Proceedings of the Swiss Needle Cast Workshop: What we know, what we can do

Christchurch, 26th March 2015

Mari Suontama and Heidi Dungey

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FORWARD

Proceedings of the Swiss Needle Cast Workshop: What we know, what we can do

Mari Suontama, Heidi Dungey

Douglas-fir (*Pseudotsuga menziesii*) has been grown in New Zealand for more than 160 years and is the country's second most important softwood species. New Zealand-grown Douglas-fir has the equivalent properties when compared with Douglas-fir grown in its native environment in the Pacific Northwest of North America. The timber is light, strong and stable, with naturally durable heartwood. Early tree growth is initially about 50% slower than radiata pine at about one metre of height growth per year, but this gradually accelerates to impressive volumes of 50 m^3 per hectare per year on some sites.

The arrival of Swiss needle cast (SNC, *Phaeocryptopus gaeumannii*) in New Zealand in the late 1950s resulted in significant diameter increment loss in Douglas-fir stands, particularly in the North Island. If the problem of Swiss needle cast could be solved, there would be considerable and renewed interest in growing more Douglas-fir.

The purpose of the Swiss Needle Cast workshop – What we know, what we can do – held in Christchurch, 26th March 2015, was to review the current research knowledge and develop a plan to mitigate the effects of the disease. This proceedings brings together the workshop presentations and conclusions from breakout group discussions.

The workshop programme started with Dr Ian Hood (Scion) discussing the pathology and development of the disease in New Zealand then Dr Mike Watt (Scion) outlined predictions under different climate change scenarios. Professor Doug Maguire (Oregon State University) summarised the American experience with the disease and how they were managing their forests and living with SNC. New Zealand industry perspectives followed, and potential genetic solutions from Scion researchers. Workshop participants split into breakout groups to 'brainstorm' and prioritise research ideas for the last hour.

In summary, the participants thought that genetic solutions offered the best opportunity for long term mitigation of the effects of the disease. In the short term, thinning and good stand management were the practical actions forest managers could undertake to reduce the impact of the disease.

We would like to thank all presenters for their contribution to this workshop. In particular, Professor Doug Maguire and Dr Ian Hood, who both have extensive experience in this area. Dr John Moore is gratefully acknowledged for facilitating the workshop. Also, we thank Lynn Bulman, Joy Wraight, and Dr Annette Brockerhoff for the workshop arrangements. The workshop was organised as a part of the Forest Growers Levy Trust, and Scion's Core funded Diversified Species Research Programme.

Dr Heidi Dungey

Science Leader, Scion

Rotorua

May 2015

Proceedings of the Swiss Needle Cast Workshop:
What we know, what we can do

Mari Suontama, Scion, Heidi Dungey,
Scion, Rotorua, New Zealand

April 2015

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Swiss Needle Cast Workshop

Swiss needle cast (SNC) is one of the most important challenges for the continued prosperity of the Douglas-fir industry in New Zealand. If we can solve or even mitigate the effects of this needle disease, we are likely to see more of this species planted, especially with improved seed promising improved growth rate and the likelihood of a reduced rotation age.

Douglas-fir is amongst the world's most traded timber species and large markets already exist. Perseverance with solving the SNC problem will provide New Zealand forest growers with another profitable product for their forest portfolio.

The Swiss Needle Cast Workshop was held 26th March 2015 in Christchurch. There were 20 participants from both industry and research providers.

This proceedings includes the presentations and conclusions. The programme is included in Appendix One. Conclusions from with workshop breakout discussion groups are provided below.

Swiss Needle Cast workshop conclusions

Breakout Group Discussion 1

Top priority would be to develop a Douglas-fir genomic SNP chip (s*ingle nucleotide polymorphism*) and to start phenotyping the 1996 progeny trials in Kaingaroa, where SNC is present. RapidEye (satellite) and LiDAR (airborne) remotely sensed data are already available from the FOA/Scion Growing Confidence in Forestry's Future (GCFF) programme. It would be important to seek relationships between crown attributes and leaf area index (LAI), so that the effects of SNC on needle retention could be quantified.

It would be a high priority to have good confidence in the Douglas-fir growth and yield base models – and to be sure that needle retention is incorporated into the Douglas-fir 500 Index growth model available in Forecaster (and the Calculator). This will give resource managers more confidence to manipulate stands to cope with the threat of needle infection, after they have done some scenario analysis with the models.

There is a large opportunity to continue to monitor Permanent Sample Plots (PSPs) for needle retention, maybe with soil sampling to build relationships with nutrition. Additionally, there are LUCAS plots (Land-use and Carbon Analysis System) and plots in post-1989 forests (particularly, Ernslaw One and Blakely Pacific ETS-FMA plots, i.e., Emission Trading Scheme - Forest Management Approach plots) that would be available for RNC disease and needle retention monitoring.

There was a question around whether endophytes could help in preventing SNC. This is currently being investigated with radiata pine – if it works, this approach could be initiated with Douglas-fir.

Unmanned aerial vehicles (UAVs) fitted with LiDAR units could be intensively used to remotely assess trials, e.g., 1959 and 1996 breeding trials.

It would be possible to develop a 'full stop counter' to count fungal fruiting bodies on needles using photogrammetric techniques to quickly assay relative infection levels relating to needle loss and growth.

Re-validation of climate models was considered to be low priority.

Breakout Group Discussion 2

The question arose around interactions with endophytes. Endophytes could be used to look at health. The FOA levy may provide good opportunities to finance this kind of research.

Early inoculation of seedlings in the nursery and measuring a response to SNC at this stage could be a method to identify the most susceptible trees (germplasm). There is a need to get everything in seed orchards grafted, and then run an inoculation trial on these grafts to calculate estimates of SNC breeding values. Also, there is a need to develop a methodology to produce spore suspension/macerated hyphae for inoculation tests.

There was interest to keep up conventional tree breeding, and create SNC resistant/tolerant breeds from existing information. Also, we should estimate breeding values for diameter at breast height (DBH), SNC and stiffness, and simultaneously select the best trees from those traits.

There is the potential to look at species mixtures in a stand to see if this will mitigate the spread of infection, however, according to Doug Maguire, this approach does not seem to have much effect.

The use of genomics is important – particularly as *Pseudotsuga sinensis* (Chinese Douglas-fir) is reputedly immune to SNC, so maybe we should graft it up and put it into inoculation tests. Also, *Pseudotsuga flahaultii* (Mexican Douglas-fir) is reputed to have better resistance to SNC than New Zealand *Pseudotsuga menziesii* seedlots in a 1967 trial.

Systemic fungicides – by stem injection – but, is there any other way of getting it ‘in there’ – could this approach be used to clean up existing stands?

The question arose of Red Needle Cast (RNC) potentially infecting Douglas-fir, as well.

Mycorrhizal associations – if infected trees that are carrying only one year’s needles and also only have one mycorrhizal association – what does this mean? If we want more mycorrhizal species in association, can we put more in there?

It is important to know about the new spray technologies that are being used, which have better control of droplet size. Can there be some better control than was achieved in the past? Cost/benefit analysis would be needed to know the economics of doing this.

Thinning to maintain good vigour to reduce stress on trees – stand density measurement. Use stand density measurement techniques to give practical guidelines on how to apply effective thinning regimes. There are two thinning trials in Kaingaroa (FR191 & FR212) that could be useful for this.

Risk – how to incorporate this into our decision making – currently, growth and yield models are based on data with the absence of disturbance, i.e., best-case scenarios, only.

Swiss Needle Cast Workshop Presentations

Ian Hood, Scion: Swiss Needle Cast in New Zealand – what do we know?

Michael Watt, Scion: Climate and Swiss Needle Cast

Doug Maguire, Oregon State University: Douglas-fir silviculture in the presence of Swiss Needle Cast

Phil De La Mare, Ernslaw One:Ernslaw One Ltd's Experience

Peter Oliver, City Forests: City Forests' Overview

Lindsay Bulman, Scion: Swiss needle cast – A pathologist's perspective

Mari Suontama, Scion: Genetic solutions

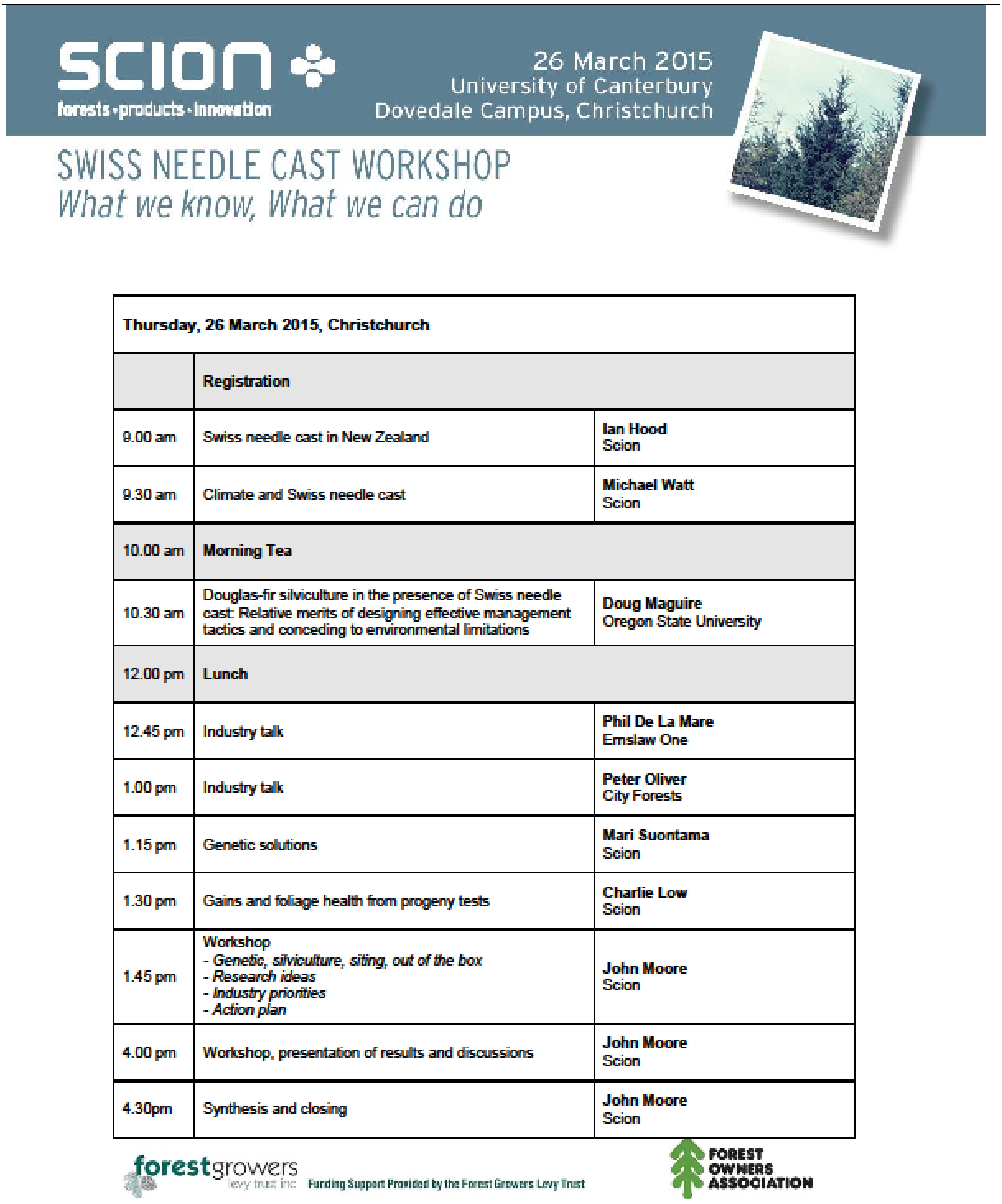
Charlie Low, Scion: Gains and foliar health from progeny test

Summary

Genetic solutions offered the best opportunity for long term mitigation of the effects of the disease in the long term.

Thinning and good stand management were the practical actions forest managers could undertake to reduce the impact of the disease in the short term.

Appendix A: Programme of the Swiss Needle Cast Workshop



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26 March 2015
University of Canterbury
Dovedale Campus, Christchurch

SWISS NEEDLE CAST WORKSHOP
What we know, What we can do

Thursday, 26 March 2015, Christchurch		
	Registration	
9.00 am	Swiss needle cast in New Zealand	**Ian Hood** Scion
9.30 am	Climate and Swiss needle cast	**Michael Watt** Scion
10.00 am	**Morning Tea**	
10.30 am	Douglas-fir silviculture in the presence of Swiss needle cast: Relative merits of designing effective management tactics and conceding to environmental limitations	**Doug Maguire** Oregon State University
12.00 pm	**Lunch**	
12.45 pm	Industry talk	**Phil De La Mare** Ernslaw One
1.00 pm	Industry talk	**Peter Oliver** City Forests
1.15 pm	Genetic solutions	**Mari Suontama** Scion
1.30 pm	Gains and foliage health from progeny tests	**Charlie Low** Scion
1.45 pm	Workshop - *Genetic, silviculture, siting, out of the box* - *Research ideas* - *Industry priorities* - *Action plan*	**John Moore** Scion
4.00 pm	Workshop, presentation of results and discussions	**John Moore** Scion
4.30pm	Synthesis and closing	**John Moore** Scion

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Swiss needle cast in New Zealand - what *do* we know?

Ian Hood

Presented to the Scion-Industry Swiss Needle Cast Workshop, Christchurch, 26 March 2015

Presentation Outline

1. Some history

2. The biology of the associated fungus (*Phaeocrypyopus gaeumannii*)

3. Is it the cause of SNC?

4. How can we manage it?

5. Latest research

1. Some history

1959 - The fungus first found in central North Island Douglas fir

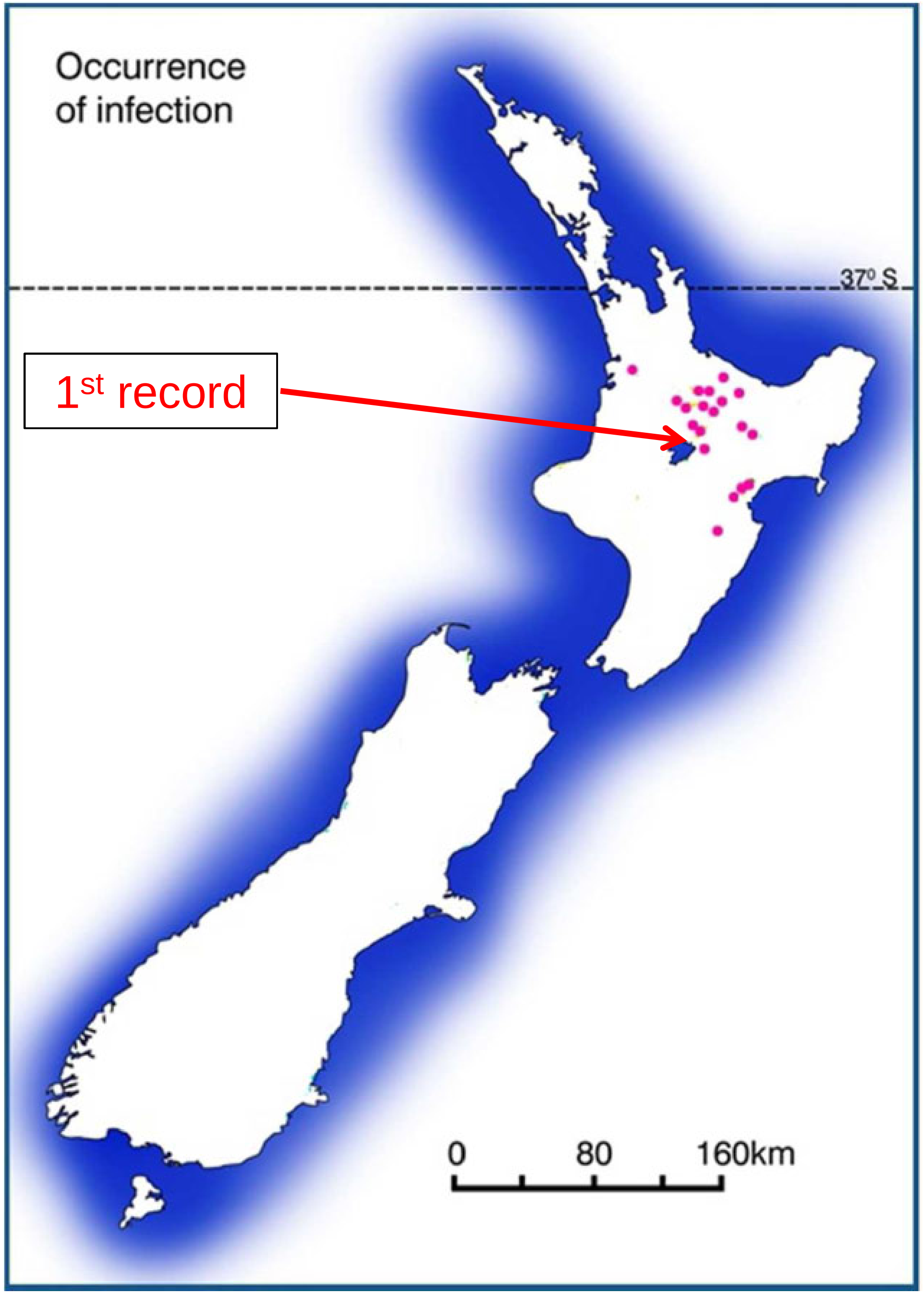
Swiss needle cast was not always with us….!

A survey was immediately conducted……..

1959 distribution of *Phaeocryptopus gaeumannii*

John Gilmour

Douglas fir green and healthy



Bartholomew Timbers Ltd., Te Whetu, Mamakus, near Tokoroa

Healthy Douglas fir.

1962 – “off colour” symptoms appeared in older central North Island stands.

South Island stands healthy with high foliage retention.

Early-mid 1970s - much concern arose.

Detected a growth increment decline dating back to the mid 1960s.

From 18 down to 11m^3/ha/year, and more.

Total loss in one large forest estimated at 140, 000 m^3.

A REVIEW OF DOUGLAS FIR IN NEW ZEALAND

16–19 SEPTEMBER, 1974

Compiled by R.N. James

Edited by R.N. James and E.H. Bunn

NEW ZEALAND FOREST SERVICE

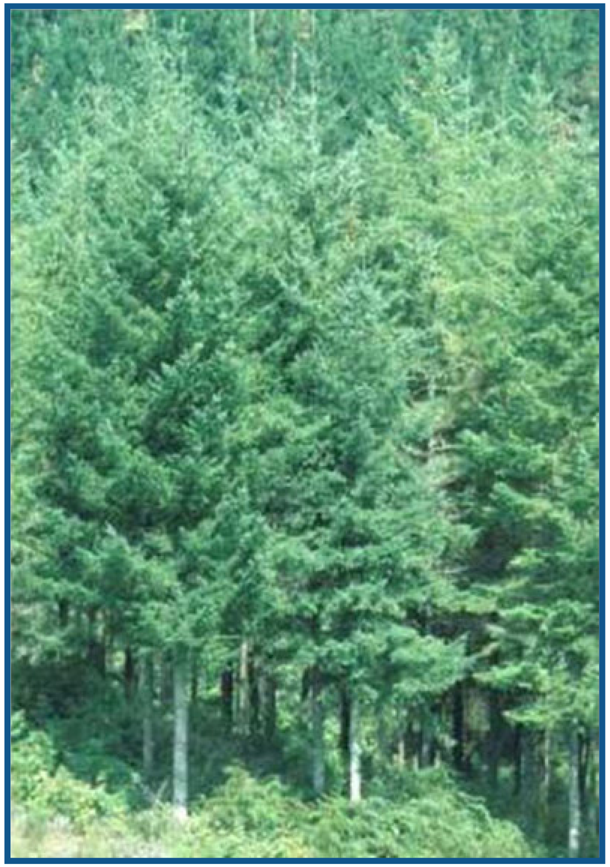
M.J. Conway, Director–General of Forests
C. Bassett, Director of Research

1978

Late 1970s -

Epidemics of indigenous lepidopterous caterpillars in older SNC stands, central North Island (*Pseudocoremia suavis*).

Severe periodic defoliation.



1985

Young second-rotation infected stands growing at only 60-74% of the first rotation pre-*Phaeocryptopus* crop.

– Bruce Manley

1990s –

Much “old crop” (50- to 70-year-old) central North Island Douglas fir harvested and logs exported to North America.

MANAGEMENT POLICY FOR DOUGLAS FIR

NEW ZEALAND FOREST SERVICE

WORKSHOP – NELSON

26–28 MARCH, 1985

1987 into 1990s

Roughly coincidental with privatization of State forests leading to a new era of Douglas fir forestry……

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2. The biology of the associated fungus

Essential knowledge as a basis for developing control.

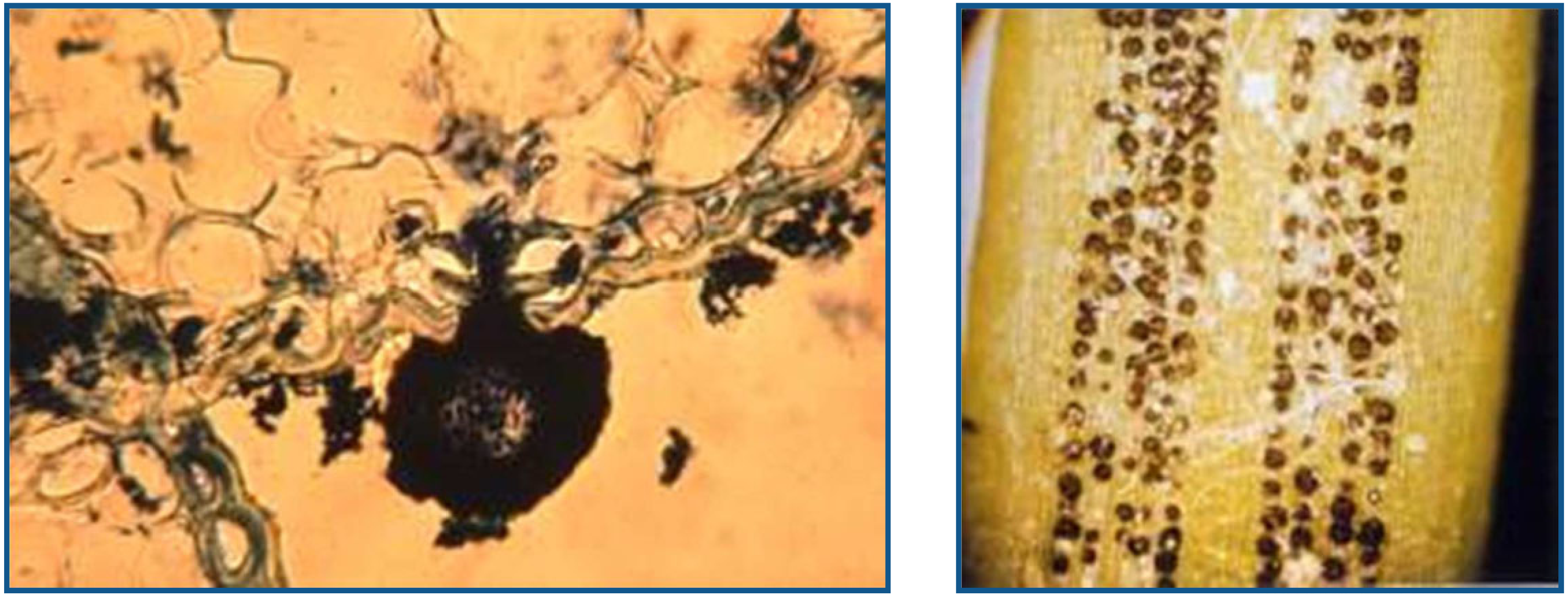
- Identity
- Spread
- Life cycle

Identity:
Phaeocryptopus gaeumannii.

A microscopic fungus.

Mycelium ramifies within needles.

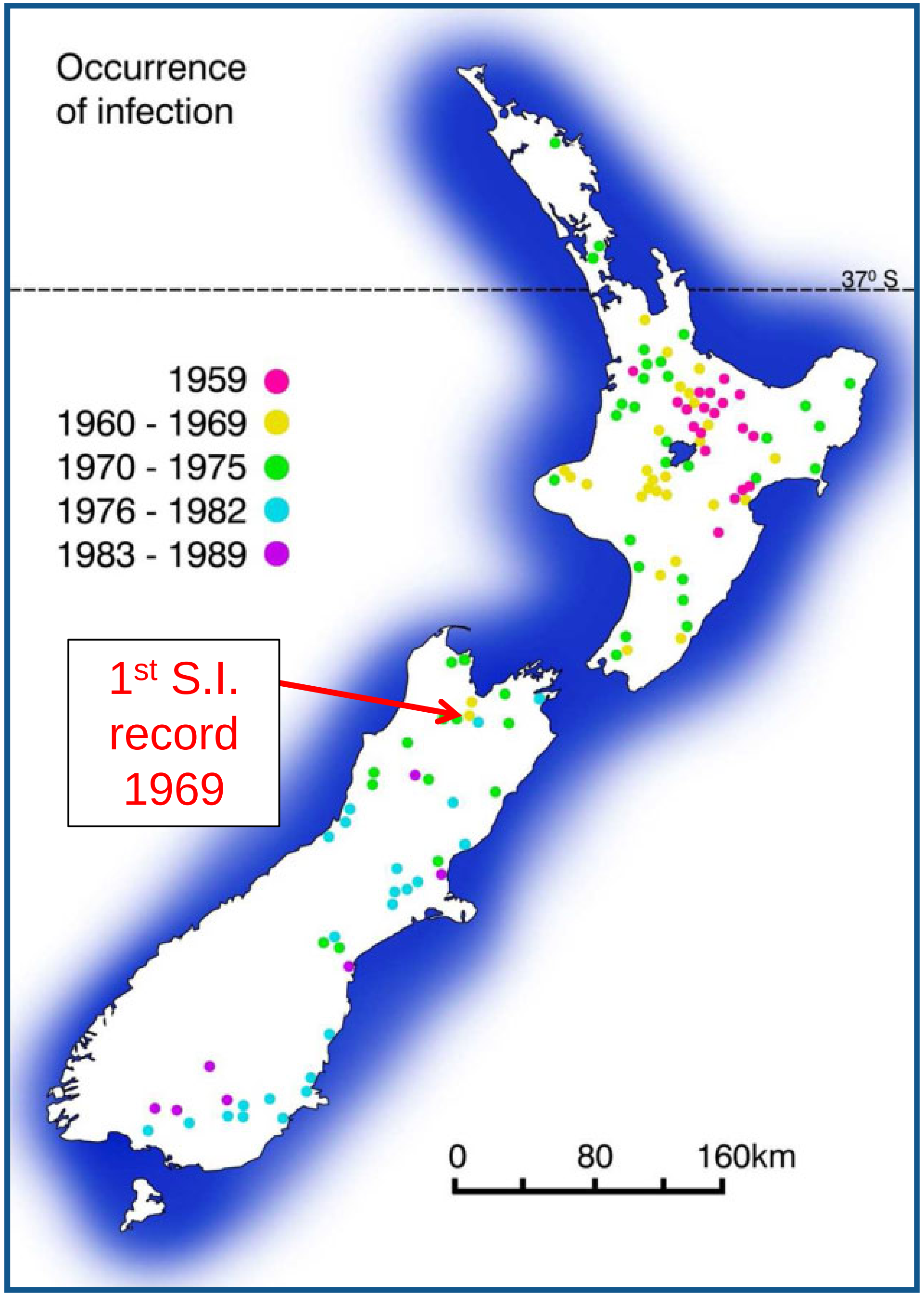
Fruiting bodies emerge from needle pores (stomata).



