was created from ash wood by Oden.

- Often appears in old literature, artwork and poetry
- Historically used for weapons, tools, cart wheels…
- Popular ornamental tree (parks, gardens, hedges)

"Omens", which guided actions and decisions.

Hurley stick, hurling ball

Sources: Friedrich Wilhelm Heine (1886); https://www.theashproject.org.uk/; University of Kent; Dr. Peter Wöllauer

F. excelsior as an ecological species

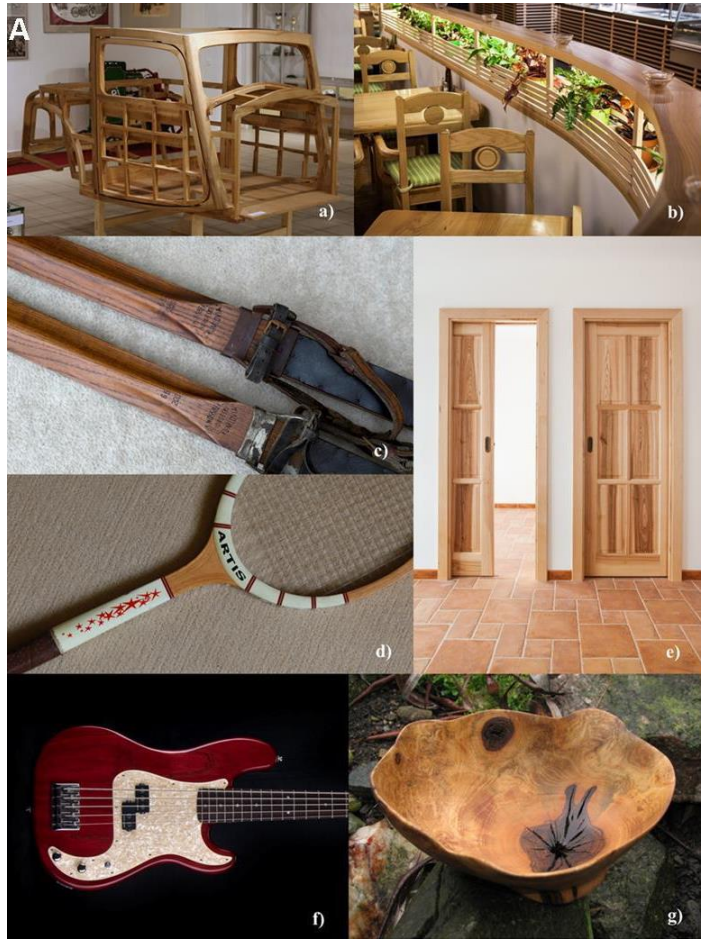
- Ash trees are found in on marginal lands
  - ➢Calcareous soils, floodplain forests and ravine forests
- Therefore, provides important ecosystem services
  - ➢Especially in already compromised flood plain forests

- There are **> 1000 known associated species**
  - approx. 150 are obligate or highly-associated species
  - these species include fungi, invertebrates, lichens…
  - … as well as wood mice, squirrels, birds and bats…
  - … and the scarce fritillary (*Euphydryas maturna*)

Mitchell *et al.* (2014); Hultberg *et al.* (2020)

Euphydryas maturna
Source: Wikipedia

F. excelsior as a commercial species



Source: Rozsypalek *et al.* (2017)

Tree characteristics

- Relatively fast growing
- High regeneration potential
- Drought resistant (climate change)

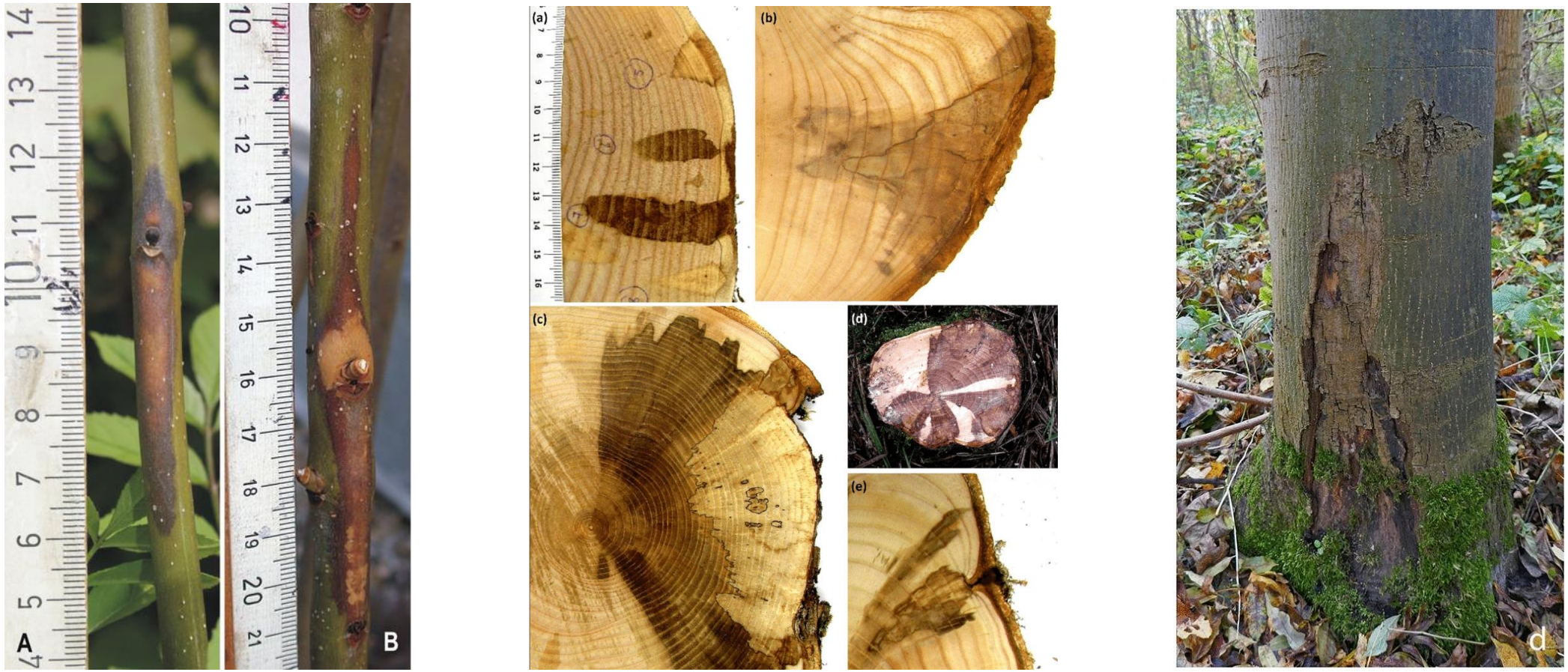
Wood as a commercial material

- Excellent wood properties (hard but elastic)
- Commonly used for tool handles, high quality furniture, sports equipment, musical instruments, veneer, flooring

New devastating disease

Images of crown defoliation and crown dieback in mature ash trees (*Fraxinus excelsior*)

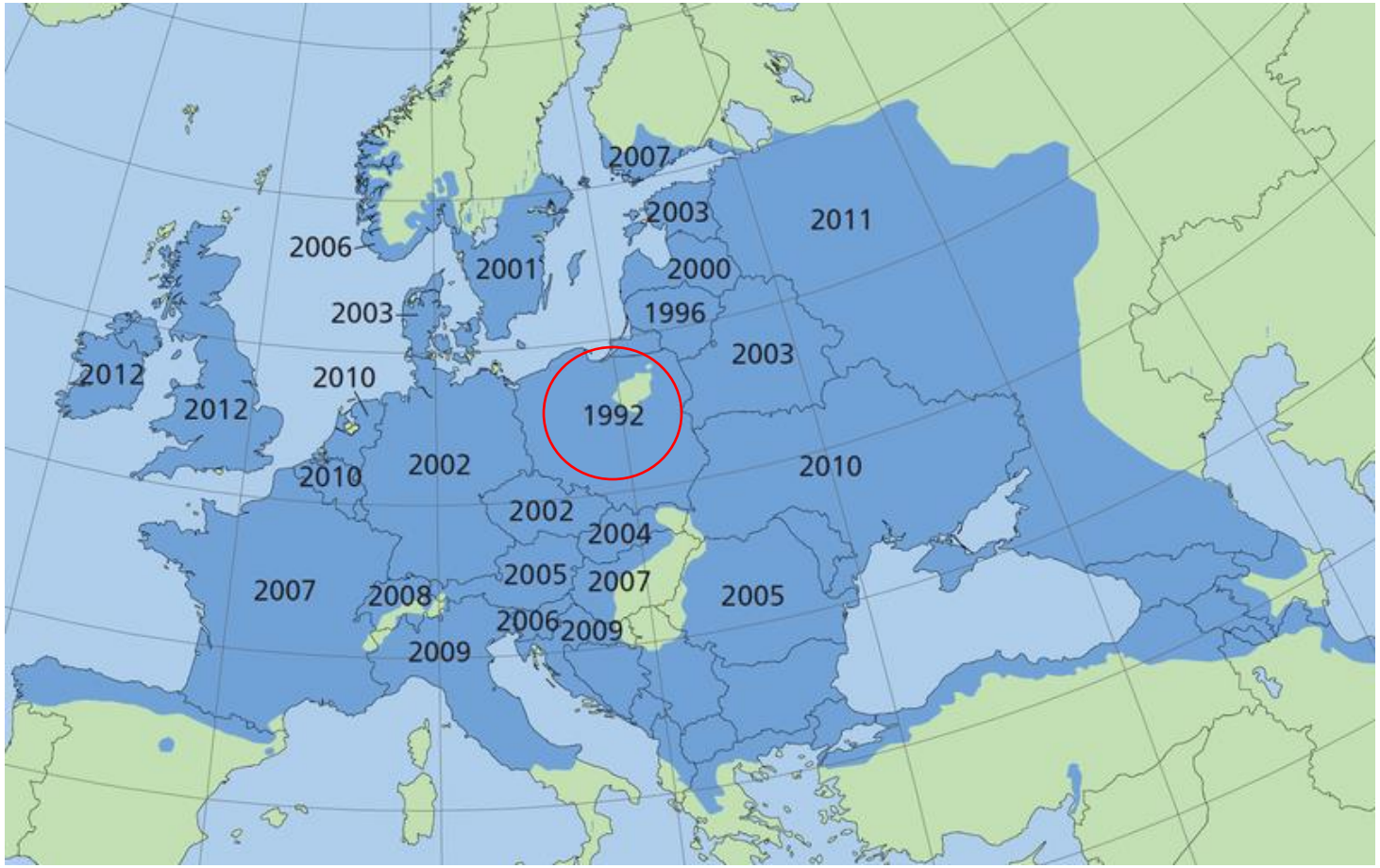
New devastating disease



Necrotic lesion on stem of saplings (A, B); overview of differently developed collar necroses on investigated stem discs (a, b, c, d, e); and stem collar necrosis / rot (d)

Sources from the left: Kirisits *et al.* (2012); Enderle *et al.* (2017); Langer *et al.* (2022)

Spread of Disease in Europe

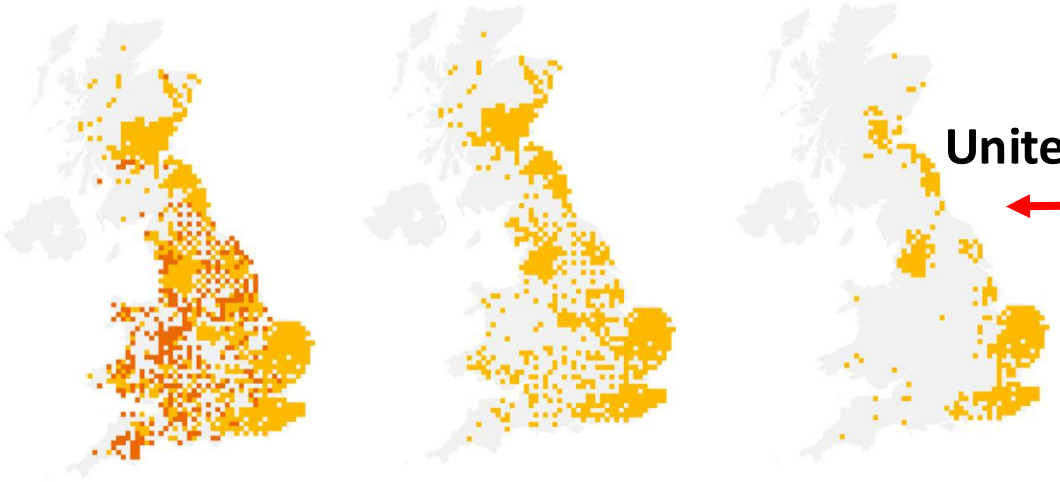


The disease was first detected in Europe in 1992 in Poland. The year when ash dieback was observed is given for each country. In blue: The natural range of *F. excelsior* (© EUFORGEN).

Confirmed ash dieback infection sites since first detection in 2012

Guardian graphic. Source: Forestry Commission

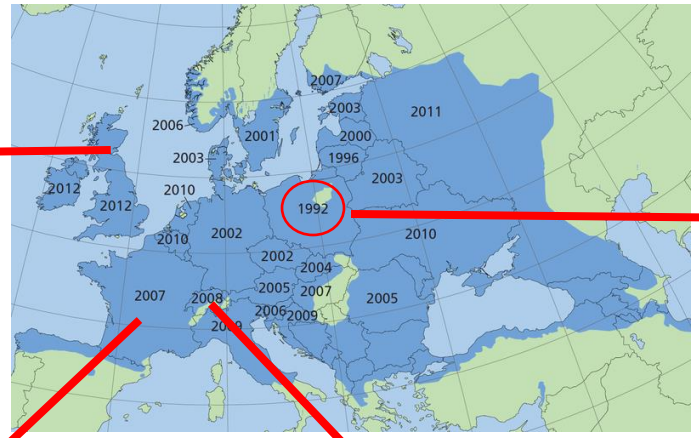
The disease spread rapidly across Europe



New cases in 2016 | By end of 2015 | By end of 2014

United Kingdom

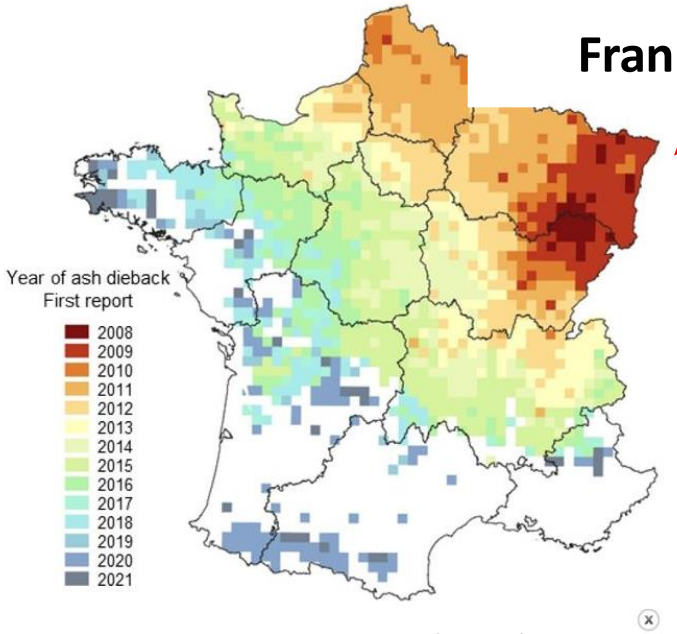
2012



First detected in **Poland** in 1992

France

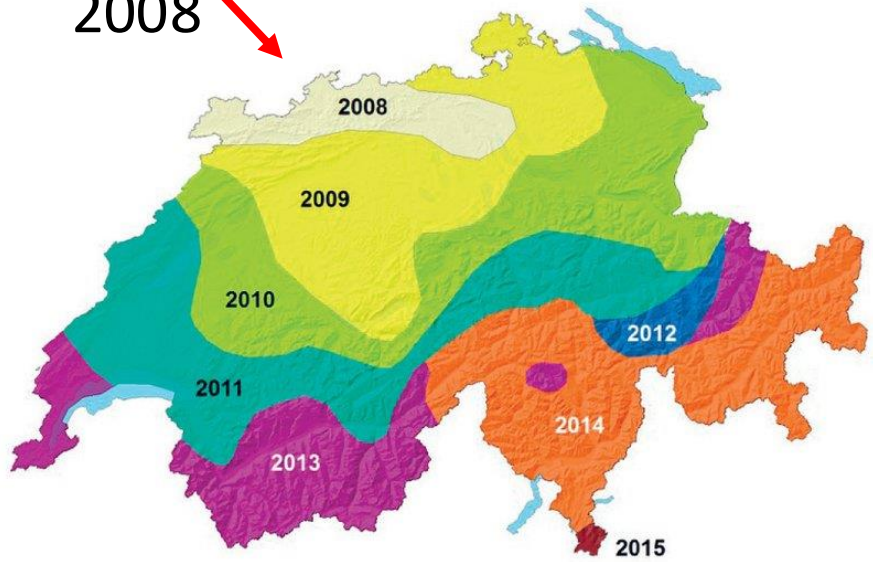
2008



Marçais *et al.* (2022)

Switzerland

2008



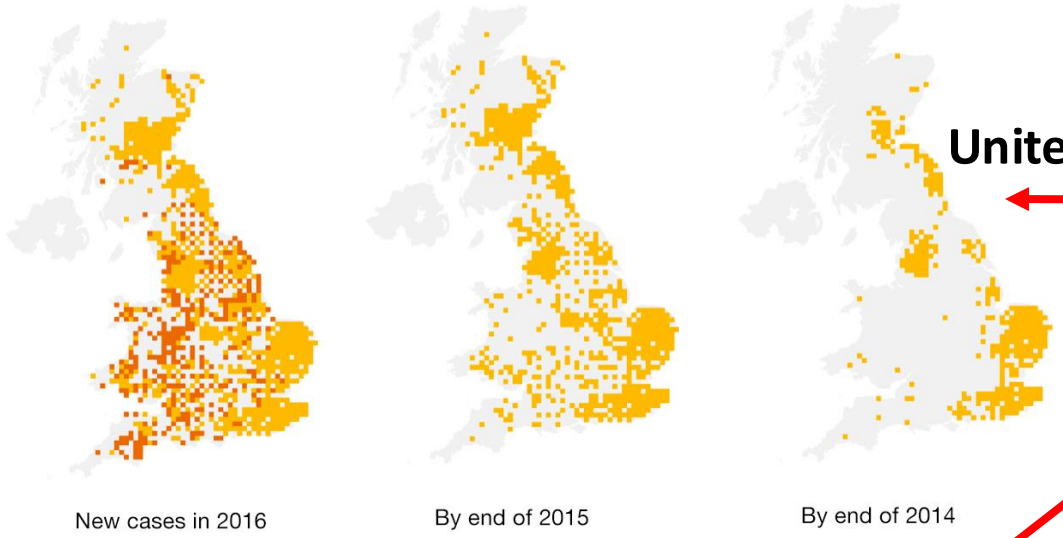
Rigling *et al.* (2016)

11

Confirmed ash dieback infection sites since first detection in 2012

Guardian graphic. Source: Forestry Commission

The disease spread rapidly across Europe



United Kingdom

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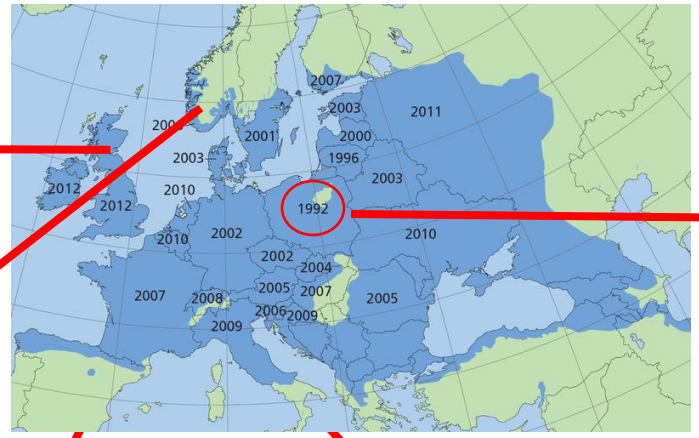

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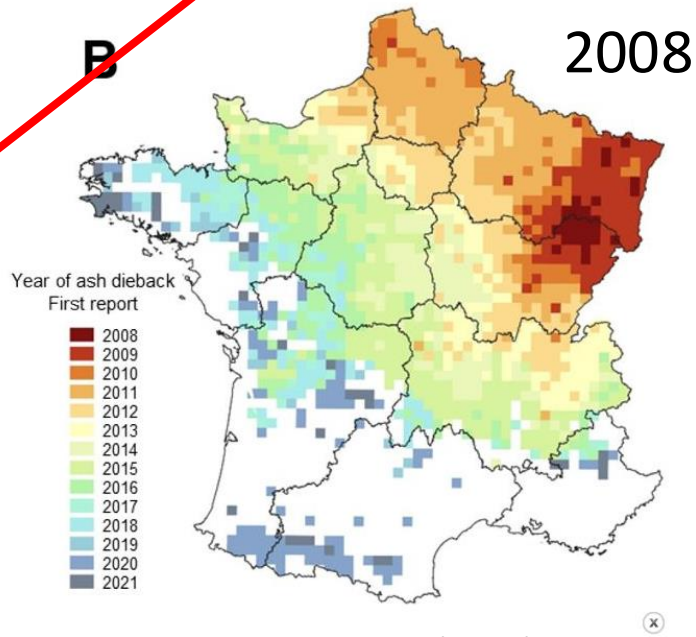

