Widespread *Phytophthora* infestations of nursery stock in Central Europe as major pathway of Phytophthora diseases of forests and semi-natural ecosystems

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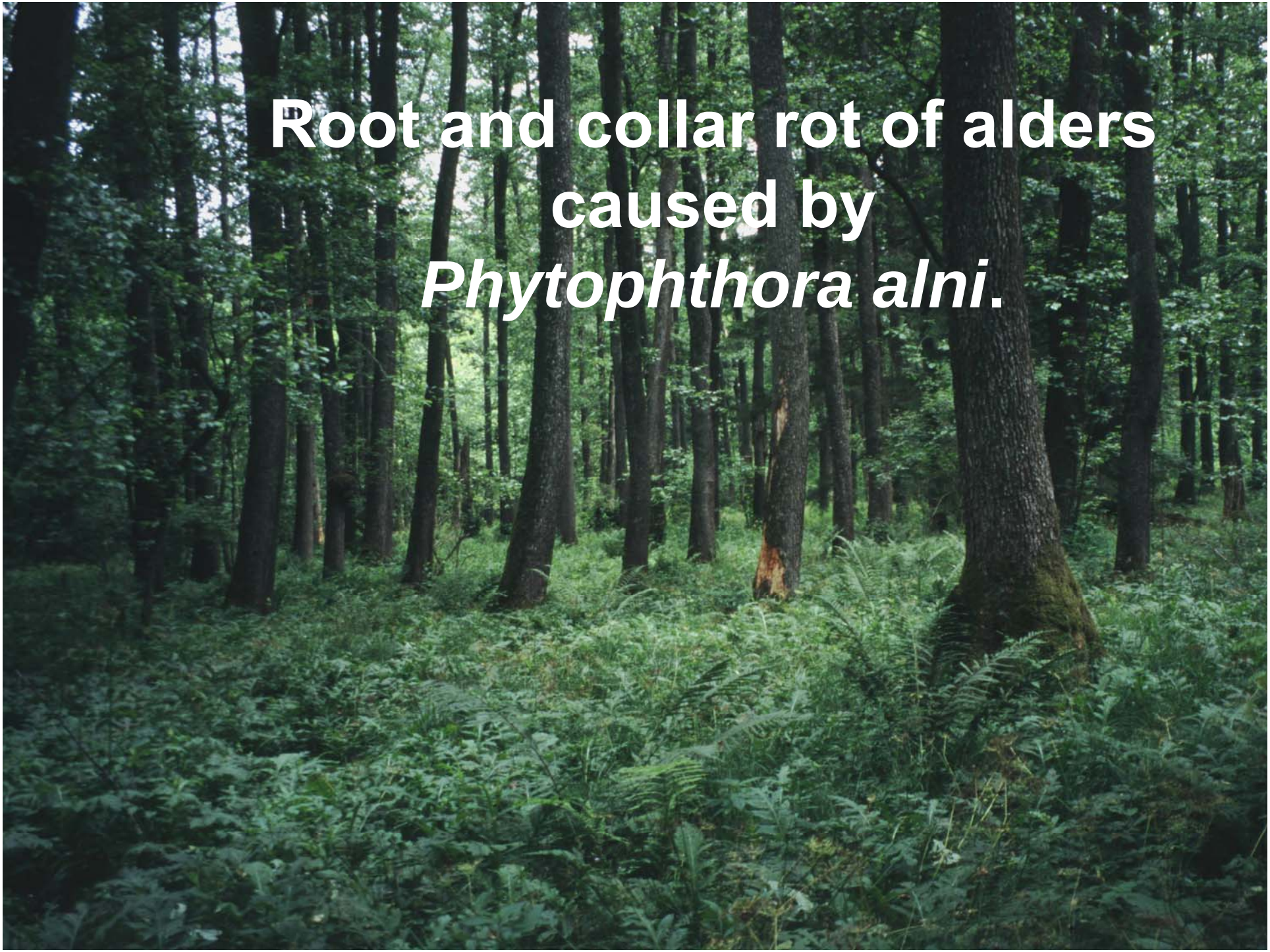
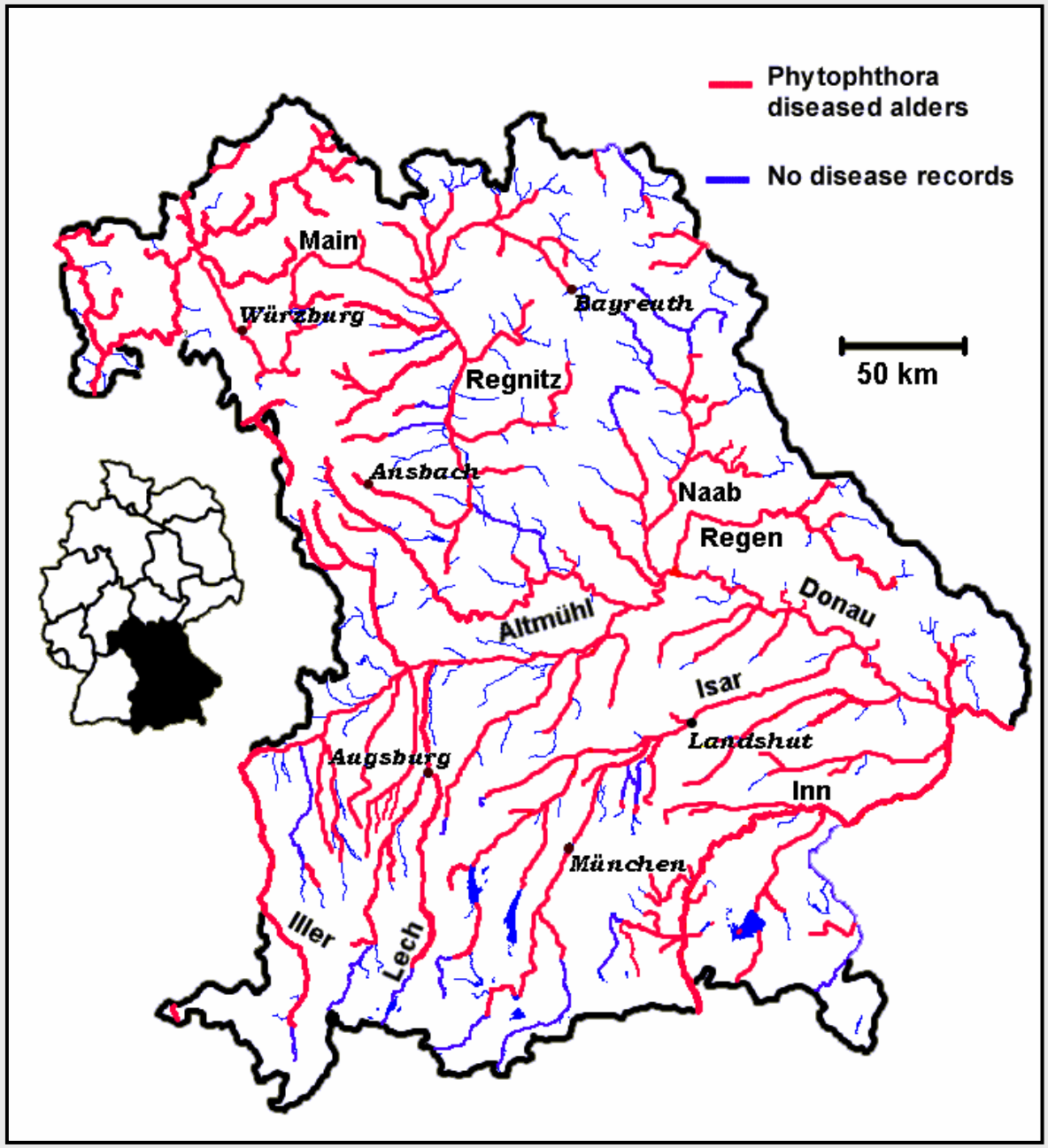