Spread:

Distribution monitoring programme

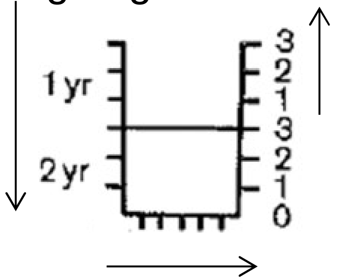
Took nearly three decades to spread through the whole country



1st S.I. record 1969

Spread within forests (infection on 1- and 2-year-foliage)

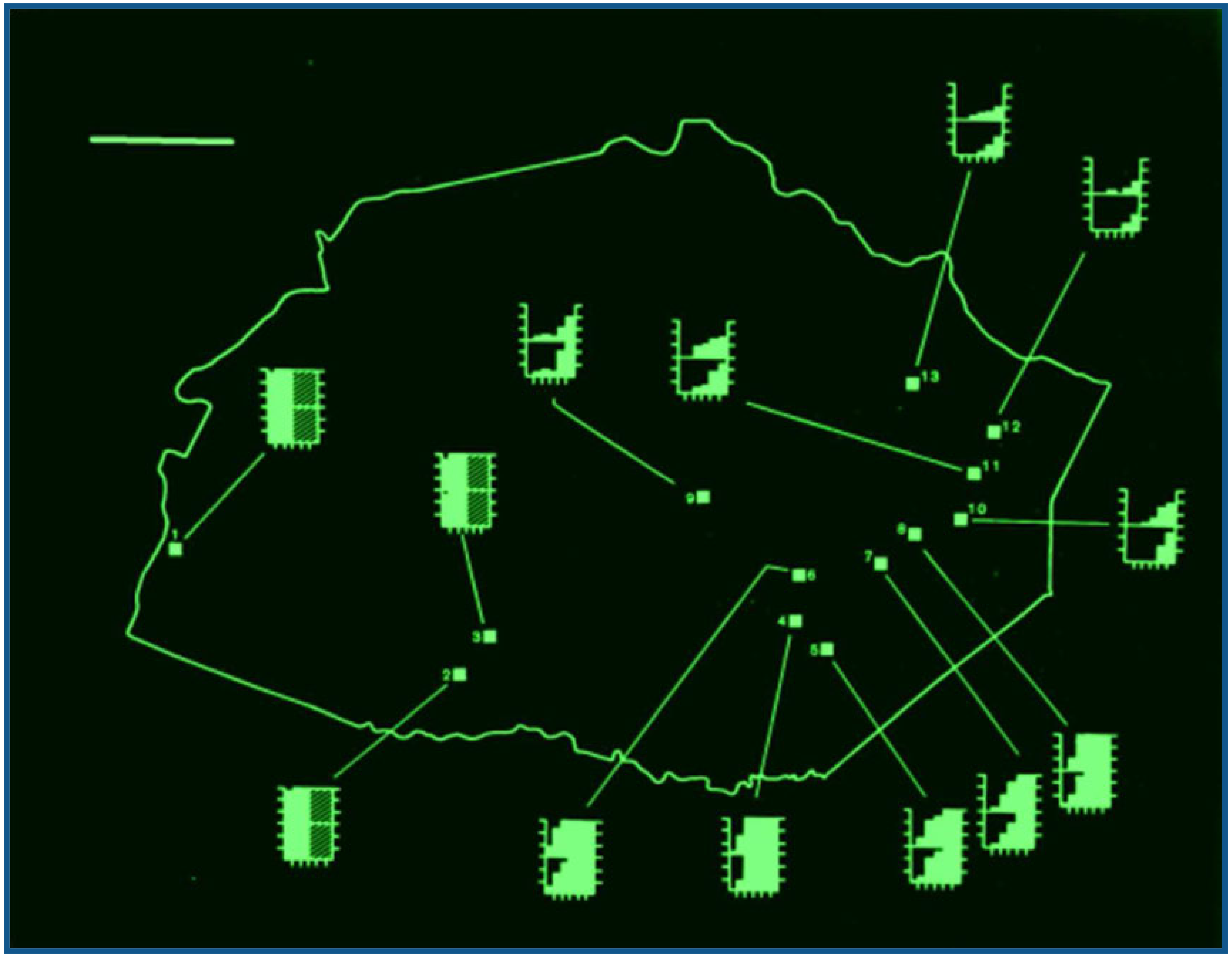
Foliage age class



Infection score

Year assessed
(yr0-start, yr1,yr2,yr3,yr4)

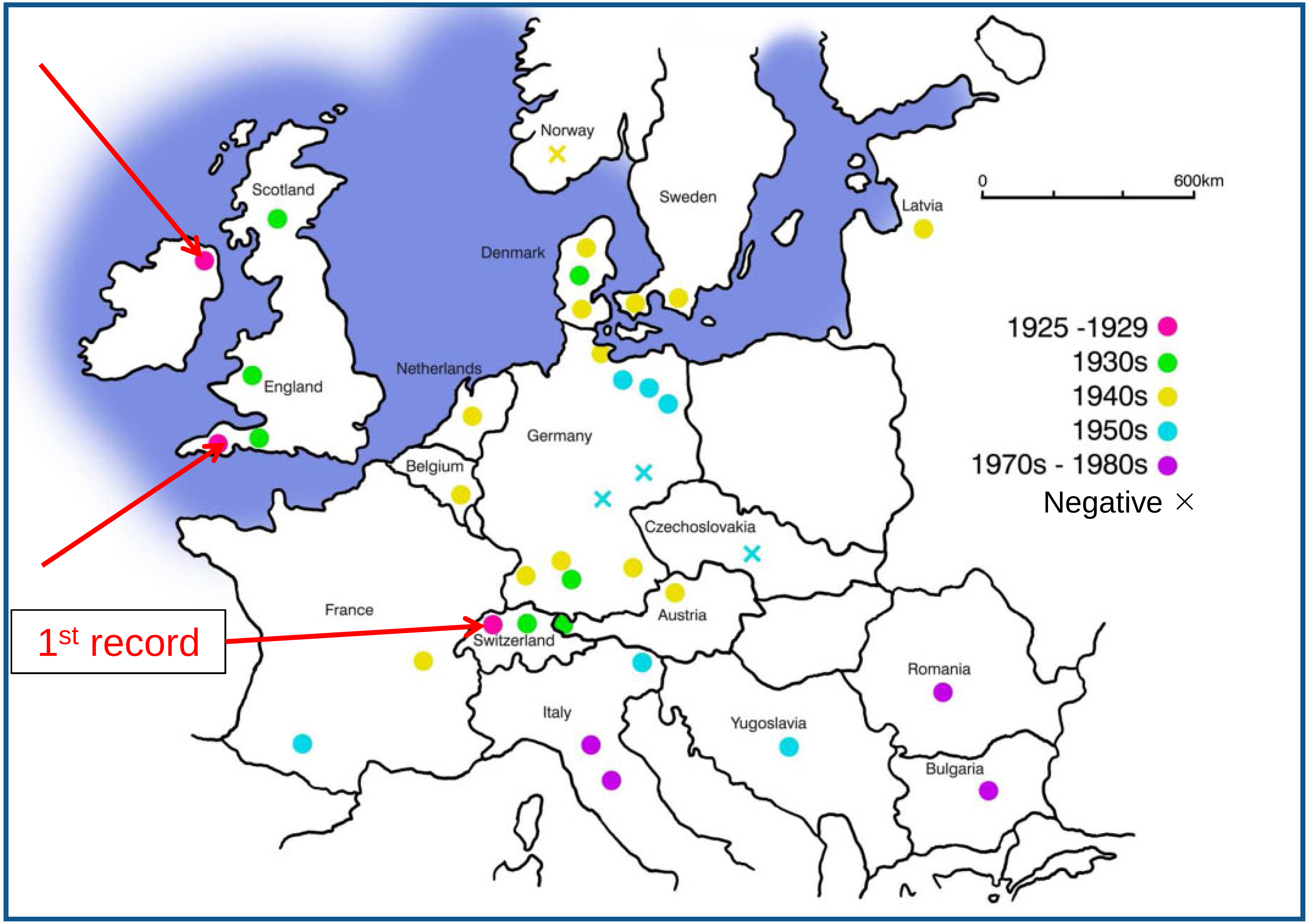
Slow build-up in a young New Zealand forest.



Bar: 1 kilometre

Monitoring plots

Spread in Europe – also slow

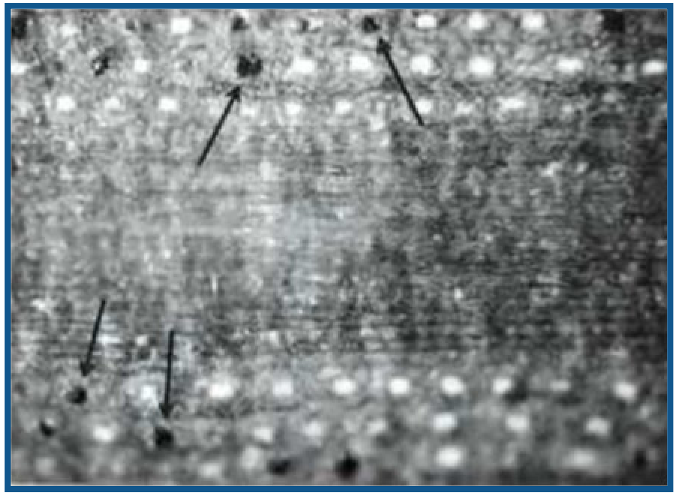


1st record

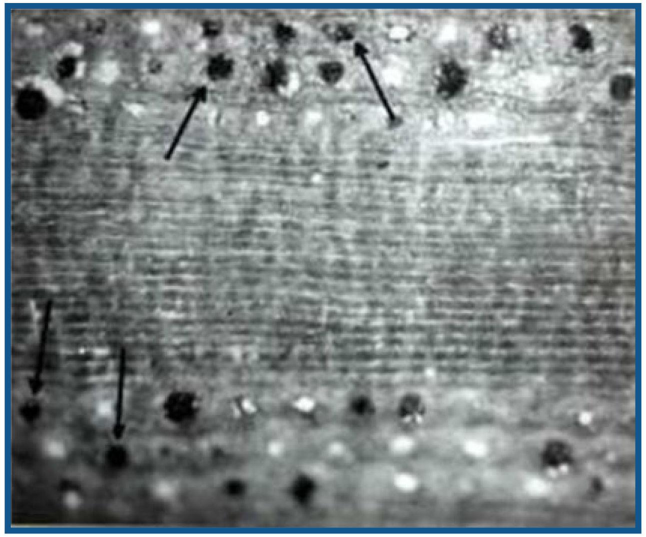
First regional records as in literature.

LIFE CYCLE - essential knowledge for disease management:

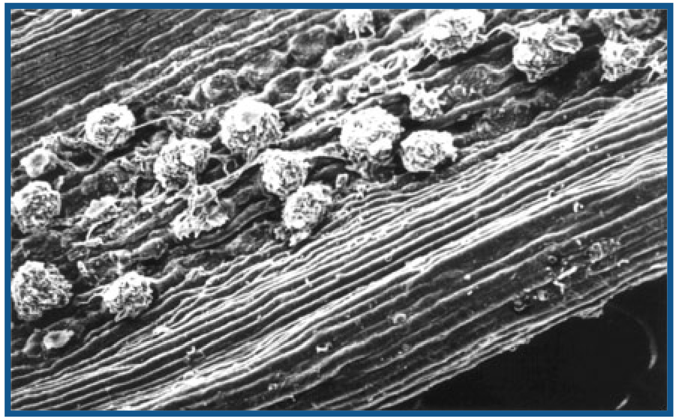
Fruitbody initials first appear on current/older needles in March



April
(Autumn)



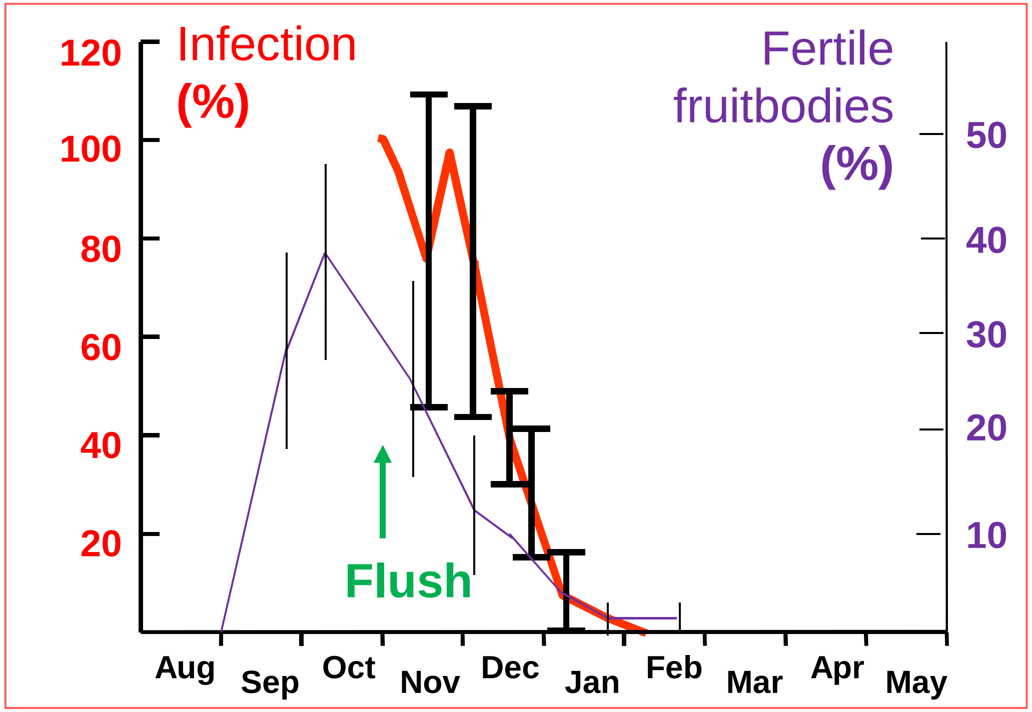
July
(Winter)



Mature by
September
(early Spring)

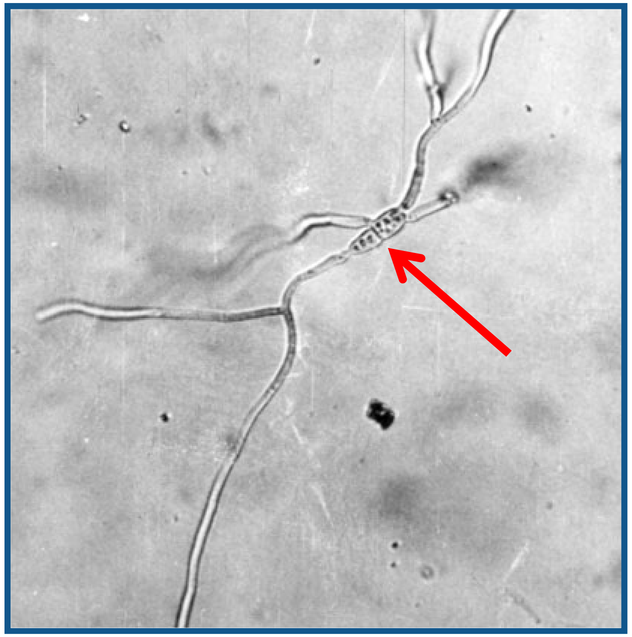
Spores in spore sacs

Inoculum production and infection period studies



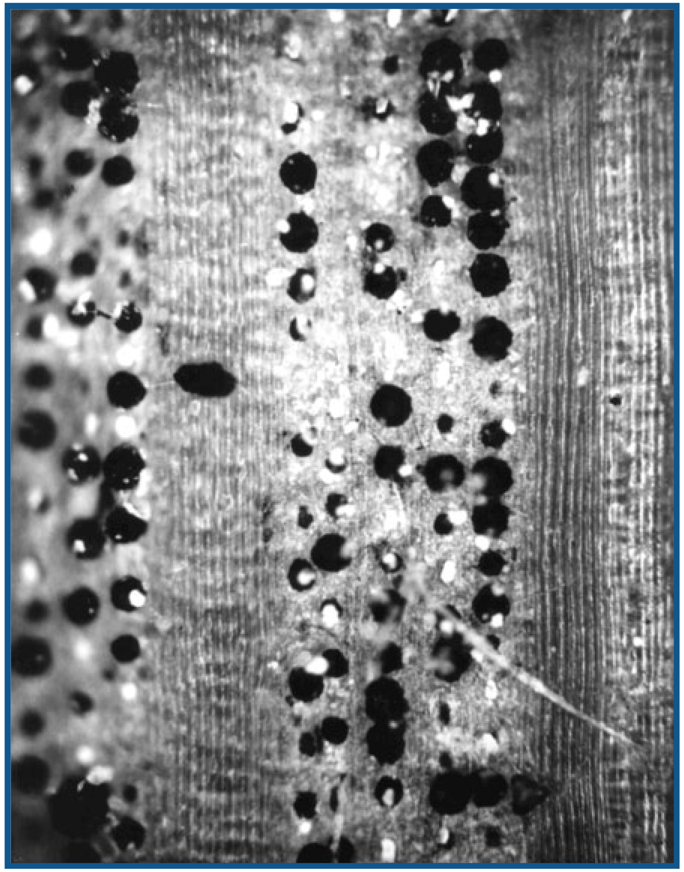
Spores first appear in September; present until February

Most infection on current foliage. Occurs from November (late Spring) until January (early summer)



Ascospore germinates on surface and hyphae enter needle.

Spore dispersal local.



Successive crops of fruitbodies produced on older needles each season

Some key points:

- Peak infection coincides with new flush (November)
- New fruitbody initials appear in March, mature by September
- Older needles are only slightly susceptible
- But new fruitbodies appear each year, so, older needles have more
- Only one disease cycle per year
- Greatest chlorosis in winter prior to spring flush

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3. Is *Phaeocryptopus gaeumannii* the cause of Swiss needle cast?

“Much infected Douglas fir is green and healthy, so it’s not doing anything! It’s something else”

- Comparison with experience overseas.
- Studies on trees.
- Pathogenicity studies on potted plants.

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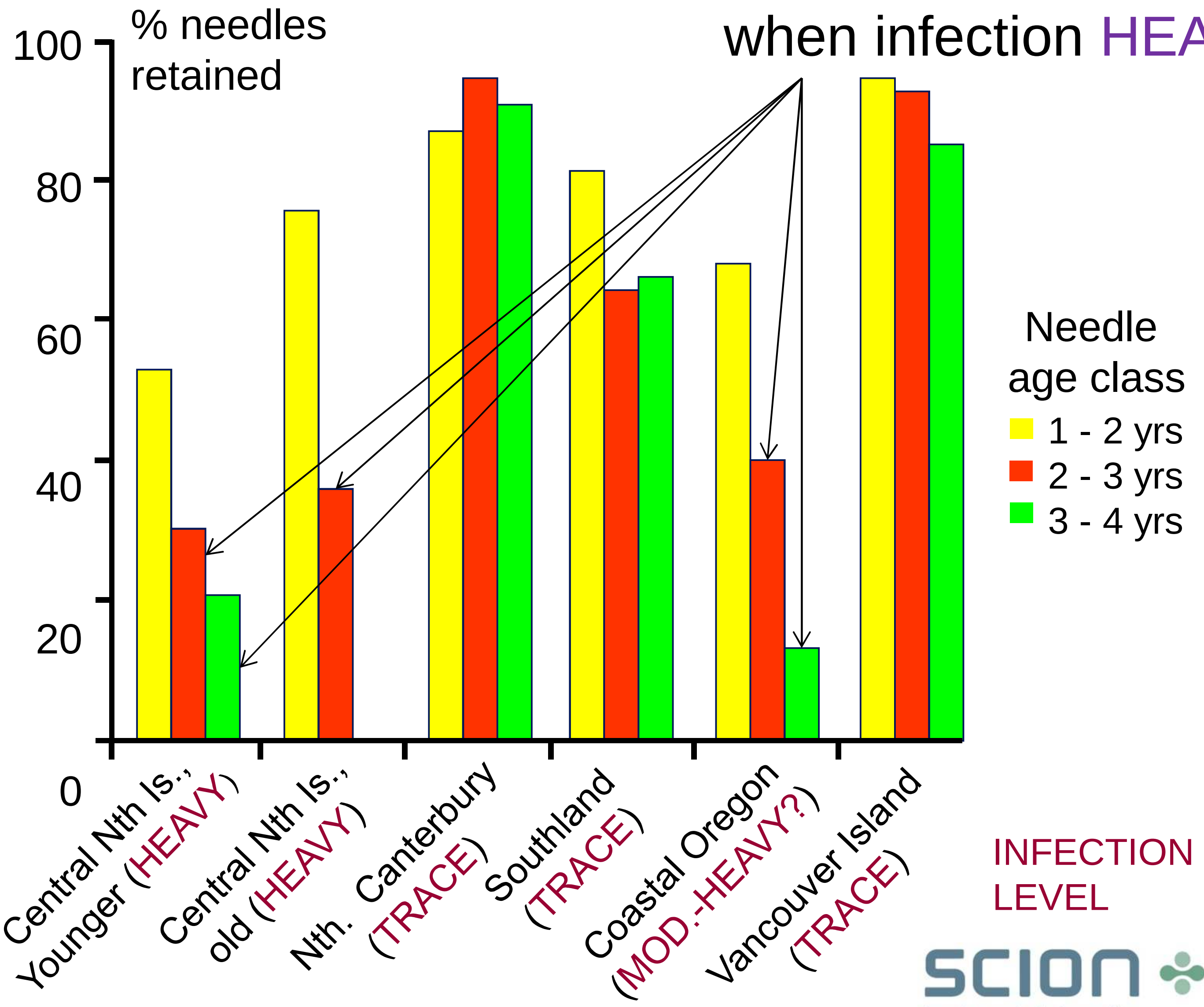
Comparison with experience overseas.

Places with HEAVY infection have lower needle retention

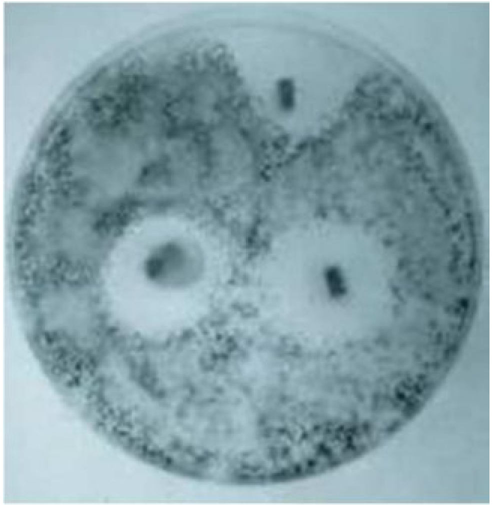
Older needles shed prematurely when infection HEAVY.



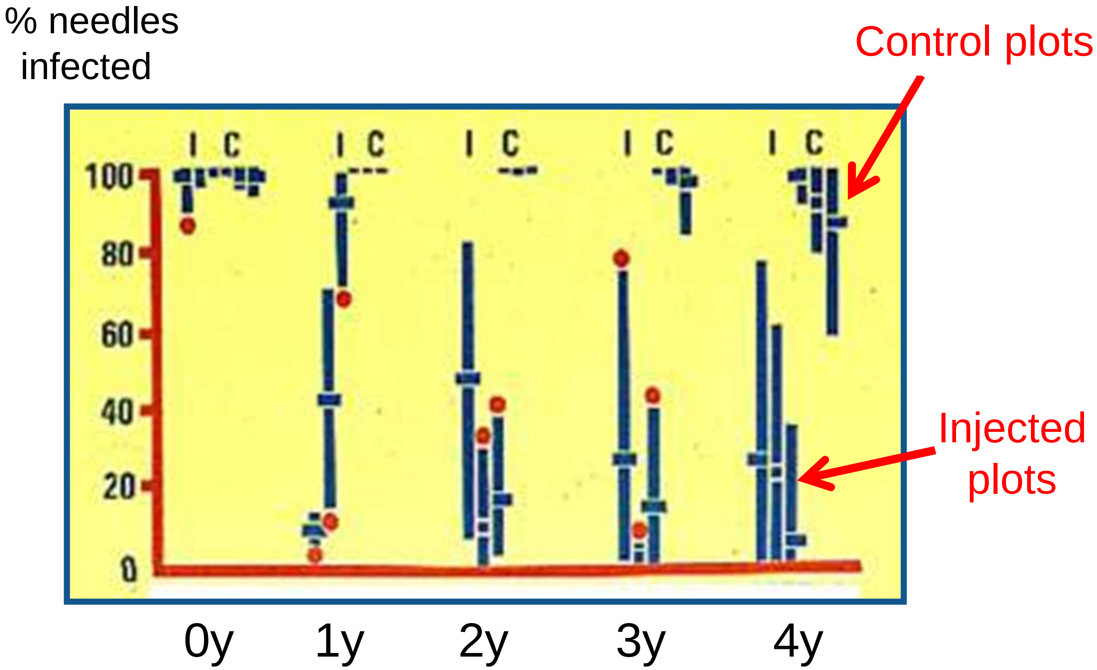
Studies on trees.

If reduce infection, does foliage retention increase?

Stem injection of carbendazim fungicide into 19-year-old trees



Bioassay – carbendazim reached infected needles

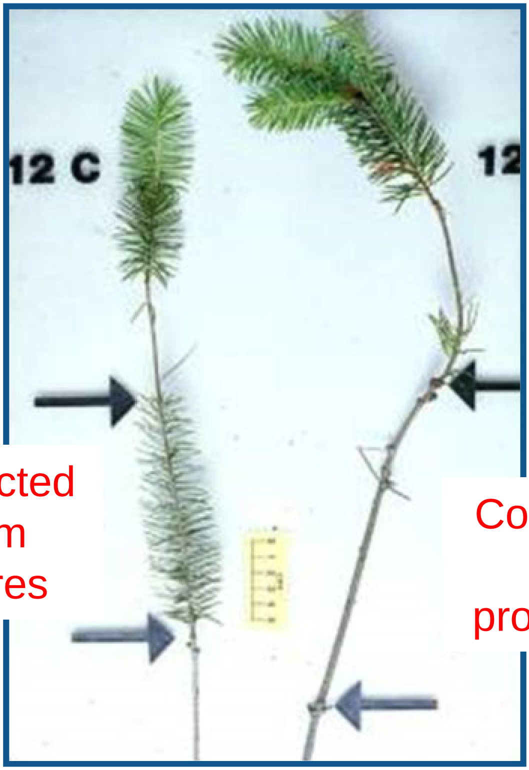


% infection reduced in successive years after injections

From injected tree (right) and un-injected control tree (left)

Appeared to get improved foliage retention by reducing infection.

Other studies: If reduce infection, does foliage retention increase?



Enclosed in transparent cellulose bags when in new flush

Fungicide dipped when in new flush

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Protected for 1 year
in glasshouse.

Again suggests *P. gaeumannii* is the cause of needle shedding.

Pathogenicity study with potted seedlings (means)

Seedlot	Inoculated /Control	No. plants	1- to 2-year-old needles		CO_2 exchange (light) mg/g (dry weight) /hour (current needles)
			Infection (% needles infected)	Needle retention (% whole plant dry weight)	
1	I	20	95	1.9	6.0
	C	17	1	3.5	7.5
			***	***	*
2	I	10	26	1.8	
	C	12	3	6.4	
			***	***	
3	I	8	12	2.9	
	C	14	1	5.2	
			**	**	

PROVED *P. gaeumannii* is the cause.