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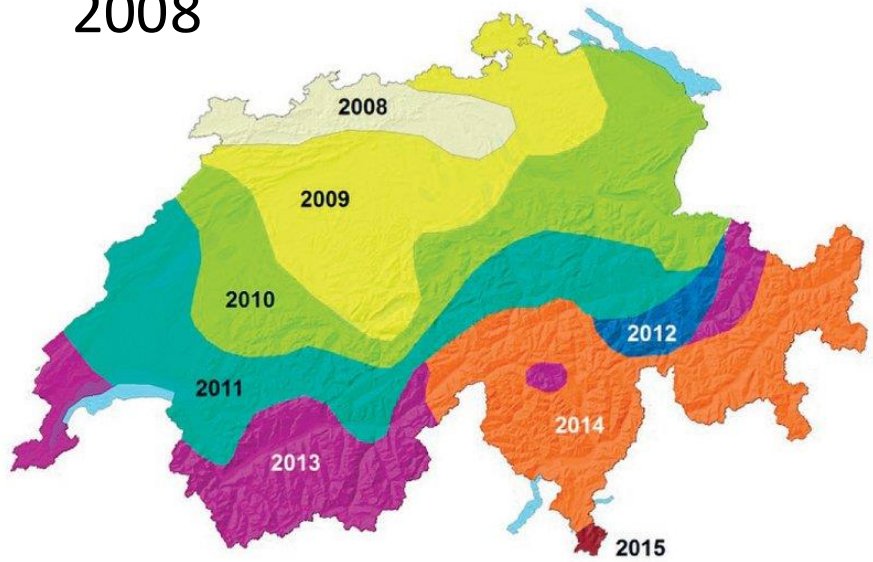
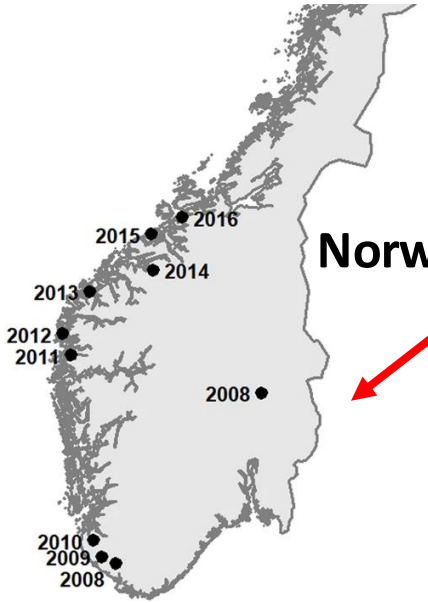


Rigling *et al.* (2016)

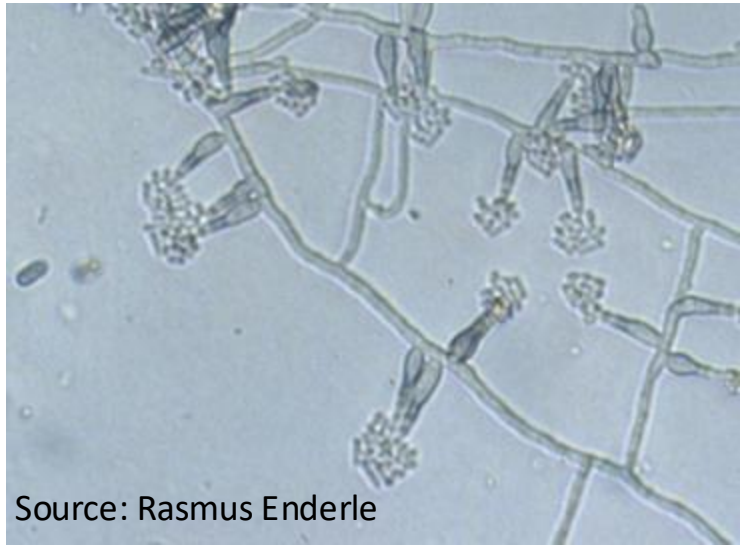
Norway

2008



Díaz-Yáñez *et al.* (2020)

What is causal agent of the disease?



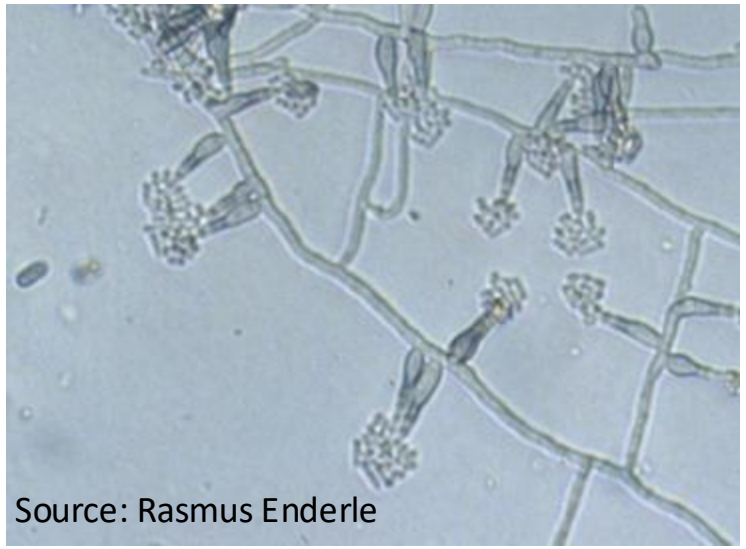
Source: Rasmus Enderle

Source: Baral *et al.* (2014)

- In 2006, the anamorph (asexual reproductive stage) is identified and named ***Chalara fraxinea* sp. nov.**
- In 2009, the teleomorph (sexual reproductive state) is tentatively identified as ***Hymenoscyphus albidus.***
- However, ***H. albidus*** is widespread in Europe, had **never been reported to be pathogenic in plants**.

What is causal agent of the disease?

Source: Baral *et al.* (2014)


Source: Rasmus Enderle

- Then, reclassified as a cryptic species: ***H. pseudoalbidus***
- *H. pseudoalbidus* exhibits a **distinct morphology**, **mating system** and is **genetically divergent** from *H. albidus*

  -> H. pseudoalbidus is classified as a separate species
- In 2014, it was renamed as ***Hymenoscyphus fraxineus***

Introduction of an exotic fungus

Manchurian ash (*F. mandshurica*) is host to a saprotrophic fungus, called *H. fraxineus*

Natural distribution of *F. mandshurica* in Asia (see shaded area)

Manchurian ash (*F. mandshurica*)

Source (left): Cleary *et al.* (2016); Baral *et al*. (2014)

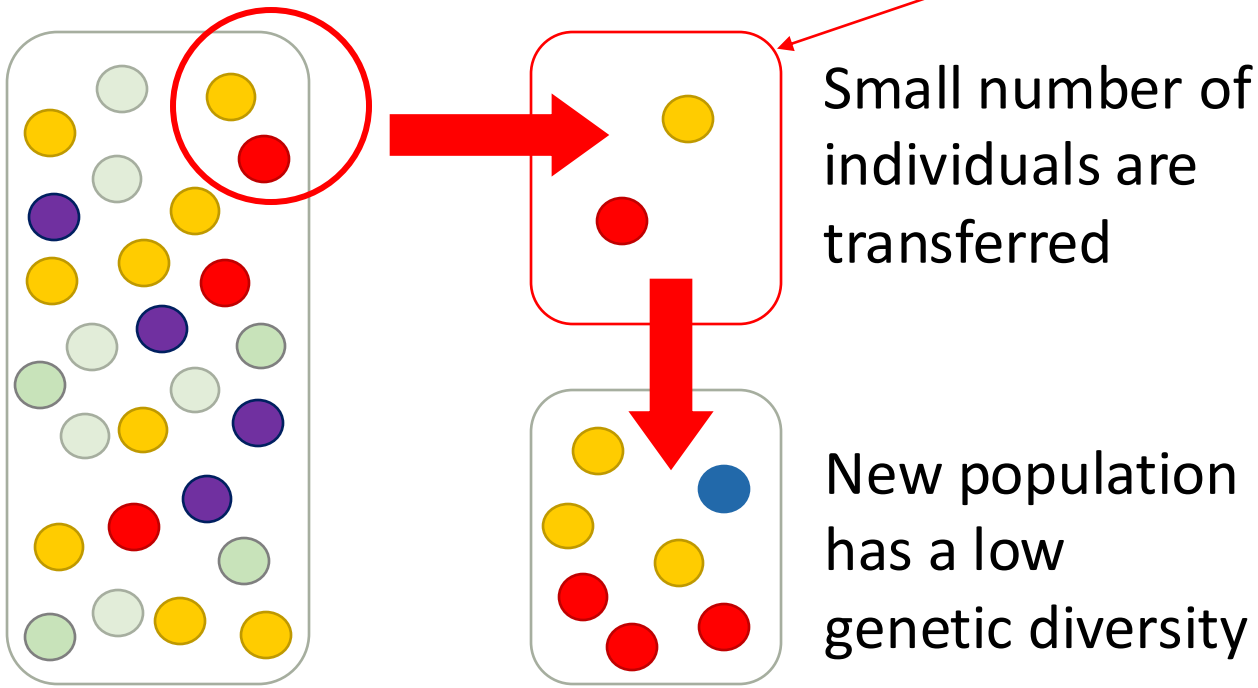
Source (right): NetPS Plant Finder

Introduction of an exotic fungus

High genetic diversity of fungus in Asia

Source: Cleary *et al.* (2016)

Founder effect



The invasion was founded by two divergent individuals (McMullan *et al.* 2018)

Introduction of an exotic fungus

Saprotrophic fungus

Source: Baral *et al.* (2014)

H. fraxineus

Globilisation: Plant trade

Host jump to naïve host

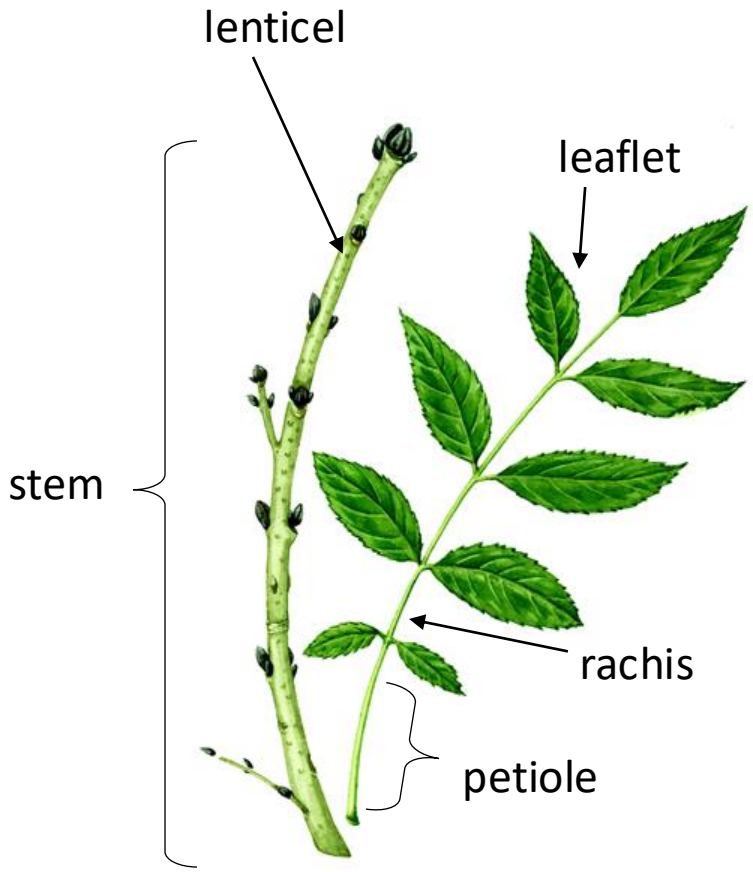

Source: Rasmus Enderle

European ash (*F. excelsior*)

It is possibly introduced in **nursery stock of Manchurian ash** from Asia into Europe.
Successfully colonises the European ash (*F. excelsior*), **a novel and naïve host in Europe**.

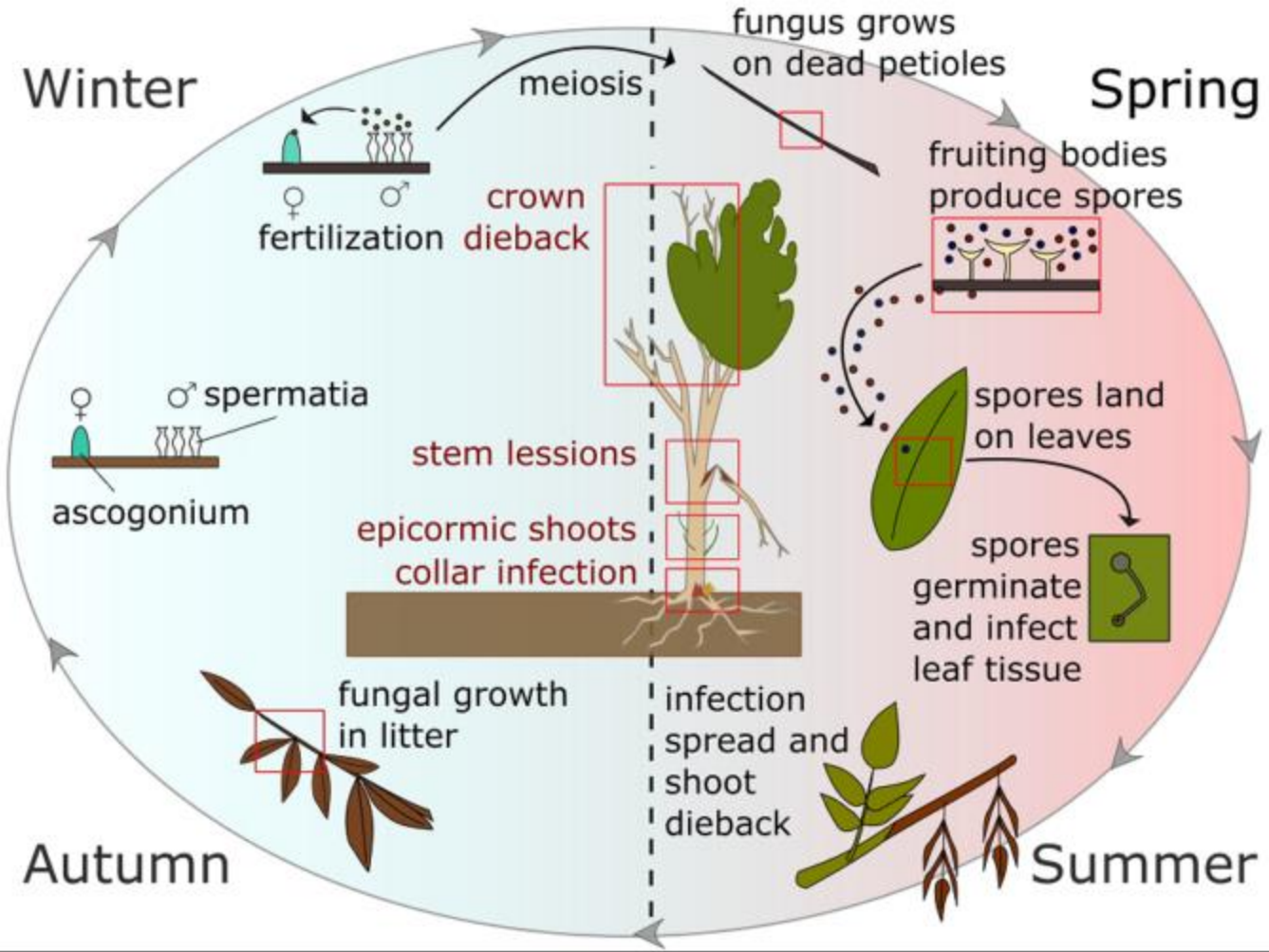
Symptoms

Sources: Kirisits *et al.* (2012); Enderle *et al.* (2017); Langer *et al.* (2022); Andrin Gross; Lewis White



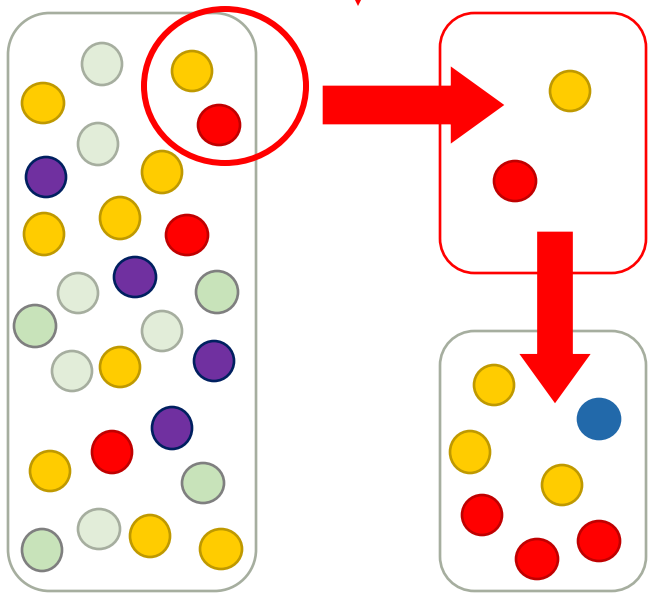
fruiting bodies on a fallen petiole

Life cycle of *H. fraxineus*

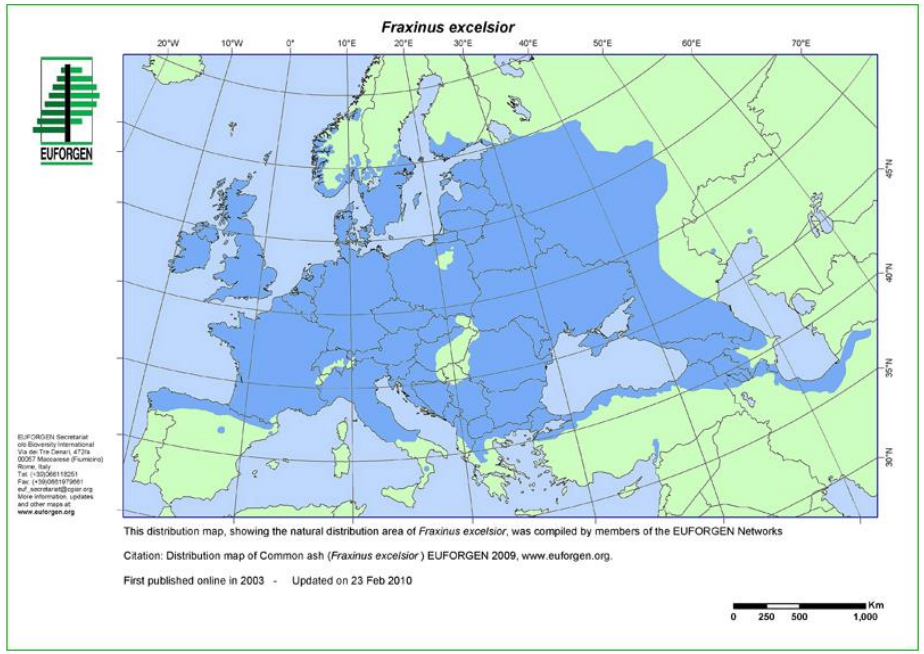


Summary

Loss of genetic diversity



New environmental range



Novel host species

The Disease Triangle

An epidemic requires:

- (i) a virulent pathogen with a high reproduction rate

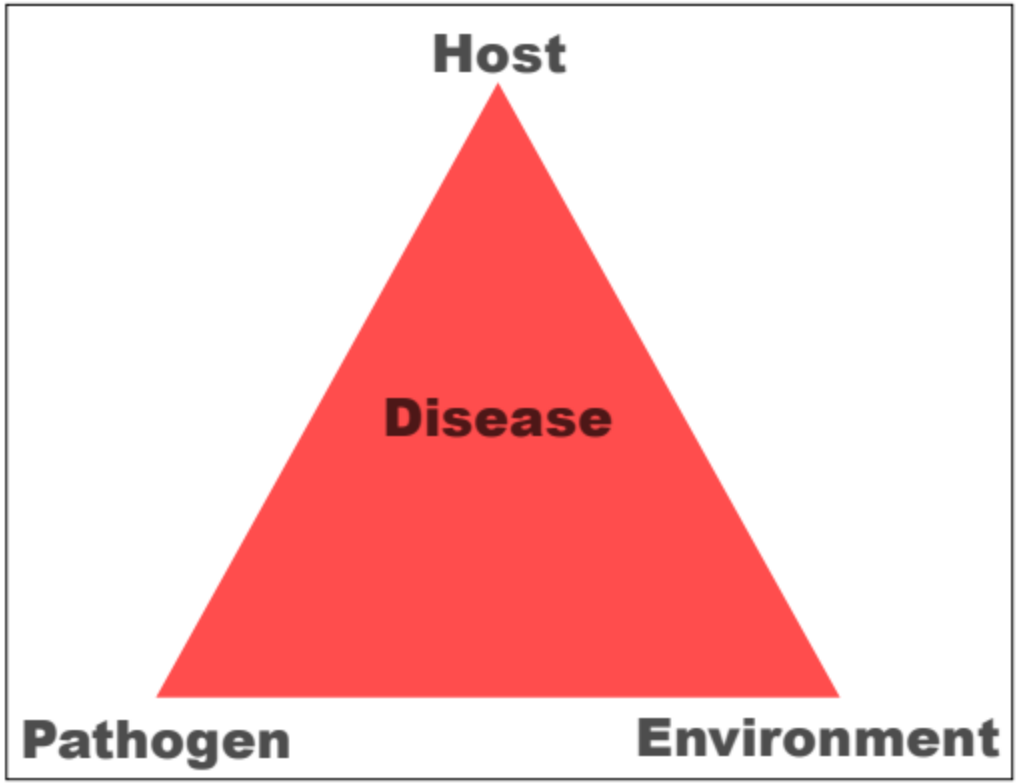
  -> ***H. fraxineus***

- (ii) an accumulation of susceptible host

  -> **European ash**

- (iii) suitable environmental conditions for the pathogen

  -> **Central Europe**



Source: https://www.ncforestservice.gov/

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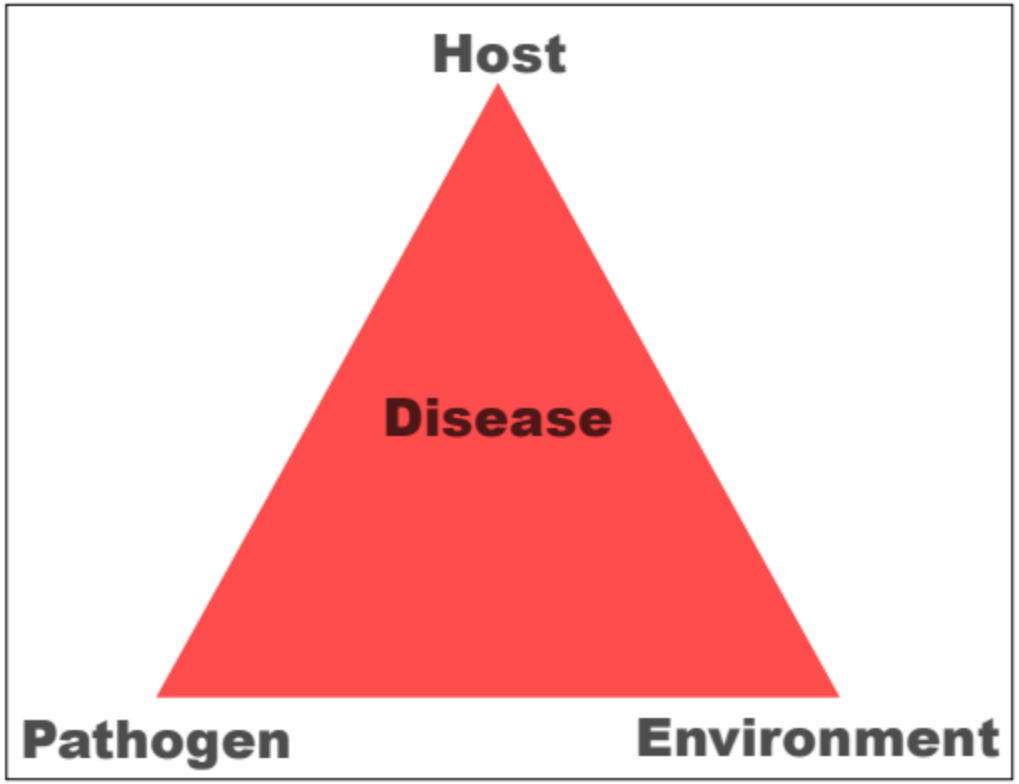

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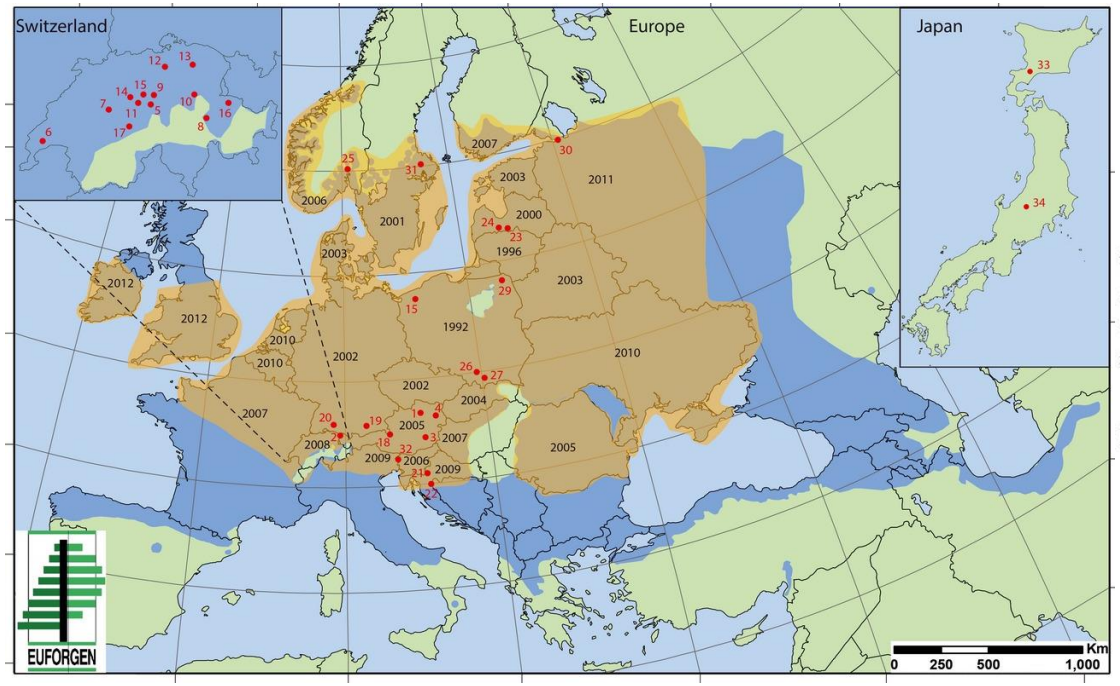
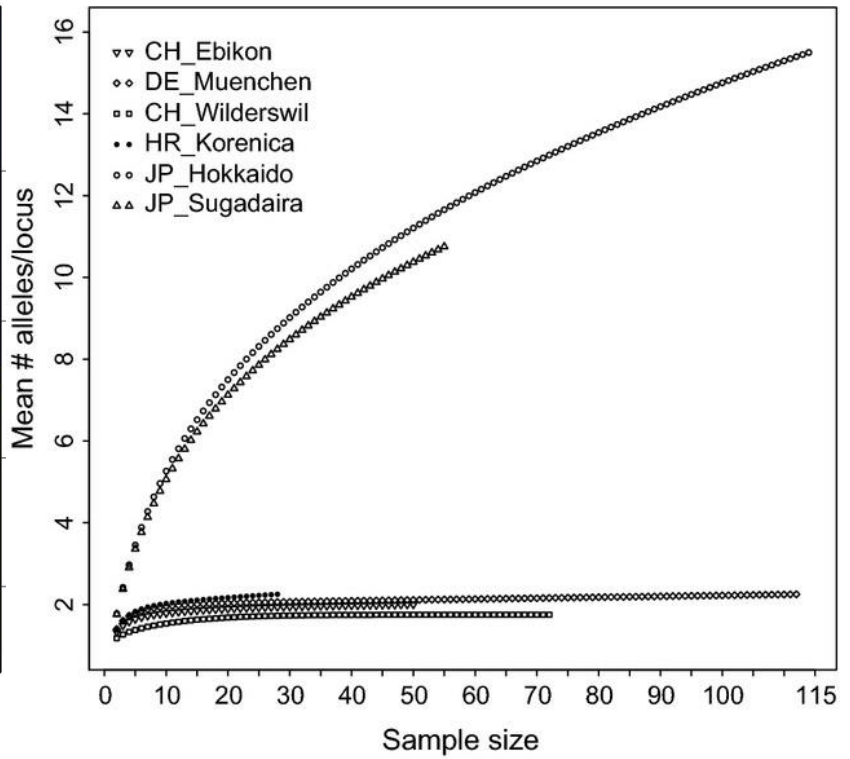
Genetic diversity of *H. fraxineus*



Gross *et al*. (2014)

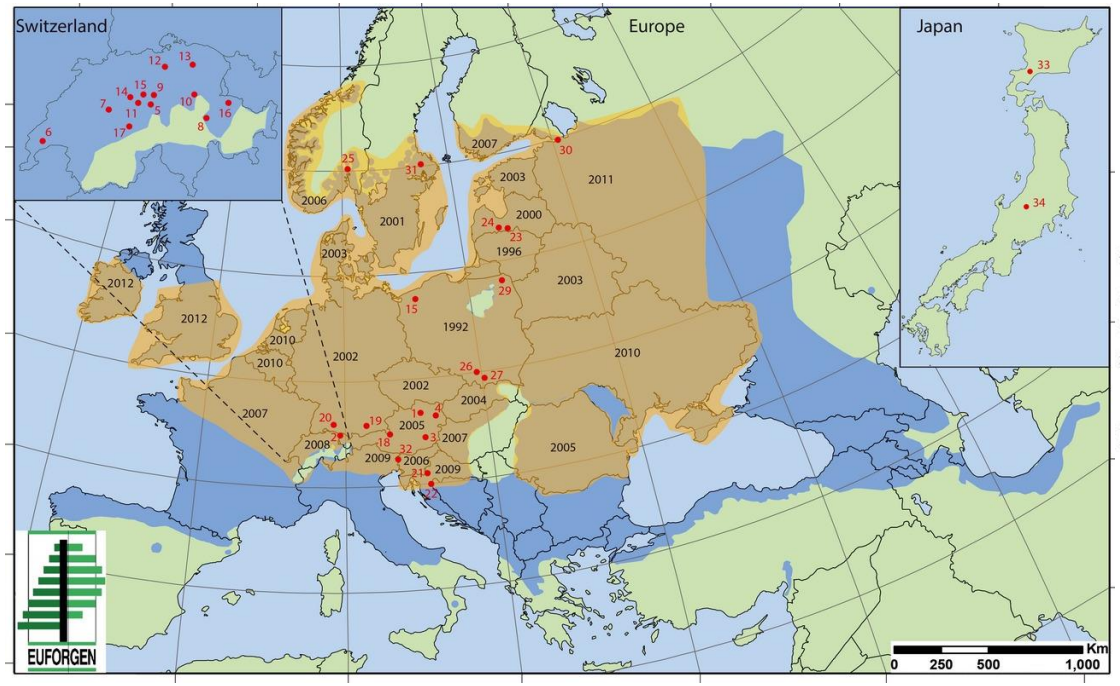


JP - Japan

HR - Croatia
DE - Germany
CH - Switzerland
CH - Switzerland

Genetic diversity is higher in Japan than in Europe, as expected (Gross *et al.* 2014).

Genetic diversity of *H. fraxineus*



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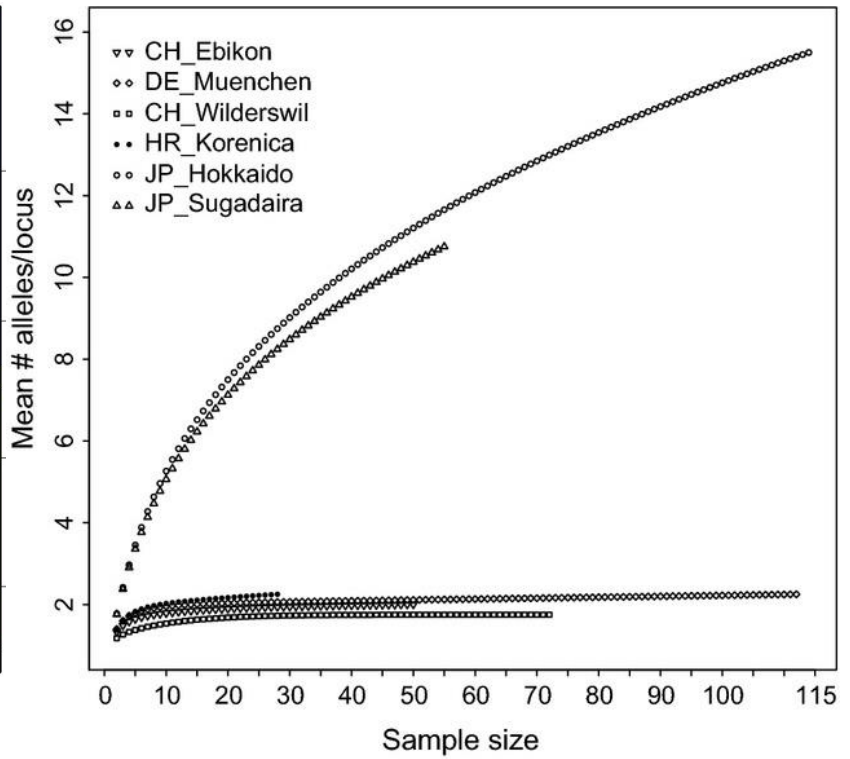
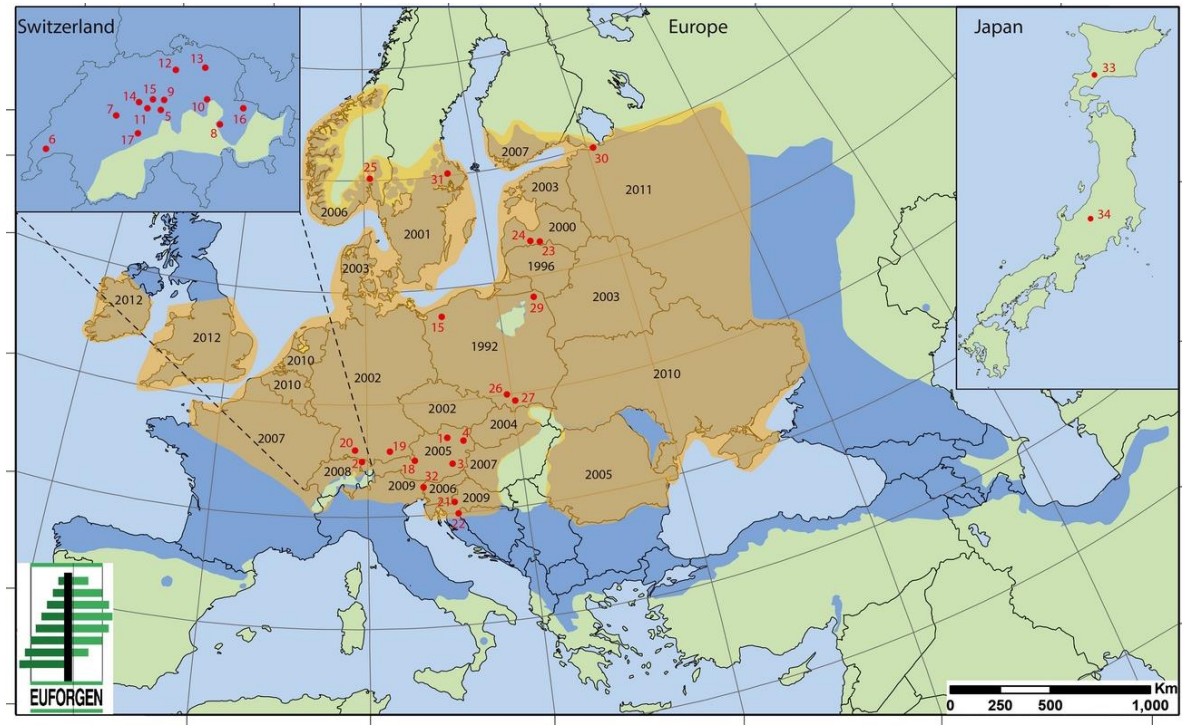
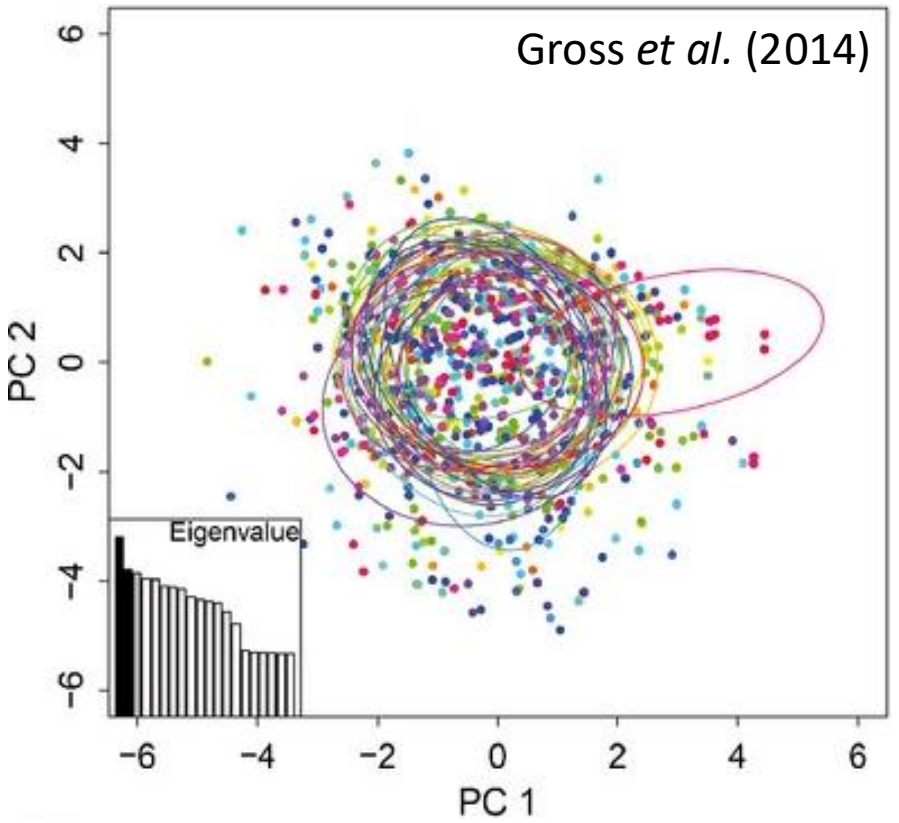


- Genetic diversity of the fungus was **low in Poland, where the disease was first detected**
- From there, the genetic diversity increased slightly in a westwards direction
- But, it was **also lower at the epidemic's front** in Switzerland (CH).