Root and collar rot of alders
caused by
Phytophthora alni.

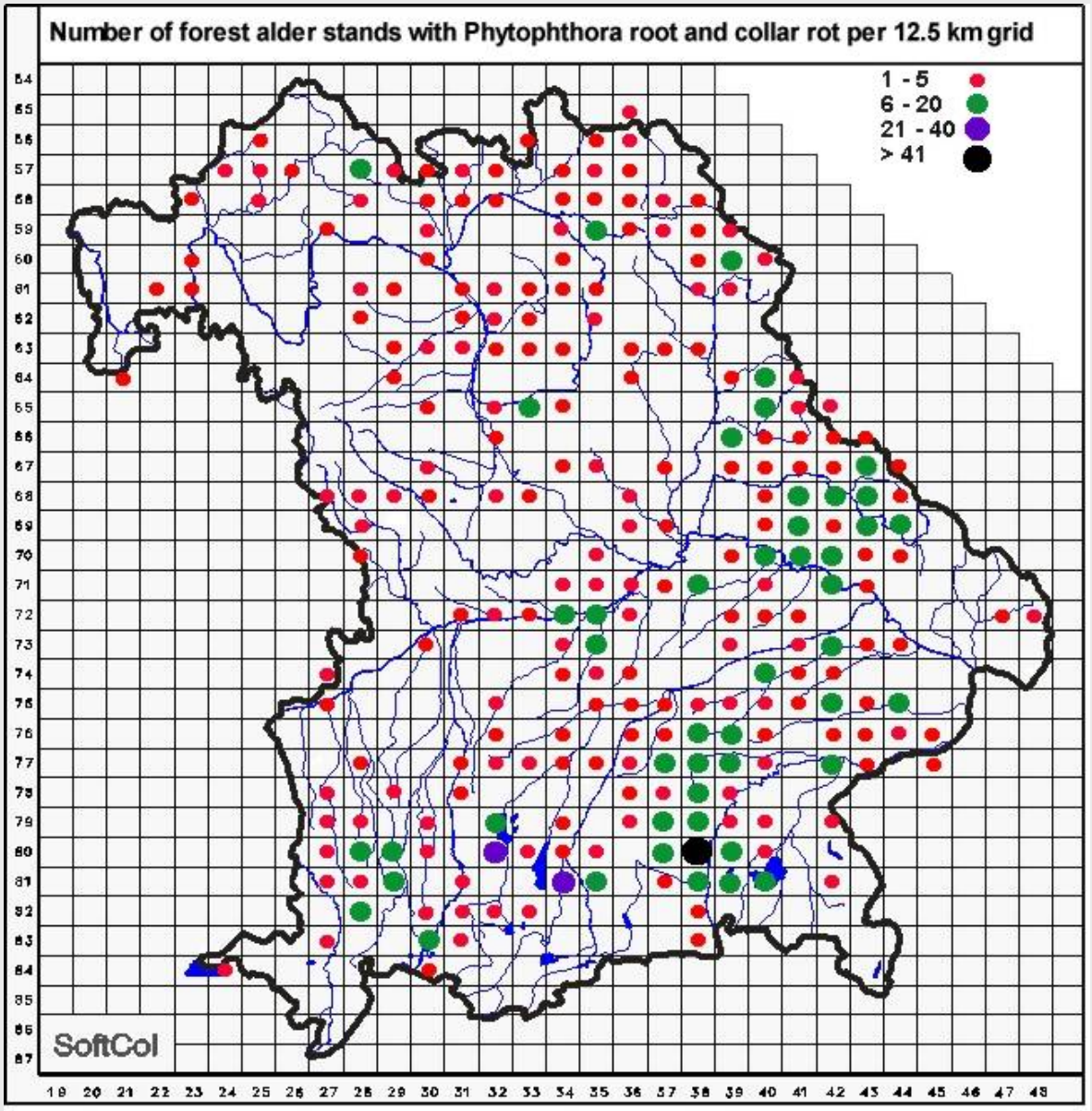
Mature common alders (*Alnus glutinosa*).

Grey alder *A. incana* with collar rot caused by *P. alni*.