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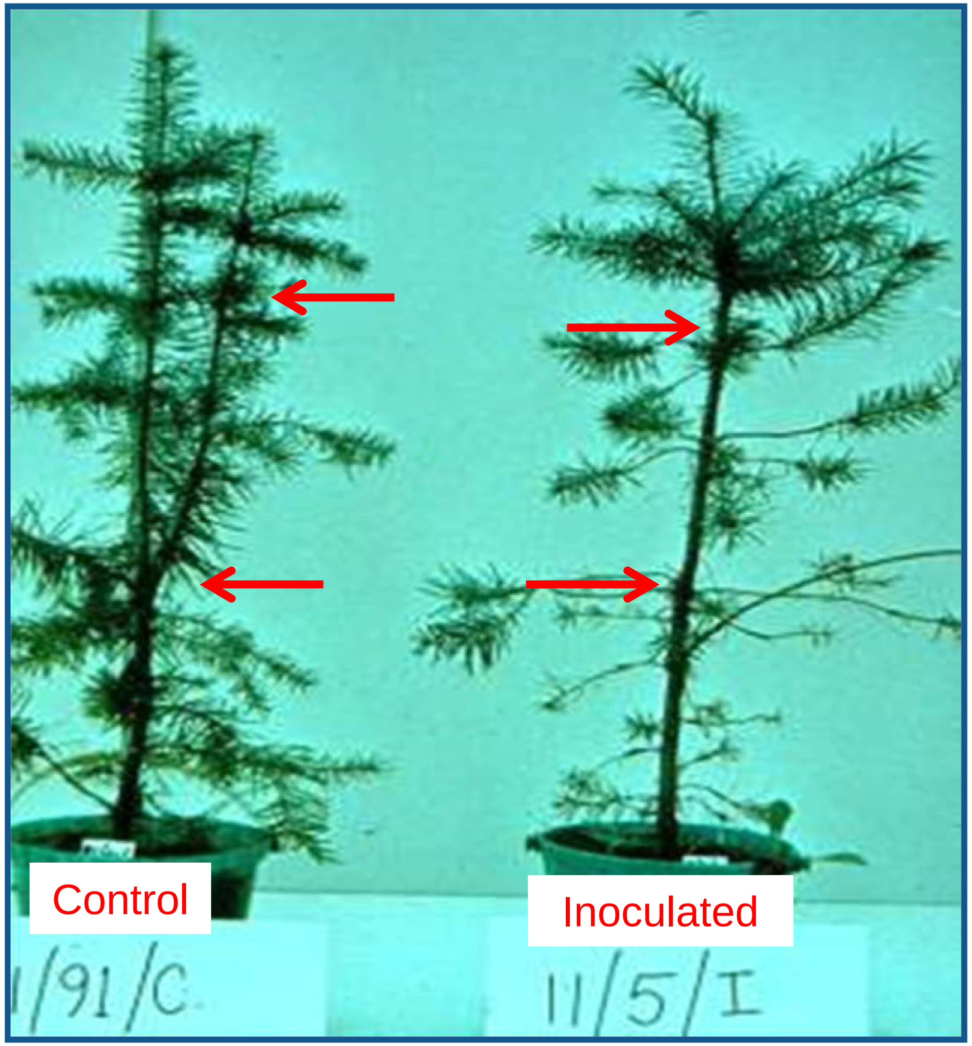
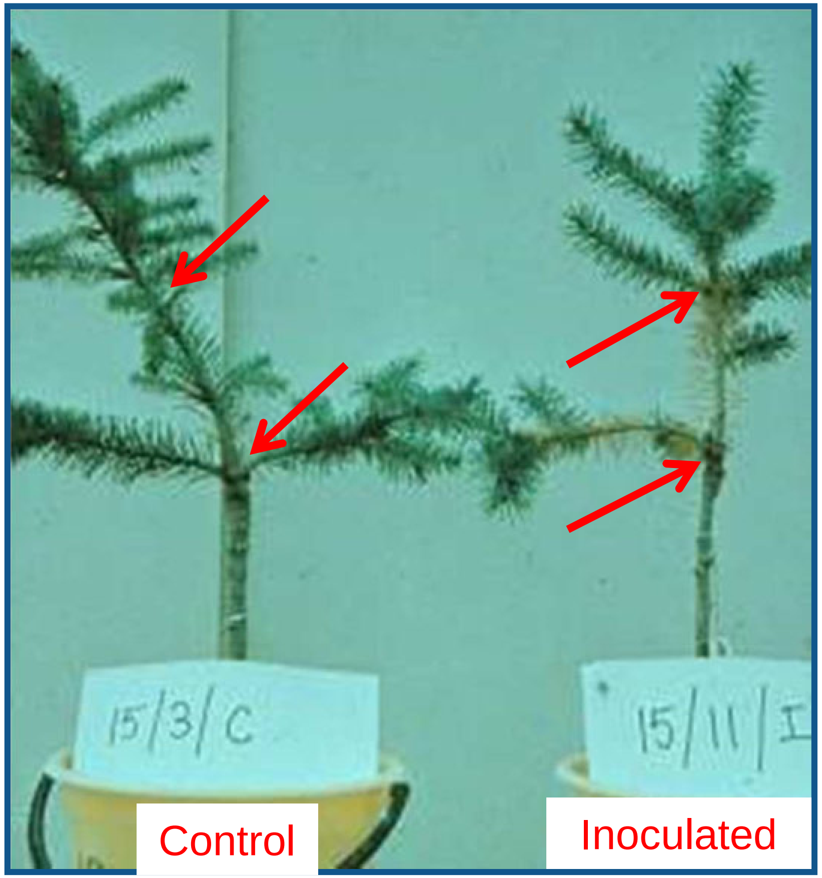
Pathogenicity studies on potted plants.



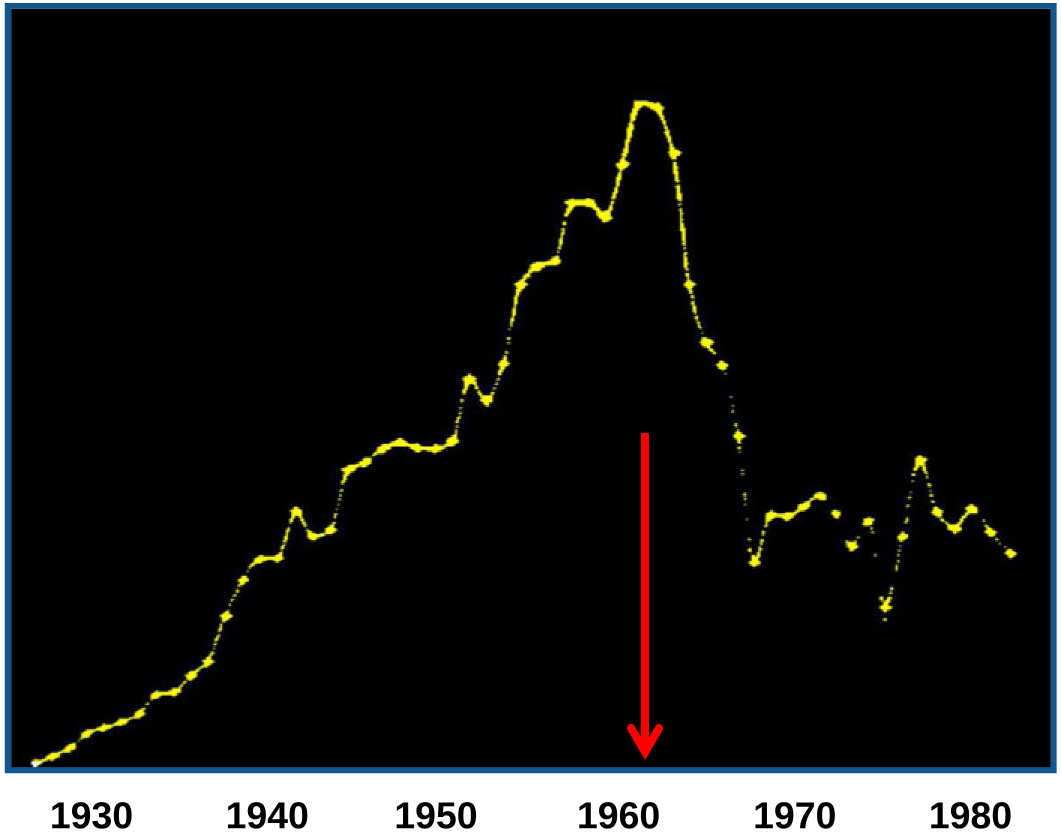
Seedlings



Grafted cuttings

Infected foliage shed prematurely.

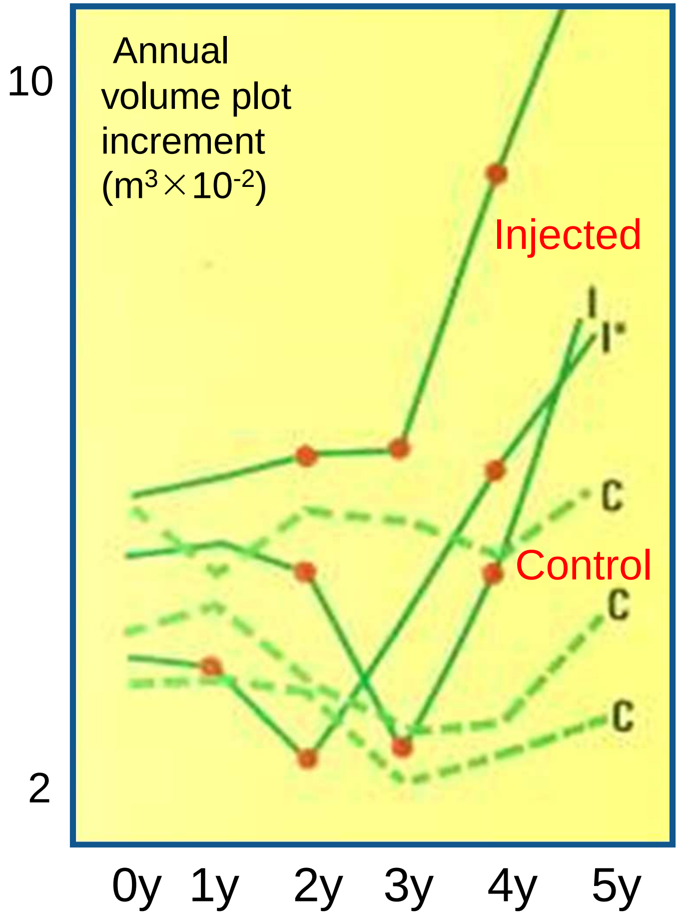
Also, further indications that SNC causes growth decline



Current annual volume increment/ ha
(average from three trees)

(b) from stem analysis: Nod Kay

(a) previous stem injection study



4. How can we manage it?

- Fungicidal control?
- Silviculture (thinning)?
- Genetic (selection for resistance/tolerance)?

Te Whetu

Fungicidal control (seedlings).

Timing based on the life cycle studies.

Two applications to runoff (3 and 9 weeks after flush) gave good control (<10% of untreated control infection).

Successful fungicides: benomyl*, triforine, cuprous oxide*, copper oxychloride*.

*Applied with a surfactant.

Three applications even better.

Potted seedlings under a diseased stand providing good inoculum.

Fungicidal control (stands).

Sprayed new spring foliage with fungicide
(triforine/copper oxychloride)

in a 19-year-old stand

Results after 2 years

	Control /Sprayed	No. plots	% needles infected	
			Mean	95% CL
Aerial	Con Spray	3 3	100 98	98-100 96-100
Hand	Con Spray	3 2	100 19	100 0-47

Hand spraying reduced infection; aerial did not work; .

Other trials conducted; only marginally effective. Why?

Unable to get full coverage?

Spray pads and seedling test plants in cleared band across flight path.

Subsequent success with chlorothalonil fungicide in Wisconsin, Washington, Oregon.

Not tried here.

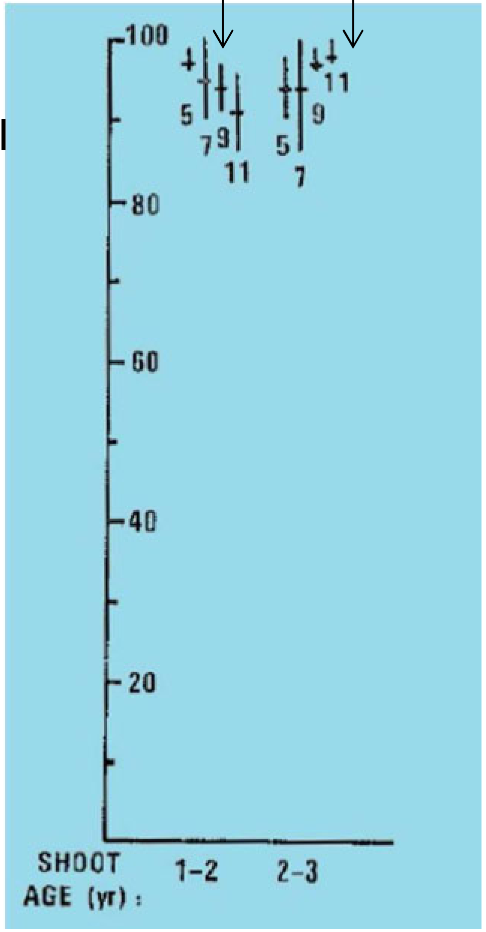
Silviculture (thinning).

Would the resultant ventilation and drying reduce infection?

- Thinning did not reduce infection or increase foliage retention
- Thinning did not lead to increased growth per ha
- Thinning *did* lead to larger trees with deeper crowns
- Nor did thinning affect a lightly infected stand
  (Vancouver Is.)

Crown depth (whorls)

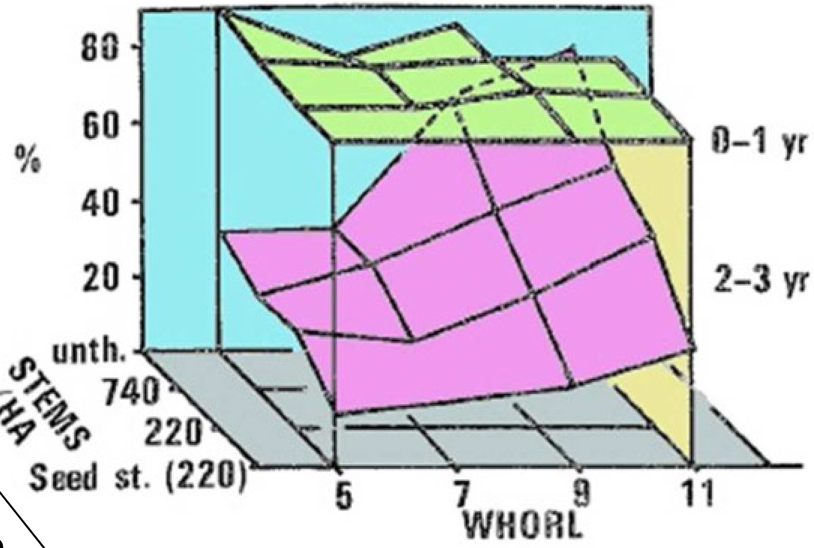
% needles infected (all stockings combined)



Foliage age class

Infection (not affected by stocking)

% needles retained



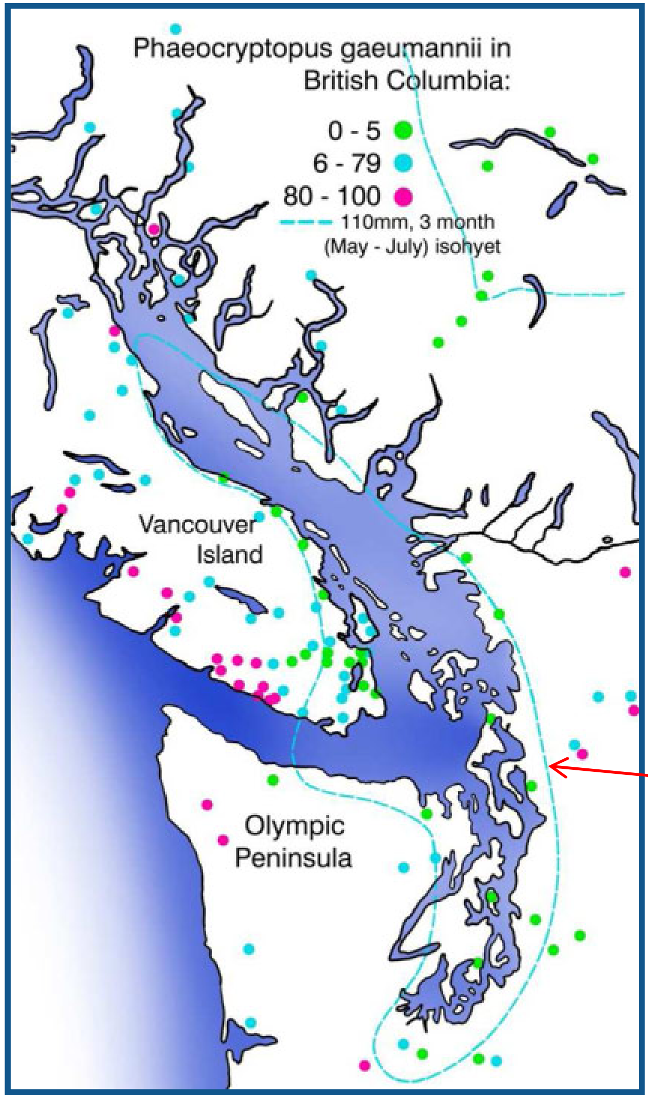
Foliage age class

Greater stocking

Greater crown depth

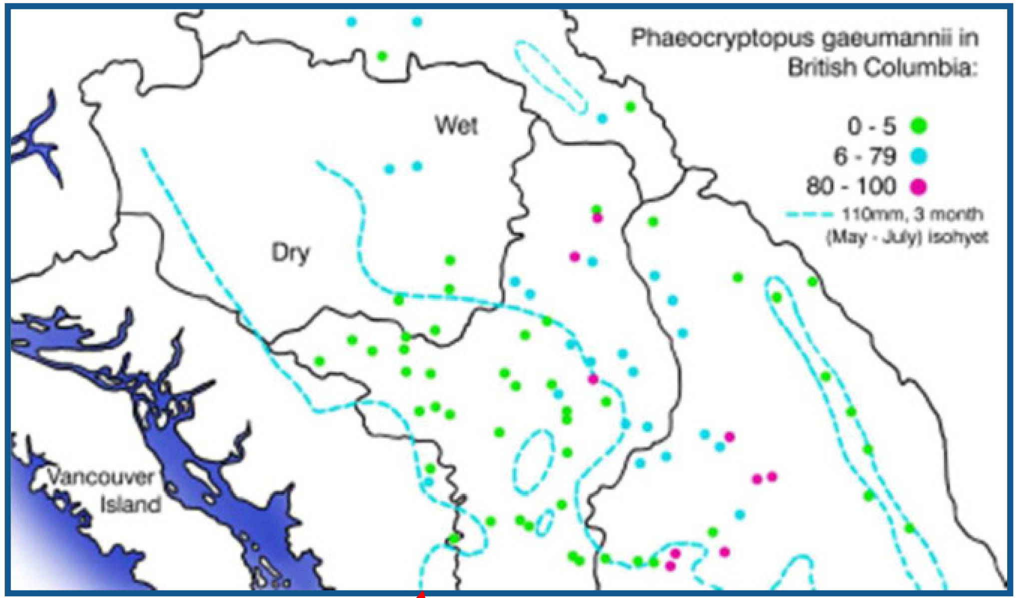
Needle retention

Genetic selection.



Heavy infection where high spring rainfall

Survey in British Columbia (1981)



3-month rainfall (May-July) = 110 mm

In most of New Zealand, Spring rainfall (September - November) > 200 mm (250-300mm, central North Island)

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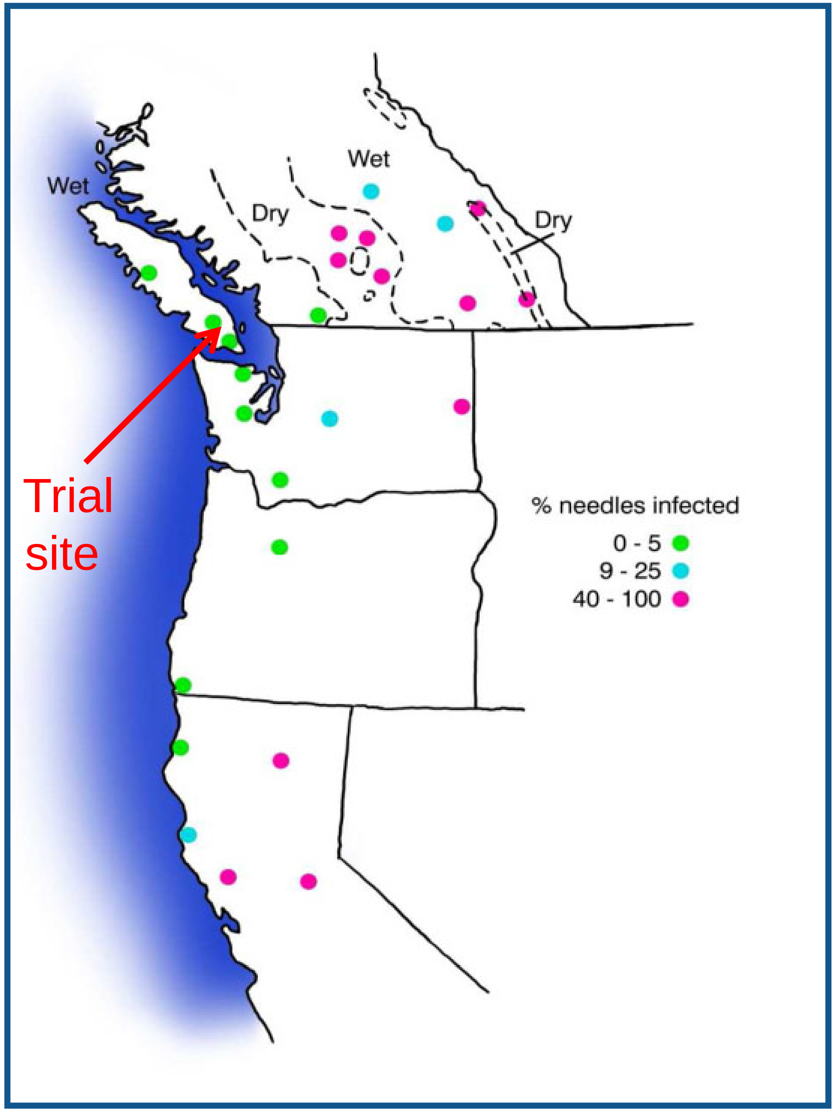

Infection on provenances/clones, Cowichan Lake,Vancouver Island (Spring rainfall <110 mm)

- Natural selection for resistance
- i.e. resistance indirectly related to spring rainfall on the broad scale

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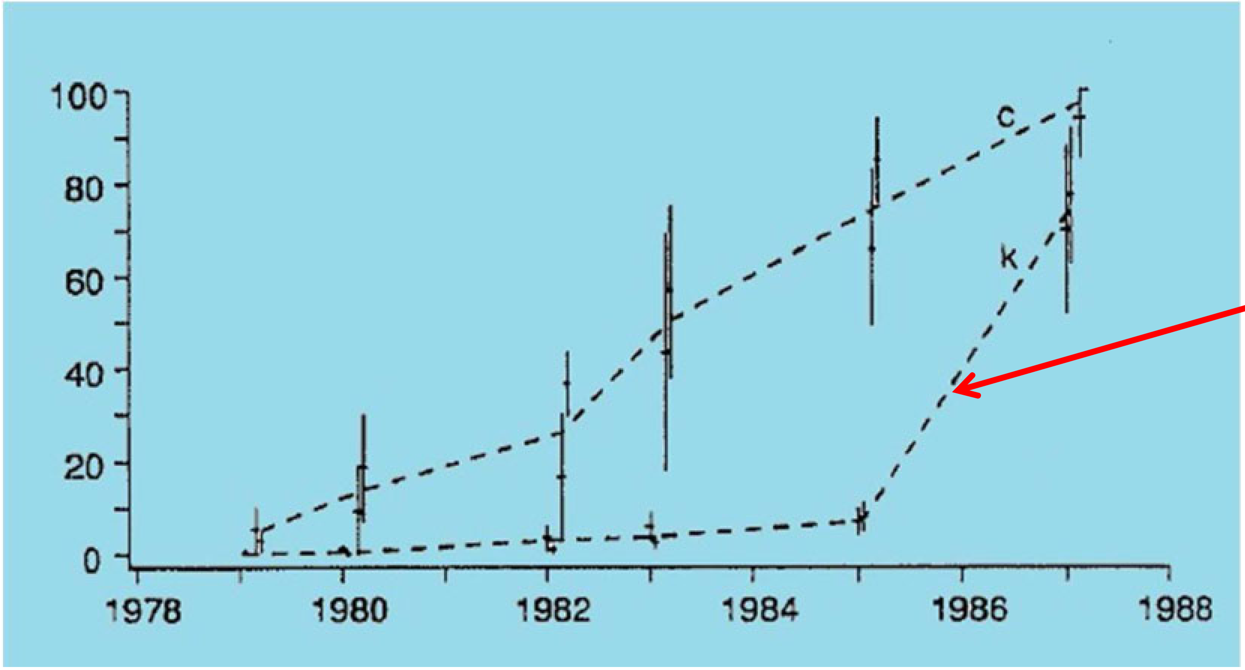
Arrival of infection at Hanmer Forest



% needles infected (means and 95% CLs)

Genuine genetic resistance (as in B.C.)

But, eventually all with high infection.

High spring rainfall (> 200 mm) allows inoculum pressure to build up?
Phenotypically over-rides genetic resistance?

Mean % needles retained, seedlot 'k' (primary order shoots), Hanmer

Age class (years)	Plot No.	1979	1987	
4	1	58	33	*
	2	66	15	***
5	1	27	2	**
	2	21	5	***

Shoot from same crown position in one South Island tree, 8 years apart

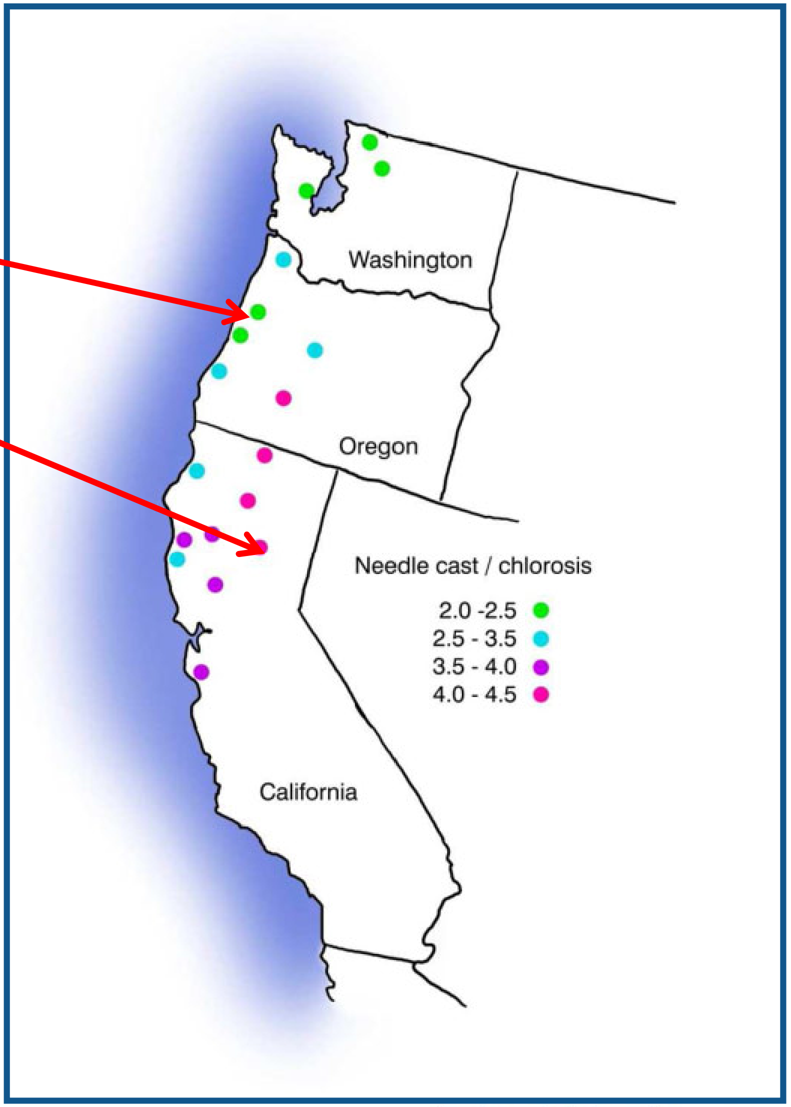
August 1979; natural infection, trace only

August 1987; natural infection, 90%

But despite high infection significant tolerance occurs (variation in foliage retention)

1959 provenance trial – early (1970) SNC survey with Mile Wilcox

Rotorua site, 11 years old; Willamette, Or (left) and Inskip, Ca (right)



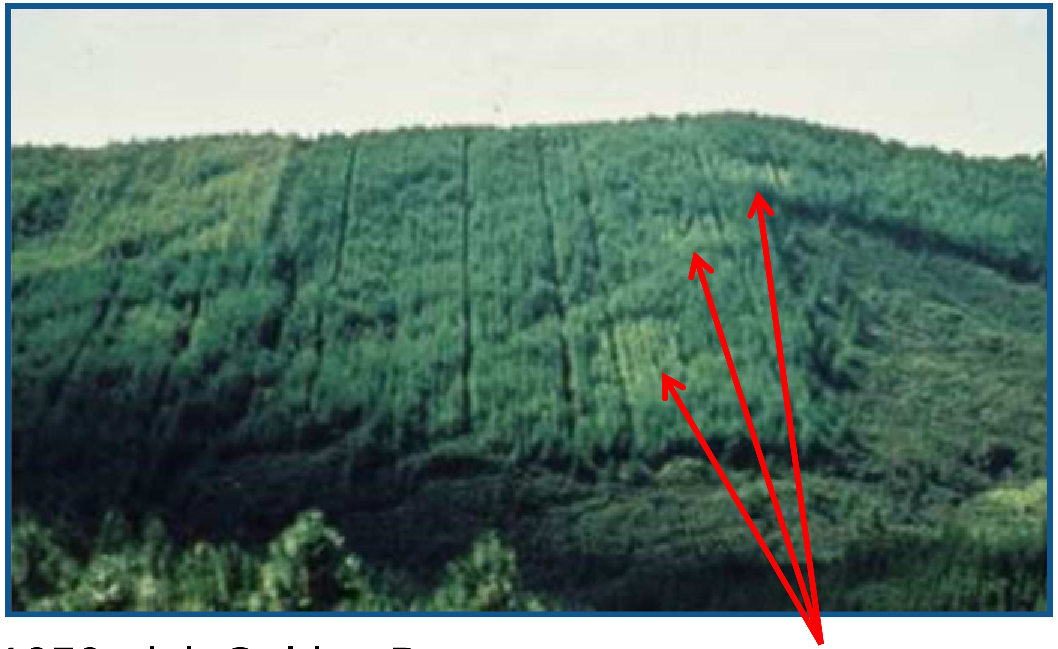
- Wa and Or provenances were healthier despite heavy infection (more tolerant)
- Best growth by coastal California ‘fog belt’ provenances
- Significant within-provenance variation in needle retention/chlorosis

Phenotypic tolerance even among the better provenances (age 13 years)

Six coastal Oregon and California provenances (2-year-old needles)					
Site	Near Tokoroa			Hanmer	
Infection (0-3 scale, all provenances)	3 (high)	NS		0.1 (trace)	NS
% needles retained (individual provenances)	72	a		79	a
	68	a		85	a
	62	a		78	a
	57	ab		80	a
	43	bc		80	a
	40	c		79	a

Genetic selection offers the best answer to Swiss needle cast.