Genetic diversity of *H. fraxineus*

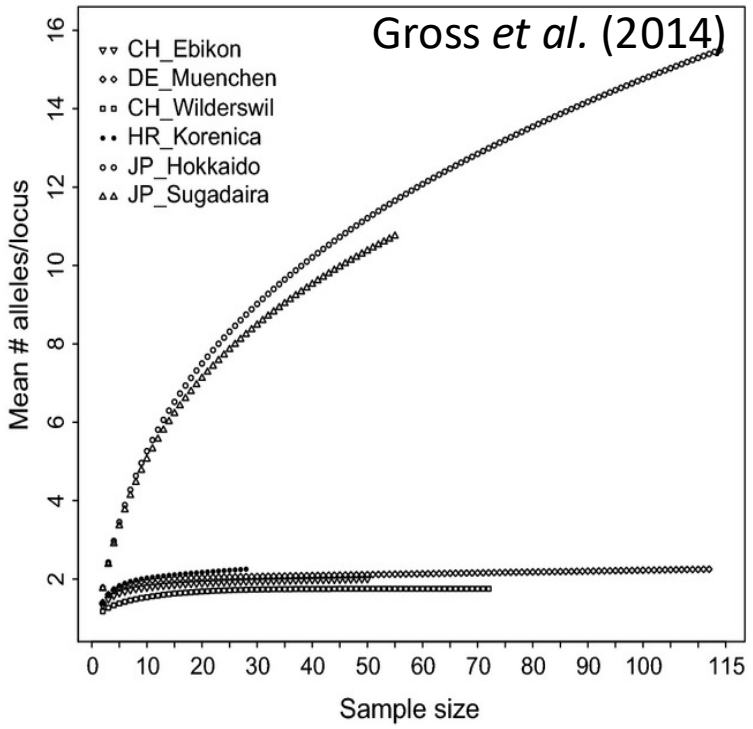


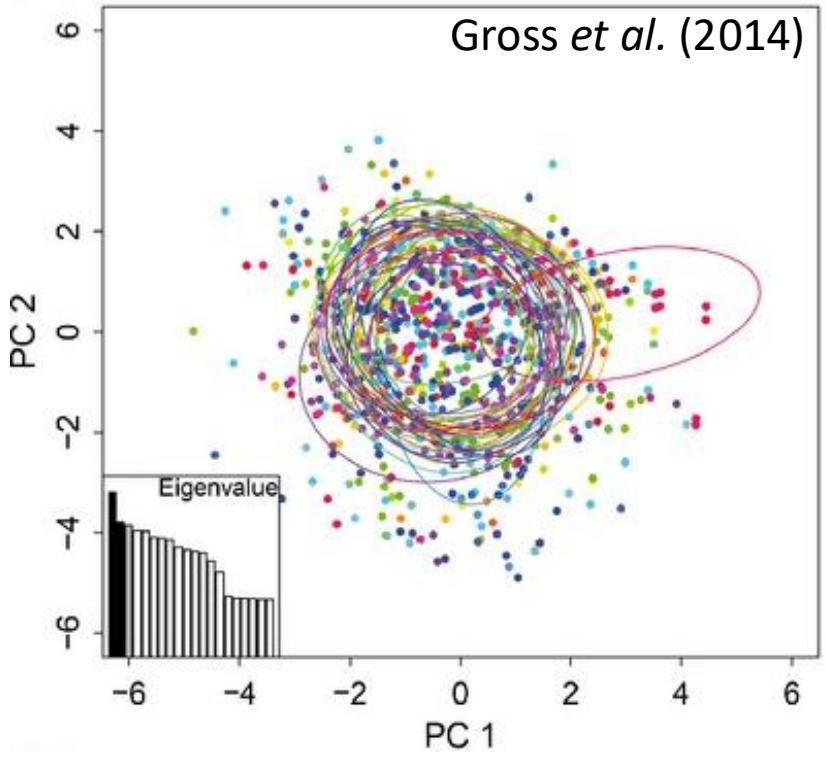


No evident population structure was found in Europe (Gross *et al.* 2014).

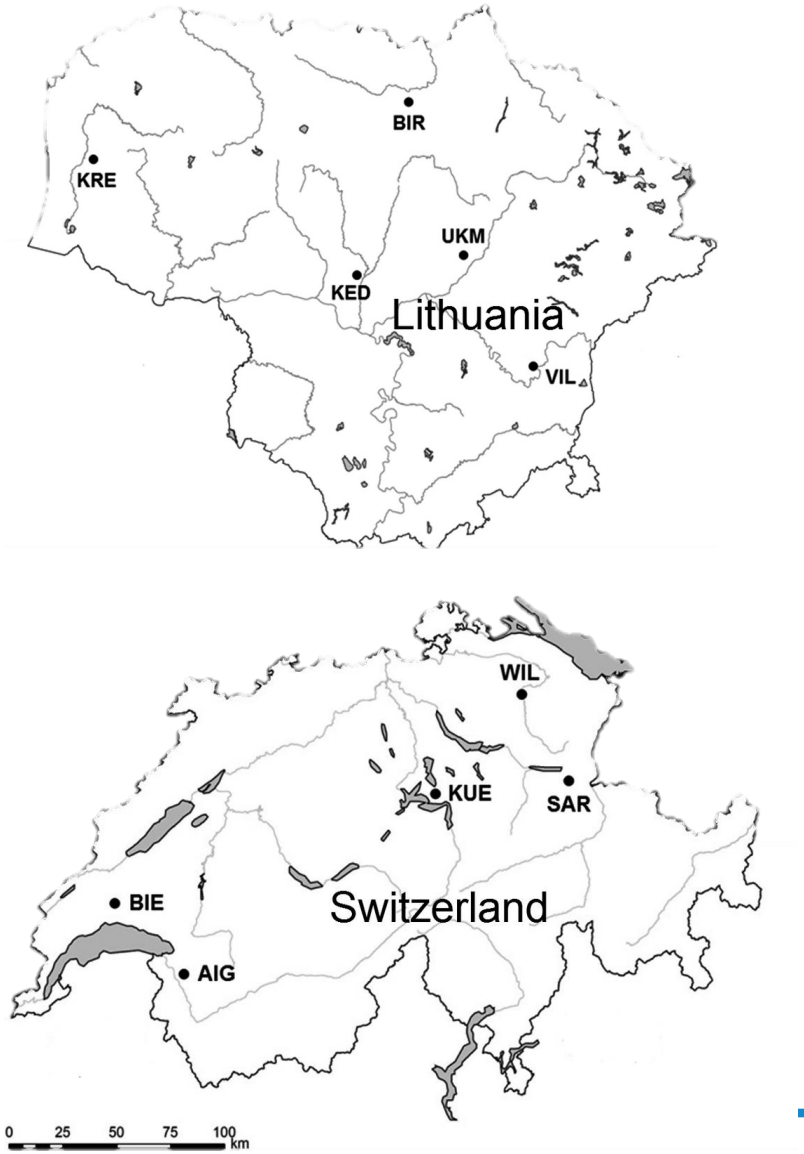
Virulence of *H. fraxineus*

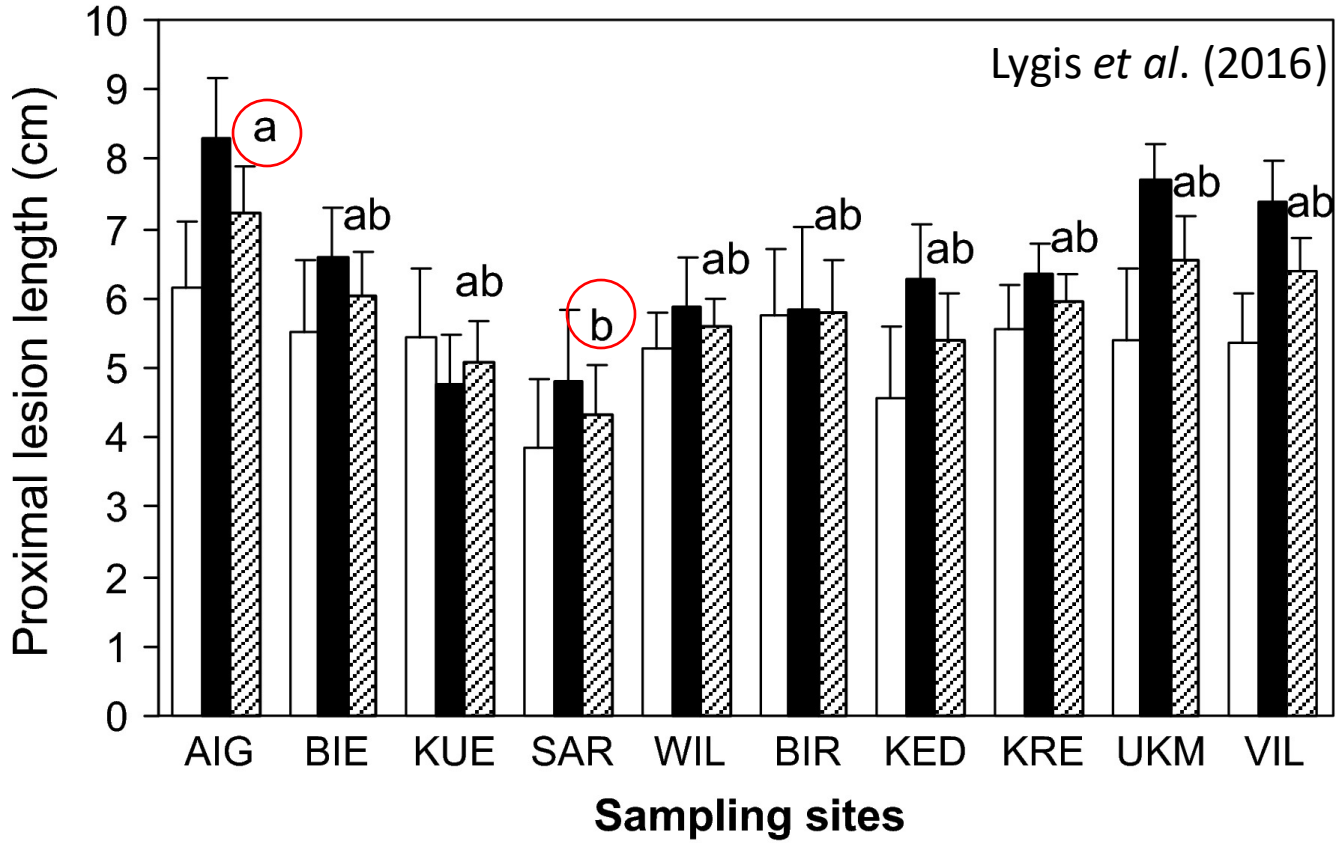
Despite low genetic variation and high frequency of genetic admixture, large differences in virulence are observed in infection experiments…





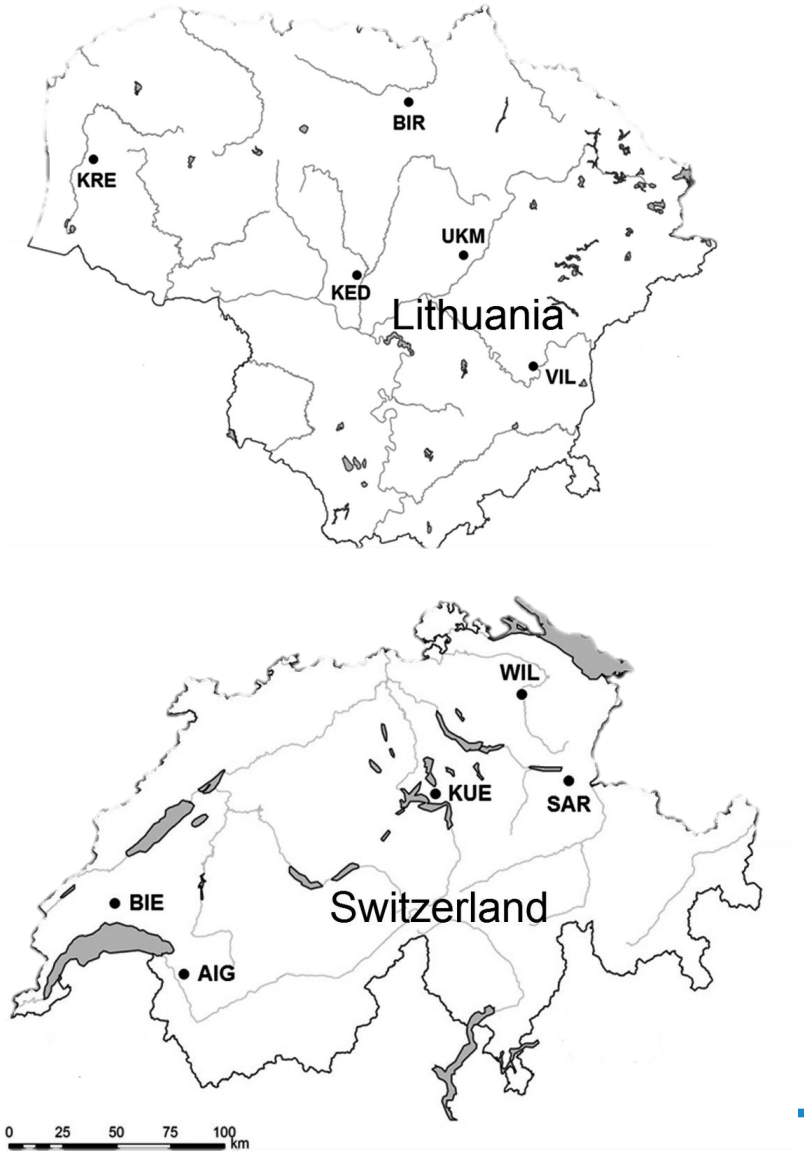
Virulence of *H. fraxineus* in Europe

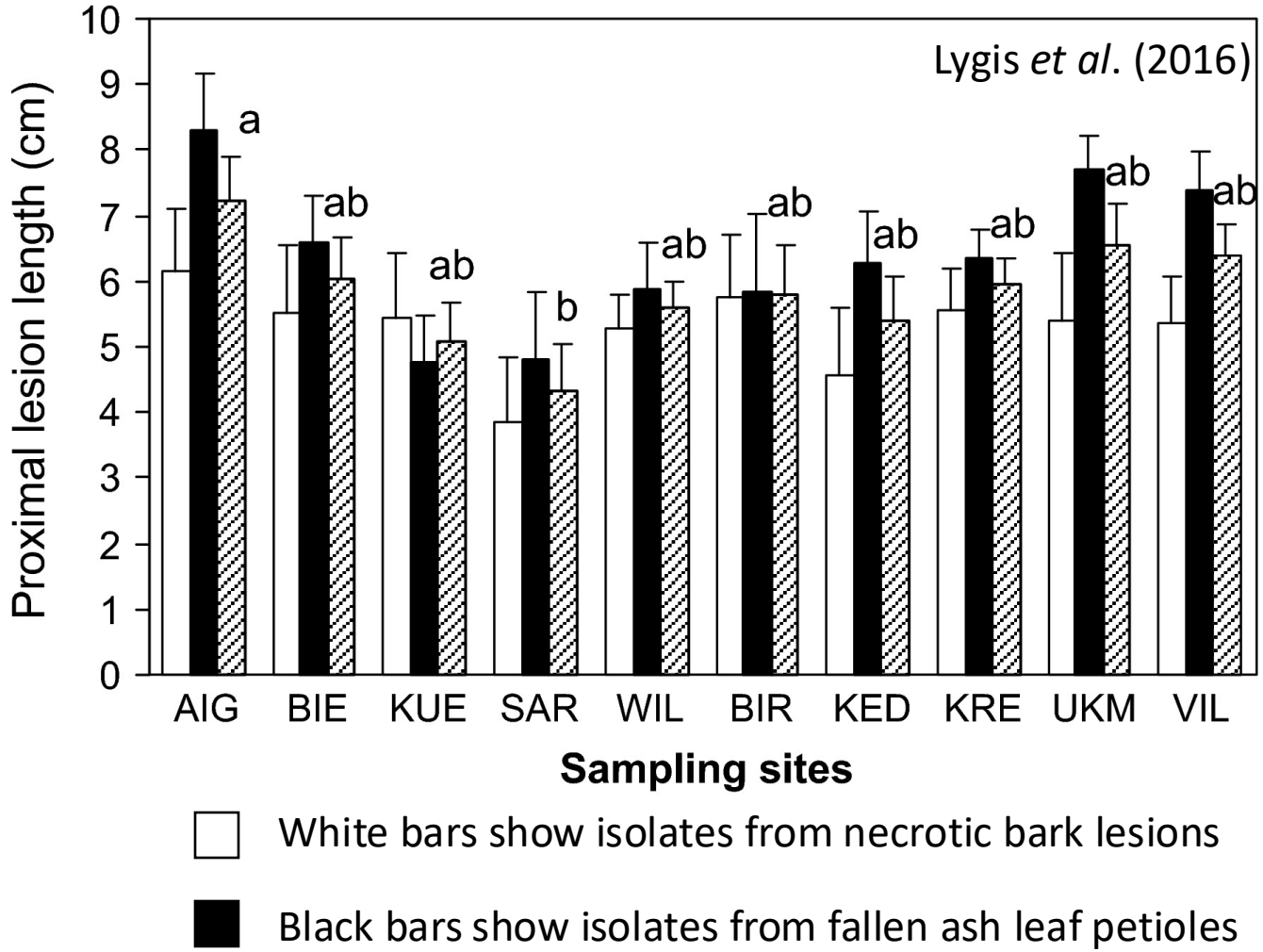




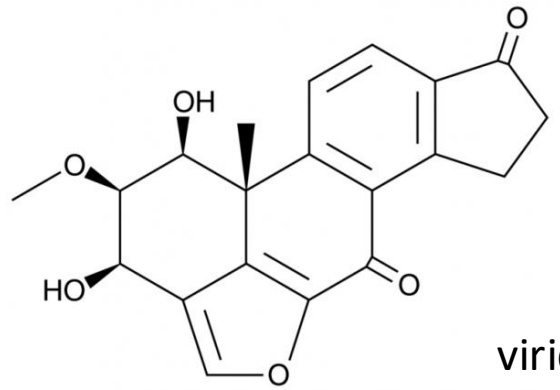
Hatched bars show the mean lesion length for all the isolates combined.

Virulence of *H. fraxineus* in Europe





Virulence of *H. fraxineus*



viridiol

https://www.biomol.com/de/

Many plant pathogens use toxins to attack host cells

- Viridiol has phytotoxic effects on ash seedlings
  - ➢ **However, high production is also observed in non-pathogenic *H. albidus***

- Polyphenoloxidases are involved in lignin degradation during infection
  - ➢ **However, the same is true for the non-pathogenic *H. albidus***

On susceptible exotic hosts the necrotrophic behaviour is seemingly accentuated.

- ➢ **The mechanism driving this shift in behaviour is still unknown.**

The Disease Triangle

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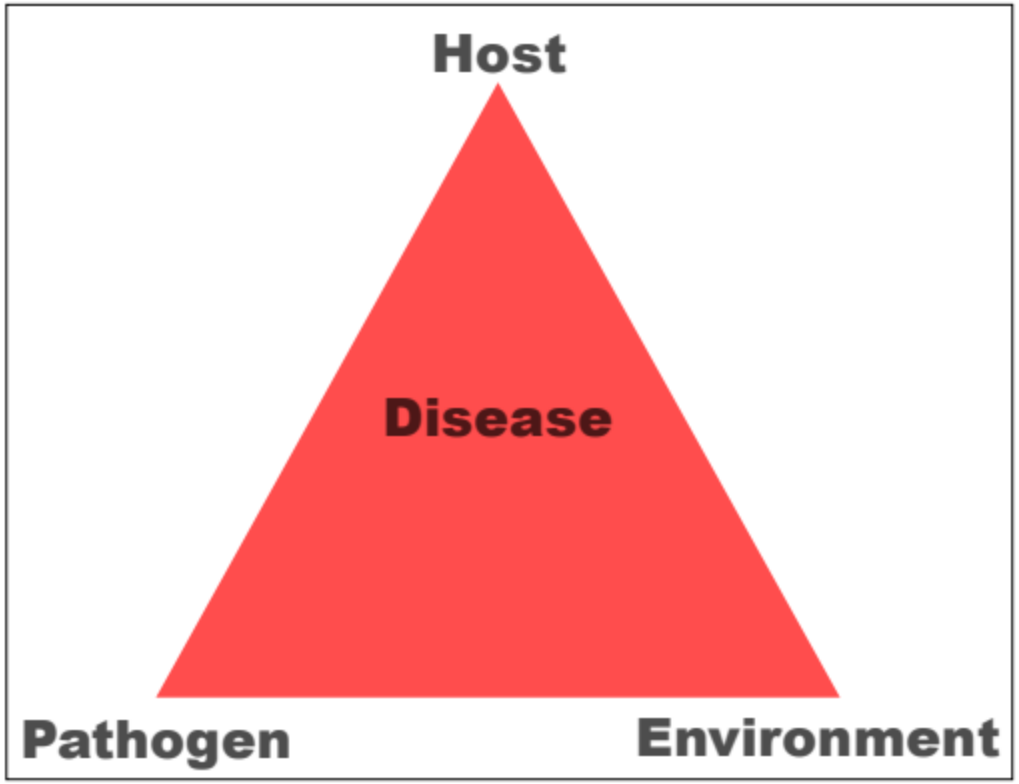


Source: https://www.ncforestservice.gov/

Susceptibility of the host, *F. excelsior*

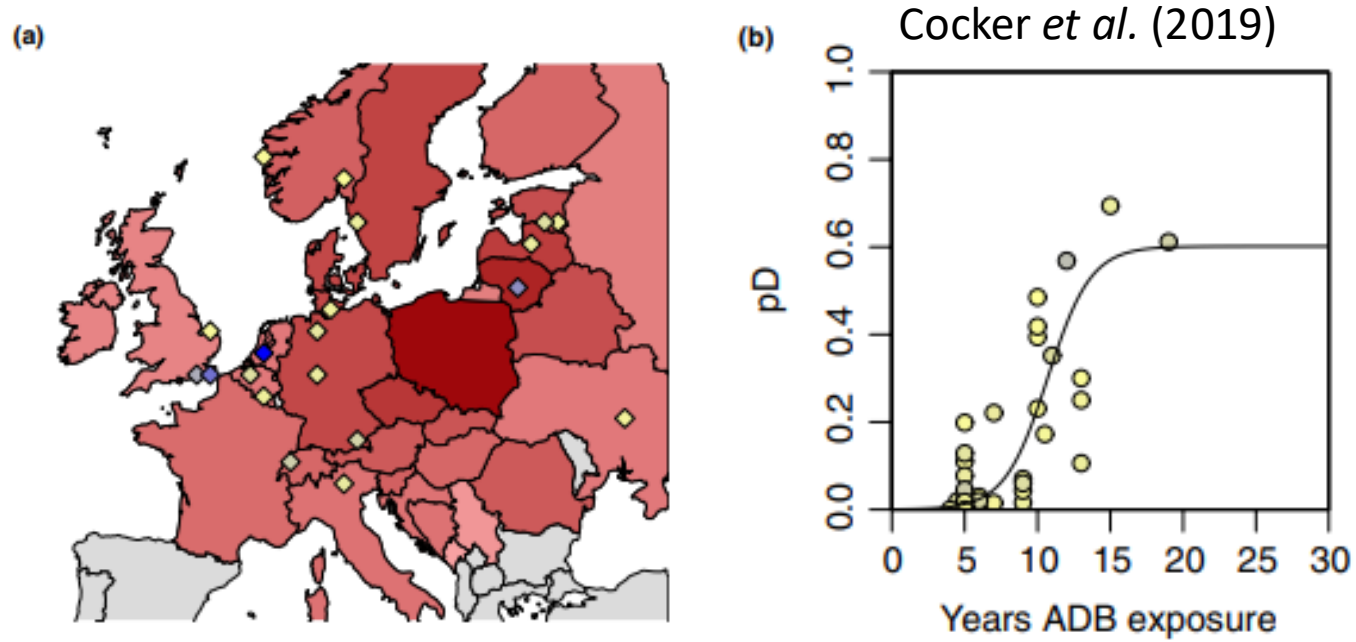
The European ash was the second or third most frequent deciduous tree species in Central Europe, accounting for approx. 1% of forests.