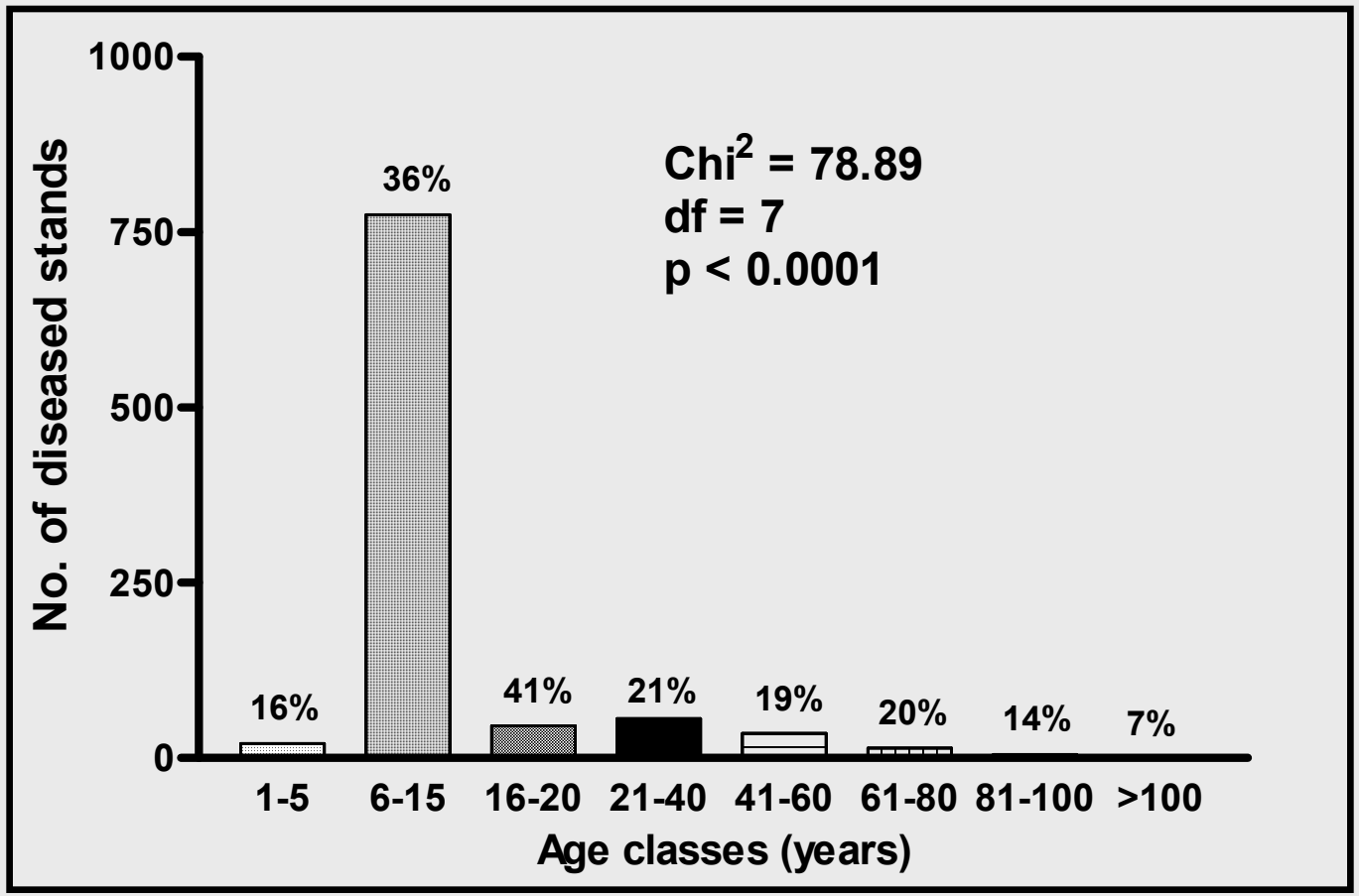


Occurrence of *P. alni* root and collar rot of alders along main rivers in Bavaria.

Distribution of *P. alni* infested forest stands in Bavaria.

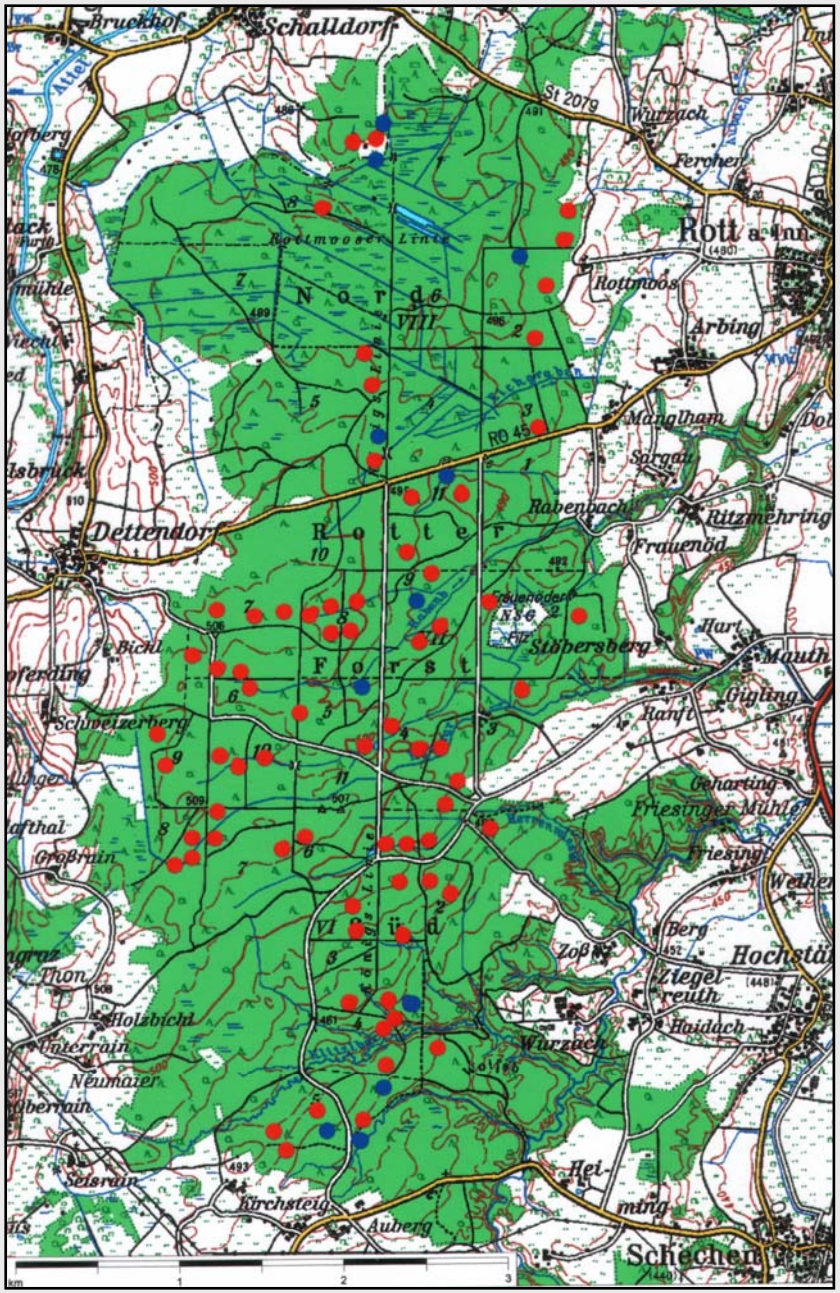


Number and proportion of diseased forest alder stands in different age classes in Bavaria.



46 % of stands <21 years were growing on non-flooded sites and 92 % of them were planted!

***P. alni* infected plantation**
on former agricultural land.



Introduction and spread of *P. alni* in the common alder forest ‘Rotter Forst‘.