More on this from
Heidi/Mari/Charlie et al.



1959 trial, Golden Downs Forest (ca. age 13yr)…

Very susceptible provenances

...and in Gwavas Forest (ca. age 11yr)

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5. Latest research

(1) A growth impact study

(Leith Knowles, Mark Kimberley, Ian Hood,
Dave Palmer and others).

Aims:

(a) relate the known arrival of *P*. *gaeumannii* at each forest to subsequent growth decline due to SNC

(b) map the growth loss regionally to assist growers in optimum siting of Douglas fir plantations

(2) A collaboration between Scion and Oregon State University

(2005-2008, Jeff Stone, Mike Watt, Ian Hood, Dave Palmer and others).

- Two surveys (two years apart)
- Evaluated infection and needle retention
- Sites throughout New Zealand
- In young stands of the same host genetic material as far as possible.

Aims:

(a) to examine the relationship between SNC and climate factors in order to:

- (i) validate it by comparing with a similar association determined in Oregon
- (ii) to use this information to predict and map for growers the best sites for establishing Douglas fir.

(b) investigate the genetic makeup of the *P. gaeumannii* isolates from these sites to understand the nature of the pathogen population in New Zealand.

Both these projects ran very successfully.

Much new solid information that will require a separate presentation!

Thanks to many people who assisted in field and laboratory, to forest staff and companies, and to a number of funding sources, all too numerous to name individually!

END

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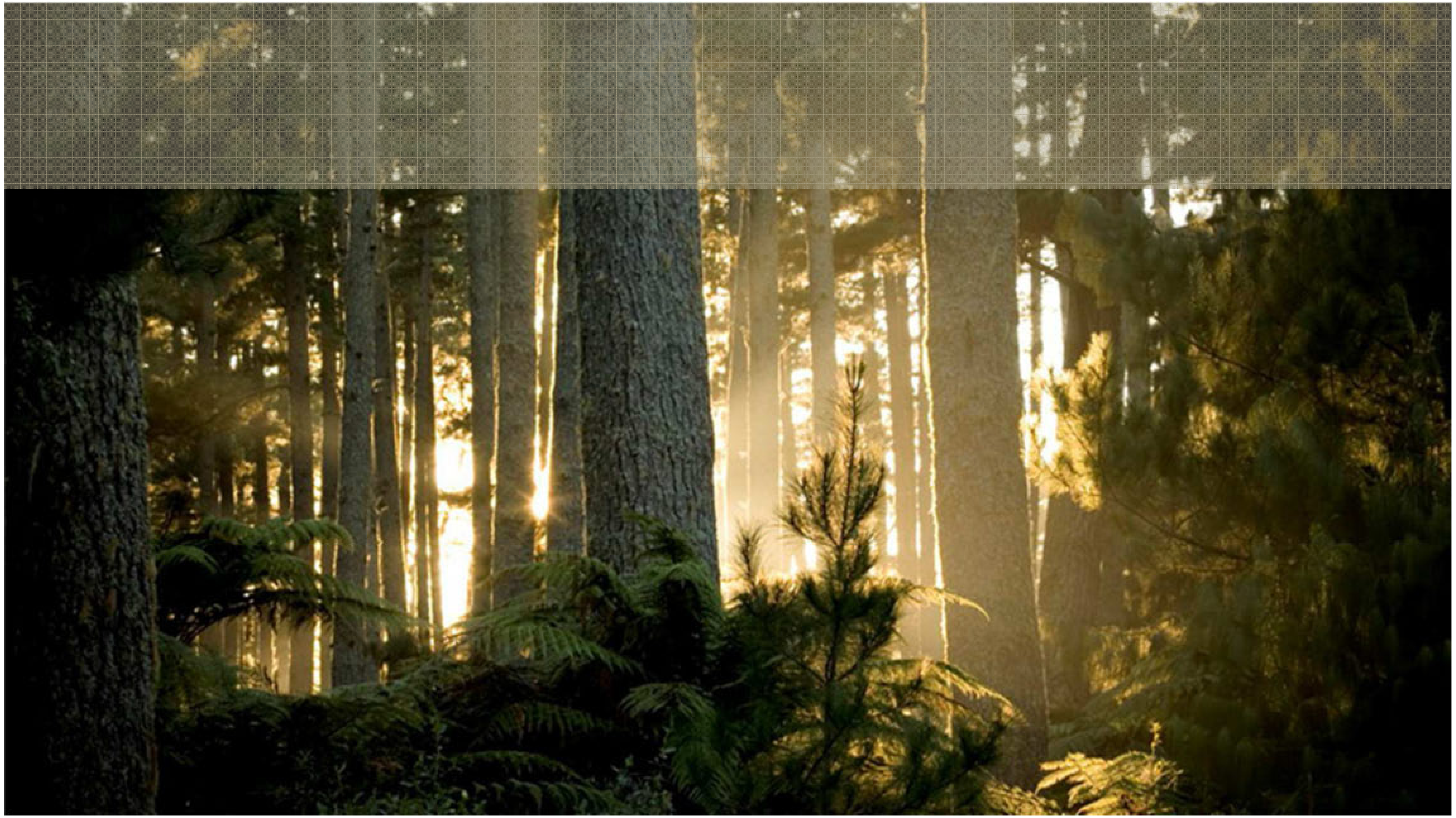
Climate and Swiss Needle Cast

Michael Watt, Mark Kimberley, Jeffrey Stone, Ian Hood, David Palmer



Introduction

- Climate is an important environmental determinant of pathogens and disease

- Pathogens and disease responsive to environment vs. trees

- Swiss needle cast important foliage disease of Douglas-fir

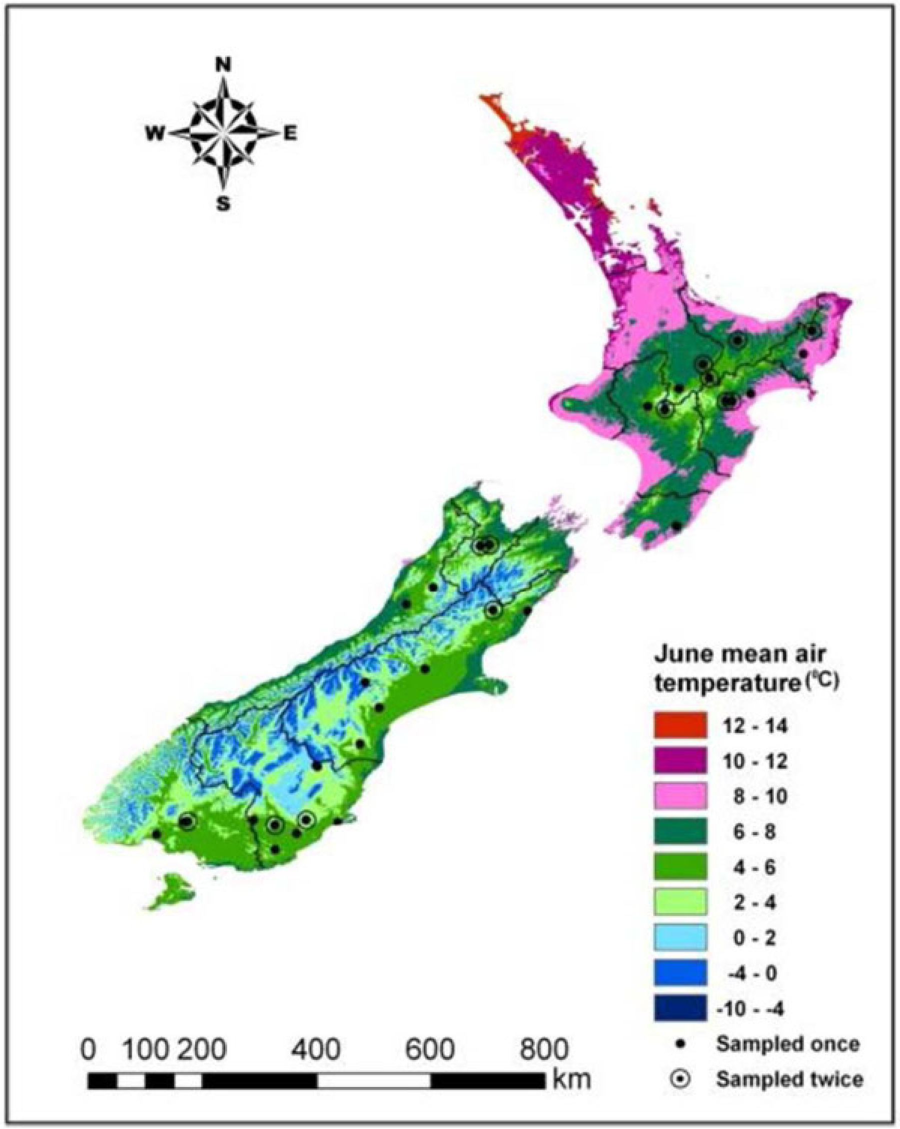
- SNC shown to cause average volume reductions in Douglas fir of 30% but the severity ranges widely

Objectives

- Model and map how climate affects colonisation index of *Phaeocryptopus gaeumannii* and needle retention for Douglas fir
- Utilise arrival year data and growth data to test whether a change in growth rate could be detected as, or soon after SNC became established
- Test whether climatic factors had any modifying effect on the growth loss caused by the arrival of SNC

Methods

- Samples from 34 sites
- Plantation age 10-15 years
- 10 of 34 sites part of Douglas fir trial series
- Three seedlots represented:
  - Fort Bragg
  - Coastal Oregon
  - Washington



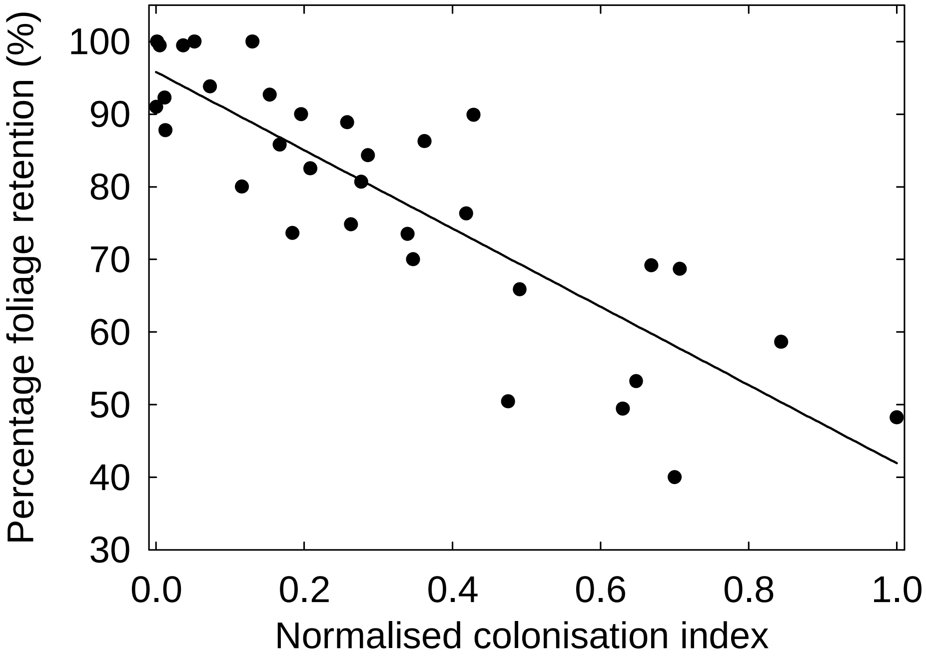
Measurements

- Colonisation Index
  - The proportion of stomata blocked by fungal fruitbodies of the last two age classes

- Foliage retention
  - The sum of the retention scores for the last four internodes

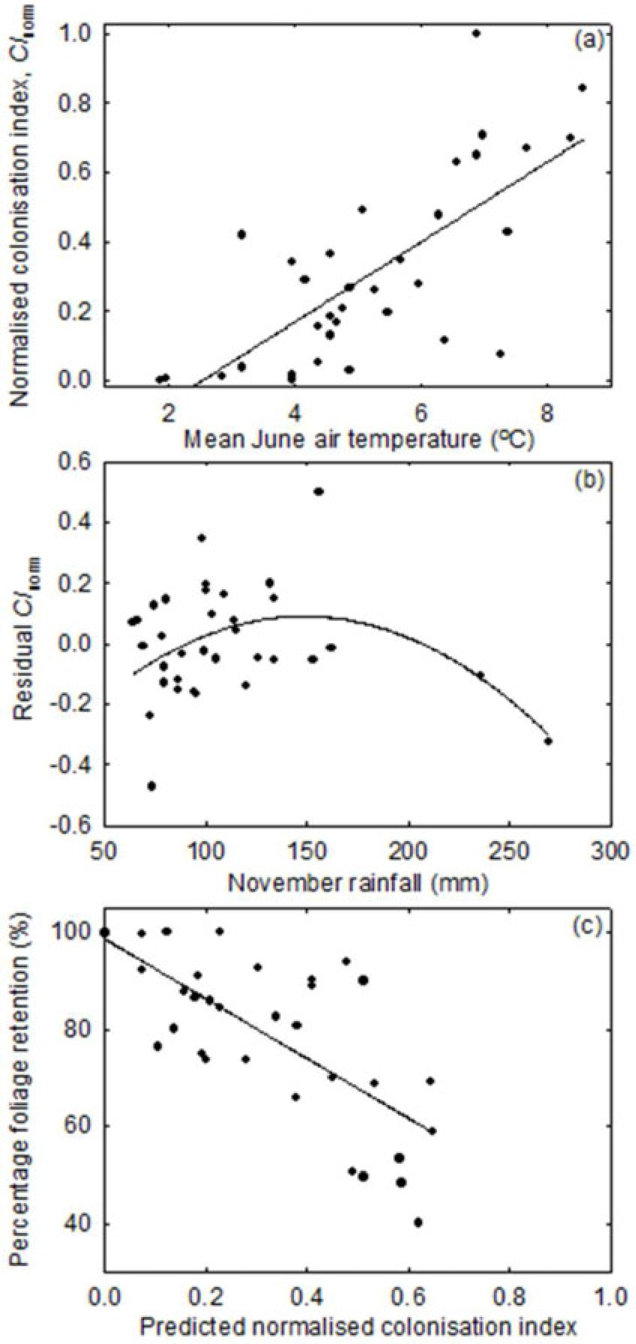
Results

- A strong relationship found between foliage retention and colonisation index

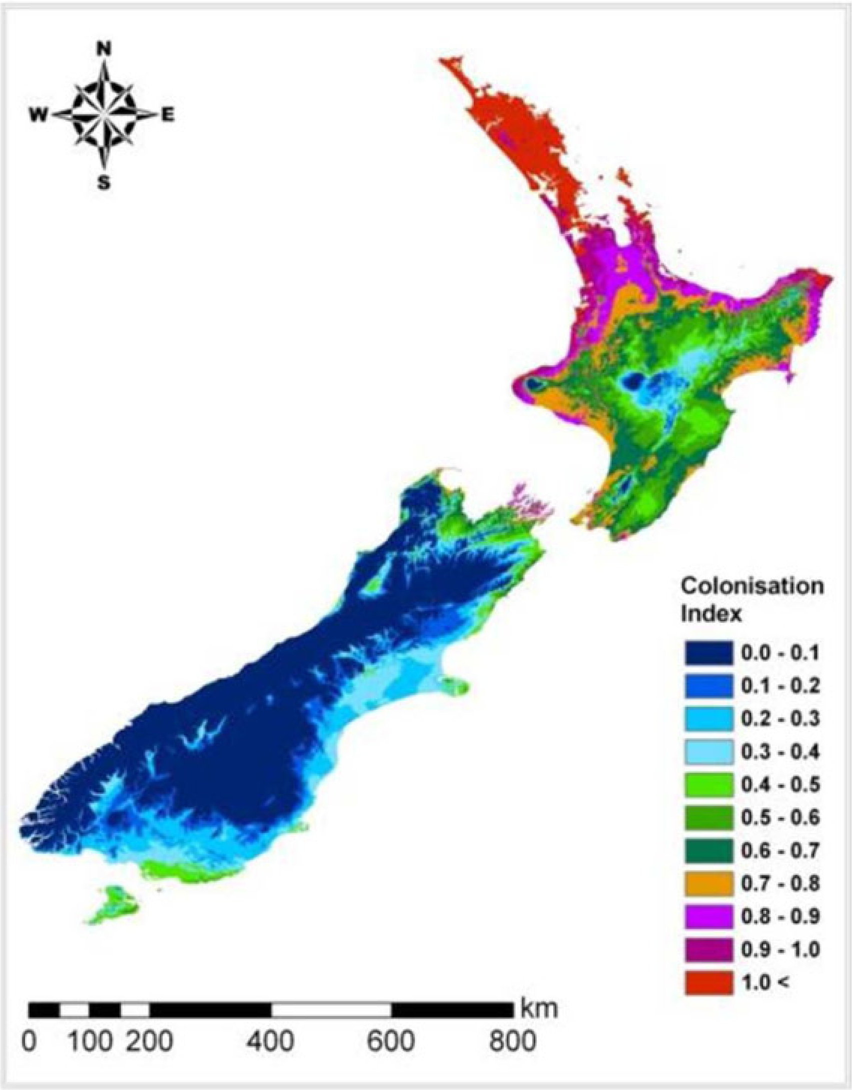


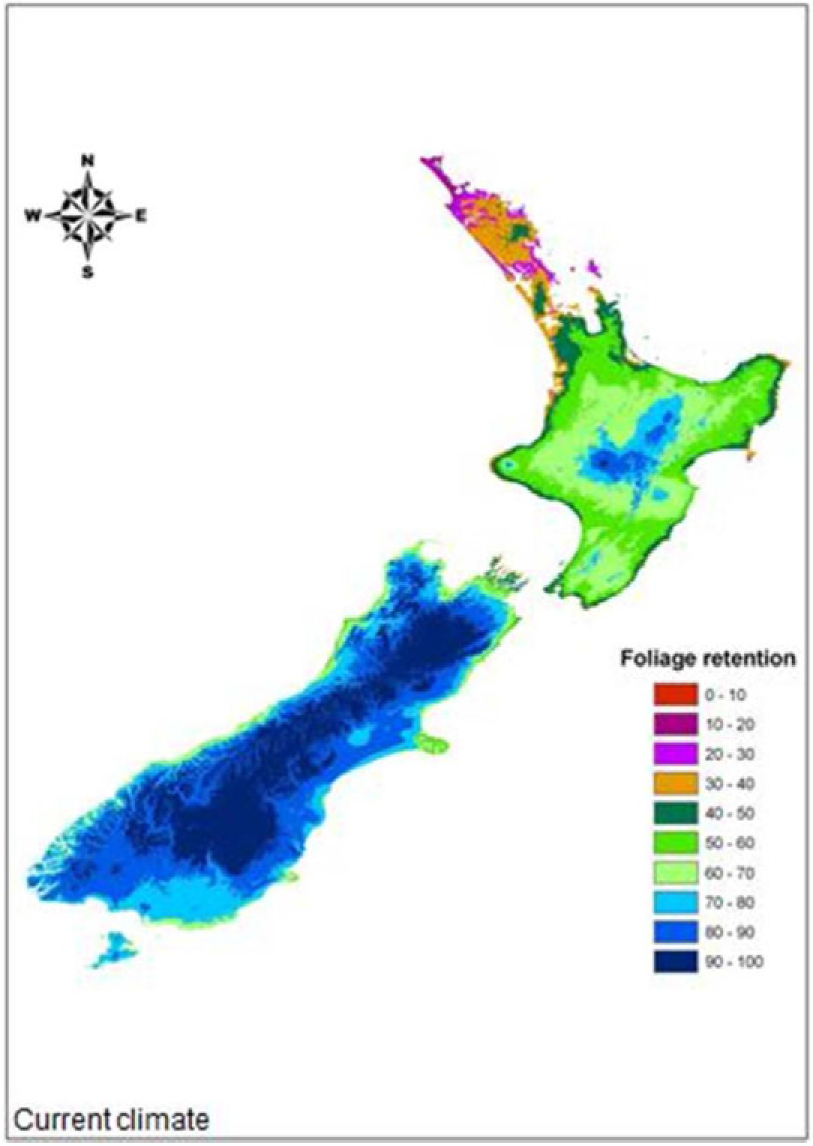
Results

- Colonisation index significantly related to mean June air temperature and November rainfall
- Predictions of colonisation index used to derive foliage retention



Maps of colonisation index and foliage retention



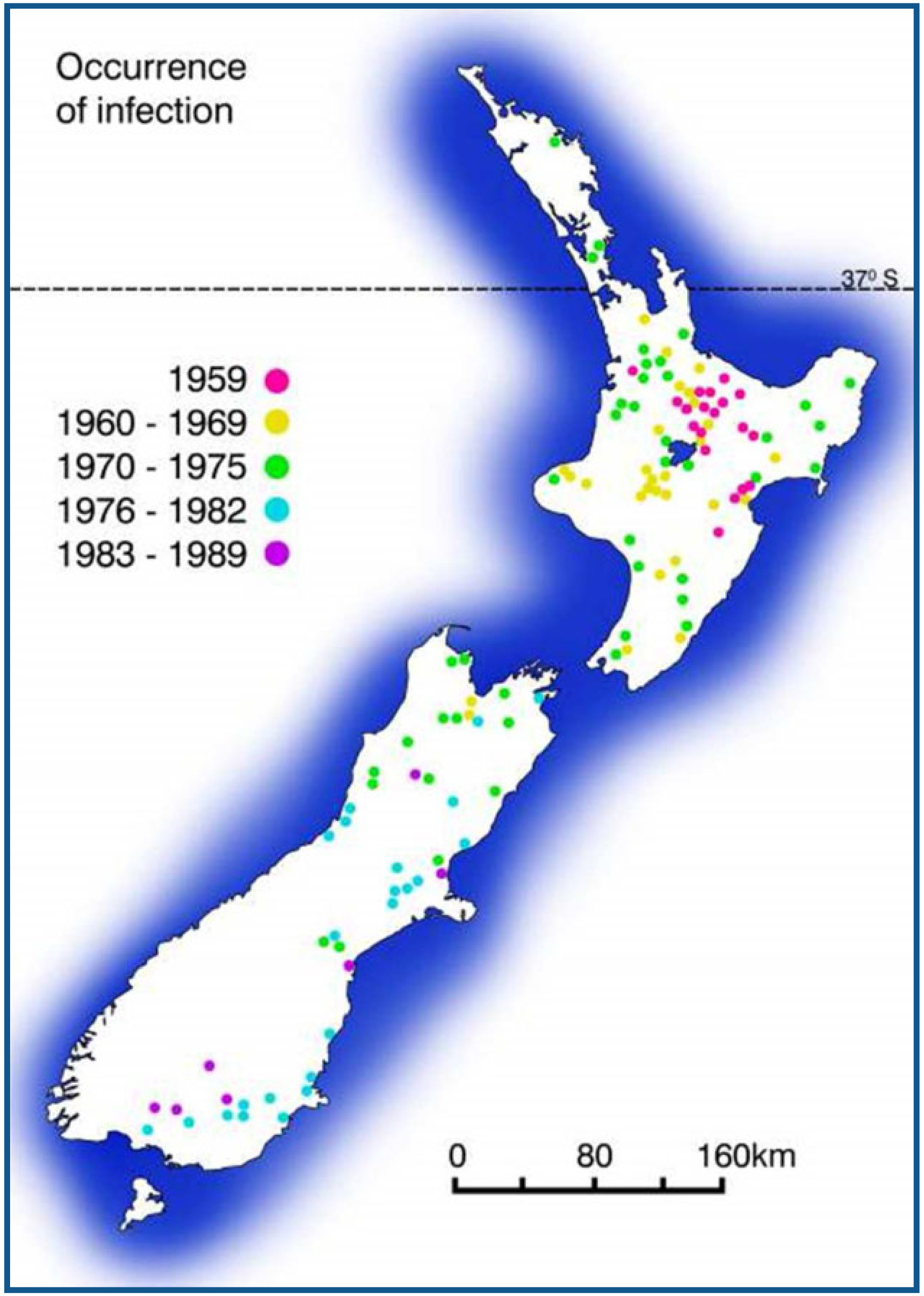


Analysis of growth loss

- Swiss needle cast was first discovered in New Zealand in 1959 and spread across the country during the subsequent 30 years
- Records of the year the disease was first observed are available for many forests in New Zealand
- Growth data from numerous PSPs covering the period are also available
- By combining these two sources of information, it should be possible to quantify the effect of the disease on tree growth

Data used in analysis

1. Records of year of first detection of *Phaeocryptopus* by forest

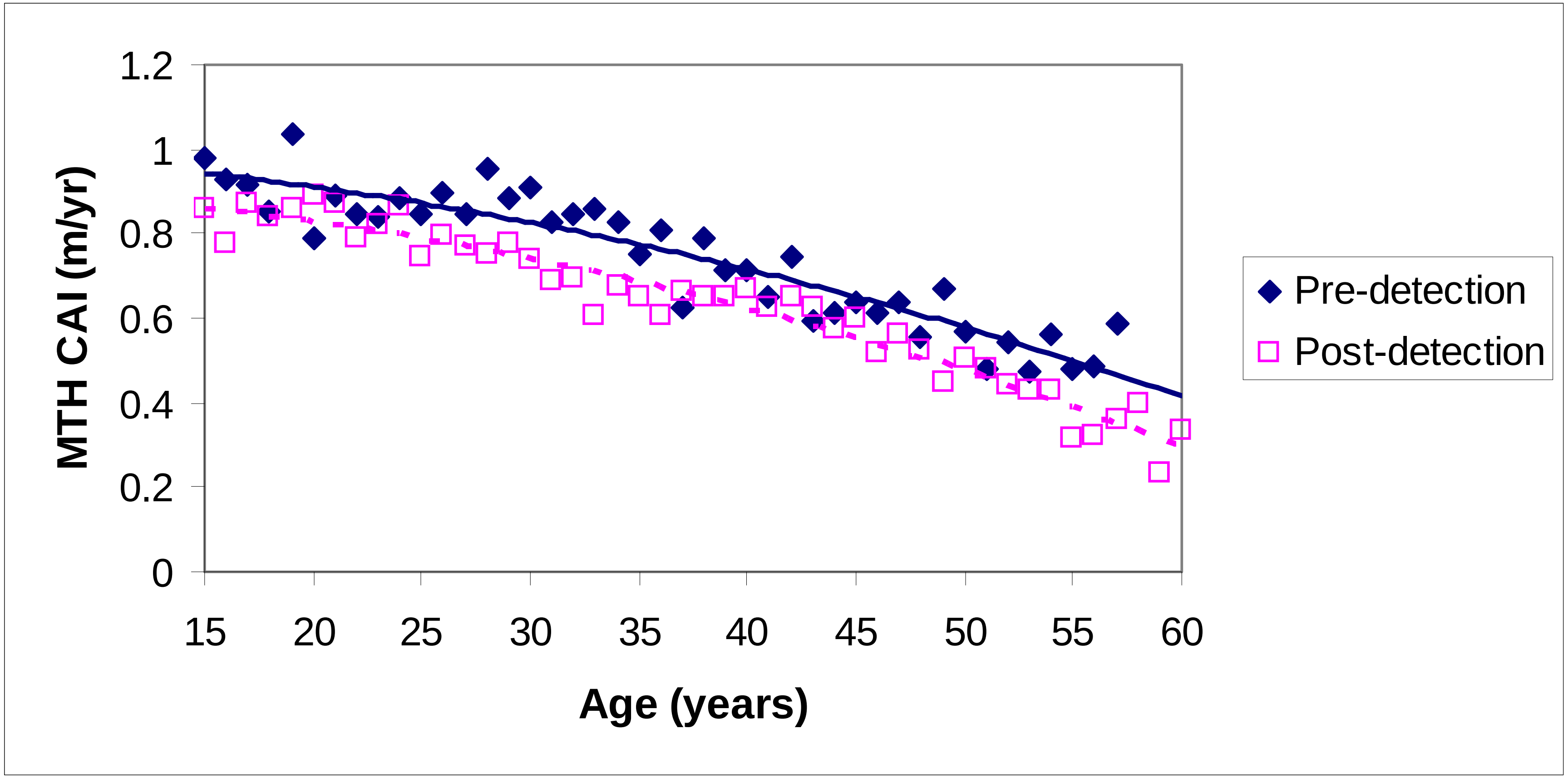


Data used in analysis (cont.)