There is high susceptibility in European ash genotypes

- approx. **95% of trees are considered susceptible**, showing significant symptoms and mortality

Susceptibility of the host, *F. excelsior*

No site had 100% mortality, even after 20 years of disease presence.



Cocker *et al.* (2019)

(a) Geographical distribution of woodlands (larger sampling marked blue, fewer trees in yellow).
(b) Logistical model for mortality of woodland ash trees (pD, proportion of dead trees) over time.

Susceptibility of Novel Host

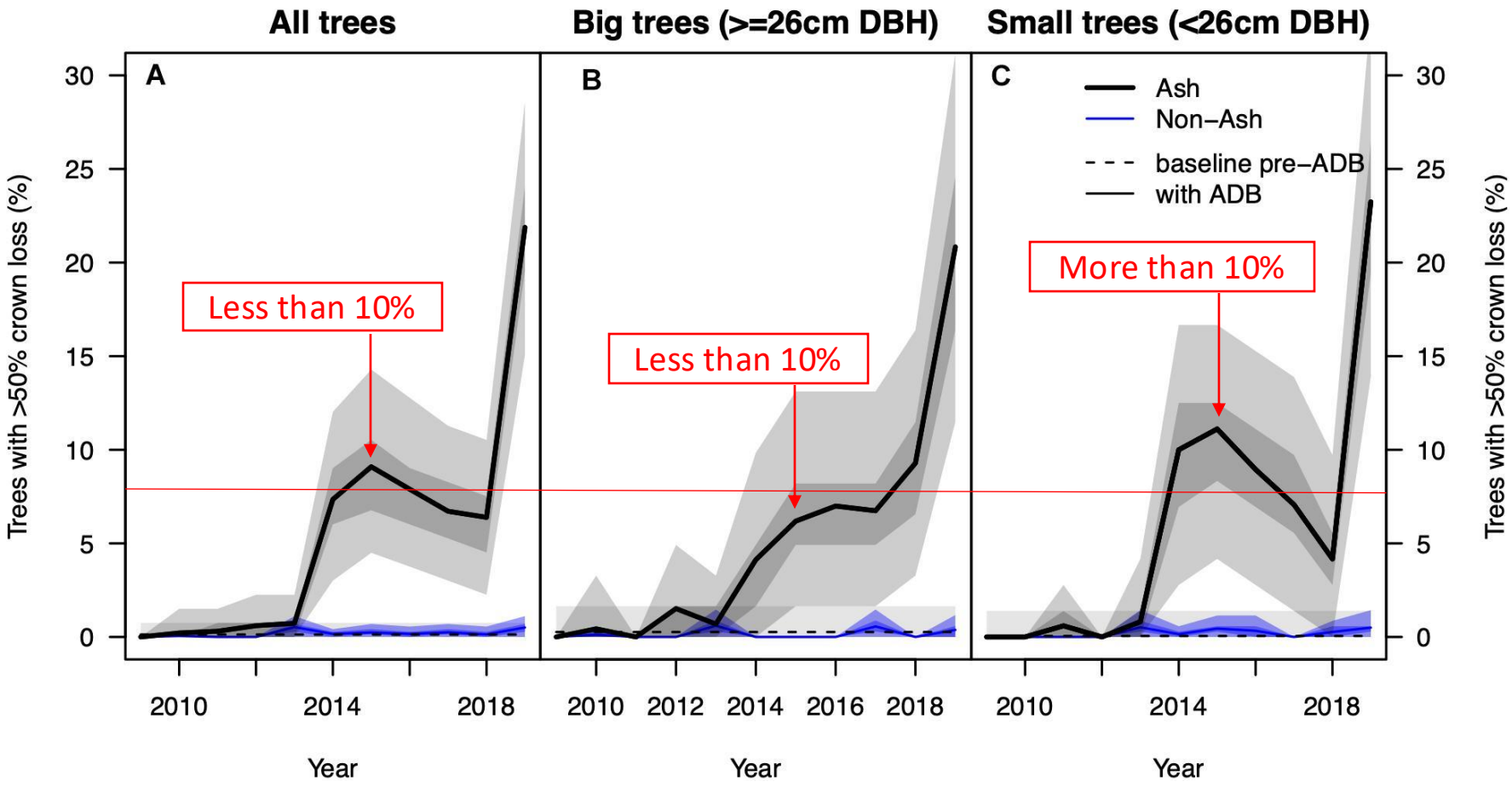
Tree Characteristics

Individual Tree Characteristics	Symptoms are more severe…
Host species	… *F. excelsior*, compared to *F. angustifolia*
Gender	… male trees
Age	… younger trees
Diameter at breast height (DBH)	… trees with smaller DBH
Crown surface projection	… trees with smaller crowns

Certain tree characteristics are associated with more severe symptoms in European ash trees

Case study in Switzerland

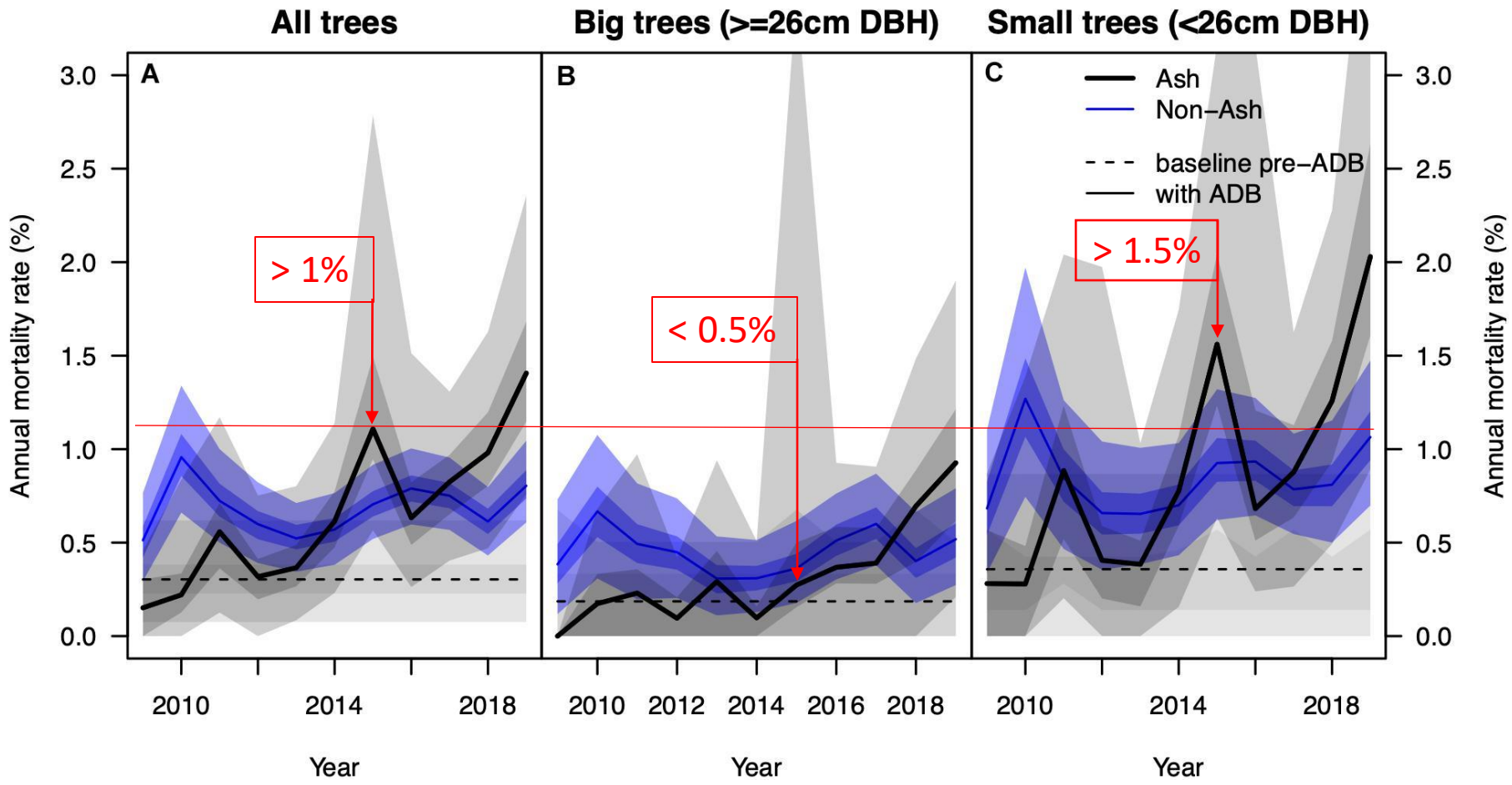
Crown loss is higher in trees with a small DBH



Klesse *et al.* (2021)

Case study in Switzerland

Mortality is also higher in trees with a small DBH



Klesse *et al.* (2021)

35

Susceptibility of Novel Host

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Diameter at breast height (DBH)	… trees with smaller DBH
Crown surface projection	… trees with smaller crowns

Individual Tree Characteristics	Symptoms are more severe…
Phenology in spring	… producing leaves later (flushing)
Leaf senescence/ leaf shedding in autumn	… shedding leaves later

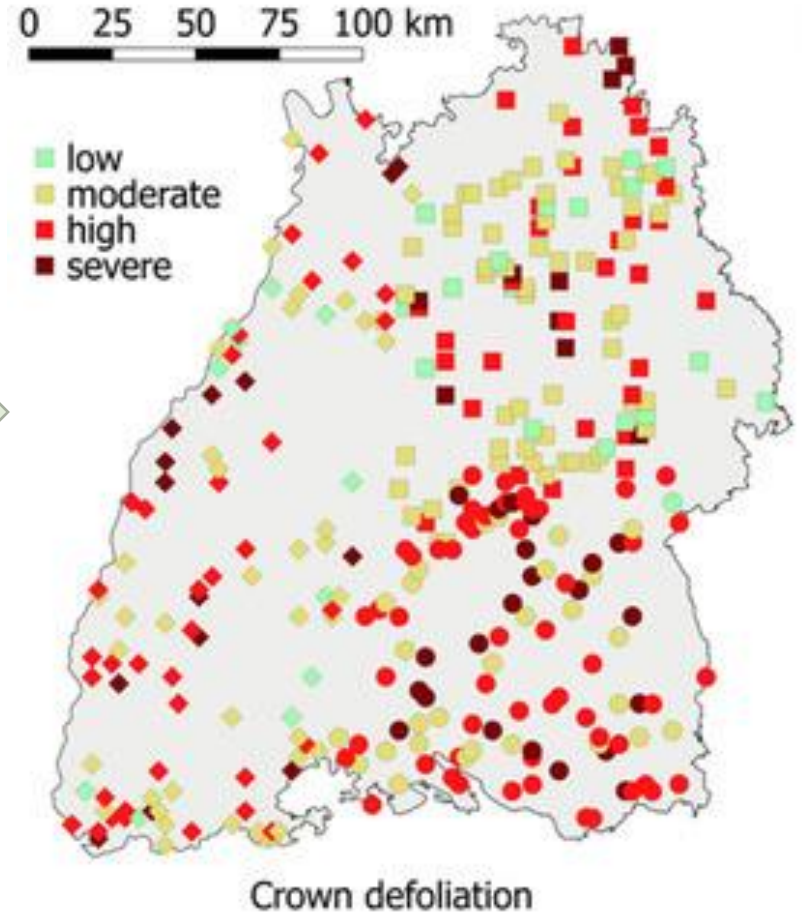
Enderle *et al.* (2019)

Susceptibility of Novel Host

Site and Environmental Conditions

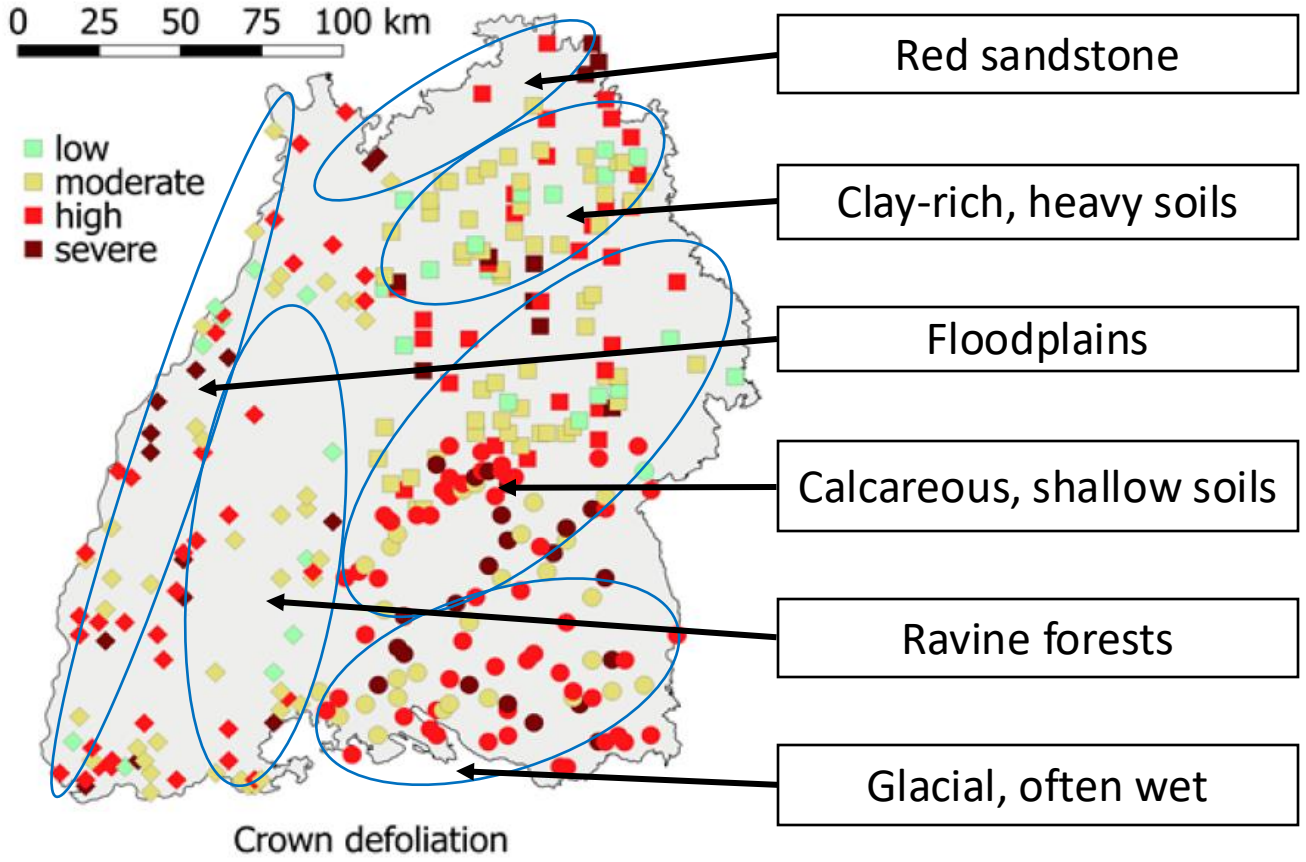
Site and Environmental Conditions	Symptoms are more severe…
Stand species composition	… pure ash stands, plantations
Stand composition (shaded vs. open)	… shaded forested sites
Altitude	… lower altitude
Temperature	… low to moderate temperature
Moisture, humidity	… more humid sites
Soil type	… unspecified

Crown Defoliation



Enderle *et al.* (2018)

Crown Defoliation

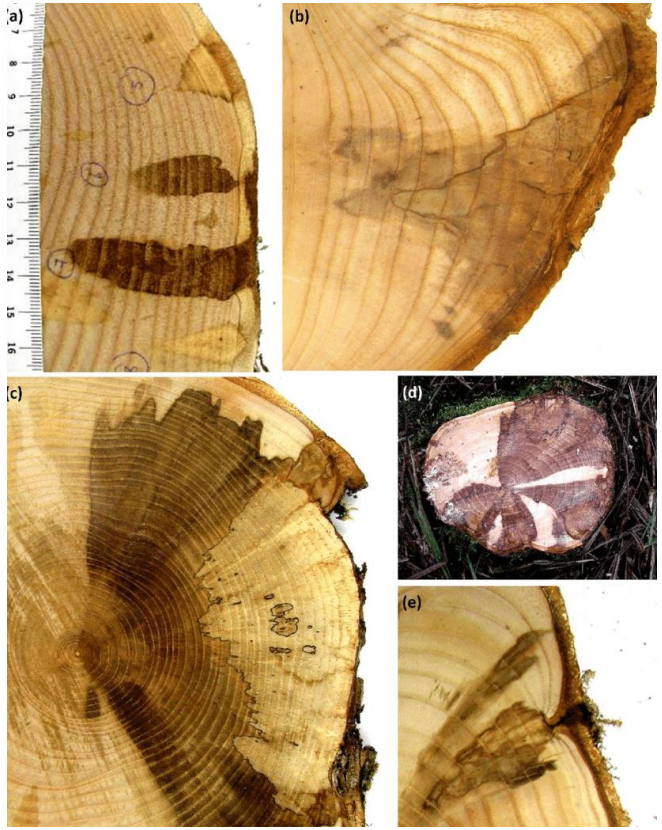


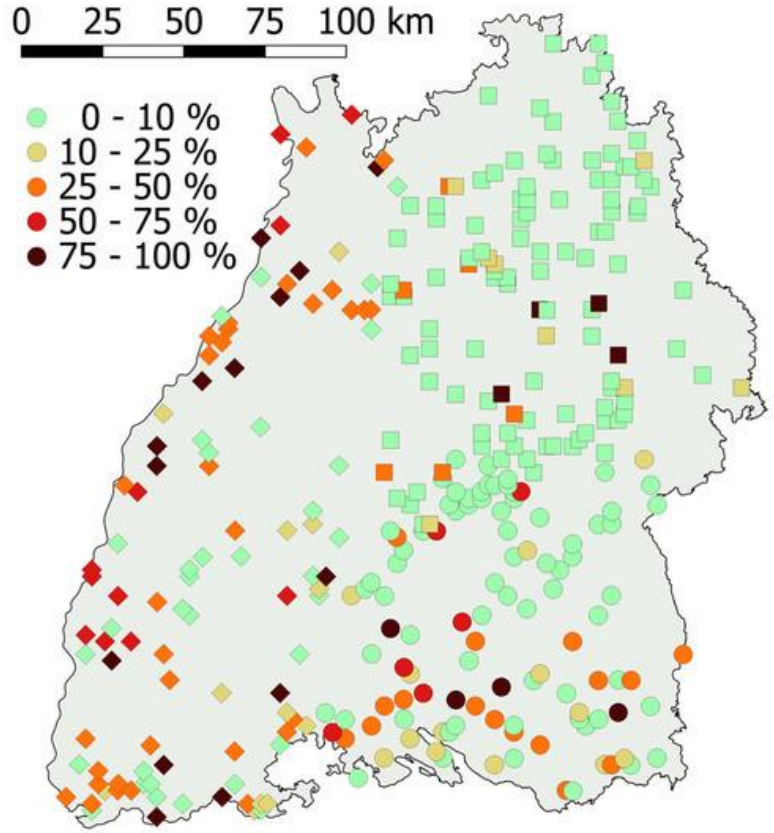
- Trees were **healthiest** in north-east
- **Healthiest trees were on drier sites** in north-east on heavy, clay-rich soils
- Severe defoliation was found on the floodplains or water-influenced sites
- The tested factors did not have a significant influence in this study