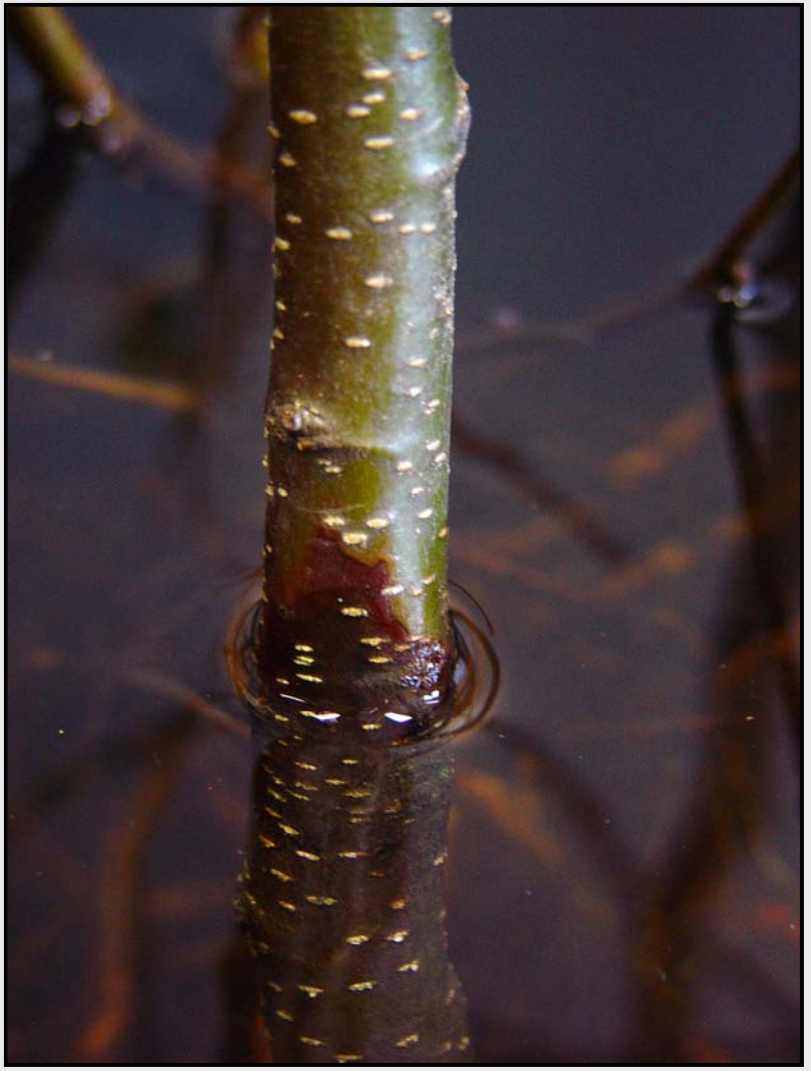
Correlation between the use of infested nursery stock in catchments and the dieback of riparian alder stands.

	No. of rivers with alder dieback	No. of rivers without alder dieback	Total
Occurrence of infested plantations in the catchment	58	0	58
Absence of infested plantations in the catchment	2	25	27
Total	60	25	85

Relative risk = 13.5;
95% - confidence interval: 3.556 – 51.24;
Fishers exact test: p <0.0001

Sampling of alder seedlings from a nursery field.

Baiting procedure.



Development of root and collar rot in visibly healthy alder plants from nurseries in Bavaria and Brandenburg after artificial flooding.

Phytophthora infestations of alder fields in Bavarian nurseries

	Alder species [1]	*Phytophthora* – species [2]									
		PAA	PAA x CAM	CAM	MEG	CAC	CIT	GON	QUE	PSEU	P. chlam.
	Nurseries buying in plants for resale and using river water										
Nursery 1	GLU	X									
Nursery 2	GLU		X	X	X		X	X			X
	INC	X		X	-		X	X			X
	VIR			X			X				
Nursery 3	GLU				X		X	X			X
Nursery 4	GLU	X		X				X			X
	Nurseries growing alder plants from seeds and using well or tap water										
Nursery 5	GLU				X	X	X				
Nursery 6	GLU								X		
Nursery 7	GLU			X	X	X	X				
Nursery 8	GLU					X	X			X	

[1] GLU = *Alnus glutinosa*, INC = *A. incana*, VIR = *A. viridis*.

[2] PAA = *P. alni* ssp. *alni*, PAA x CAM = putative backcrosses between *P. alni* ssp. *alni* and *P. cambivora* (according to ITS data), CAM = *P. cambivora*, MEG = *P. megasperma*, CAC = *P. cactorum*, CIT = *P. citricola*, GON = *P. gonapodyides*, QUE = *P. quercina*, PSEU = *P. pseudosyringae*, P. chlam. = 'P. taxon Pgchlamydo'.

Phytophthora infestations of alder fields in Eastern German nurseries

	Phytophthora species [1] and irrigation water			
	2003		2004 Only well water	2005 Only well water
Nursery 1	Well water	-	GON	-
Nursery 2	Not tested		Not tested	-
Nursery 3	River water	PAA	Not tested	Not tested
Nursery 4	River water	PAA	-	Not tested
Nursery 5	River water	PAA PAU CAM	CAM	CAM SYR
Nursery 6	Not tested		-	-
Nursery 7	River water	-	Not tested	Not tested
Nursery 8	Well water [2]	PAA	-	-
Nursery 9	Well water	PAA	Not tested	Not tested
Nursery 10	Well water	-	Not tested	Not tested
Nursery 11	Lake water	-	-	CAC
Nursery 12	Not tested		CAM	CAM
Nursery 13	Not tested		-	Not tested
Nursery 14	Well water	-	-	-

[1] PAA = *P. alni* ssp. *alni* (standard variant), PAU = *P. alni* ssp. *uniformis* (Swedish variant), CAM = *P. cambivora*, CAC = *P. cactorum*, GON = *P. gonapodyides*, SYR = *P. syringae*.


European oak decline

Healthy *Quercus robur*
with dense vigorous crown.

Declining *Quercus robur* with severe crown dieback.

Declining stand of *Quercus robur*.

Stand of *Quercus petraea* with high mortality.

Healthy and destroyed fine root systems of mature *Quercus robur* trees.

Necrotic lesions and dieback of *Quercus robur* coarse roots.

Occurrence of soilborne *Phytophthora* species in oak stands in Europe and Turkey

	No. of stands	Year	No. of stands with *Phytophthora* [1]								
			Total	QUE	CAM	CIT	CAC	CIN	GON	PSEU	P. spp.
Germany	21	1994-1996	19	5	4	14	1		3	1	
South	35	1997-1999	19	18	7	7	2		3	2	5
Germany	15	1995-2000	10	9		2					
North / East	47	2000-2002	22	11	6	1	1				11
	7	2006	5	5							
Austria	35	1999-2001	17	11		7			2		4
Switzerland	4	1995-2005	4			3		1			1
France	24	1995-1996	7					7			
	60	1998-2000	31	13	3	11			6	6	14
UK	20	1998-1999	12	8	2	3			5		1
Sweden	27	2000-2002	11	10	1		1				
Spain/Portugal	9	1991-1992	6					6			4
Spain	9	1994-1995	6					6			
Spain	3	1998-1999	3					3			1
Portugal	1	2006	1	1				1			
Italy	5	1995	4	3		1					
	30	1998-2000	19	6	4	10	4	4	2		5
Poland	3	2000-2003	2					1			1
Hungary	3	1995	3	1		2					
Slovenia	1	1995	1			1					
Serbia	6	2003	6	6		2					
Turkey	51	1999-2001	38	29		4		1	2		9
Total	416		256	136	27	68	9	30	23	9	56
Proportion			62 %	33 %	7 %	16 %	2 %	7 %	6 %	2 %	14 %

[1] QUE = *P. quercina*, CAM = *P. cambivora*, CIT = *P. citricola*, CAC = *P. cactorum*, GON = *P. gonapodyides*, PSEU = *P. pseudosyringae*, P. spp. = *P. cryptogea*, *P. gallica*, *P. europaea*, *P. megasperma*, *P. syringae*, *P. psychrophila*, *P. uliginosa* , and unknown *Phytophthora* taxa.