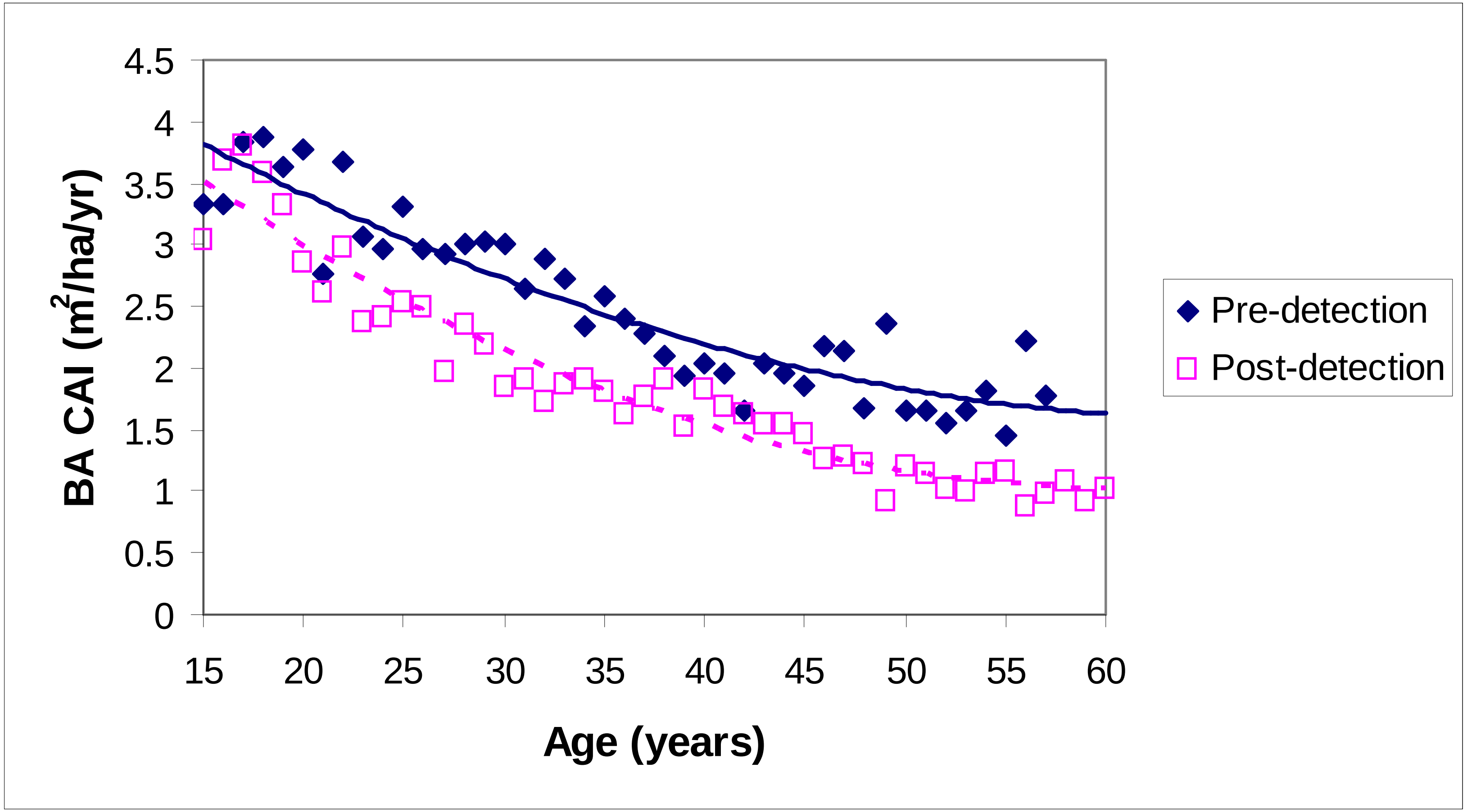
2. Growth data from PSPs

Region	No. of PSPs
Bay of Plenty	62
Gisborne	1
Hawkes Bay	2
Waikato	13
Wanganui/Manawatu	7
Nelson	57
Marlborough	7
Canterbury	55
West Coast	20
Otago	59
Southland	29
Total	312

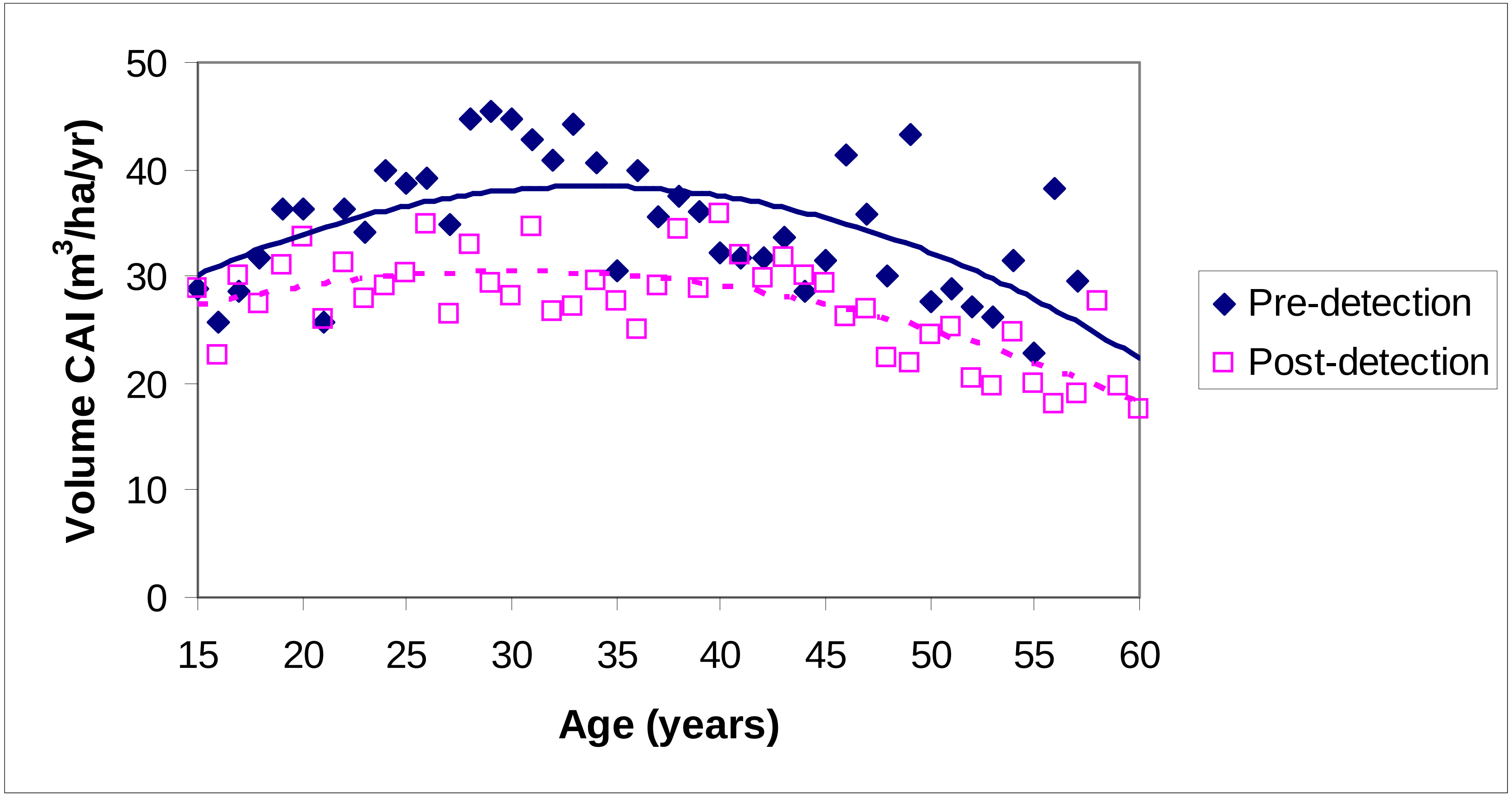
MTH growth rate (CAI) before and after infection



BA growth rate (CAI) before and after infection



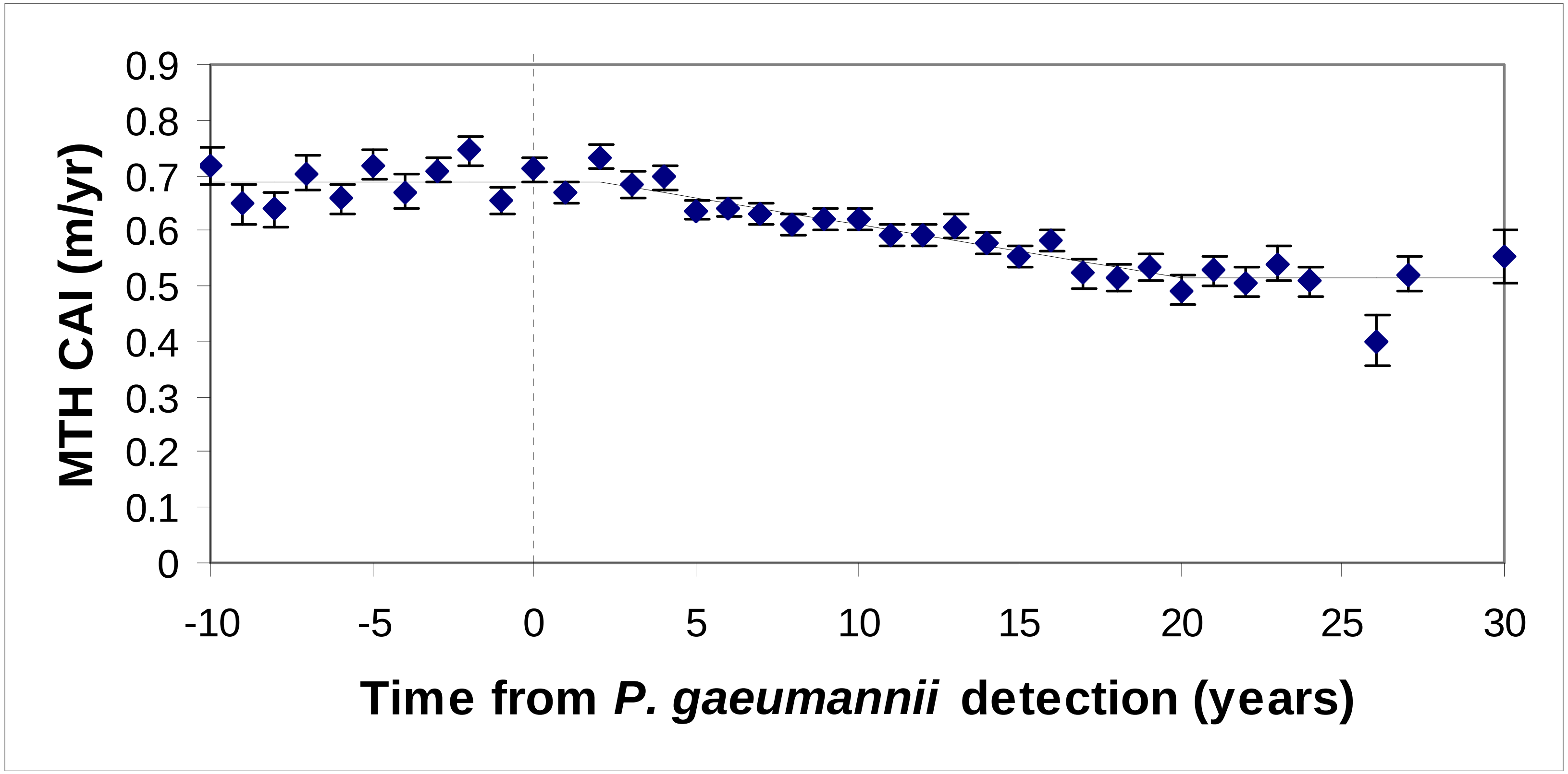
Volume growth rate (CAI) before and after infection



Analysis Methods

- For each PSP measurement increment, calculate Volume, MTH, and BA increments, and mortality
- Model these increments as functions of age, stocking, and years since arrival of disease
- Fit a change-point function to model growth decline due to the disease
- Incorporate climatic variables into the model to determine effects of climate on growth decline

Adjusted MTH CAI versus time from disease detection



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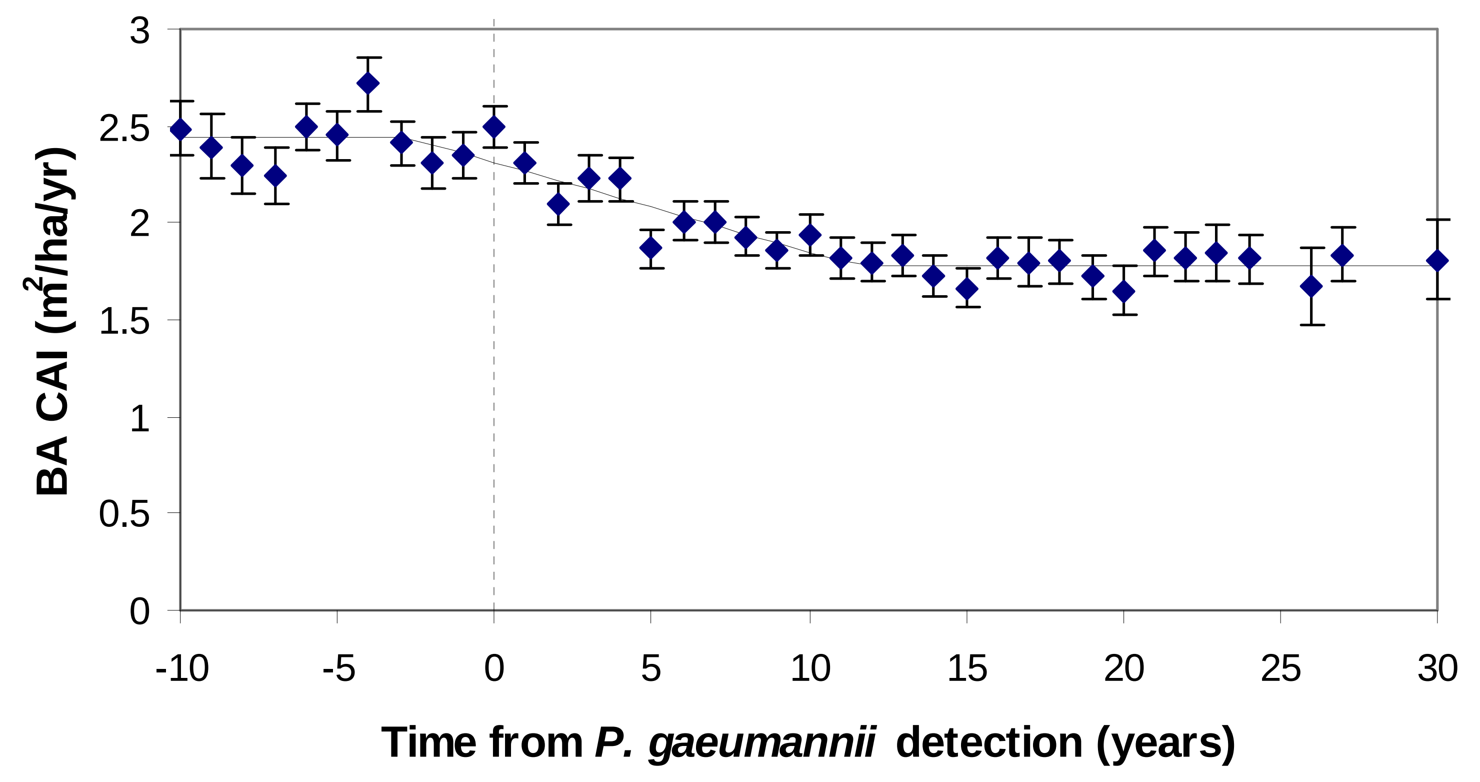
Adjusted BA CAI versus time from disease detection



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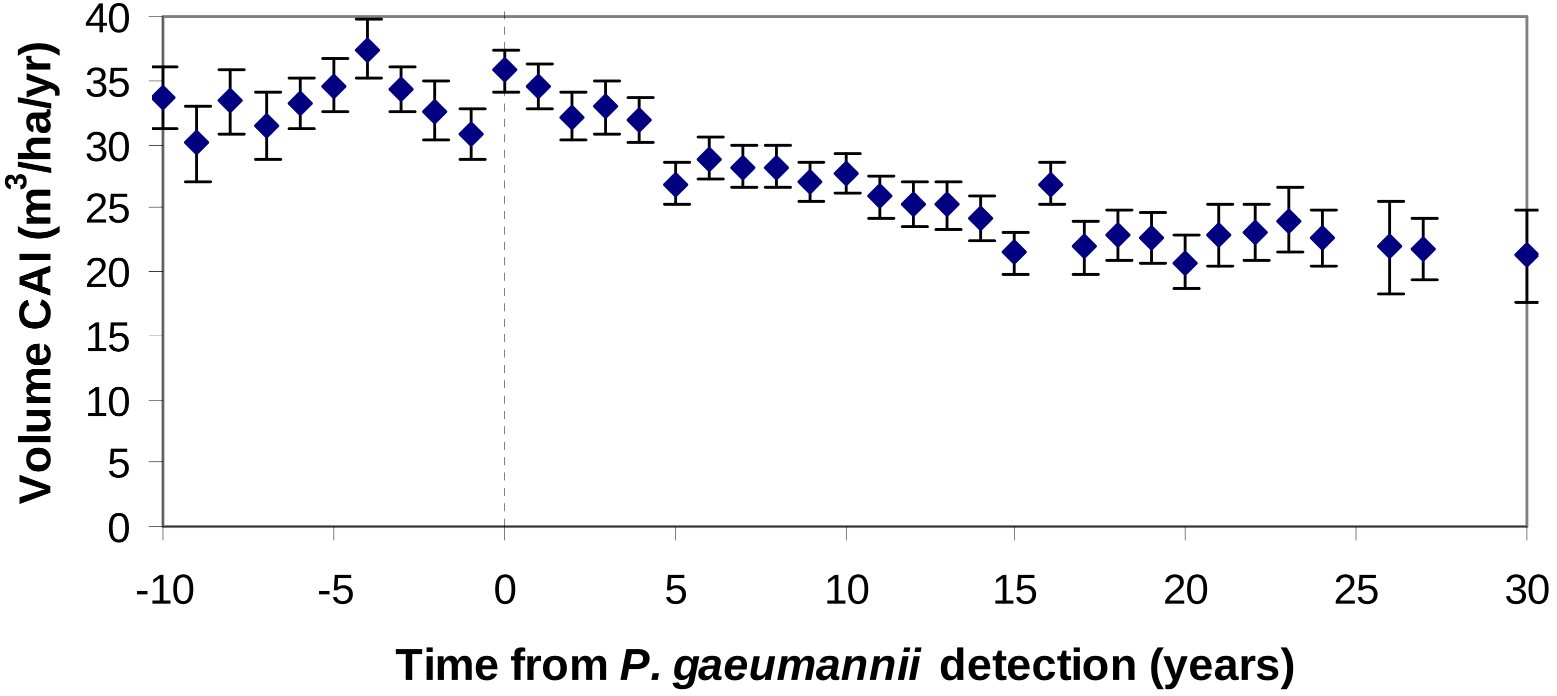
Adjusted Volume CAI versus time from disease detection



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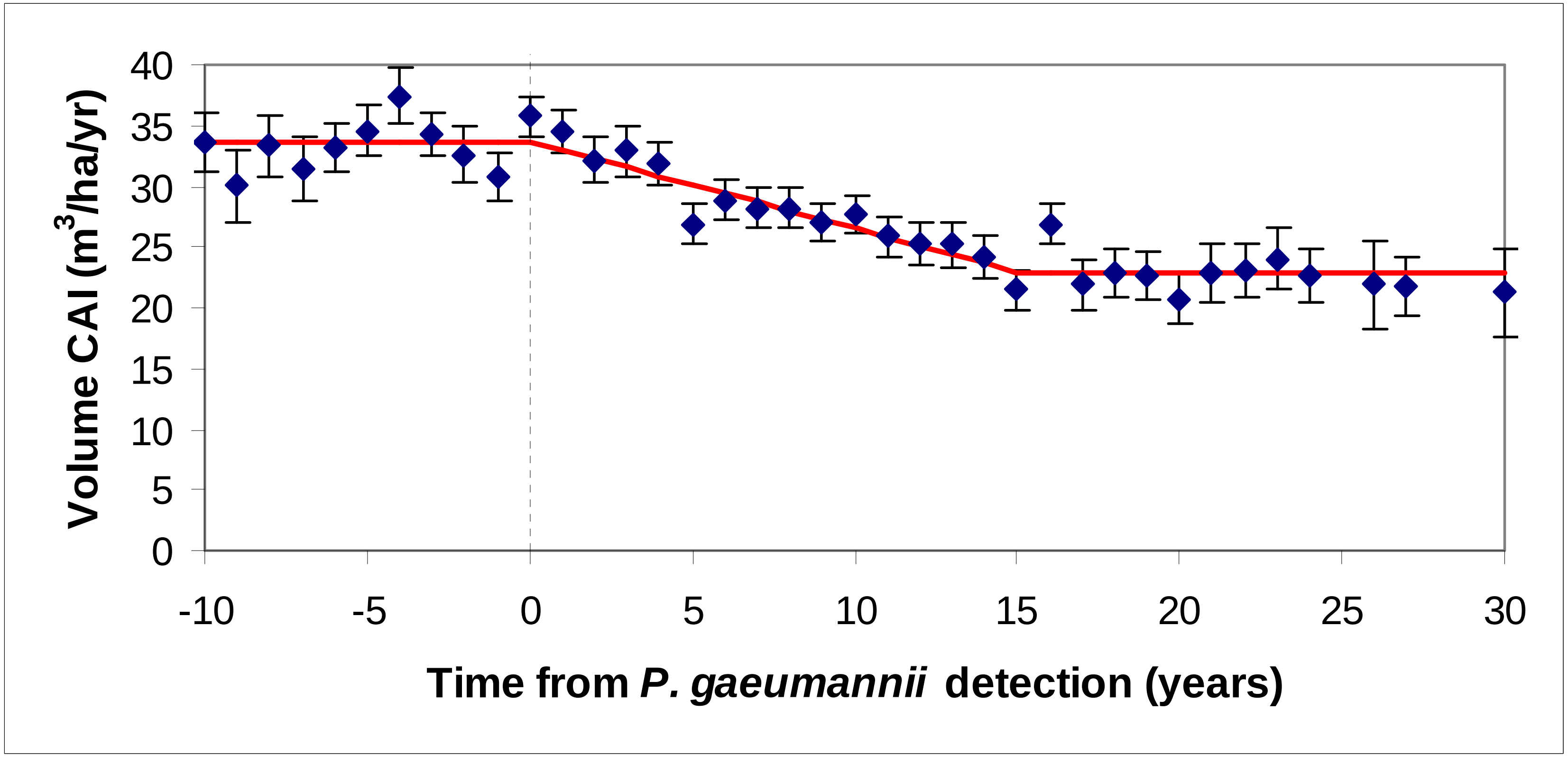
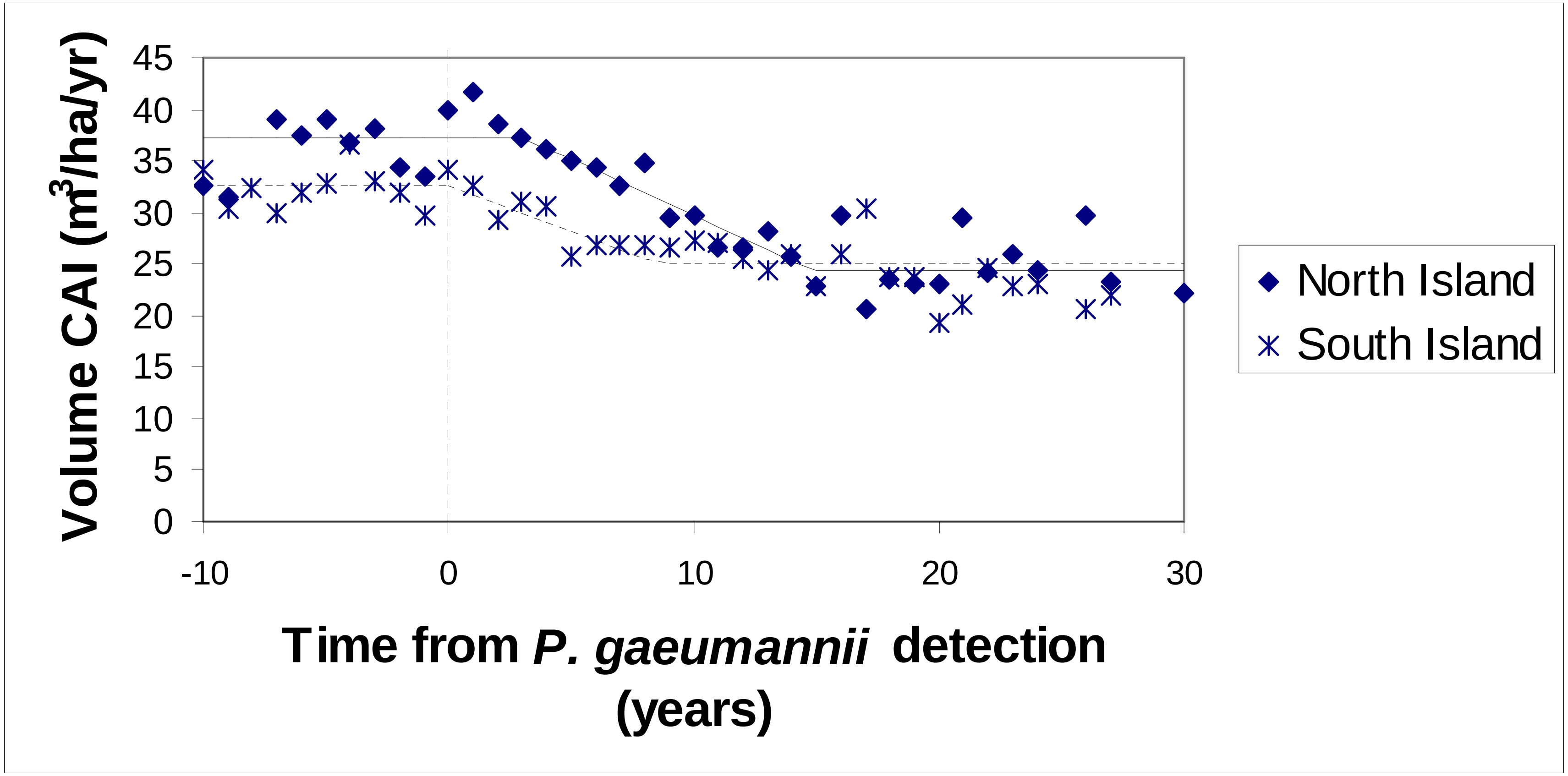
Adjusted Volume CAI versus time from disease detection