Enderle *et al.* (2018)

39

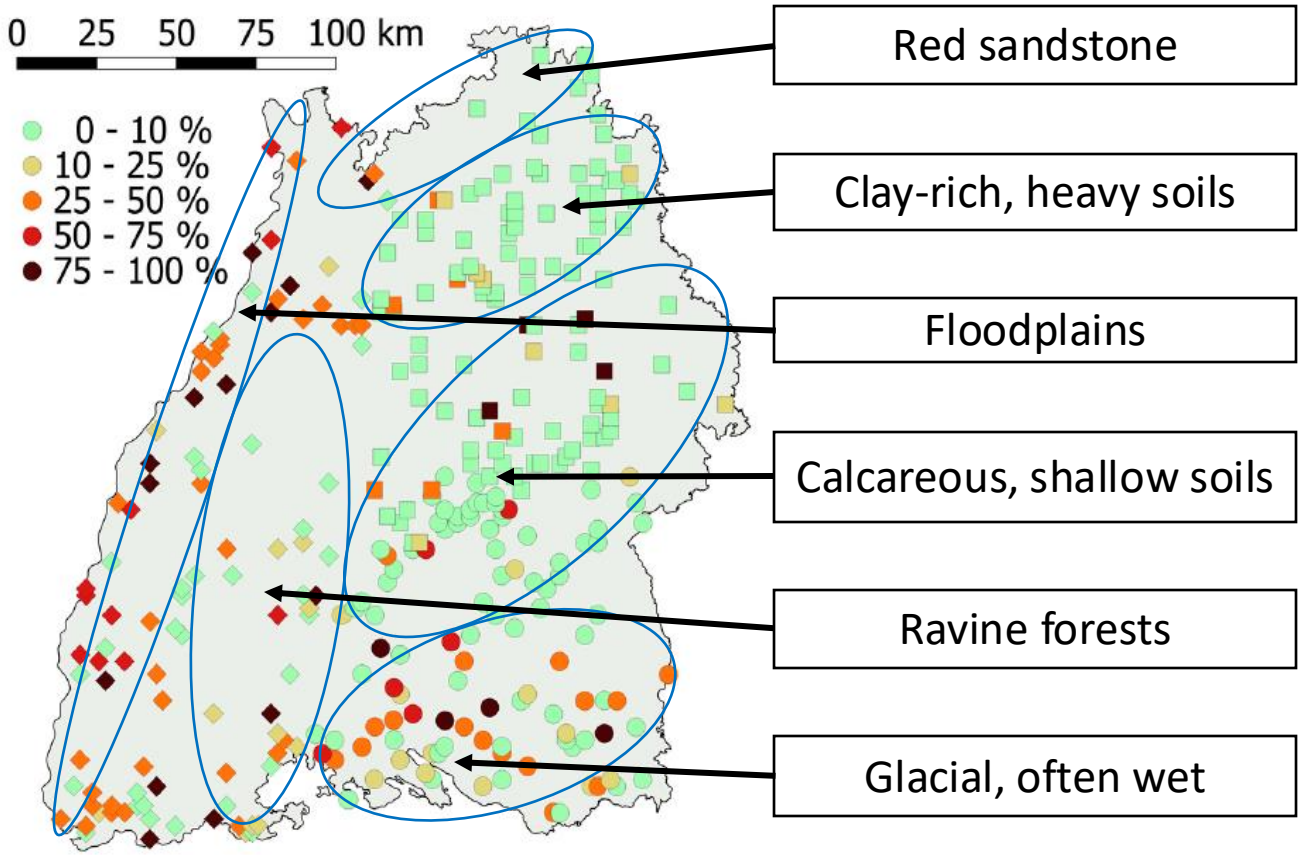
Root Collar Necroses





Sources: Enderle *et al.* (2017, 2018); Langer *et al.* (2022)

Root Collar Necroses



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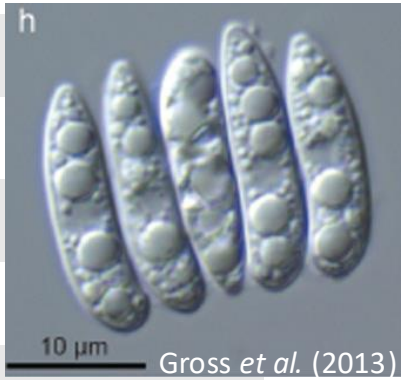
- Severe defoliation was found on the floodplains or water-influenced sites
- The tested factors did not have a significant influence in this study

Enderle *et al.* (2018)

Summary

Influencing factors	Symptoms are more severe…
Host species	
Gender	
Age	
Diameter at breast height (DBH)	
Crown surface projection	
Phenology in spring	
Leaf senescence/ leaf shedding in autumn	
Stand species composition	
Stand composition (shaded vs. open)	
Altitude	
Temperature	
Moisture, humidity	
Soil type	



Gross *et al.* (2013)


Source: Wikipedia

Summary

Influencing factors	Symptoms are more severe…
Host species	… *F. excelsior*, compared to *F. angustifolia*
Gender	… male trees
Age	… younger trees
Diameter at breast height (DBH)	… trees with smaller DBH
Crown surface projection	… trees with smaller crowns
Phenology in spring	… producing leaves later (flushing)
Leaf senescence/ leaf shedding in autumn	… shedding leaves later
Stand species composition	… pure ash stands, plantations
Stand composition (shaded vs. open)	… shaded forested sites
Altitude	… lower altitude
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Moisture, humidity	… more humid sites
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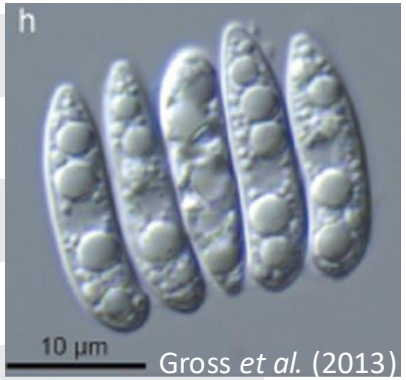


Gross *et al.* (2013)


Source: Wikipedia

Susceptibility to Secondary Colonisers

***Armillaria spp.*, the honey fungus**

Armillaria spp., is known to colonise necrosis caused by *H. fraxineus*

These secondary colonisers pose additional health and safety risks

Fruiting bodies of *Armillaria spp*. on mature ash tree

Susceptibility to Secondary Colonisers

Hylesinus spp.

- ash trees infected by ADB are predisposed to *Hylesinus* spp.
  - ***Hylesinus crenatus***
  - ***Hylesinus fraxini***


Maarten de Groot

Hylesinus cranatus


Source: György Csóka

Hylesinus fraxini


Source: Mark Skevington


György Csóka

The Disease Triangle

An epidemic requires:

- (i) a virulent pathogen with a high reproduction rate

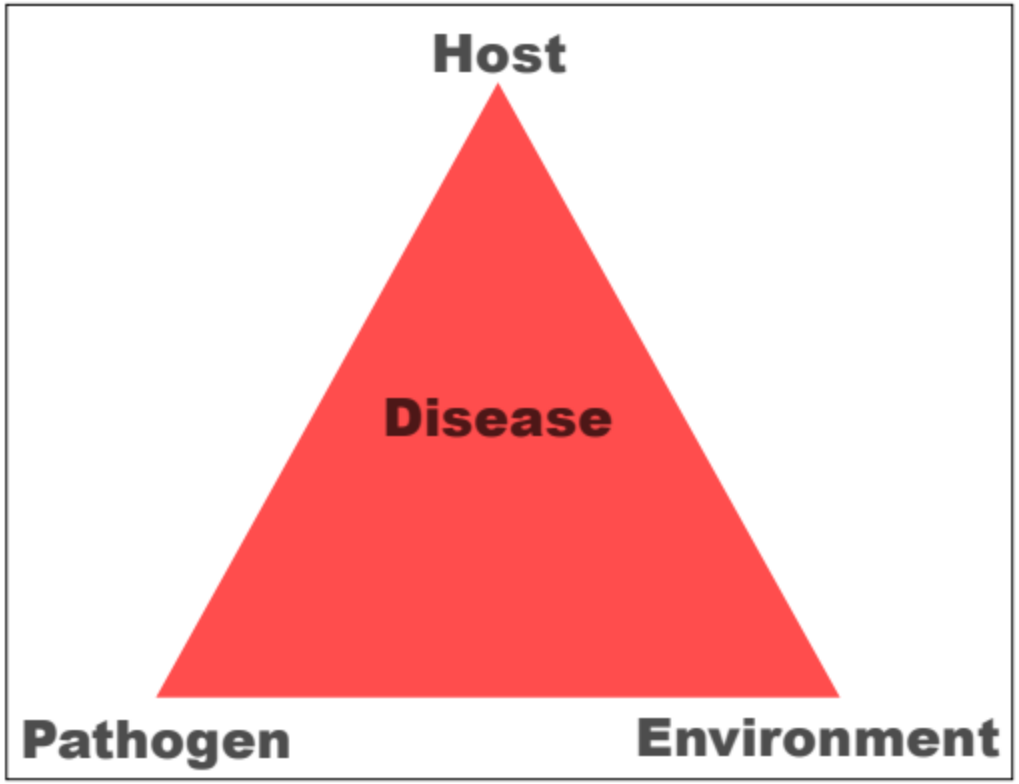
  -> ***H. fraxineus***

- (ii) an accumulation of susceptible host

  -> **European ash**

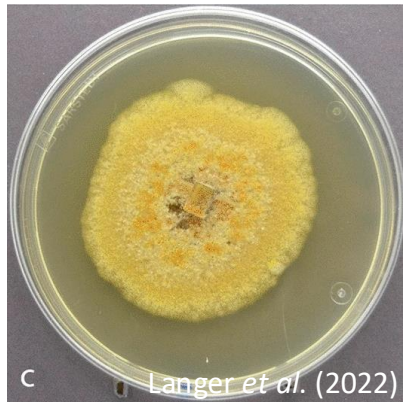
- (iii) suitable environmental conditions for the pathogen

  -> **Central Europe**



Source: https://www.ncforestservice.gov/

Environmental Factors

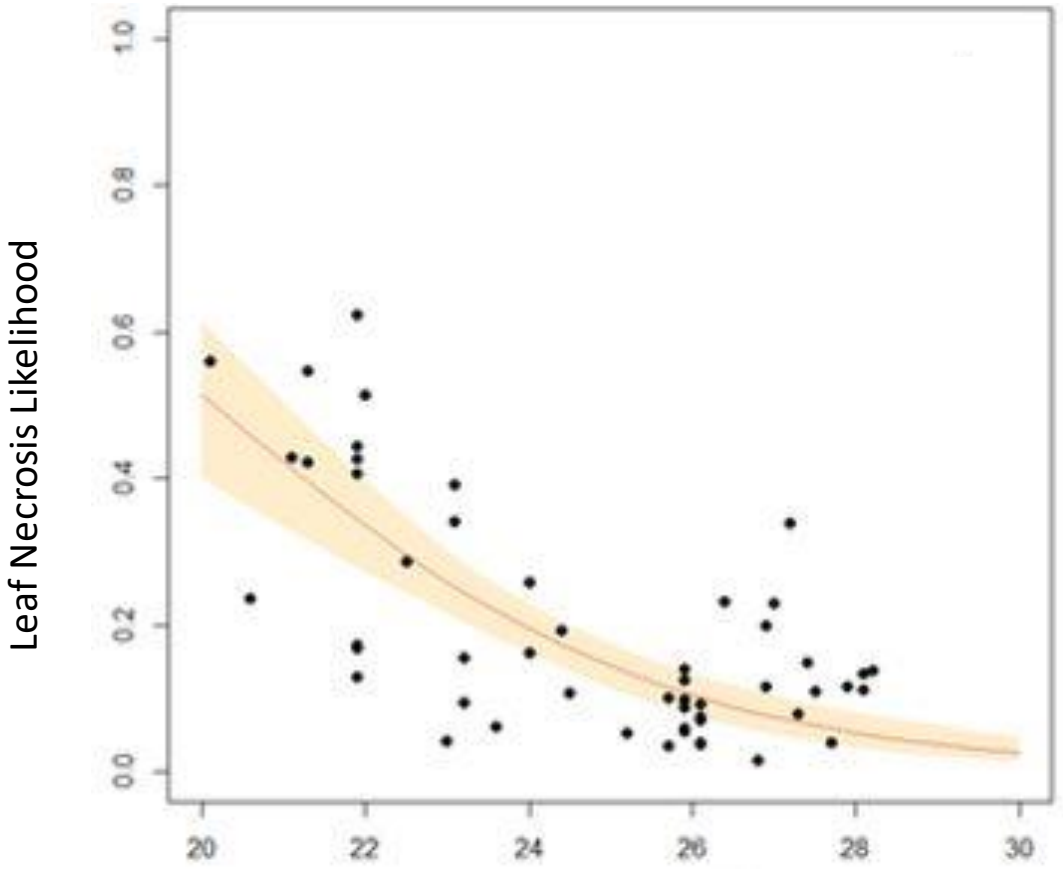


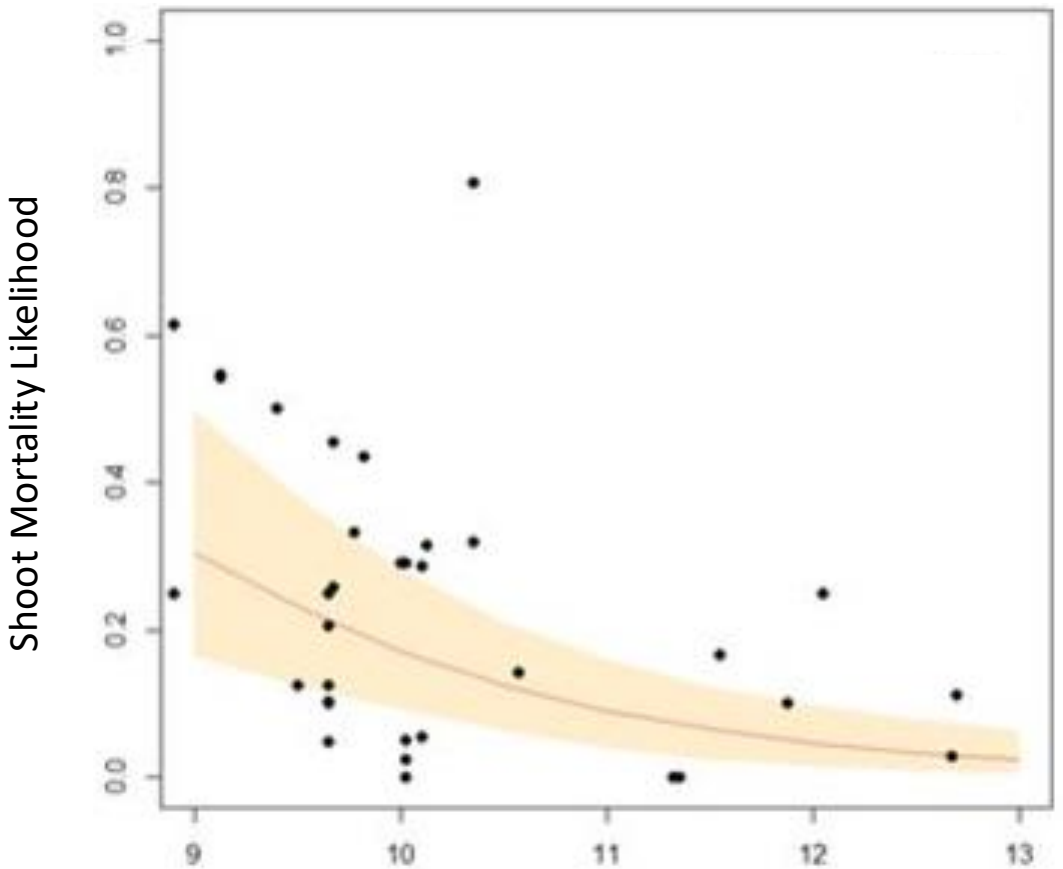
- **20 °C is optimum** for mycelial growth in culture (ceases at 30 °C)
  - ➢ In ash tissues the fungus appears to be more **heat sensitive**.

- Ascospores are produced abundantly during spring and summer
- Ascospore melanization after ejection and attachment to a host surface suggest ability to withstand adverse conditions *in-planta*.
- **Ascospores are drought sensitive**, spores can desiccate within 24 h

Gross *et al.* (2013); Kowalski and Bartnik (2010); Pham *et al*. (2013); Kirisits *et al*. (2009); Timmermann *et al*. (2011); Henson *et al*. (1999)

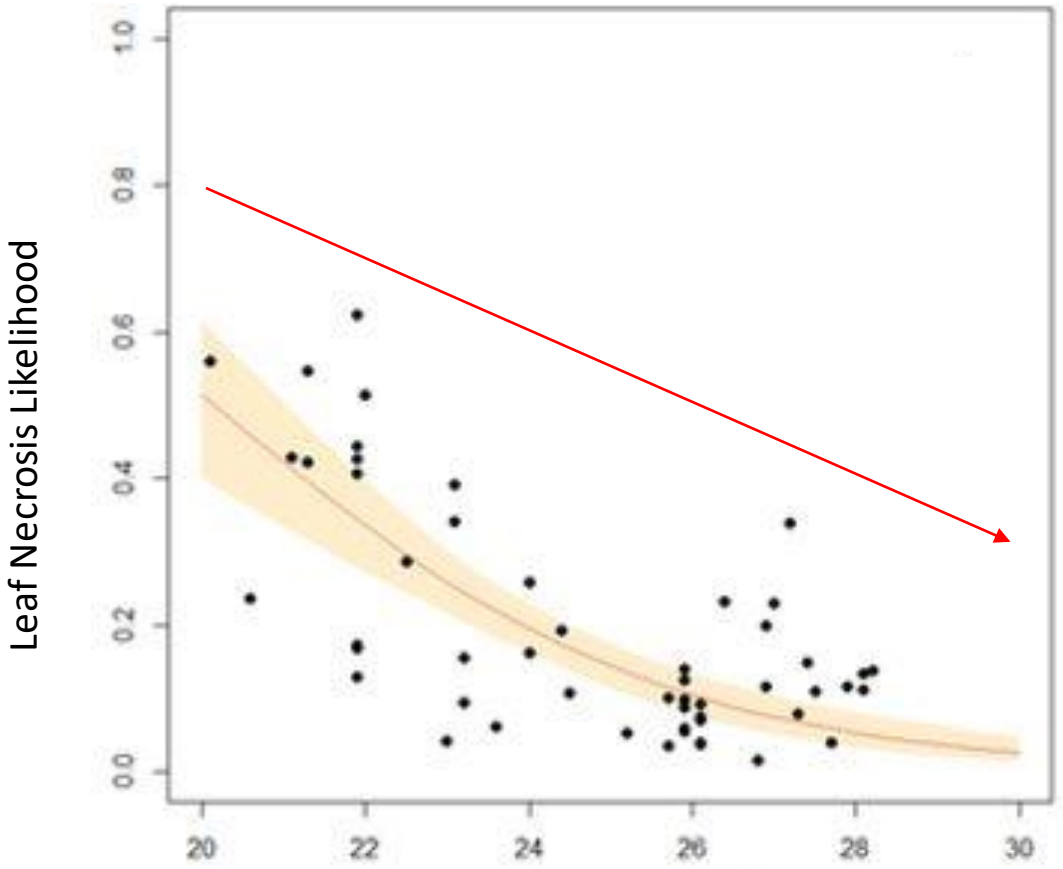
Climate change. Good News?