Phytophthora – infestation of oak fields of German nurseries.

	Year	*Phytophthora* – species [1]						
		QUE	CIT	CAC	CRY	MEG	PSEU	P. spp.
Nursery 1	1998	X						
Nursery 2	1999	X	X		X			X
	2000	X						
Nursery 3	2000	X						
Nursery 4	2002	X	X	X		X		
Nursery 5	2004	X		X				
Nursery 6	2006		X	X				
Nursery 7	2007	X	X				X	
	2007		X					
Nursery 8	2007							
	2007			X				
Infested nurseries		75%	50%	50%	13%	13%	13%	13%

[1] CAM = *P. cambivora*, CIT = *P. citricola*, CAC = *P. cactorum*, GON = *P. gonapodyides*, MEG = *P. megasperma*, QUE = *P. quercina*, PSEU = *P. pseudosyringae*, P. sp. = unknown heterothallic *Phytophthora* species.

Phytophthora infestation of oak plantations in Germany, Luxembourg and Switzerland

	Age	Year	*Phytophthora* – species [1]						
			QUE	CAM	CIT	CAC	CRY	MEG	P. sp.
Plantation 1	8 (6)	1995			X				
Plantation 2 [2]	10 (1)	1999	X		X		X		X
Plantation 3	10 (1)	2000	X						
Plantation 4	8-15 (3-7)	2002	X		X	X		X	
Plantation 5 [3]	15 (2)	2003			X			X	
Plantation 6	15 (13)	2007							
Plantation 7	8 (6)	2007							
Plantation 8	8 (6)	2007							
Plantation 9	8 (6)	2007	X	X				X	
Plantation 10	7 (5)	2007	X						
Infested plantations			50%	10%	40%	10%	10%	30%	10%

[1] CAM = *P. cambivora*, CIT = *P. citricola*, CAC = *P. cactorum*, GON = *P. gonapodyides*, MEG = *P. megasperma*, QUE = *P. quercina*, P. sp. = unknown heterothallic *Phytophthora* species.

[2] Plantation near Zurich, Switzerland.

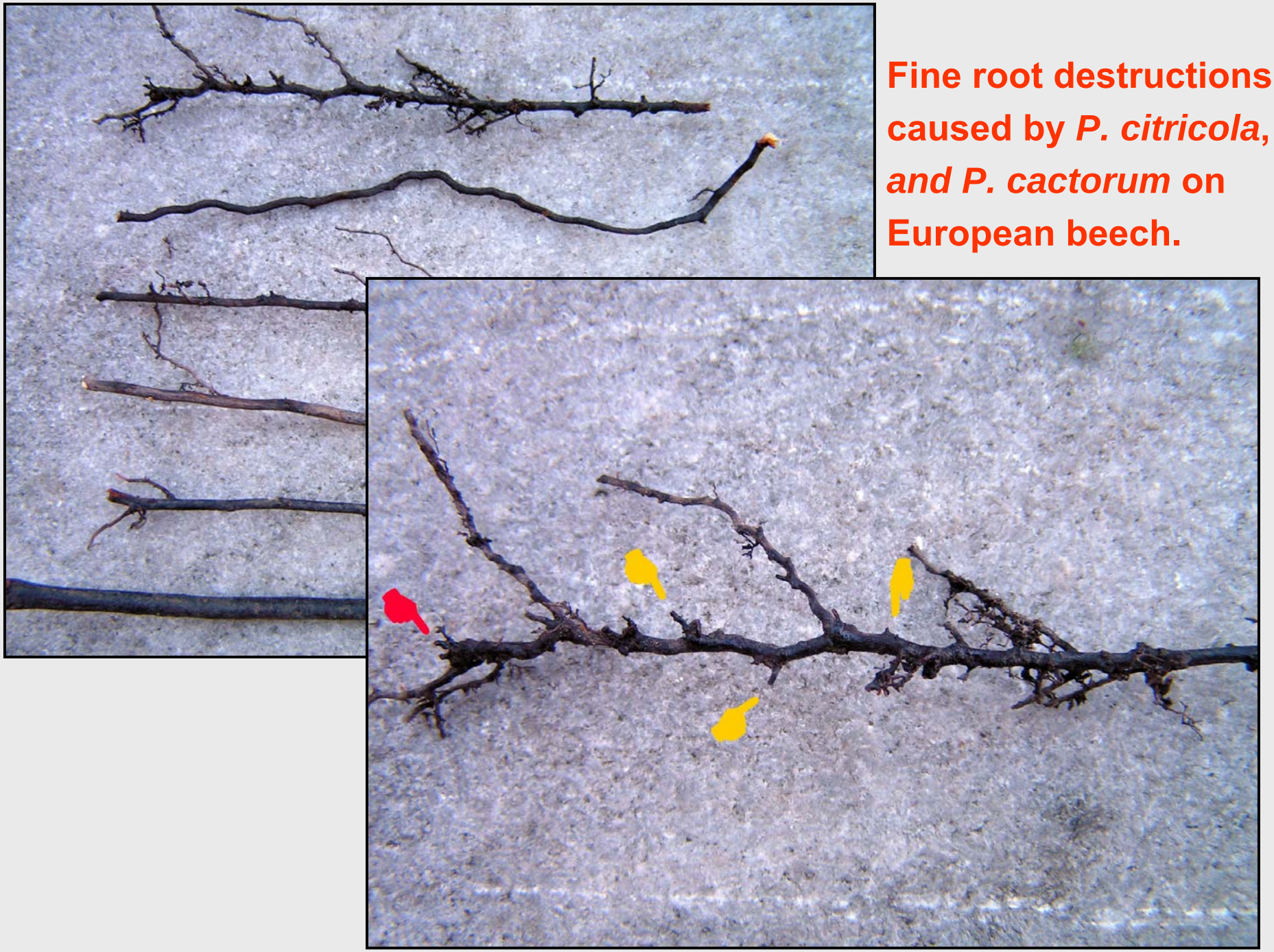
[3] Plantation in Luxembourg.