Volume CAI in North & South Islands vs. time from detection



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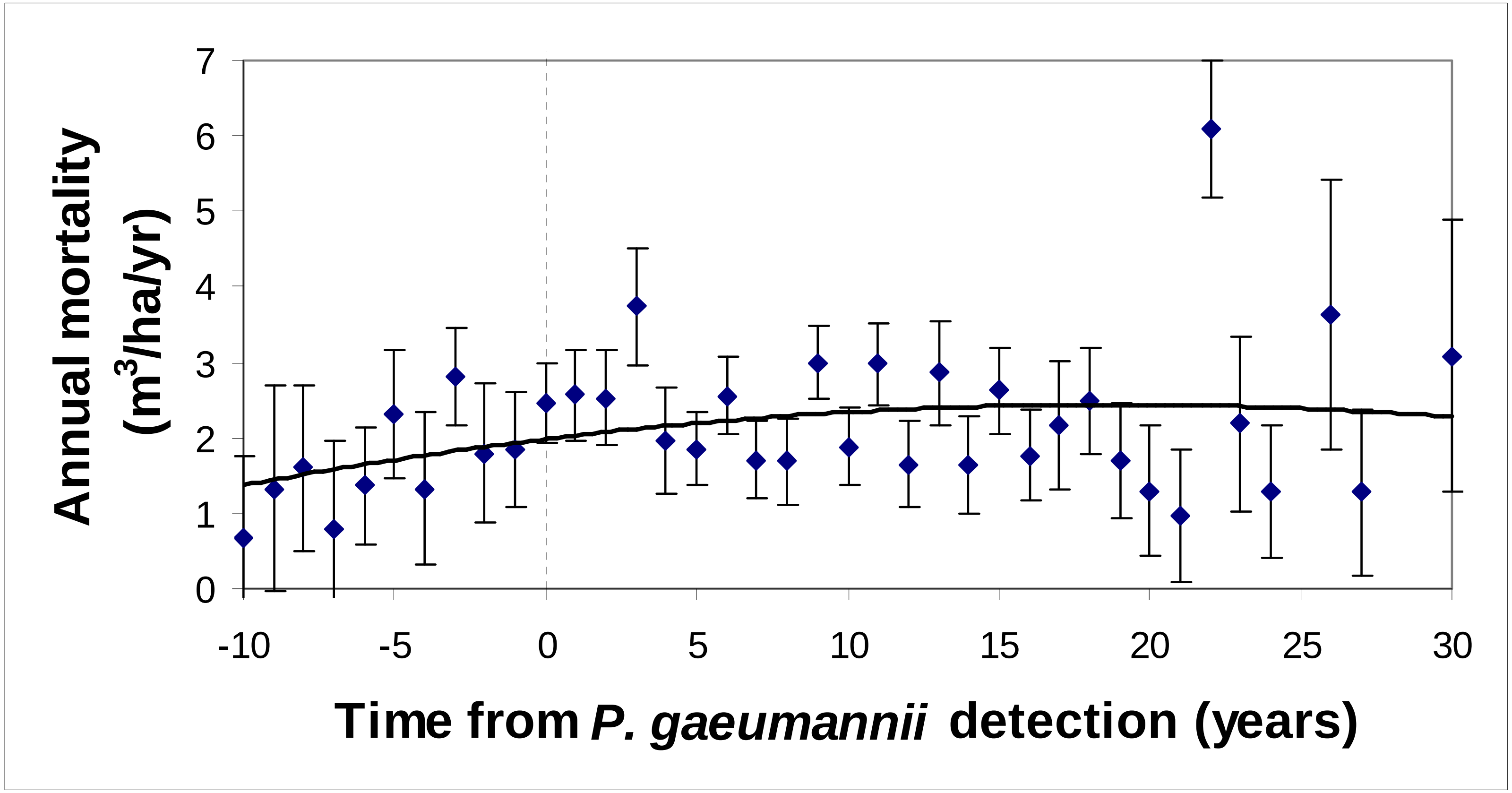
Annual mortality versus time from disease detection



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Average effect of disease nationally

- Reduction in Volume CAI of live trees of 10.7 m^3/ha/yr (from 33.6 to 22.9 m^3/ha/yr)
- Minor but statistically non-significant increase in mortality of 0.3 m^3/ha/yr (from 2.0 to 2.3 m^3/ha/yr)
- Overall, the disease reduced the growth rate of living trees but had no effect on mortality

Growth loss parameters

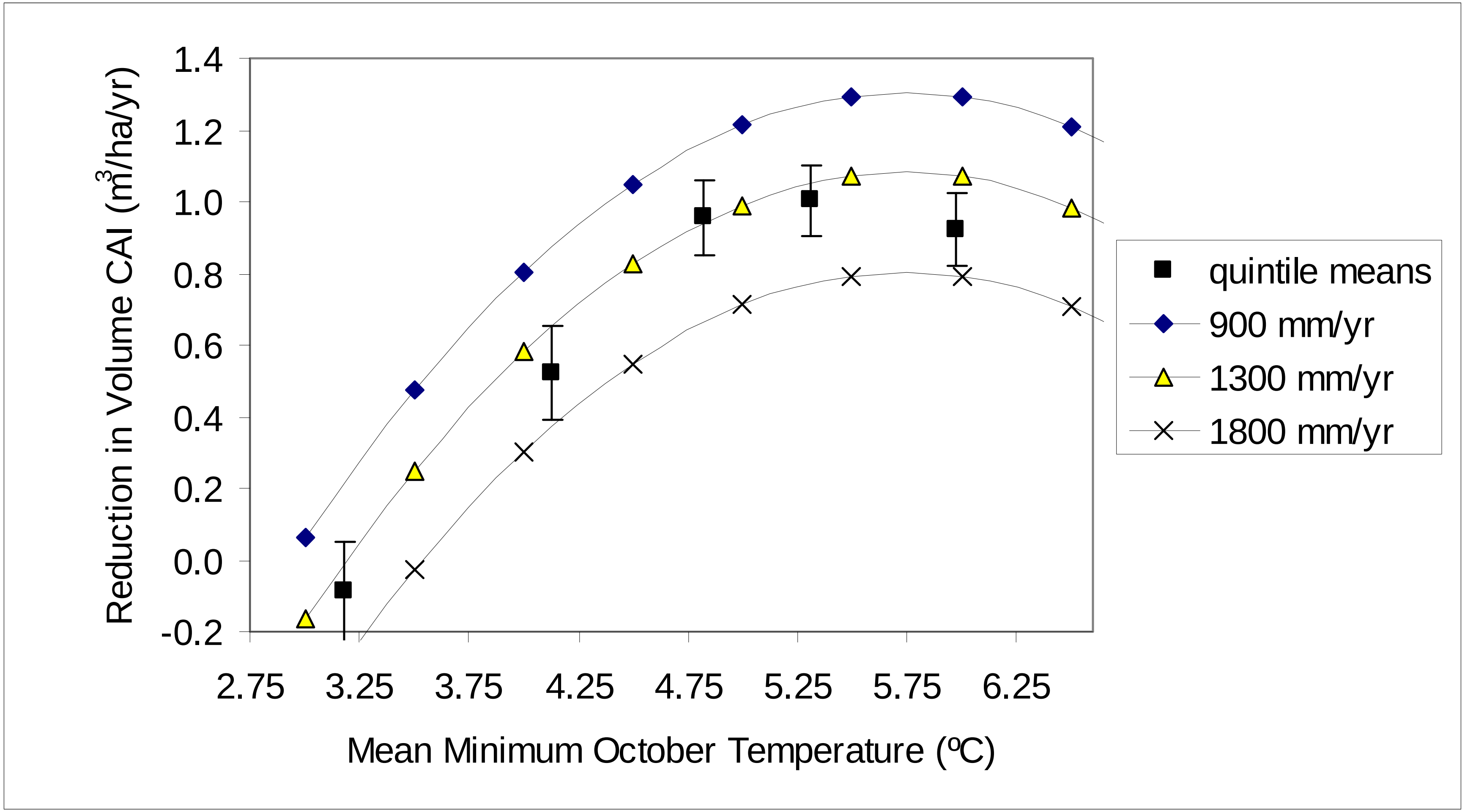
Variable	Data	Reduction %	Loss start year after initial detection	Years to max. growth loss
Volume	All N.Z.	31.9	0.2	14.9
	N. I.	34.6	3.0	11.9
	S. I.	22.9	0.1	8.4
MTH	All N.Z.	25.4	2.0	17.9
	N. I.	27.0	3.9	13.7
	S. I.	22.8	1.8	18.9
BA	All N.Z.	27.3	-2.8	14.3
	N. I.	35.5	1.3	10.1
	S. I.	19.5	-0.5	5.4

Estimated loss in NPV

Discount rate	North Island $/ha	South Island $/ha	National loss $millions[1]
4%	7000	3900	515
6%	2600	1500	193
8%	1100	600	77

[1] based on 83,000ha in S.I. and 27,000ha in N.I.

Effect of climate on growth decline



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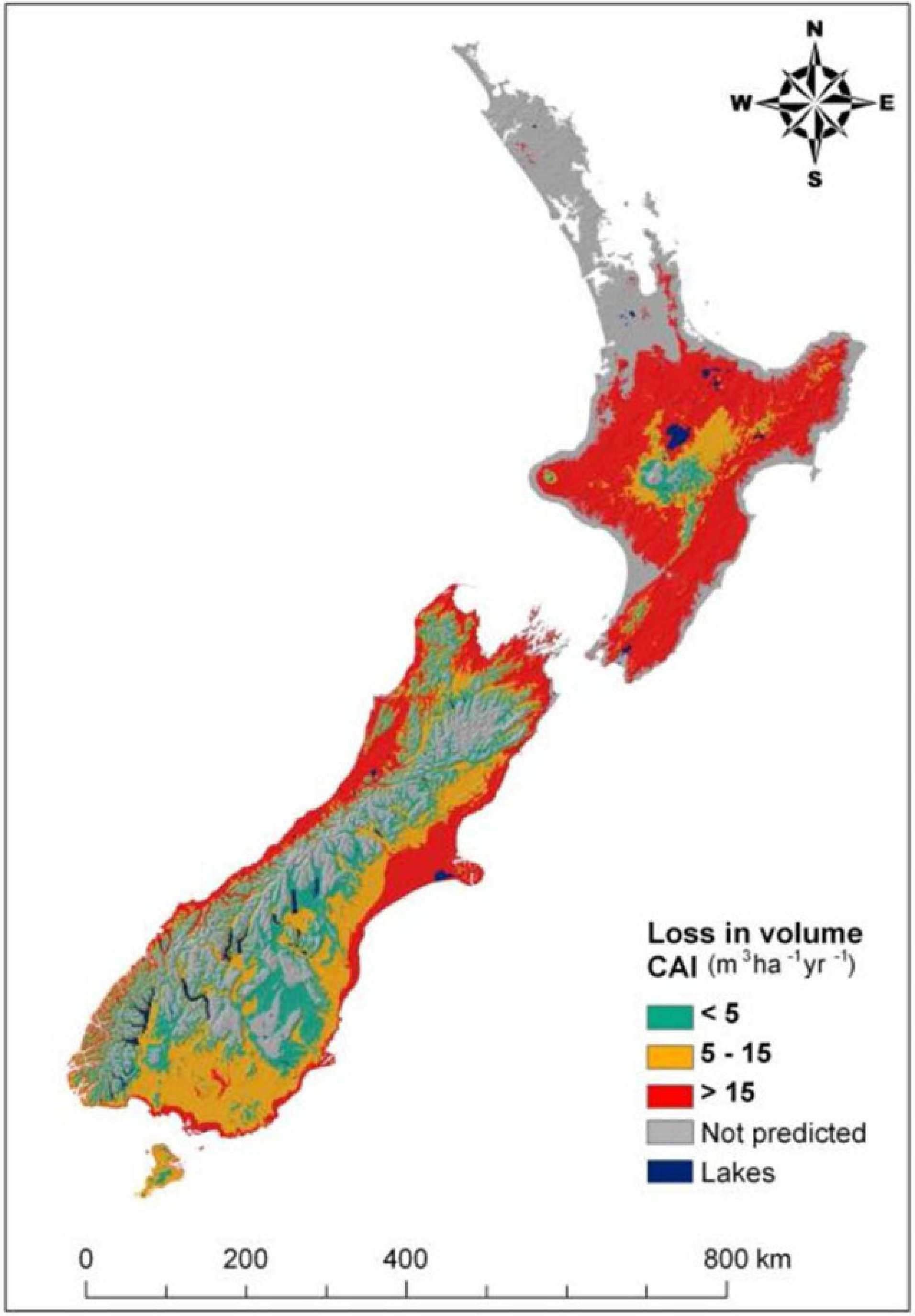
Predicted loss in volume CAI



Conclusions

- Colonisation index of pathogen and foliage retention of Douglas-fir strongly related to climate
- Air temperature during June was the key climatic factor
- Swiss needle cast affected both diameter and height growth
- There was no significant effect on mortality

Conclusions

- Growth losses equate to NPV loss of 600-7000$/ha
- Growth reduction was greatest on warmer sites with little growth loss on sites with October minimum temperature < 3.3ºC
- Despite the disease, current Douglas-fir growth rates are comparable to pre-disease levels, presumably because of the use of genotypes better suited to N.Z. conditions

Publications

Watt, M.S.; Stone, J.K.; Hood, I.A.; Manning, L.K. (2011): Using a climate niche model to predict the direct and indirect impacts of climate change on the distribution of Douglas-fir in New Zealand. *Global Change Biology 17*: 3608-3619.

Kimberley, M.O.; Hood, I.A.; Knowles, R.L. (2011): Impact of Swiss needle-cast on Douglas-fir. *Phytopathology 101*: 583-593.

Watt, M.S.; Stone, J.K.; Hood, I.A.; Palmer, D.J. (2010): Predicting the severity of Swiss needle cast on Douglas-fir under current and future climate in New Zealand. *Forest Ecology and Management 260*: 2232-2240.

Collaborative SNC project
New Zealand - Oregon

FUNDING:

FRST contract C04X0807 (Biosecurity, Protection and Risk Management of NZ Forests)

Forest Health Research Collaborative 2010-13

Future Forests Research DF1.05

Collaborative SNC project

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All the many forest owners and companies who allowed us access to their stands and plantations.

Leith Knowles, Charlie Low, Luigi Gea, Judy Gardner, Dave Palmer, Lindsay Bulman

Wendy Sutton (OSU)

Razel Blaza, Rachel Hood, Chrystal Kelly, Brenda Smith, Tim Snell, Rita Tetenburg, Travis van den Berg

AND MANY OTHERS!!

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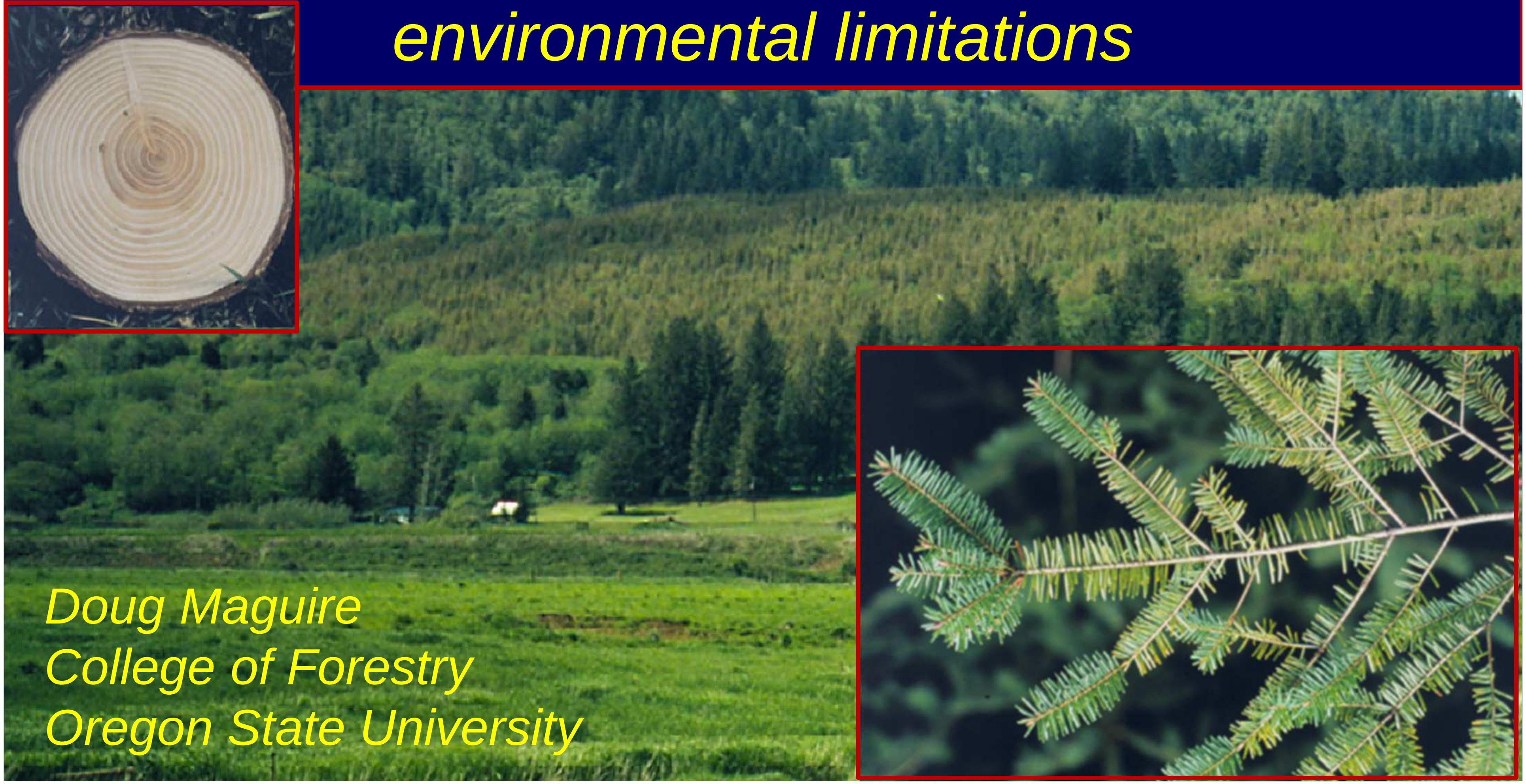
Douglas-fir silviculture in the presence of Swiss needle cast:

Relative merits of designing effective management tactics and conceding to environmental limitations



Doug Maguire
College of Forestry
Oregon State University

Douglas-fir silviculture in the presence of Swiss needle cast:

- Current status of SNC (the big picture)

- Growth impacts and silvicultural mitigation (?)

Discoloration visible from air: rough correlation with foliage retention

SNC Aerial Survey
2014

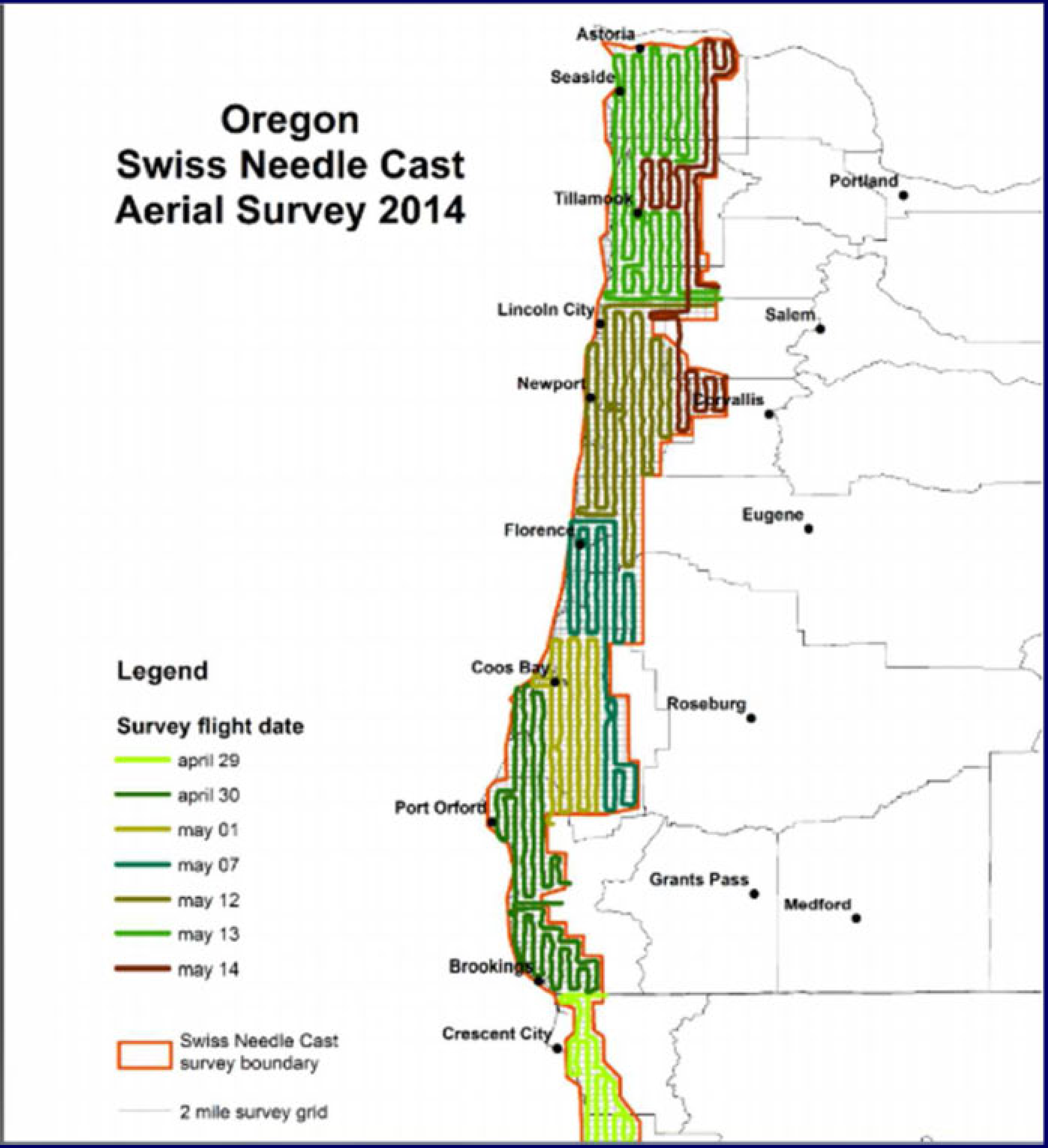
April 29, 30; May 1,7,12,13,14

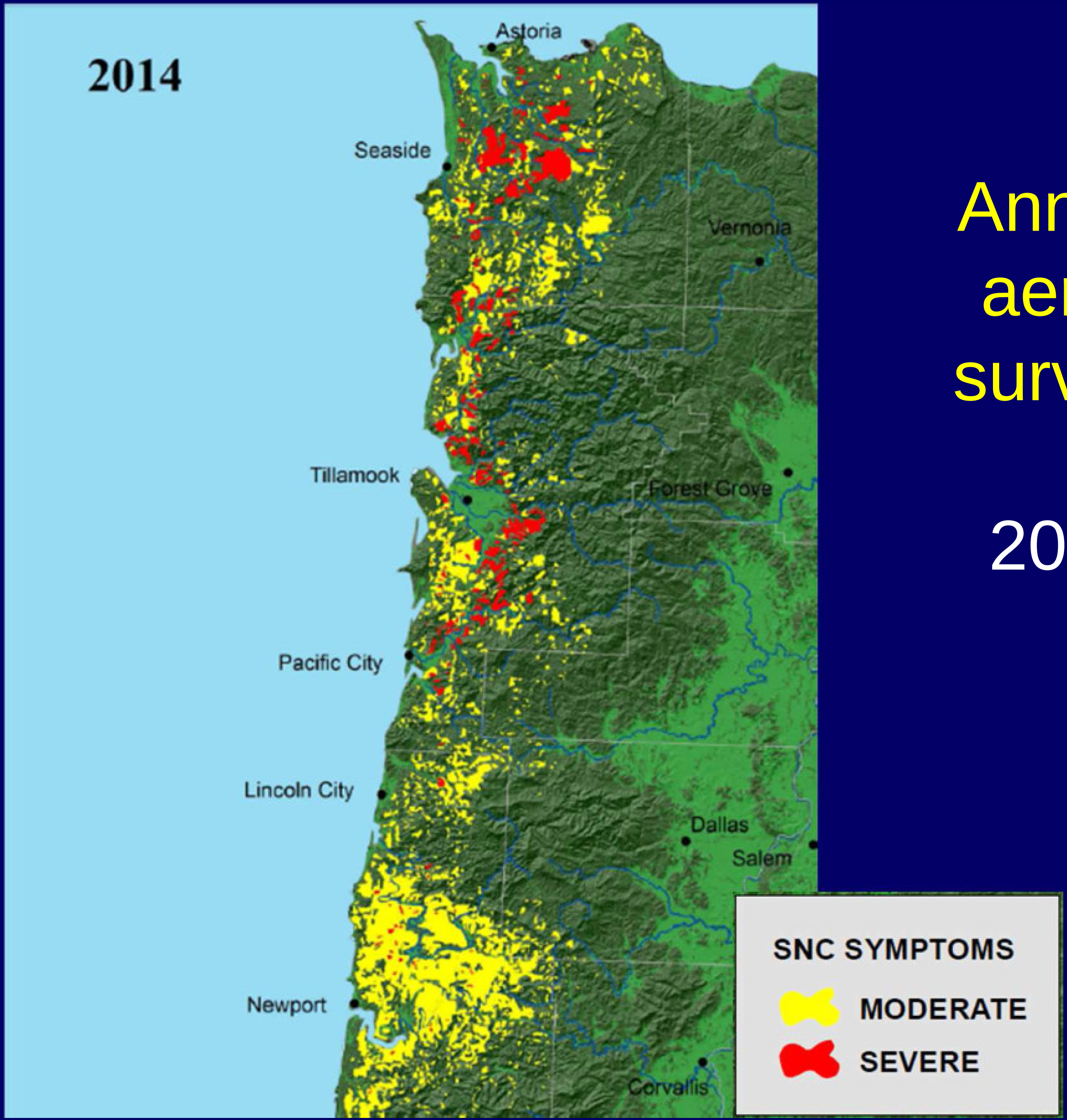
Excellent weather and symptoms during survey

Area surveyed:
  Oregon: 3,765,590 acres
  California: 778,318 acres

$20,425 (N9000V,Plane & pilot); 38 hours survey, 5 hours ferry.