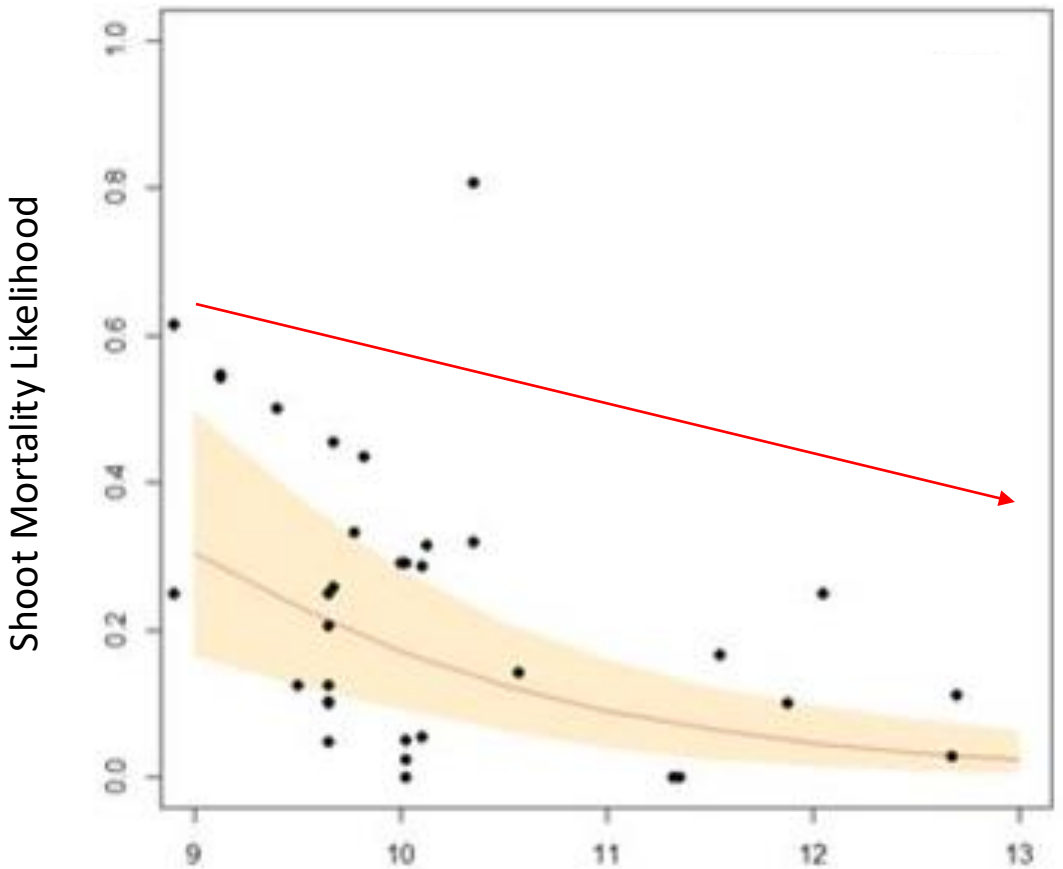




Marçais *et al.* (2022)

Climate change. Good News?





Marçais *et al.* (2022)

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The Disease Triangle

An epidemic requires:

- (i) a virulent pathogen with a high reproduction rate

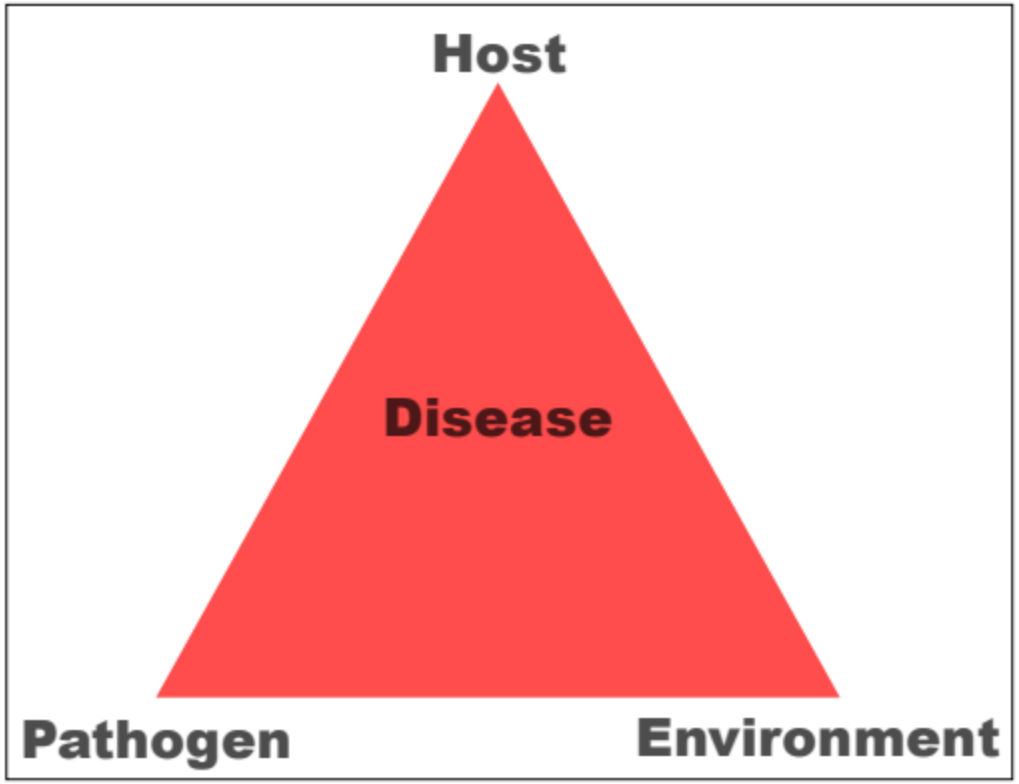
  -> ***H. fraxineus***

- (ii) an accumulation of susceptible host

  -> **European ash**

- (iii) suitable environmental conditions for the pathogen

  -> **Central Europe**



Source: https://www.ncforestservice.gov/

Disease management

We must control spread of the fungus to novel areas, specifically through trade

H. fraxineus

Sources: Baral *et al.* (2014); Rosenfeld Images Ltd.; Eigenes Werk (2010)

Forest management

The relevant strategy depends on objective, site, stand age and damage

General recommendations:

- **Maintain healthy** or slightly damaged trees
- In forests of habitat conservation value, **allow natural succession**
- **Minimise risks** for operational staff, forest visitors and infrastructure
- **Use other tree species** to regenerate or replant for commercial uses
  - *Acer, Betula, Fagus, Populus, Prunus, Quercus, Sorbus, Taxus, Tilia,* or *Ulmus spp*.
  - a.k.a. Maple, Birch, Beech, Poplar, Cherry, Oak, Rowan, Yew, Lime/ Linden, or Elm


mass.gov (2023)

Skovsgaard *et al.* (2017); FraxForFuture

Forest management

Why is it recommended to maintain also slightly damaged trees?

- The **low resistance means** ash populations will decline, which will leave only a few resistant trees to parent new generations of trees
- Healthy-looking trees are needed as **future seed trees**, thereby supporting the natural selection in favour of decreased susceptibility
- Despite long distance pollen flow, management will be necessary to **prevent inbreeding** in increasingly fragmented populations

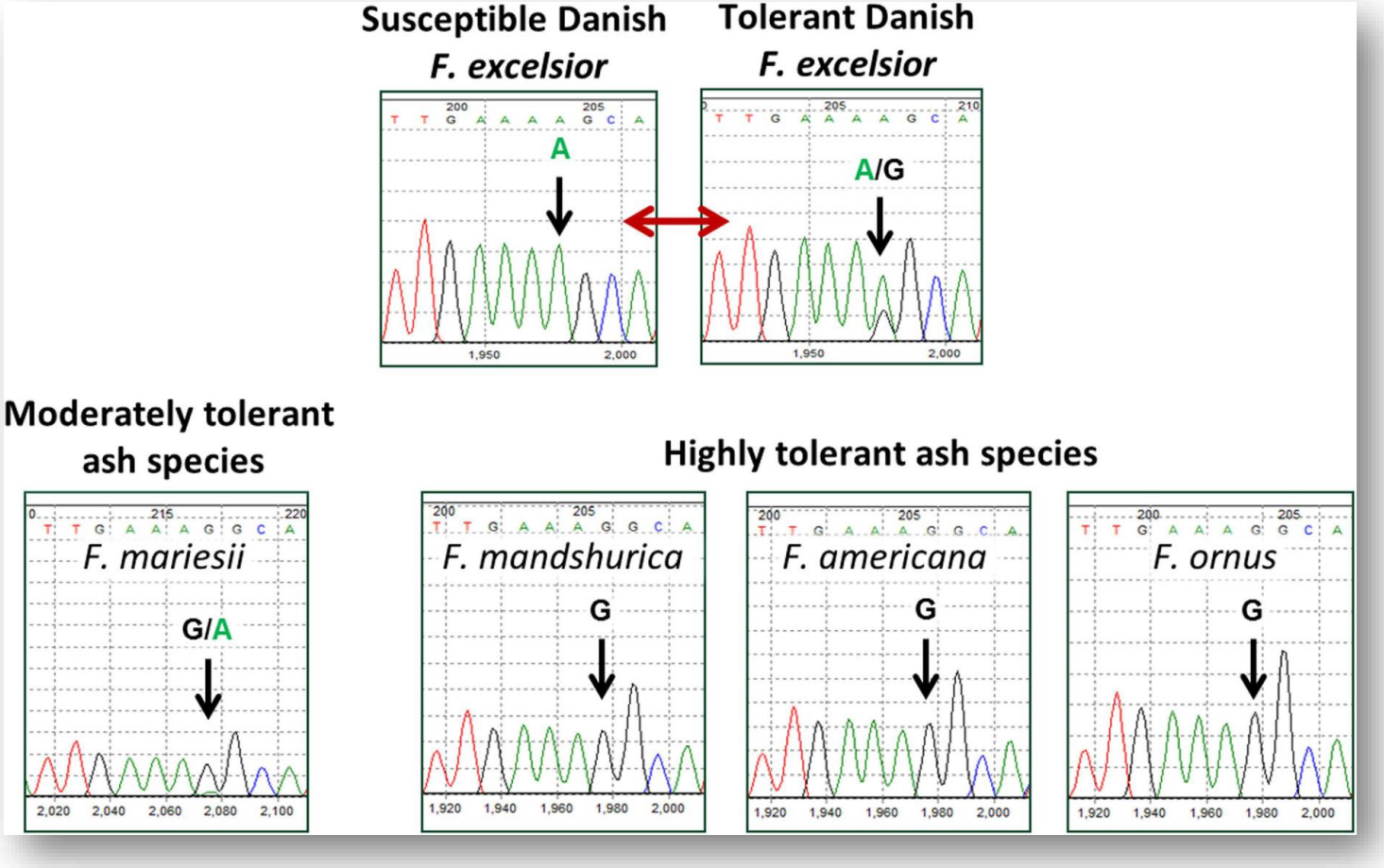
Resistance of European ash

- approx. **5% of trees are considered resistant,** showing no or only insignificant symptoms

- However, this **tolerance is heritable**, which gives reason for hope for the recovery of *F. excelsior*

Resistance of European ash

Identification of resistance markers in Danish ash trees by associative transcriptomics



Sequence chromatograms showing the cSNP position in a number of Fraxinus species

Harper *et al*. (2016)

Breeding for Resistance

Identifying and promoting genetic and heritable resistance in Europe

- *e.g.* Austrian programme “Esche in Not” (ash in distress) from 2015-2024

Source: Rasmus Enderle

Breeding for Resistance

Identifying and promoting genetic and heritable resistance in Europe

- *e.g.* Austrian programme “Esche in Not” (ash in distress) from 2015-2024

However, breeding takes decades and resistance screening is labour intensive

The establishment of seed orchards began in spring 2024
The first seed harvests are expected in approximately ten years

Source: Rasmus Enderle

Breeding for Resistance

The publication of the ash genome and subsequent genomic studies are helping

Centre for Forest Protection

About us | Why protect? | Science | Education | News | Blog | Work With Us

NEWS

30.07.2024

A new reference genome from a healthy ash tree

Our researchers have been busy creating a new genome resource

It is now possible to predict tree health with over 90% accuracy!

Costs of Breeding for Resistance?

Possible trade-offs when selecting for host resistance:

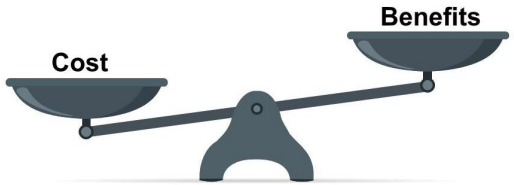
- Growth?
- Competitiveness?
- Fecundity?

Source: https://www.slideteam.net/

Costs of Breeding for Resistance?

Possible trade-offs when selecting for host resistance:

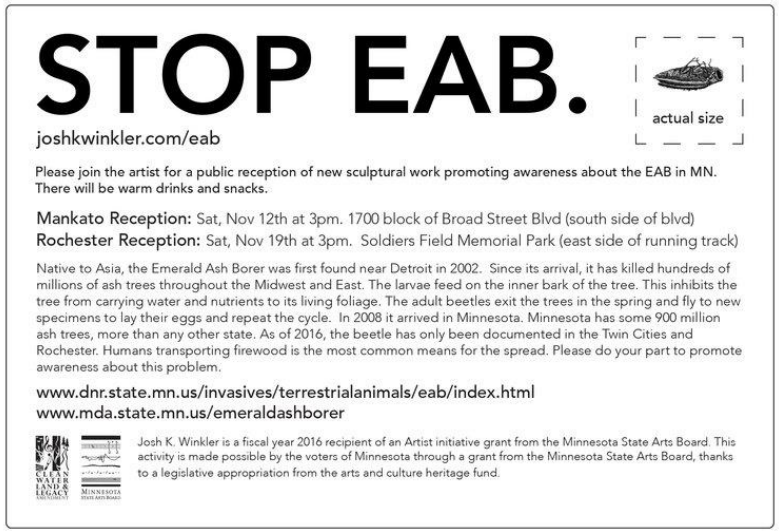
- Growth?
- Competitiveness?
- Fecundity?
- Susceptibility to novel threats?



Source: https://www.slideteam.net/

➢ **The Emerald Ash Borer** (*Agrilus planipennis*)

Emerald Ash Borer - Bad news!



- The emerald ash borer is native from East Asia
- It is an insect that seriously threatens all Northern American *Fraxinus* species

Emerald Ash Borer - Bad news!

About EAB

The emerald ash borer and why it's a threat to ash trees worldwide.

Emerald Ash Borer Impacts on American Indian Communities

Emerald ash borer (EAB) infestation is a major concern for American Indian people. Many American Indian cultures and traditions rely on ash trees for the wood needed for making baskets, lacrosse sticks, pipe stems, flutes, and medicinal remedies. The ash tree is a central figure in some traditional and religious stories told by several American Indian tribes.

EAB Network

If You Find EAB

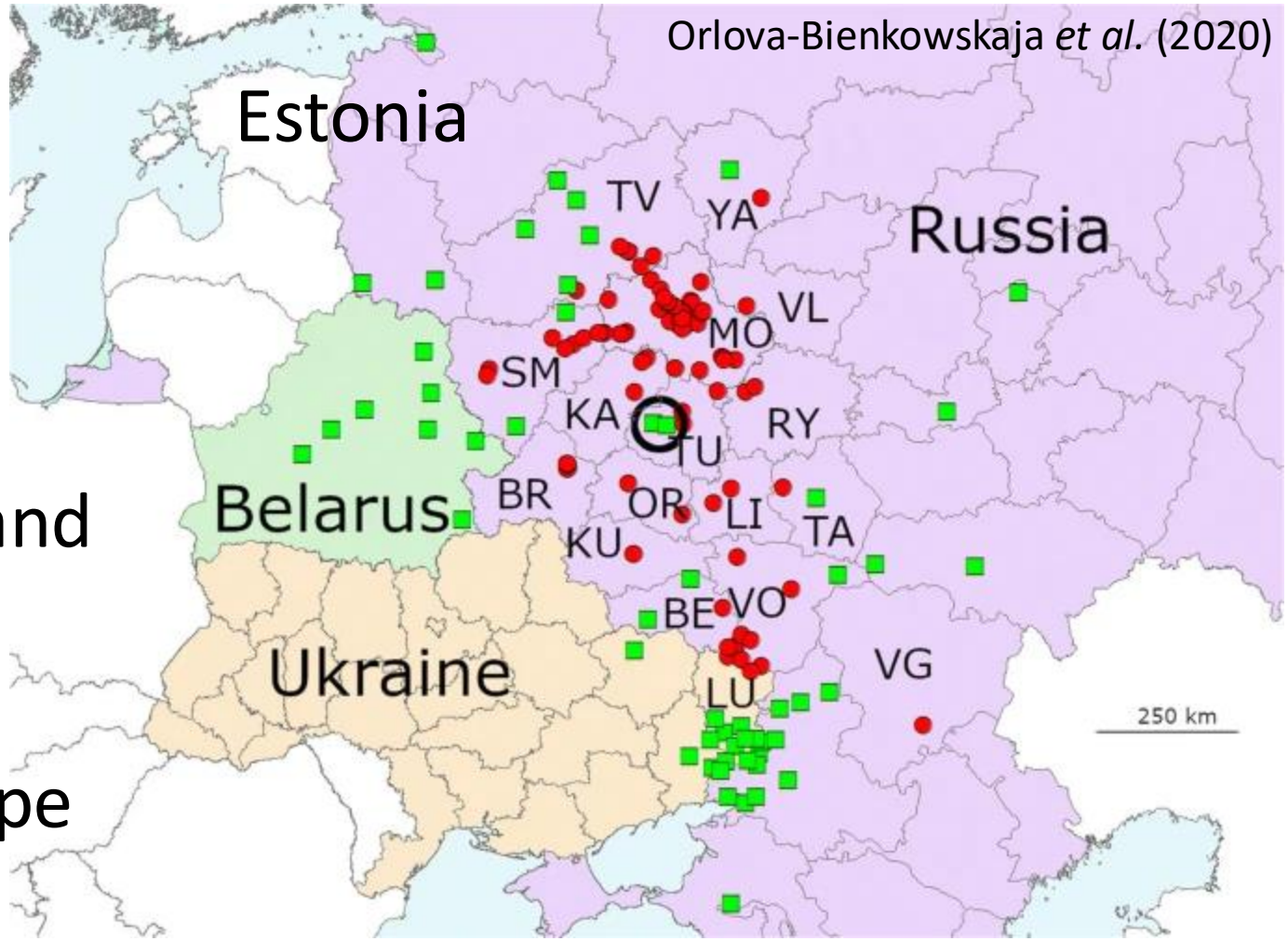
Where it is a particular state, contact resources in each state, regulations in each state, etc.)

Black Ash: A Foundational Wetland and Cultural Keystone Species

Learn about black ash ecology and the cultural signifigance of the species.

Spread of the Emerald Ash Borer

Source: Selikhovkin *et al.* (2022)

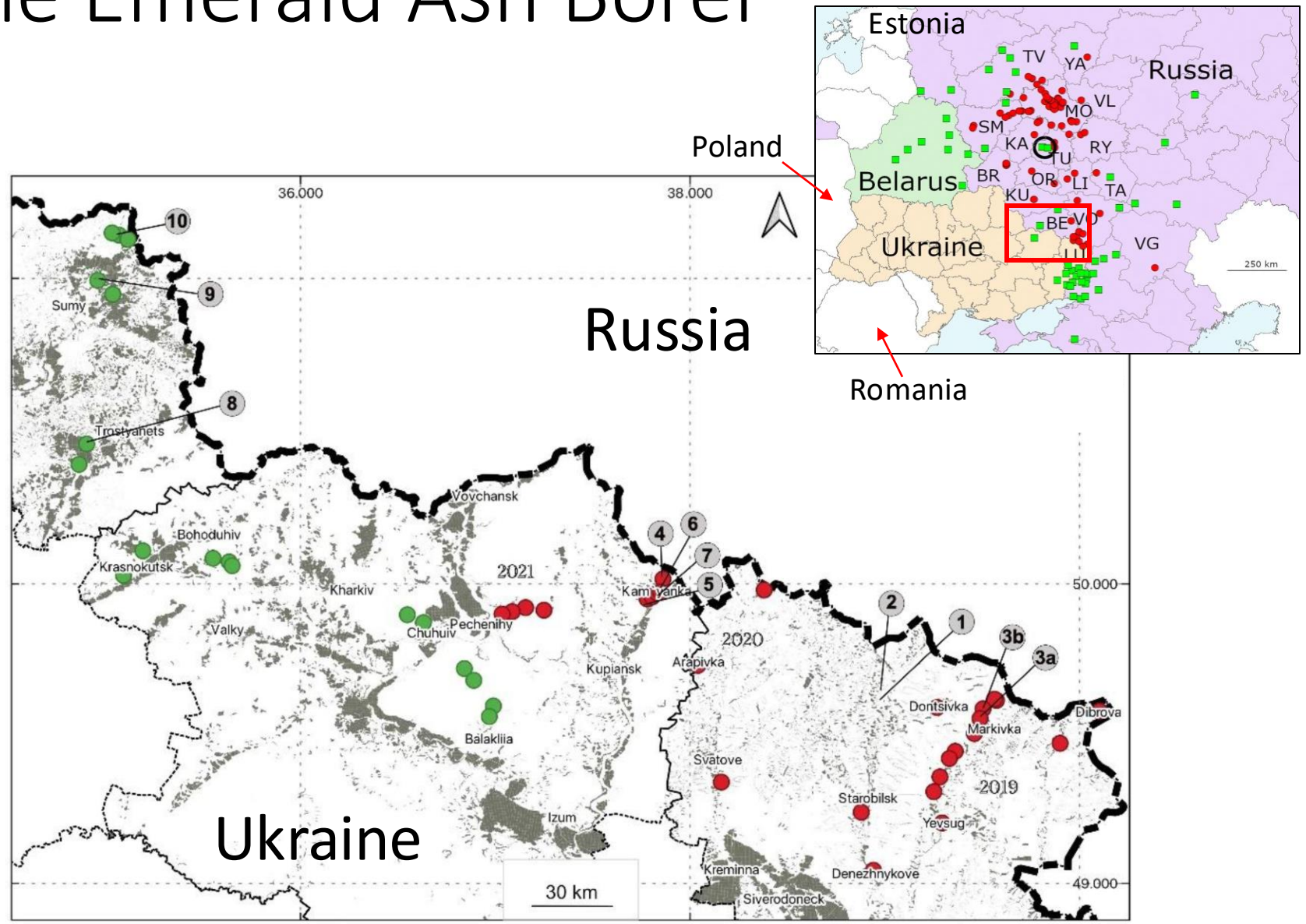


The red dots indicate the localities where the Emerald Ash Borer was detected.