Dieback and yellowing of a 10 year old *Quercus robur* in a forest plantation due to fine root losses caused by *P. citricola*.

Dieback and yellowing of planted *Quercus robur* in a park due to fine root losses caused by *P. citricola*.


Decline
of European beech

Dieback of mature beech forest caused by *P. cambivora*.



Fine root destructions caused by *P. citricola*, *and P. cactorum* on European beech.

Collar rot and aerial bleeding cankers of beech caused by *P. cambivora*.

Phytophthora species in declining beech stands in Bavaria.

Geological substrate	No. of stands (trees)	Infected stands (trees)	No. of trees with [1] CAM	CIT	CAC	GON	P. spp.
Limestone	**23** (57)	**21** (38)	**5** (7)	**17** (26)	**3** (3)	**2** (2)	
Flysch	**6** (16)	**5** (11)	**3** (4)	**5** (7)			
Granite	**2** (2)	**2** (2)				**1** (1)	**1** (1)
Conglomerate	**1** (1)	**1** (1)		**1** (1)			
Moraine Young	**20** (51)	**20** (45)	**12** (15)	**12** (24)	**2** (2)	**3** (4)	**4** (5)
Sediments: Old	**4** (12)	**4** (9)	**4** (8)	**1** (2)			
Moraine gravels	**10** (31)	**10** (28)	**1** (1)	**8** (14)	**3** (10)	**3** (4)	**2** (3)
Alluvial deposits	**10** (51)	**10** (51)		**10** (28)	**7** (36)		**5** (16)
Tertiary deposits	**20** (44)	**15** (35)	**5** (16)	**9** (16)	**5** (10)	**1** (2)	
Loess	**2** (7)	**2** (3)	**1** (1)	**2** (2)			
Claystone	**3** (9)	**3** (8)	**3** (7)	**1** (2)			
Gypsum	**4** (16)	**4** (13)	**3** (9)	**1** (3)	**1** (1)		**1** (1)
Mylonite	**1** (2)	**1** (1)	**1** (1)				
Sandstone	**6** (15)	**6** (8)	**5** (5)	**2** (2)			**1** (1)
Total: stands	**112**	**104 (93%)**	**43 (38%)**	**69 (62%)**	**21 (19%)**	**10 (9 %)**	**14 (13%)**
trees	**314**	**253 (81%)**	**74 (24%)**	**127 (41%)**	**62 (20%)**	**13 (4%)**	**27 (9%)**

[1] **CAM = *P. cambivora*, CIT = *P. citricola*, CAC = *P. cactorum*, GON = *P. gonapodyides*, P. spp. = *P. pseudosyringae*, *P. syringae*, *Phytophthora* taxon 'P. g. chlamydo', *P. uliginosa* and unknown *Phytophthora* species.**

Occurrence of *Phytophthora* species in beech fields of forest and horticultural nurseries in Bavaria.

	Year	*Phytophthora* – species [1]							
		CAM	CIT	CAC	GON	MEG	QUE	PSEU	P. sp.
Nursery 1	2002	X	X		X	X			
Nursery 2	2003	X							X
	2003	X		X					
Nursery 3	2002	X							
	2003		X	X					
Nursery 4	2003		X	X					
	2003			X			X		
Nursery 5	2001		X	X				X	
Nursery 6	2004	X	X	X		X			
Nursery 7	2001			X					
Nursery 8	2005		X	X					
Nursery 9	2007	X							
Infested nurseries		56%	67%	78%	11%	11%	11%	11%	11%

[1] CAM = *P. cambivora*, CIT = *P. citricola*, CAC = *P. cactorum*, GON = *P. gonapodyides*, MEG = *P. megasperma*, QUE = *P. quercina*, PSEU = *P. pseudosyringae*, P. sp. = unknown heterothallic *Phytophthora* species.

Occurrence of *Phytophthora* species in beech fields of forest nurseries in Lower-Saxony.

	Year	*Phytophthora* species [1]				
		CAM	CIT	CAC	GON	PSEU
Nursery 1	2003	X	X			
Nursery 2	2003	X	X	X		
Nursery 3	2003				X	
Nursery 4	2003			X		
Nursery 5	2003					X
Nursery 6	2003					
Infested nurseries		33%	33%	33%	17%	17%

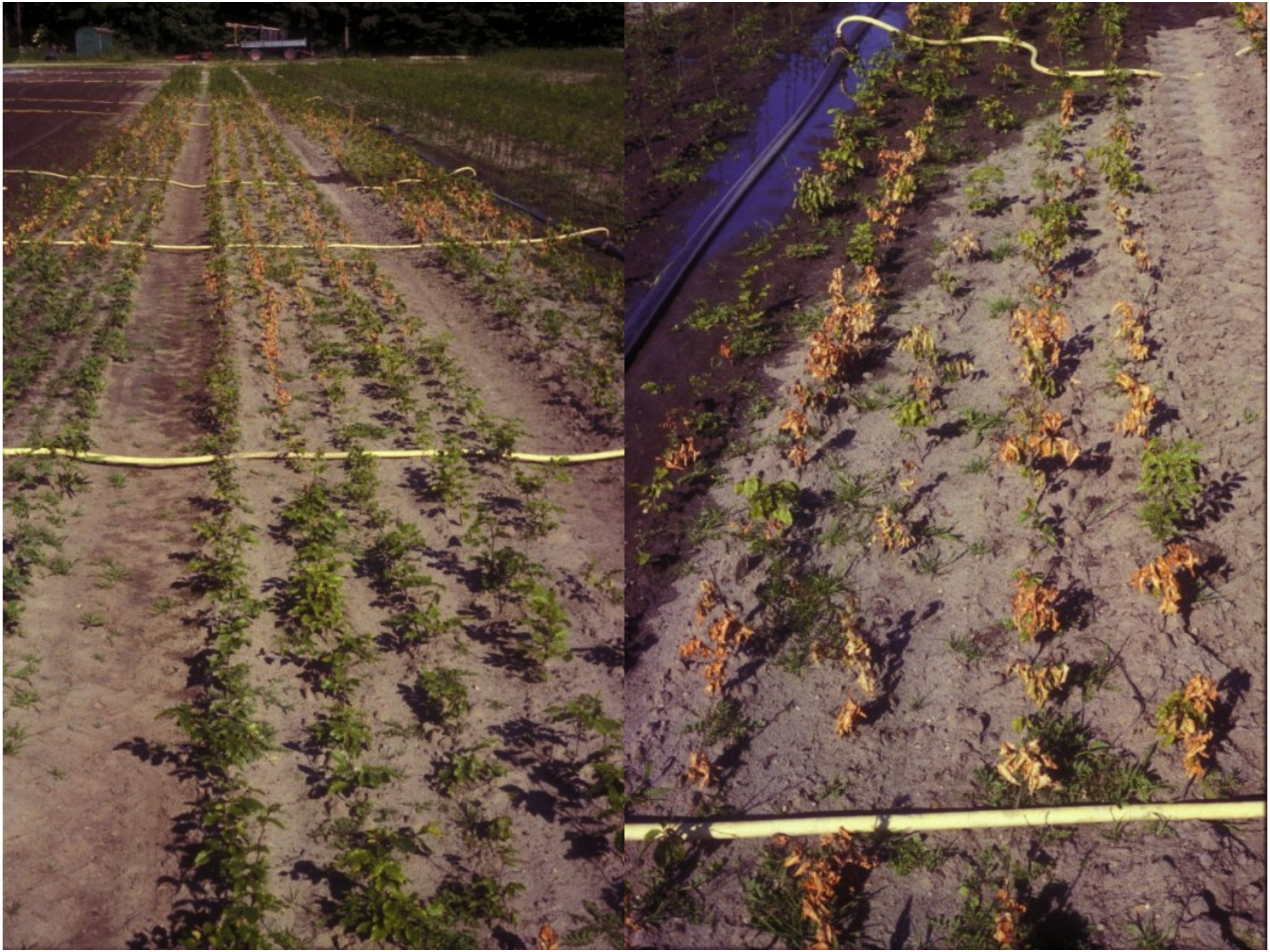
[1] CAM = *P. cambivora*, CIT = *P. citricola*, CAC = *P. cactorum*, GON = *P. gonapodyides*, PSEU = *P. pseudosyringae*.