Prolonged wet spring weather in preceding years (2012 & 2013)





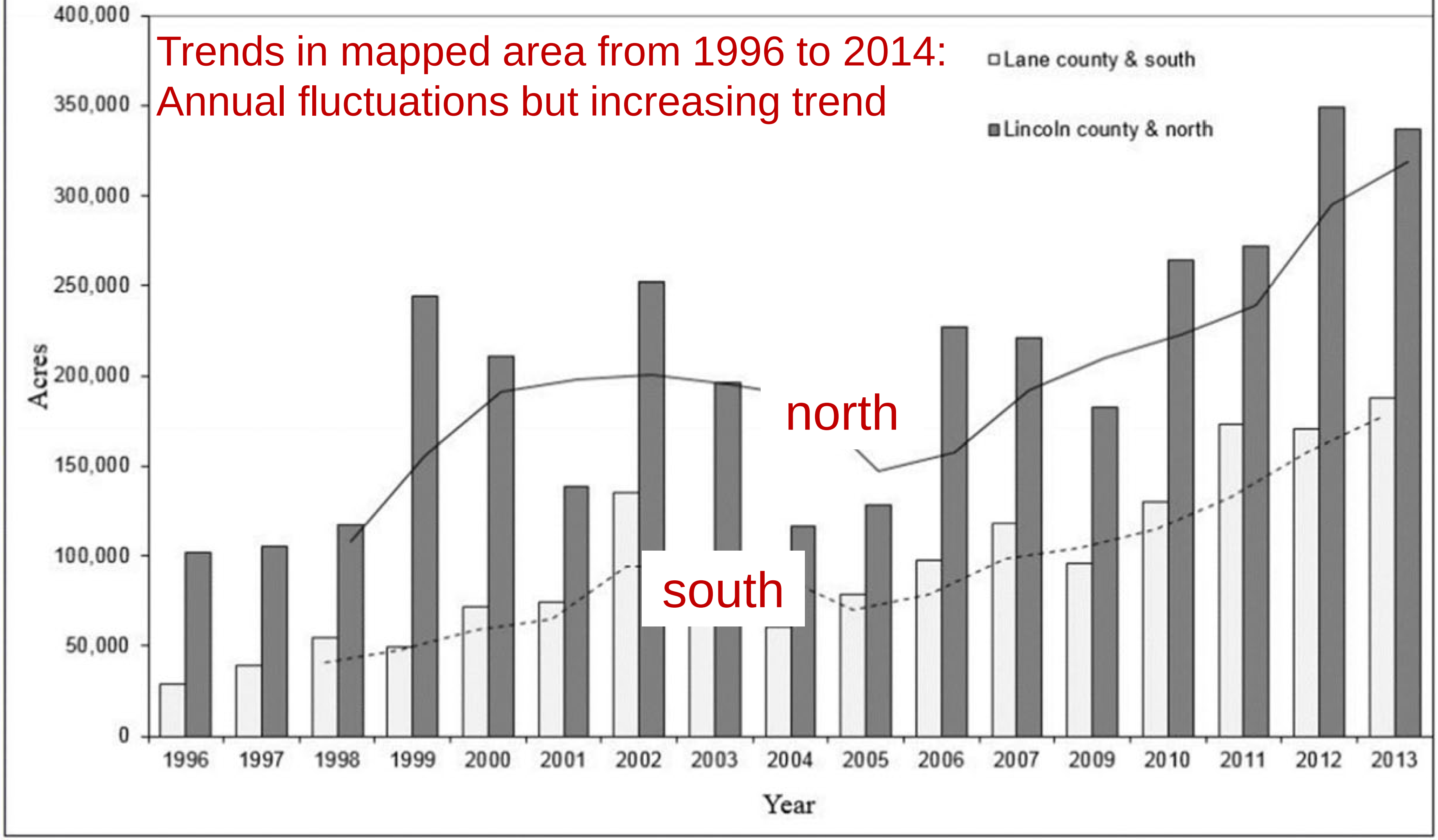
Annual aerial survey:

2014

"blast zone" or "epicenter"

Trends in SNC distribution from 1996 to 2014: Annual fluctuations and spatial shifts.

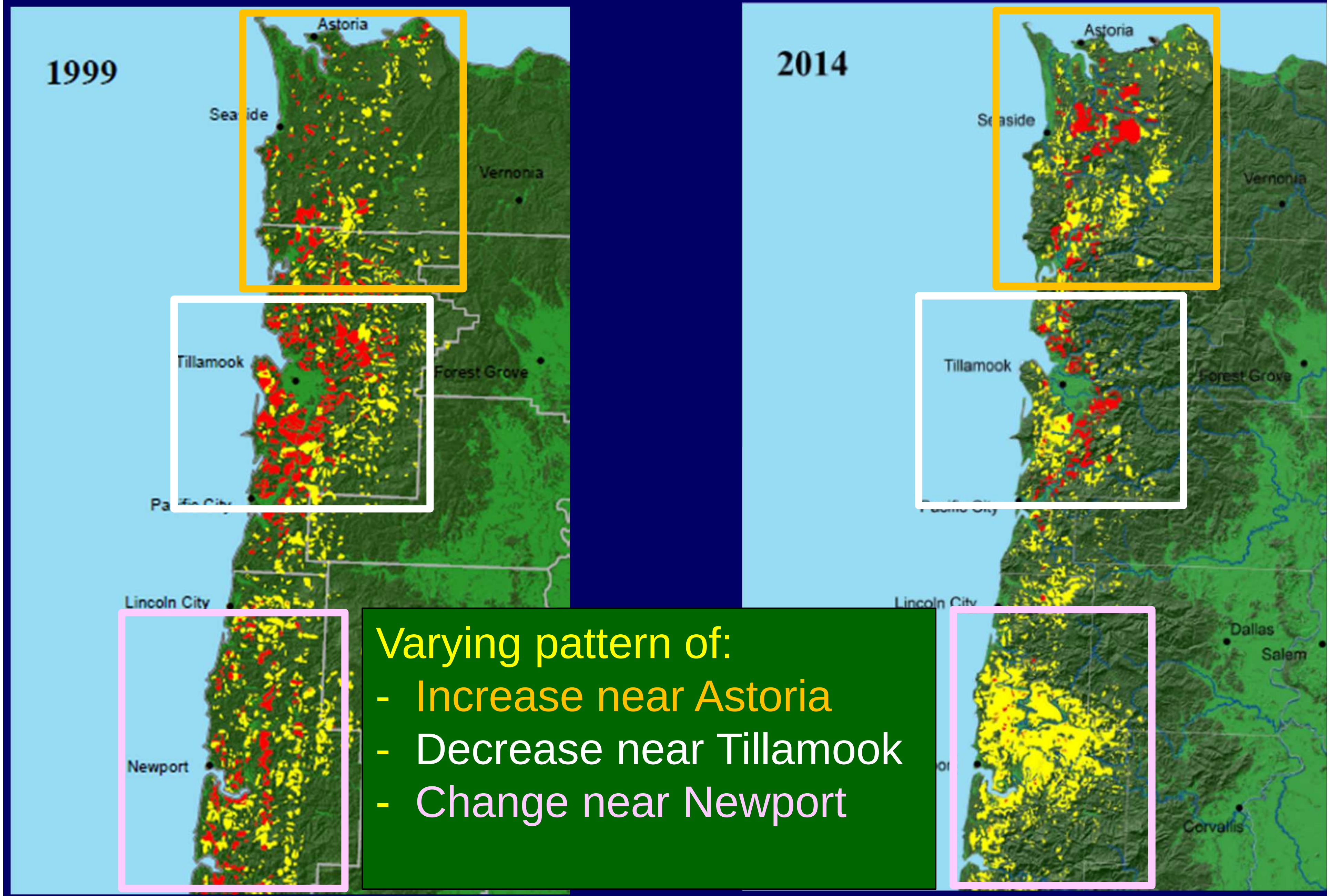
Area of Douglas-fir forest with Swiss needle cast symptoms, 1996-2014



Trends in mapped area from 1996 to 2014:
Annual fluctuations but increasing trend

north

south



Varying pattern of:

- Increase near Astoria
- Decrease near Tillamook
- Change near Newport

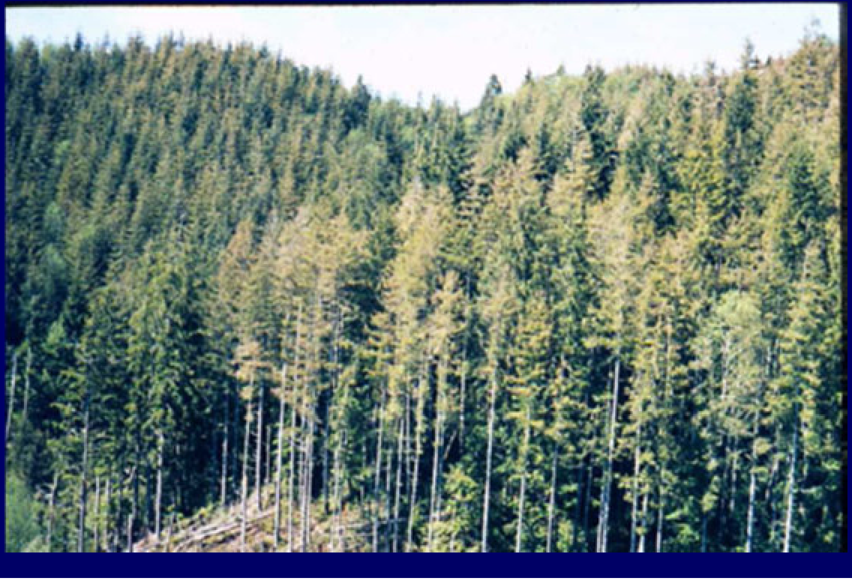
Douglas-fir silviculture in the presence of Swiss needle cast:

- Current status of SNC (the big picture)

- Growth impacts and silvicultural mitigation (?)

Growth impacts and silvicultural mitigation

- Growth impacts
  - Growth and mortality
  - Foliage dynamics and measures of SNC severity
- Predisposing factors
  - Soil and foliar chemistry
  - Weather/climate
- Silvicultural mitigation
  - Thinning effects
  - Fertilization
  - Fungicides



Growth impacts

1) What is the growth impact of SNC?
2) Does SNC accelerate Douglas-fir mortality?
3) How best to rate SNC severity?
4) Do stands recover from SNC? Does disease severity fluctuate?
5) What tools are available for estimating SNC growth impacts?
6) Are there predisposing conditions that suggest mitigation measures?

Growth impacts and silvicultural mitigation

- What is the growth impact of SNC?
- Does SNC accelerate Douglas-fir mortality?
- How best to rate SNC severity?
- Do stands recover from SNC? Does disease severity fluctuate?
- What tools are available for estimating SNC growth impacts?
- Are there predisposing conditions that suggest mitigation measures?

Growth Impact of Swiss needle cast

Objectives

1) To establish the magnitude of growth losses resulting from varying severity of Swiss needle cast

2) To identify tree and/or foliage attributes that can serve as indices of SNC severity and corresponding growth losses

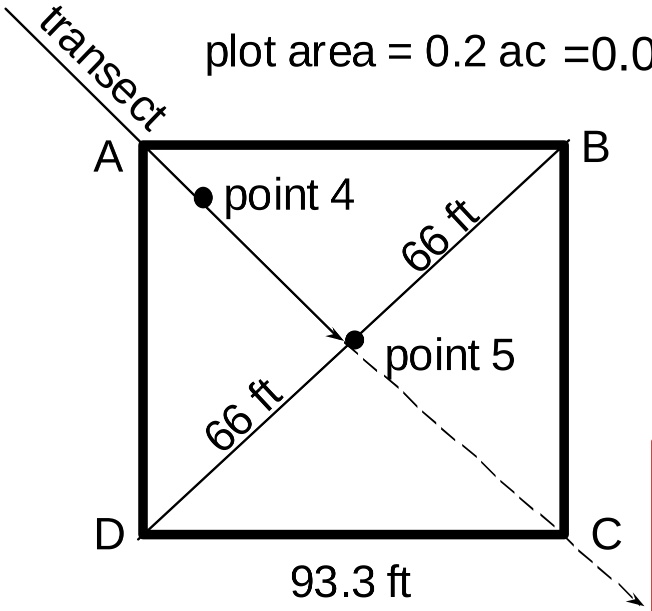
Growth Impact of Swiss needle cast

Objectives (cont'd)

3) To develop quantitative links among attributes monitored in aerial surveys, plantation surveys, and intensively measured growth plots

4) To monitor symptom severity and growth losses over time

SNCC Growth Impact Study



Retrospective

vs.

Permanent plots

Astoria →

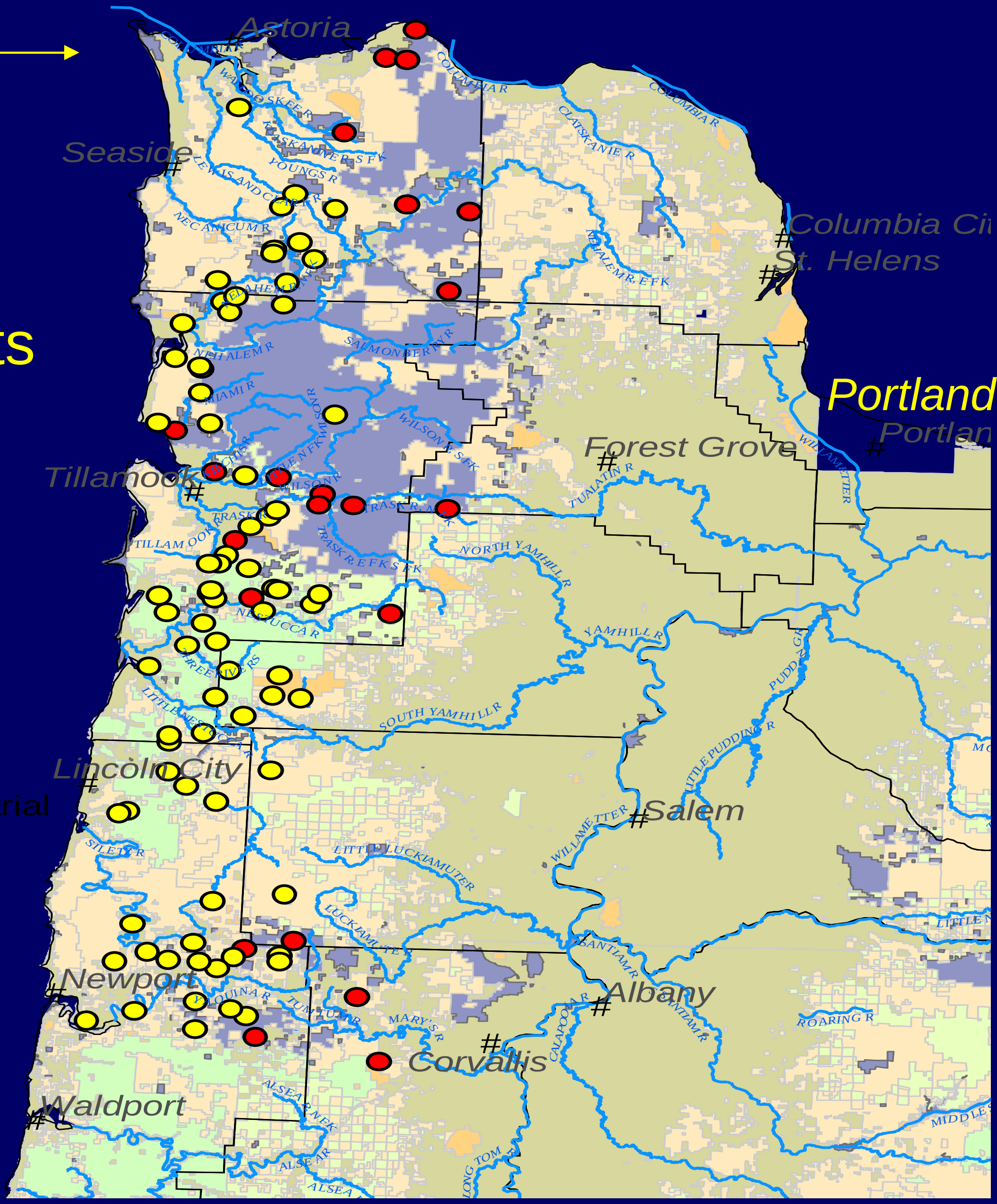
Established in 1998

- 🟡 76 Growth impact plots

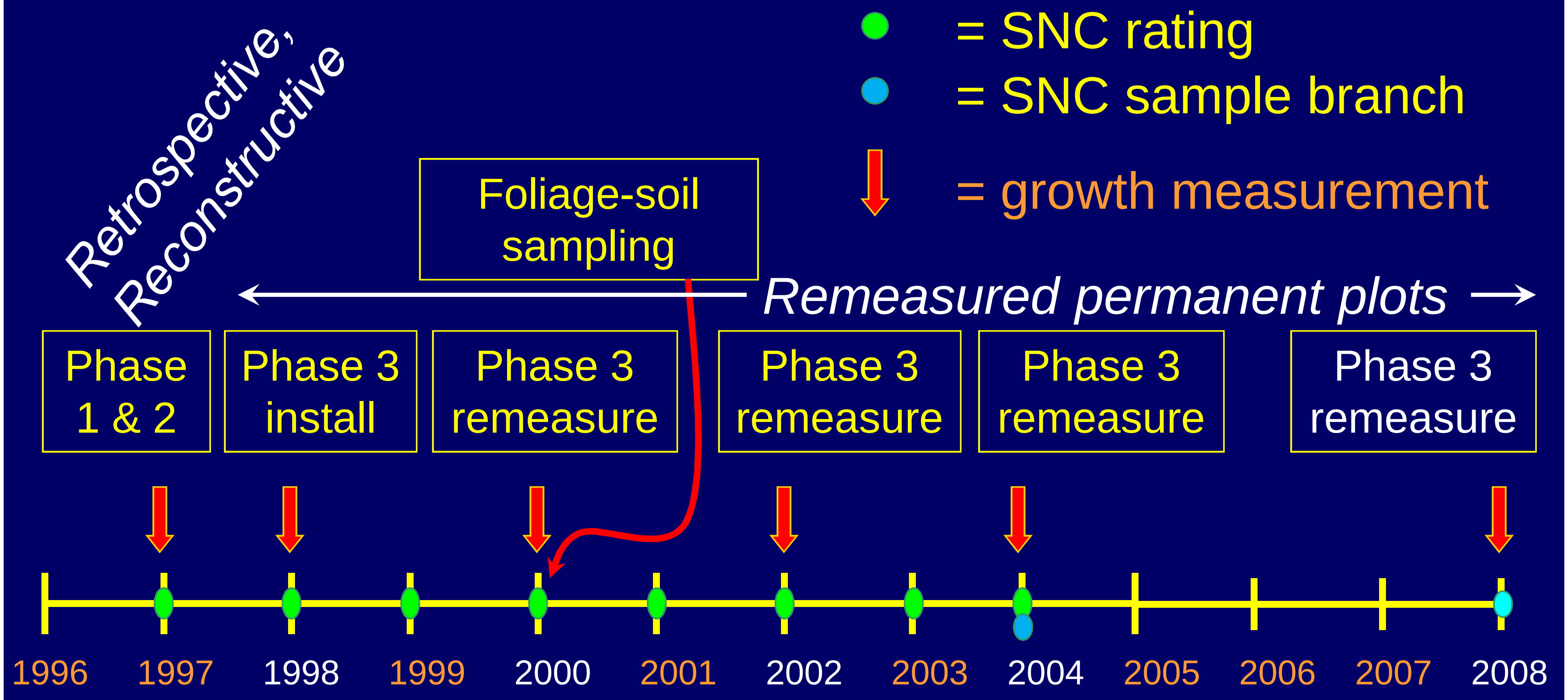
  90% Douglas-fir
  10-30 yrs old

- 🔴 22 Pre-commercial thinning plot sets

Newport →



Growth Impact Study
Remeasurement schedule



● = SNC rating

● = SNC sample branch

↓ = growth measurement

Retrospective,
Reconstructive

Foliage-soil sampling

← *Remeasured permanent plots* →

Phase 1 & 2

Phase 3 install

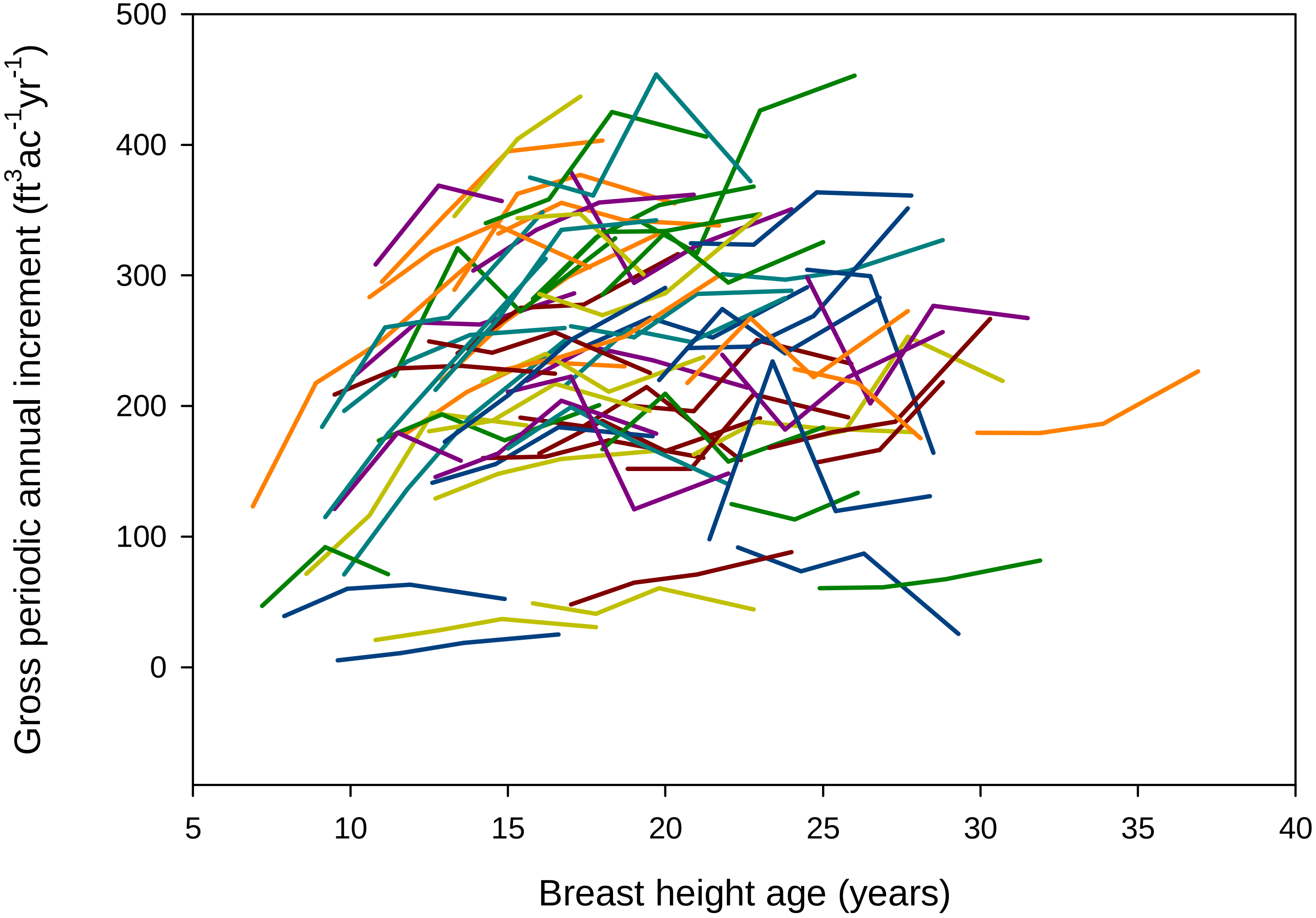
Phase 3 remeasure

Phase 3 remeasure

Phase 3 remeasure

Phase 3 remeasure

Gross periodic annual increment over breast height age



Comprehensive dataset and model

Douglas-fir stocking

Site quality

$$\ln(\mathrm{PAI}_{\mathrm{NET}}) = \beta_0 + \beta_1 \ln(\mathrm{BA}_{\mathrm{DF}}) + \beta_2 \ln(\mathrm{SI}) + \beta_3 \ln(\mathrm{A}) + \beta_4 \ln(\mathrm{FR}-0.5) + \varepsilon$$

Stand age

SNC severity

Where

$\mathrm{PAI}_{\mathrm{NET}}$ = Net periodic annual increment ($m^3ha^{-1}yr^{-1}$)

$\mathrm{BA}_{\mathrm{DF}}$ = Initial Douglas-fir basal area (m^2ha^{-1})

SI = Bruce’s site index (m at 50 years)

A = Plot average breast height age (years)

FR = Plot average foliage retention (years)

β_k = Parameters estimated from the data

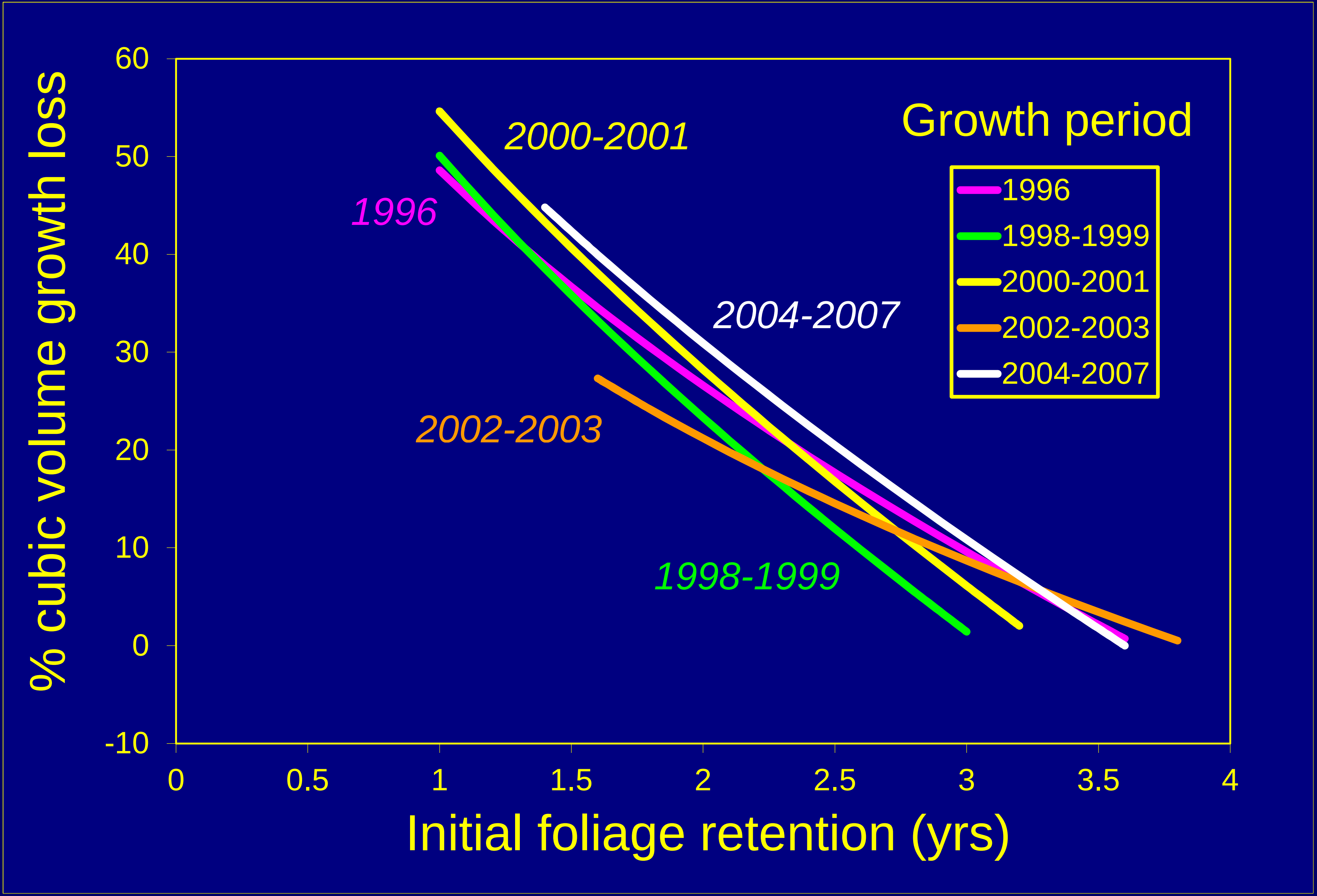
ε = Error term with variance-covariance matrix having compound symmetry for observations within a plot over time