Spread of the Emerald Ash Borer

Results from monitoring in 2021

The red dots indicate the localities where Emerald Ash Borer was detected **in Ukraine**.



Orlova-Bienkowskaja *et al.* (2020); Davydenko *et al.* (2022)

New Phytologist

Full paper | Open Access

A glimmer of hope – ash genotypes with increased resistance to ash dieback pathogen show cross-resistance to emerald ash borer

Martin M. Gossner, Anouchka Perret-Gentil, Elisabeth Britt, Valentin Queloz, Gaétan Glauser, Tim Ladd, Amanda D. Roe, Michelle Cleary, Mateusz Liziniewicz, Lene R. Nielsen ... See all authors

First published: 21 June 2023 | https://doi.org/10.1111/nph.19068 | Citations: 1


Source: M Kenis


Source: Christopher Asaro

- The ash genotypes with a higher ADB resistance also possess an increased resistance against EAB.
- These results are from Scandinavian and Swiss genotypes, with early and late instar larvae.

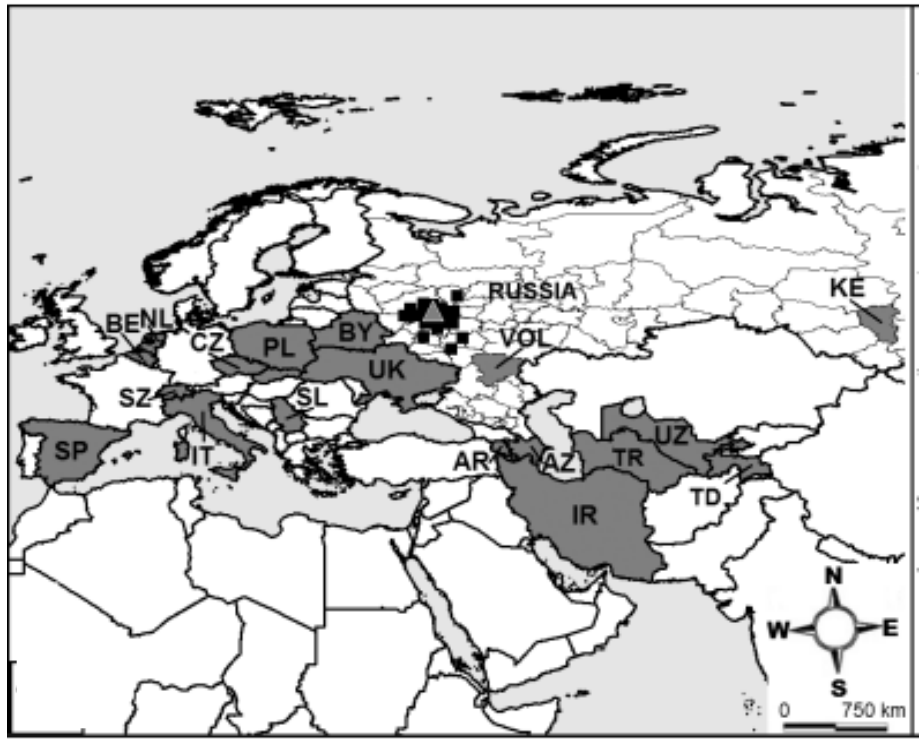
Biocontrol for Emerald Ash Borer?

There is a known parasitoid (*Spathius polonicus*) of Emerald Ash Borer

- Has successfully induced 50% mortality of Emerald Ash Borer larvae in Moscow

Musolini *et al.* (2017)

Spathius polonicus



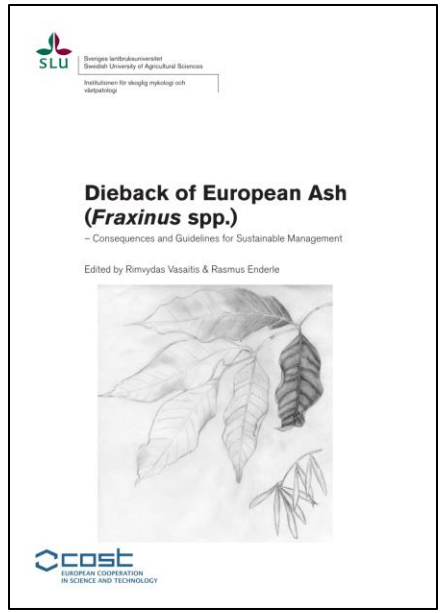
Orlova-Bienkowskaja *et al.* (2020)

Range of parasitoid (shaded areas)

Responses in research

BOKU BFW. Esche in Not

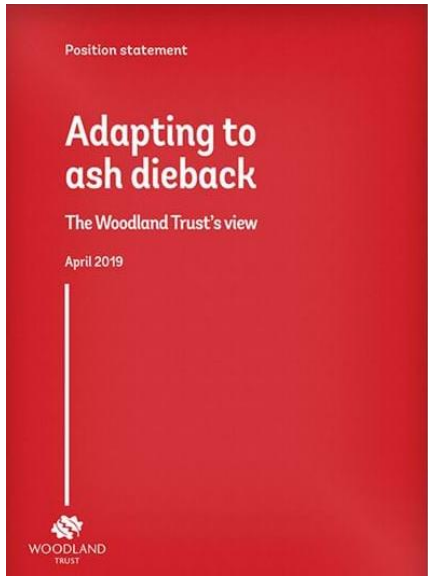
frax for future



LIVING ASH PROJECT

Royal Botanic Gardens Kew

THE ASH PROJECT



eagasc
AGRICULTURE AND FOOD DEVELOPMENT AUTHORITY

WSL

JKI

Responses in research

frax for future

- Demonstration project
- Intra-national cooperation
- Cross-disciplinary cooperation

fraxconnect — Jörg Grüner (FVA-BW)
- Network coordination
- Economic analyses

fraxgen — Ben Bubner (Thünen-Institut)
- Plus tree selection
- Genetic characterisation
- Vegetative propagation
- Resistance marker: application
- Resistance marker: development
- Genetic architecture
- Secondary metabolism and biomarkers

fraxmon — Ralf Kätzel (LFE)
- Biomarkers
- Resistance indicators
- Remote sensing: interpretation key
- Remote sensing: inventory design
- Remote sensing: modelling
- Hyperspectral imaging
- Terrestrial monitoring
- Histology

fraxpath — Gitta Langer (NW-FVA)
- Root collar necrosis: locational factors
- Root collar necrosis: histology
- Infection trials
- Fungi in the rhizosphere
- Pathogen-host interactions
- Secondary metabolites
- Hypovirulent viruses
- RNAi-mediated control
- Microbiota

fraxsilva — Ralf Nagel (NW-FVA)
- Stand dynamics
- Fundamentals in ecology

FraxVir — Susanne Jochner-Oette (KU Eichstätt)
- Remote sensing: spectral signature
- Virus diversity in ash
- Molecular monitoring
- Virus defence genes

Funding agencies:

Gefördert durch:
Bundesministerium für Ernährung und Landwirtschaft
Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit
aufgrund eines Beschlusses des Deutschen Bundestages

FNR Fachagentur Nachwachsende Rohstoffe e.V.

Waldklimafonds

Responses in research

frax for future

- Demonstration project
- International cooperation
- Cross-disciplinary cooperation

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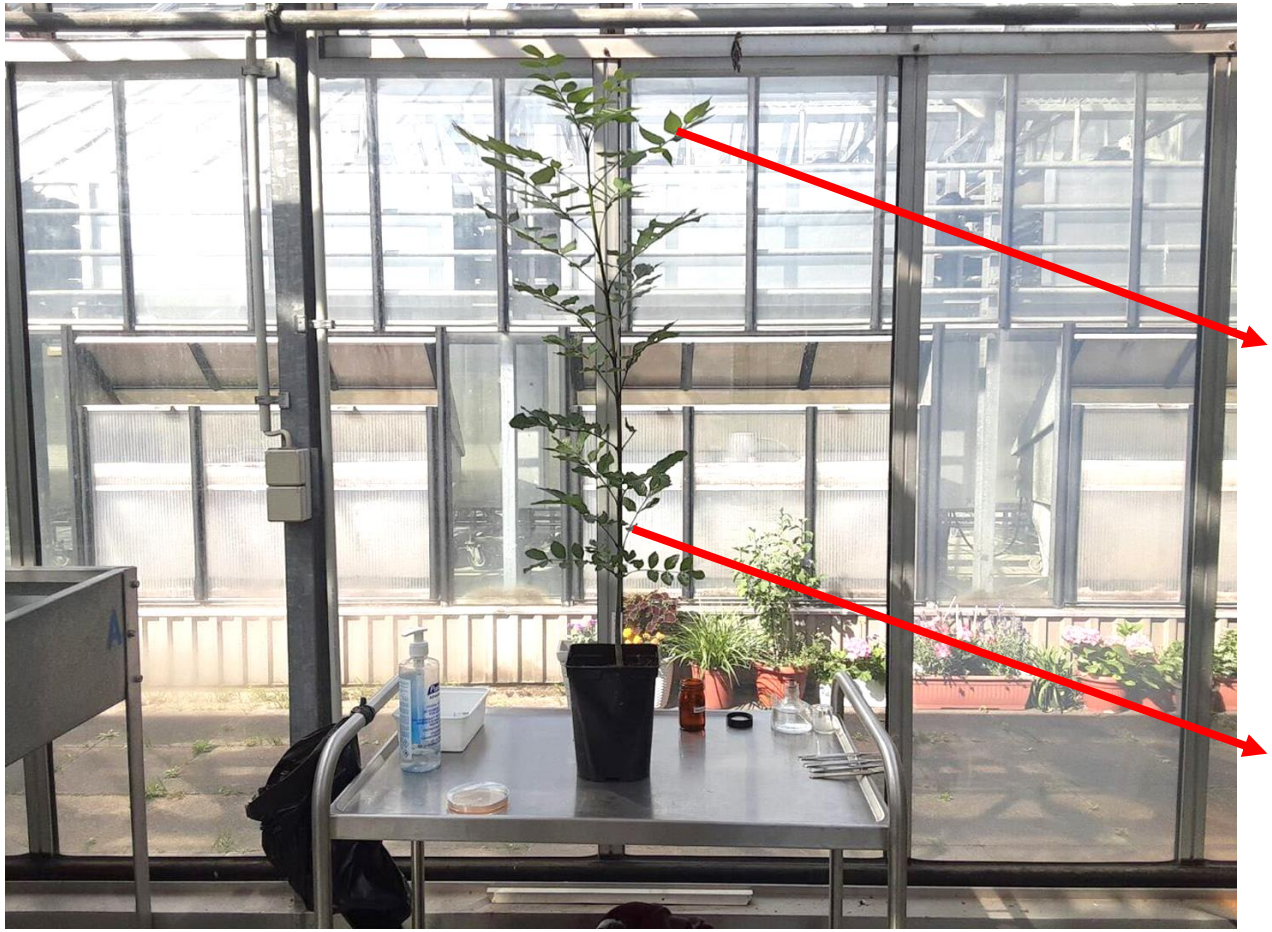
Waldklimafonds

Julius Kühn-Institut
Bundesforschungsinstitut für Kulturpflanzen
Federal Research Centre for Cultivated Plants

Infection trials with *H. fraxineus*



Infection trials with *H. fraxineus*

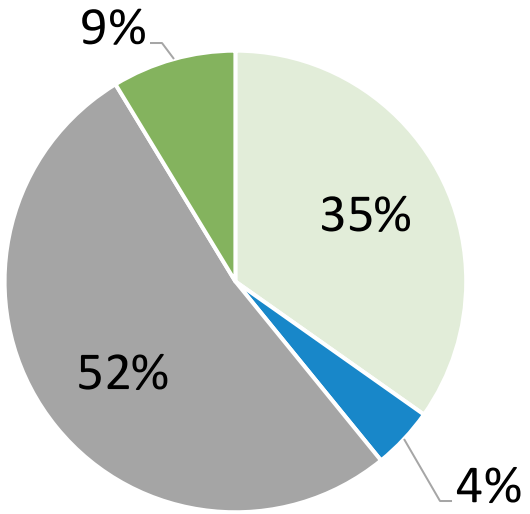
Symptom development in infected saplings *e.g.* wilting

Viruses

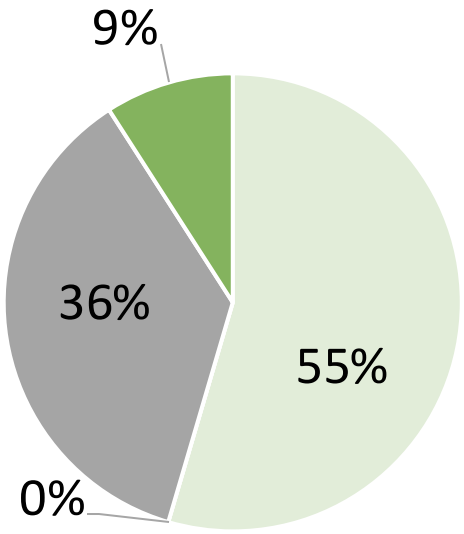
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

frax for future

HfMV1 positive



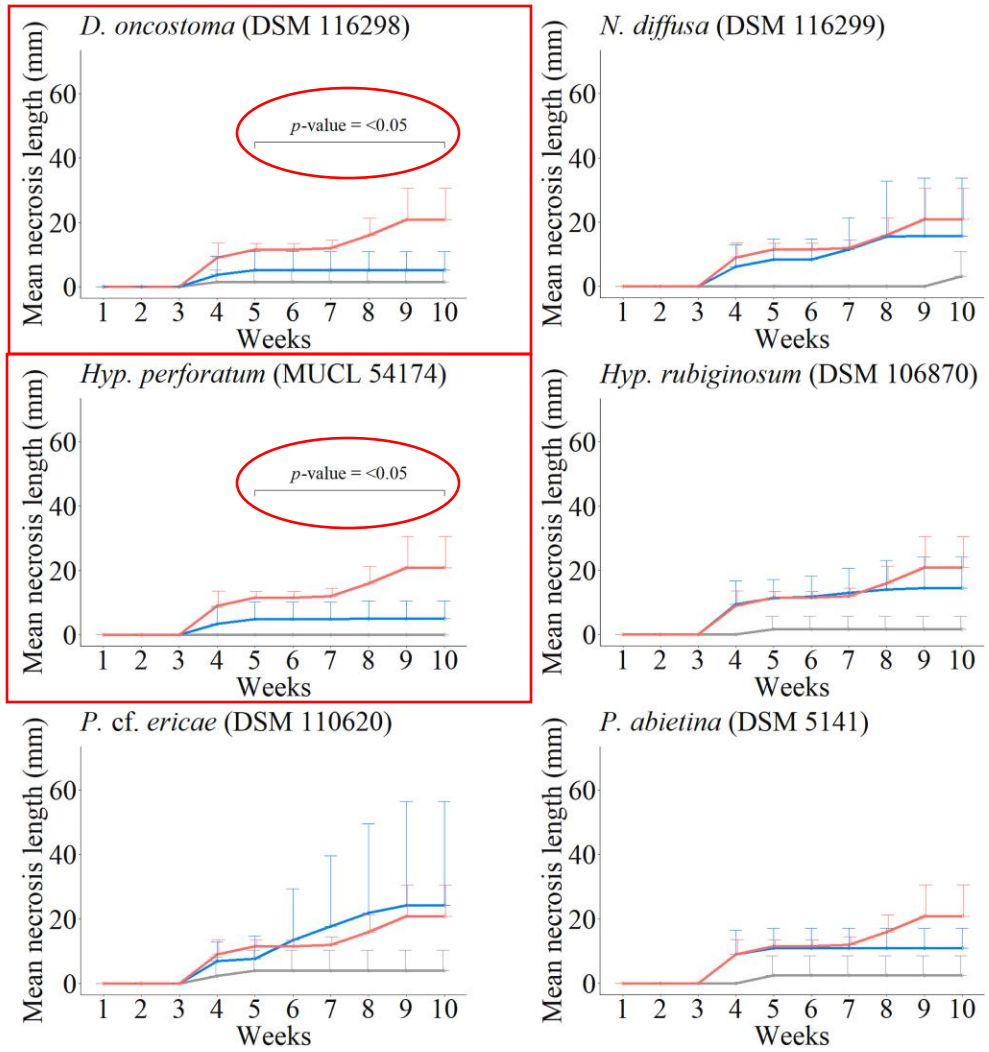
HfMV1 negative



not virulent
mid virulence
low virulence
high virulence

- Mycoviruses: HfMV1 and HaVV1
- HfMV1 showed no signs of causing hypovirulence (Lutz et al. 2024)
- HaVV1 still needs to be tested

Endophytes

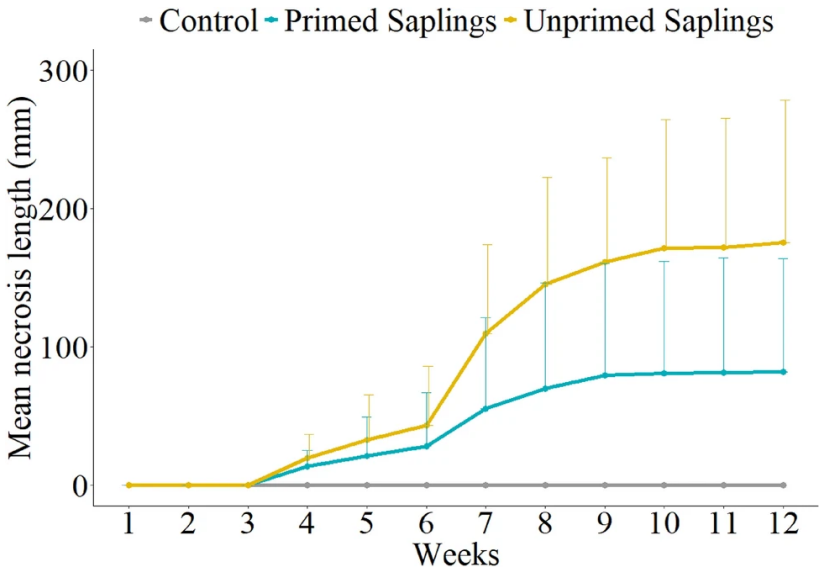


- Six fungal endophytes were selected
- Two significantly reduced necrosis length under greenhouse conditions
- More tests needed, including field trials and assessment of synergies

Priming

The primed state can be described as:

"an **augmented activated defence response** towards a pathogen" Ridley *et al.* (2025)



- Priming is an established method in agriculture
- On average, necrosis expansion was reduced by 53% in primed saplings
- More studies necessary, including to assess the long-term effectiveness

Responses in research

FraxForFuture
2020-2024

FraxForFuture 2
2025-2028

Conclusion

- European ash is threatened by *H. fraxineus*
  - ➢ socio-culturally and economically impacts

- There are many factors that can increase susceptibility
- Forest management and tree breeding can reduce losses and damages

- However, we must prevent future introductions of the fungus
- We must also be aware of climate change impacts and novel threats *e.g.* EAB

Langer *et al.* (2022)

Lewis White

Rasmus Enderle

References for further reading

- Ridley *et al.* (2025) Fungal endophytes with anti-fungal metabolites reduce symptoms of ash dieback in *Fraxinus excelsior* in a greenhouse experiment. DOI: https://10.1016/j.funbio.2025.101646
- Ridley *et al.* (2025) Priming of ash saplings with a low virulent *Hymenoscyphus fraxineus* strain as a possible disease control approach for reducing symptoms of ash dieback. DOI: https://10.1007/s41348-024-01056-z
- Lutz *et al.* (2024) Identification of viruses for biocontrol of the ash dieback disease. DOI: https://10.1007/s41348-023-00804-x
- Langer *et al.* (2022) FraxForFuture—research on European ash dieback in Germany. DOI: https://doi.org/10.1007/s41348-022-00670-z
- Marcais et al. (2022) Chapter 13 - Ash dieback. Volume 2 : Forest Tree Health. DOI: https://doi.org/10.1016/B978-0-323-85042-1.00022-7
- Vasaitis & Enderle (ed.) (2017) Dieback of European Ash (Fraxinus spp.) – Consequences and Guidelines for Sustainable Management
- Enderle & Vasaitis (ed.) (2017) Advances in Ash Dieback Research, And Some Other Invasive Diseases Of Trees
- Gross *et al.* (2013) *Hymenoscyphus pseudoalbidus*, the causal agent of European ash dieback. DOI: https://doi.org/10.1111/mpp.12073