Occurrence of *Phytophthora* species in fields of forest and horticultural nurseries in Northern Germany (2003-2007).

	Tree and shrub species [1]	No. of samples	% of samples with *Phytophthora* [2]			
			CAM	CAC	GON	SYR
Nursery 1	Qu, Fa, C-mix	3				33
Nursery 2	Ac, B-mix, C-mix	3				
Nursery 3	Qu, Fa, Al, Ac, B-mix	5		20		
Nursery 4	Ac, C-mix	2				50
Nursery 5	C-mix, B-mix	2	50	50		50
Nursery 6	Qu, Fa, Al, Pin, Pseu	5	20			
Nursery 7	Vib, C-mix, B-mix	3		67		
Nursery 8	C-mix, S-mix, Pru	3				
Nursery 9	Qu, Fa, C-mix	3				
Nursery 10	B-mix	2				
Nursery 11	S-mix	3	33			
Nursery 12	Al, Be, Fra, Pic	4			25	
Infested nurseries		38	25 %	25 %	8 %	25 %

[1] Ac = *Acer*, Al = *Alnus*, Be = *Betula*, Fa = *Fagus*, Fra = *Fraxinus*, Pic = *Picea*, Pin = *Pinus*, Pru = *Prunus*, Pseu = *Pseudotsuga*, Qu = *Quercus*, Vib = *Viburnum*, B-mix, C-mix and S-mix = mixtures of broadleaved trees, conifers and shrubs.

[2] CAM = *P. cambivora*, CAC = *P. cactorum*, GON = *P. gonapodyides*, SYR = *P. syringae*.



Disease incidences in five 8-15 year old plantations of beech, oak, maple, cherry, hornbeam, lime and ash on former agricultural land in Northern Germany

In total 2338 trees	
Fagus sylvatica	74%
Acer pseudoplatanus	54%
Prunus avium	4%
Quercus robur	0%
Carpinus betulus	0%
Tilia cordata	0%
Fraxinus excelsior	0%

Root and collar rot of planted beech trees in Northern Germany caused by *P. cambivora*.

Dieback of linden trees in Germany and Switzerland

Causal agents

P. citricola
P. cactorum
P. cambivora
P. gonapodyides
P. syringae

Dieback of maple trees in Germany

Causal agents

P. citricola
P. cactorum
P. gonapodyides
P. syringae

Phytophthora infestation of nursery fields and plantations of linden and maple trees in Germany

	Year	Tree species	No. of trees		*Phytophthora* – species [1]						
			total	infected	CAC	CAM	CIT	GON	PSEU	PSY	SYR
Nursery 1	2005	*Tilia* sp.	2	2	2				2	2	
Nursery 2	2006	*T. europaea*	16	16				16			4
Nursery 3	2007	*Tilia* sp.	4	4			4				4
Nursery 4	2007	*T. europaea*	8	6	2	3	2	1			
Nursery 5	2007	*Tilia* sp.	4	4			4	4			
Nursery 6	2007	*Acer platanoides*	5	5	5		5	2			
		A. pseudoplatanus	3	3			3				
Σ nurseries			42	40	9	3	18	23	2	2	8
Plantation 1	2005	*T. cordata*	1	1	1						
Plantation 2	2006	*T. cordata*	2	2	2						
Plantation 3	2006	*T. europaea*	3	3	3						
Plantation 4	2006	*T. cordata*	30	30	30	15	15	10			
Plantation 5	2006	*T. cordata*	3	3		3					
Plantation 6	2006	*T. cordata*	3	3			3				
Plantation 7	2006	*T. cordata*	2	2	2		2				
Plantation 8	2006	*A. pseudoplatanus*	7	5		2	4	1			
Plantation 9	2007	*A. platanoides*	1	1							1
		A. pseudoplatanus	1	1			1				
Plantation 10	2007	*A. campestre*	3	3			3				
Plantation 11	2007	*A. platanoides*	4	4			2	2			
Plantation 12	2008	*A. platanoides*	3	3			3				
Plantation 13	2008	*T. cordata*	1	1	1						
Σ Plantations			64	62	39	20	33	13			1

[1] CAC = *P. cactorum*, CAM = *P. cambivora*, CIT = *P. citricola*, GON = *P. gonapodyides*, PSEU = *P. pseudosyringae*, PSY = *P. psychrophila*, SYR = *P. syringae*.

Decline and dieback of planted young linden tree caused by *P. citricola* and *P. syringae*.

Dieback and mortality of planted young maple trees caused by *Phytophthora citricola*, *P. cambivora* and *P. gonapodyides*.

Summary

- **104 fields in 61 nurseries were screened in Germany and Austria**
  - **66 fields (64%) in 49 nurseries (80%) were infested with in total 13 *Phytophthora* species; among them the most aggressive ones to the respective tree species.**
  - **2.2 *Phytophthora* species per nursery**
    2.1 *Phytophthora* species per field
- **28 plantations of oak, beech, linden and maple were screened**
  - **26 plantations (93%) were infested with in total 11 *Phytophthora* species; among them the most aggressive ones to the respective tree species**
  - **1.7 *Phytophthora* species per plantation.**
- **In Bavaria *P. alni* was found in 362 alder plantations <21 years on non-flooded sites**

General conclusions

- **The nurseries and the plantations <20 years are infested with the same range of *Phytophthora* species which are responsible for the widespread decline and dieback of mature stands.**

- **Due to the widespread nursery infestations the new silvicultural concepts of**

  (1) planting groups of broadleaf trees in pure conifer forests or

  (2) replacing conifer forests by broadleaved or mixed forests

  in order to stabilise the forests against predicted climatic changes are highly probable to fail.

Occurence and losses caused by *Phytophthora* spp. in coniferous nursery stock in Poland

	Host plants	Number of infested nurseries (n=52)	Disease symptoms	Mortality
P. cinnamomi	*Abies alba* *Chamaecyparis lawsoniana* *C. obtusa* *Microbiota decussata* *Pinus* spp.	12	Root and collar rot	< 1% < 20% < 10% < 5%
P. citricola	*Abies* spp. *C. lawsoniana* *C. pisifera* *Picea omorica* *Thuja occidentalis* *T. plicata*	18	Collar rot and rotting of branches	< 50%
P. citrophthora ***P. cryptogea***	*C. lawsoniana* *Picea abies* *P. glauca* *Podocarpus alpinus*	2	Root and collar rot	< 5%

Occurence and losses caused by *Phytophthora* spp. in ericaceous nursery stock in Poland

	Host plants	Number of infested nurseries (n=10)	Disease symptoms	Mortality
P. cinnamomi	*Andromeda* *Bruckenthalia spiculifdia* *Calluna vulgaris* *Erica carnea* *Daboecia* *Hebe*, *Ledum* *Rhododendron* spp.	7	Collar rot and shoot dieback	< 50%
P. citricola	*Calluna vulgaris* *Erica carnea* *Pieris japonica* *Rhododendron* spp. *Vaccinium vitis-idaea*	7	Tip blight	< 30%
P. citrophthora	*Pieris japonica*	3	Tip blight	< 10%
P. nicotianae* var. *nicotianae	*Calluna vulgaris* *Skimia japonica*	4	Collar rot	< 50%
P. ramorum	*Calluna vulgaris* *Pieris japonica* *Rhododendron* spp. *Vaccinium vitis-idaea*	3	Tip blight	< 10%

Occurence and losses caused by *Phytophthora* spp. in broadleaved nursery stock in Poland

	Host plants	Number of infested nurseries (n=35)	Disease symptoms	Mortality
P. cactorum	*Photinia fraseri* *Sorbus aucuparia*	2	Leaf spots, root and collar rot	< 2%
P. cambivora	*Acer pensylvanicum*		Collar rot	< 10%
	Acer spp.	3		
	Fagus sylvatica			< 2%
P. cinnamomi	*Ilex aquifolium*	1	Collar rot	5%
P. citricola	*Buxus sempervirens*	1	Collar rot	< 20%
	Fraxinus excelsior	1		< 10%
P. citrophthora	*Syringa vulgaris* *Ilex aquifolia*	2	Collar rot and tip blight	< 10%
P. nicotianae var. nicotianae	*Acuba japonica* *Vinca minor*	3	Leaf spots, Shoot dieback	< 30%
P. ramorum	*Photinia fraseri*	1	Leaf spots	ca 10%


Management options for the production of non-infested nursery plants
• in nursery fields
• in containers

Production of container plants

Possible sources of *Phytophthora* infestation:

- **Resale of plants**
- **Splish splash from soil:** 4 *Phytophthora* species in containers of *Erica* and *Alnus* with soil contact (Jung unpublished).
- **Irrigation water**

Irrigation of nursery stock

- **Surface water:** 3 to >10 *Phytophthora* species in each river / stream (2-100 zoospores per liter)

- **Recirculation systems:** 10 *Phytophthora* species in irrigation systems of northern German container nurseries (Themann 2001, Themann *et al.* 2002)

  Risk of hybridisations (*P. alni,* *P. cactorum x nicotianae,* *P. cactorum x hedraiandra*)

➔ **Avoiding or disinfestation**

- **well water**
- **tap water**
- **sandfilter systems**
- **chlordioxide treatment**

Modern container nursery with recirculation system and sand filter

Suggested conditions for the production of non-infested nursery stock

- Production of nursery stock in containers with thermosterilised substrate
- Growing plants from seeds if possible
- Resale of plants only if coming from nurseries applying to the same growth conditions
- No use of potentially infested water (no surface water!)
- No use of fungistatic chemicals (phosphite) .
- Random controls of compliance with these growth conditions

Production of non-infested alder plants in the nursery of the BFW in Vienna.

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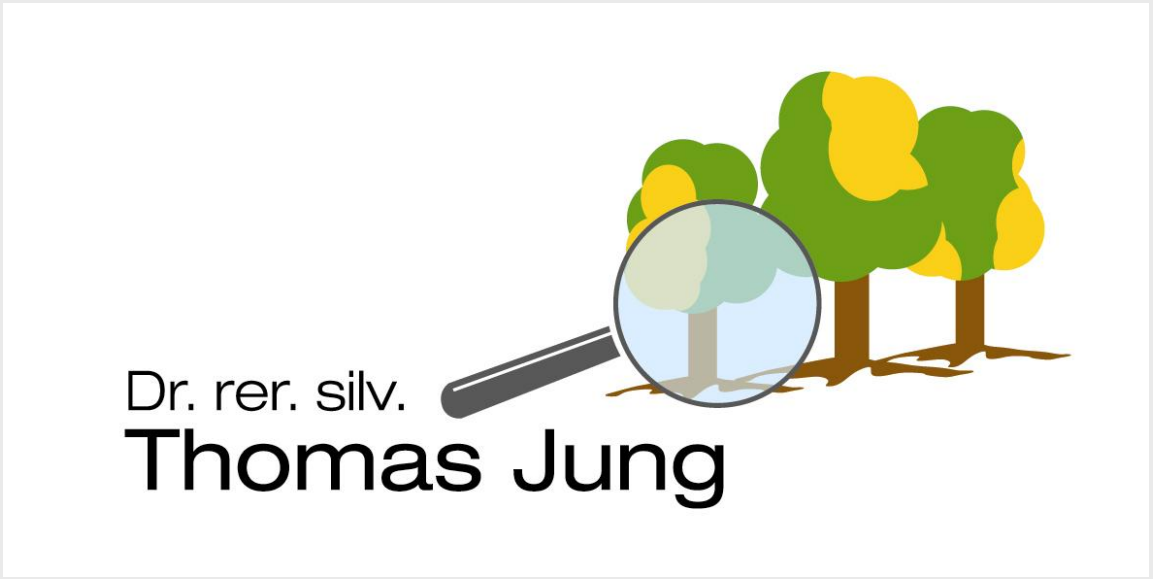

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