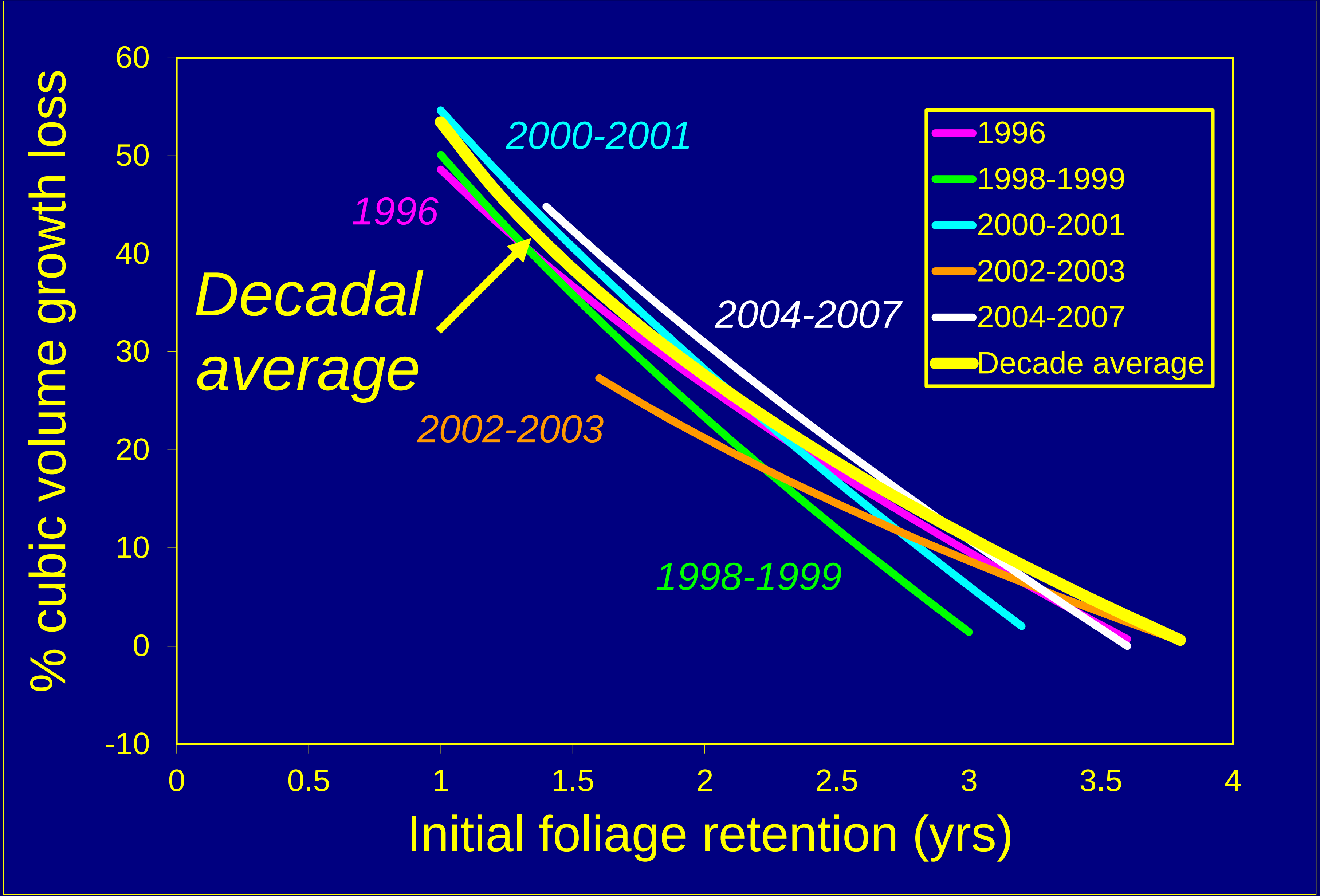
$$\ln(PAI_{NET}) = \beta_0 + \beta_1 \ln(BA_{DF}) + \beta_2 \ln(SI) + \beta_3 \ln(A) + \beta_4 \ln(FR-0.5) + \varepsilon$$

Parameter	Parameter estimate	Standard error
β_0	-3.7607	0.7626
β_1	0.02367	0.006929
β_2	1.0998	0.2015
β_3	0.6417	0.07530
β_4	0.4018	0.07657

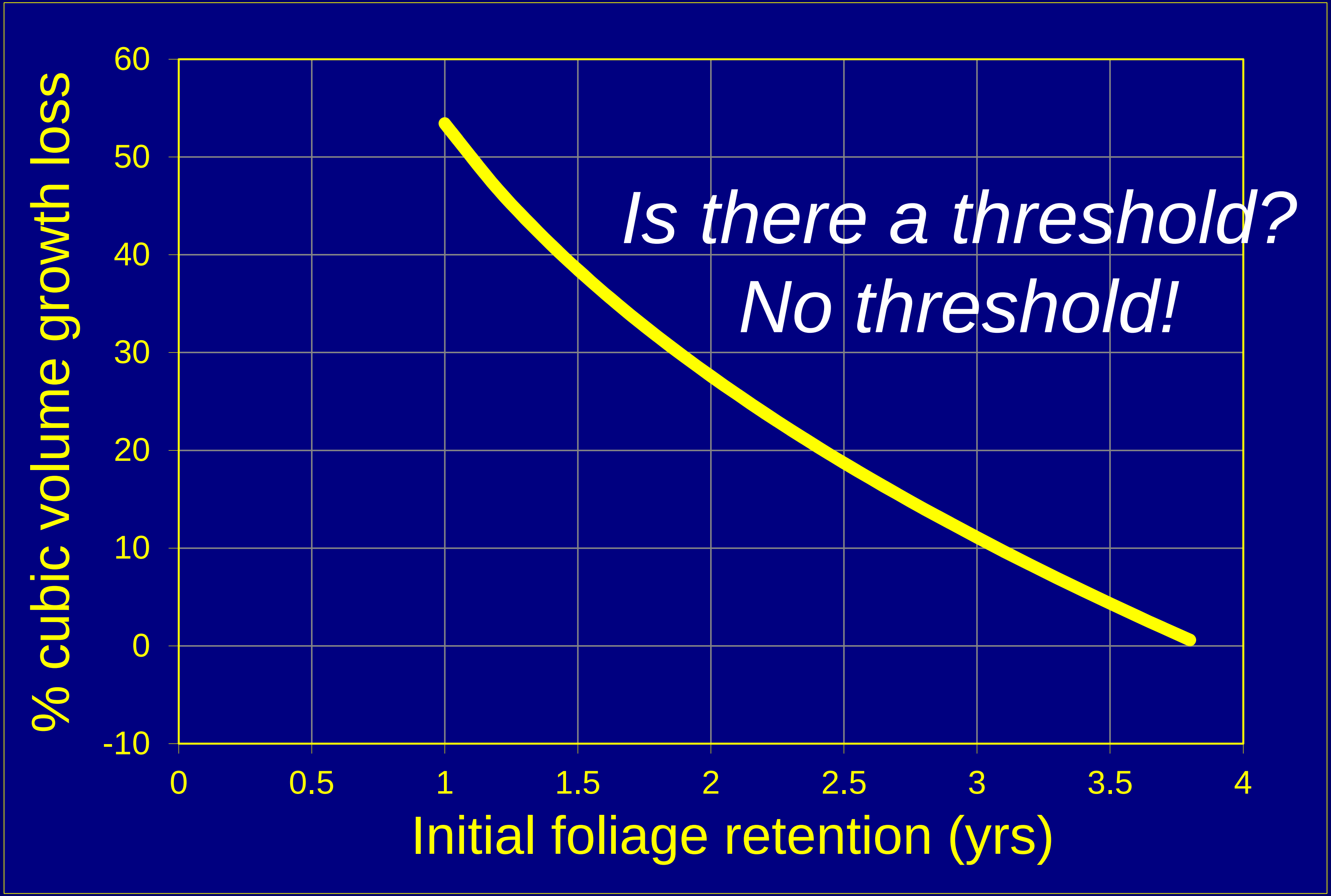
Foliage retention / SNC effect

Predicted growth losses for successive growth periods




% cubic volume growth loss
60
50
40
30
20
10
0
-10
0
0.5
1
1.5
2
2.5
3
3.5
4
Initial foliage retention (yrs)
2000-2001
1996
Decadal average
2004-2007
2002-2003
1998-1999
1996
1998-1999
2000-2001
2002-2003
2004-2007
Decade average

Average growth loss by initial foliage retention, 1998-2008



Is there a threshold?

No threshold!

Growth impacts and silvicultural mitigation

- What is the growth impact of SNC?
- Does SNC accelerate Douglas-fir mortality?
- How best to rate SNC severity?
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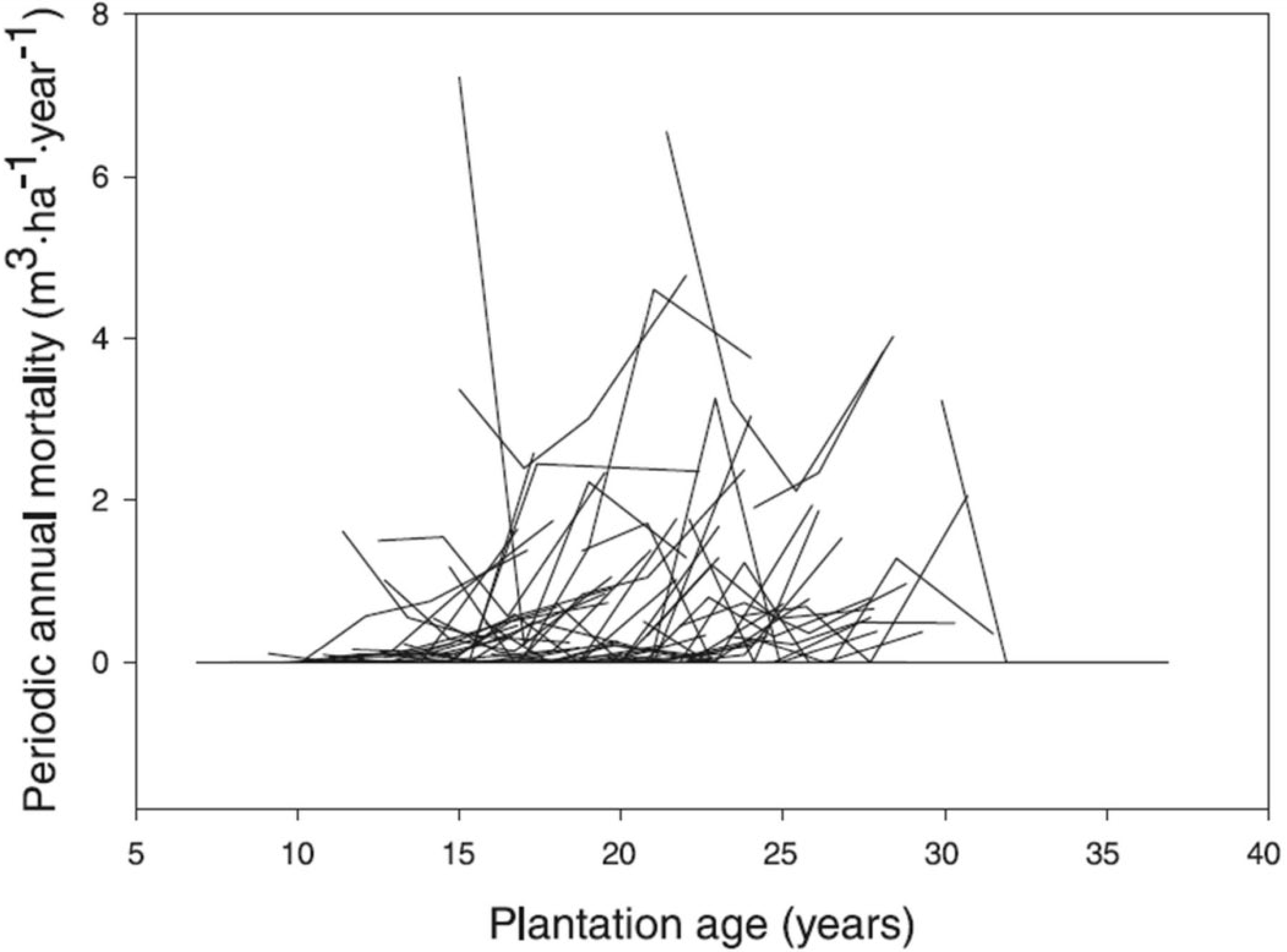

Periodic annual mortality (m³.ha⁻¹.year⁻¹)
8
6
4
2
0
5
10
15
20
25
30
35
40
Plantation age (years)

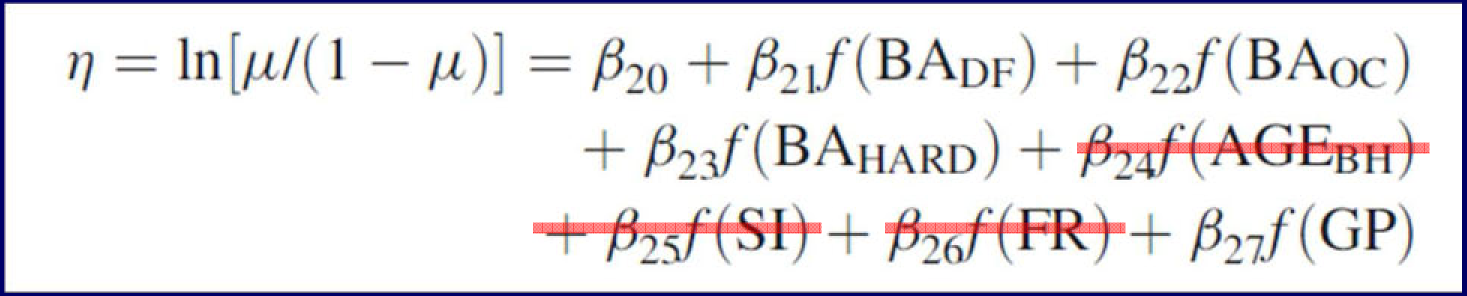
Probability of Douglas-fir mortality analyzed by binomial glm with heterogeneous Toeplitz structure for the variance-covariance matrix

$$\begin{aligned}\eta = \ln[\mu/(1-\mu)] = \beta_{20} + \beta_{21} f(\mathrm{BA_{DF}}) + \beta_{22} f(\mathrm{BA_{OC}}) \\ + \beta_{23} f(\mathrm{BA_{HARD}}) + \beta_{24} f(\mathrm{AGE_{BH}}) \\ + \beta_{25} f(\mathrm{SI}) + \beta_{26} f(\mathrm{FR}) + \beta_{27} f(\mathrm{GP})\end{aligned}$$

where

μ = probability of any mortality on the plot
$\mathrm{BA_{DF}}$ = Initial Douglas-fir basal area (m^2ha^{-1})
$\mathrm{BA_{OC}}$ = Initial basal area in other conifers (m^2ha^{-1})
$\mathrm{BA_{HARD}}$ = Initial basal area in hardwoods (m^2ha^{-1})
$\mathrm{AGE_{BH}}$ = Breast height age
SI = Bruce’s (1981) site index, m at 50 yrs
FR = Foliage retention (years)
GP = Growth period length (2 or 4 years)
β_k = Parameters to be estimated from the data

Foliage retention (SNC) has not directly influenced probability of Douglas-fir mortality occurring on a plot



$$\begin{aligned}\eta = \ln[\mu/(1-\mu)] = \beta_{20} + \beta_{21} f(\mathrm{BA_{DF}}) + \beta_{22} f(\mathrm{BA_{OC}})\\ + \beta_{23} f(\mathrm{BA_{HARD}}) + \cancel{\beta_{24} f(\mathrm{AGE_{BH}})}\\ \cancel{+ \beta_{25} f(\mathrm{SI})} + \cancel{\beta_{26} f(\mathrm{FR})} + \beta_{27} f(\mathrm{GP})\end{aligned}$$

— Not significant at α=0.05

Conditional volume lost to mortality analyzed by normal based log-linear model with heterogeneous Toeplitz structure for the variance-covariance matrix

$$\begin{aligned}\ln[\mathrm{PAM}] = \beta_{30} + \beta_{31}\ln(\mathrm{BA}_{\mathrm{DF}}) + \beta_{32}\ln(\mathrm{AGE}_{\mathrm{BH}}) \\ + \beta_{33}\ln(\mathrm{SI}) + \beta_{34}\mathrm{BA}_{\mathrm{OC}} + \beta_{35}\mathrm{BA}_{\mathrm{HARD}} \\ + \beta_{36}\ln(\mathrm{FR} - 0.5) + \varepsilon_3\end{aligned}$$

where

PAM = Periodic annual volume mortality on the plot
$\mathrm{BA}_{\mathrm{DF}}$ = Initial Douglas-fir basal area (m^2ha^{-1})
$\mathrm{BA}_{\mathrm{OC}}$ = Initial basal area in other conifers (m^2ha^{-1})
$\mathrm{BA}_{\mathrm{HARD}}$ = Initial basal area in hardwoods (m^2ha^{-1})
$\mathrm{AGE}_{\mathrm{BH}}$ = Breast height age
SI = Bruce’s (1981) site index, m at 50 yrs
FR = Foliage retention (years)
β_k = Parameters to be estimated from the data

Foliage retention (SNC) did not directly influence conditional volume mortality of Douglas-fir.

$$\begin{aligned}\ln[\mathrm{PAM}] = \beta_{30} + \beta_{31}\ln(\mathrm{BA}_{\mathrm{DF}}) + \cancel{\beta_{32}\ln(\mathrm{AGE}_{\mathrm{BH}})}\\ + \cancel{\beta_{33}\ln(\mathrm{SI})} + \beta_{34}\mathrm{BA}_{\mathrm{OC}} + \beta_{35}\mathrm{BA}_{\mathrm{HARD}}\\ + \cancel{\beta_{36}\ln(\mathrm{FR}-0.5)} + \varepsilon_3\end{aligned}$$

— Not significant at α=0.05

Growth impacts and silvicultural mitigation

- What is the growth impact of SNC?
- Does SNC accelerate Douglas-fir mortality?
- How best to rate SNC severity?
- Do stands recover from SNC? Does disease severity fluctuate?
- What tools are available for estimating SNC growth impacts?
- Are there predisposing conditions that suggest mitigation measures?

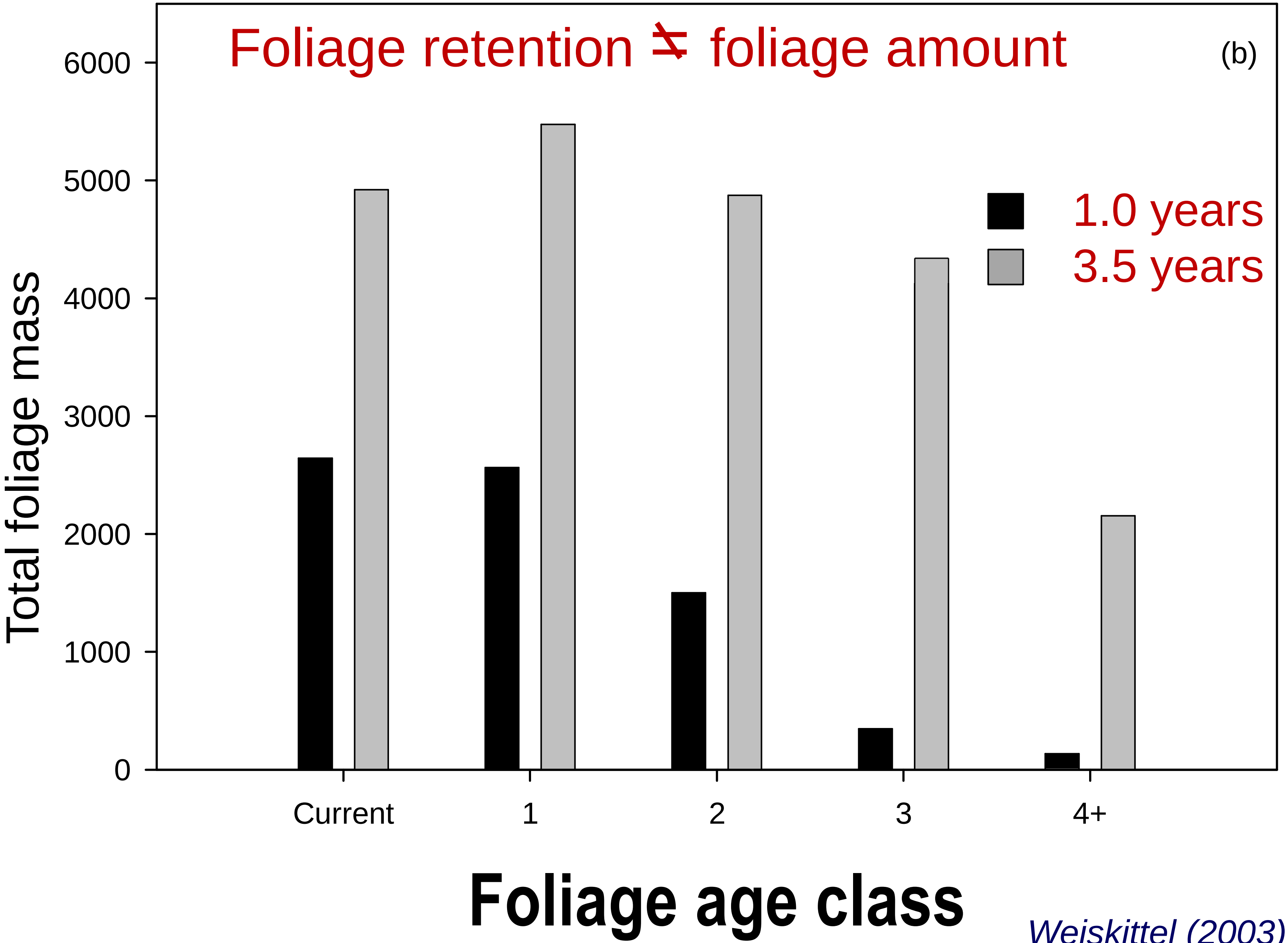
SNC severity - Foliage retention (yrs)

4.0

2.4

0.9

Foliage retention ≠ foliage amount



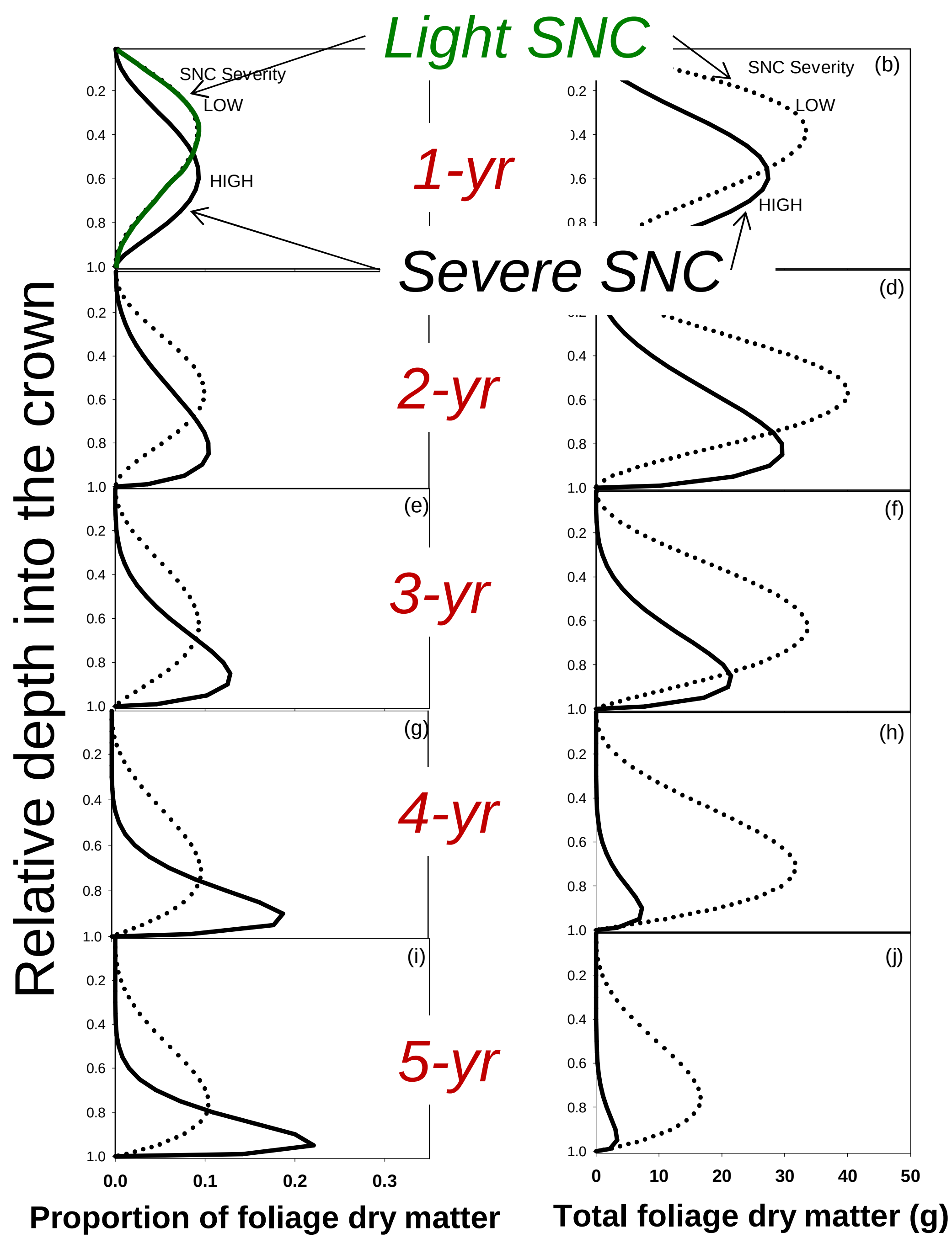
Weiskittel (2003)

How does foliage retention relate to foliage amount?

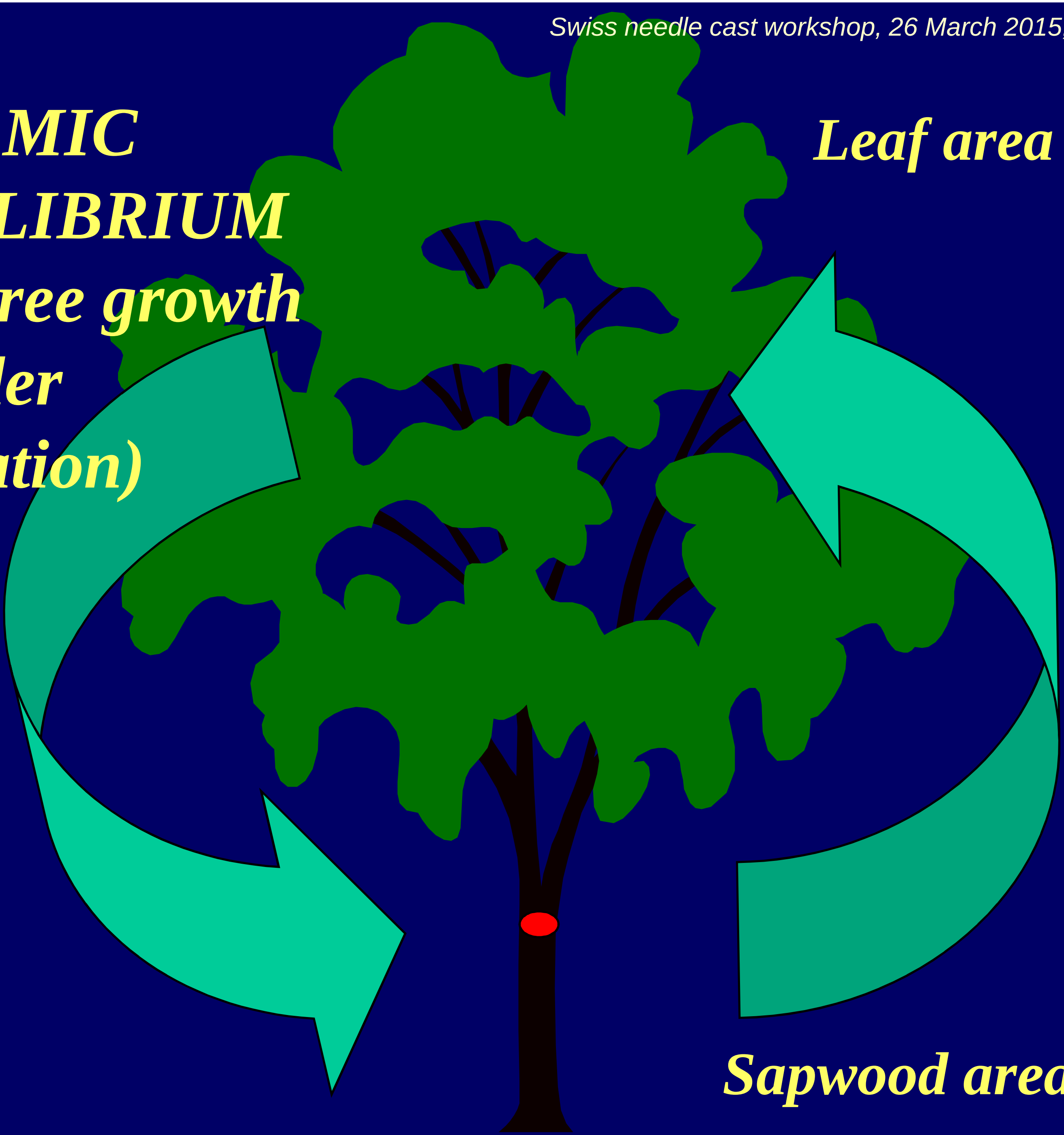
Correlated with:

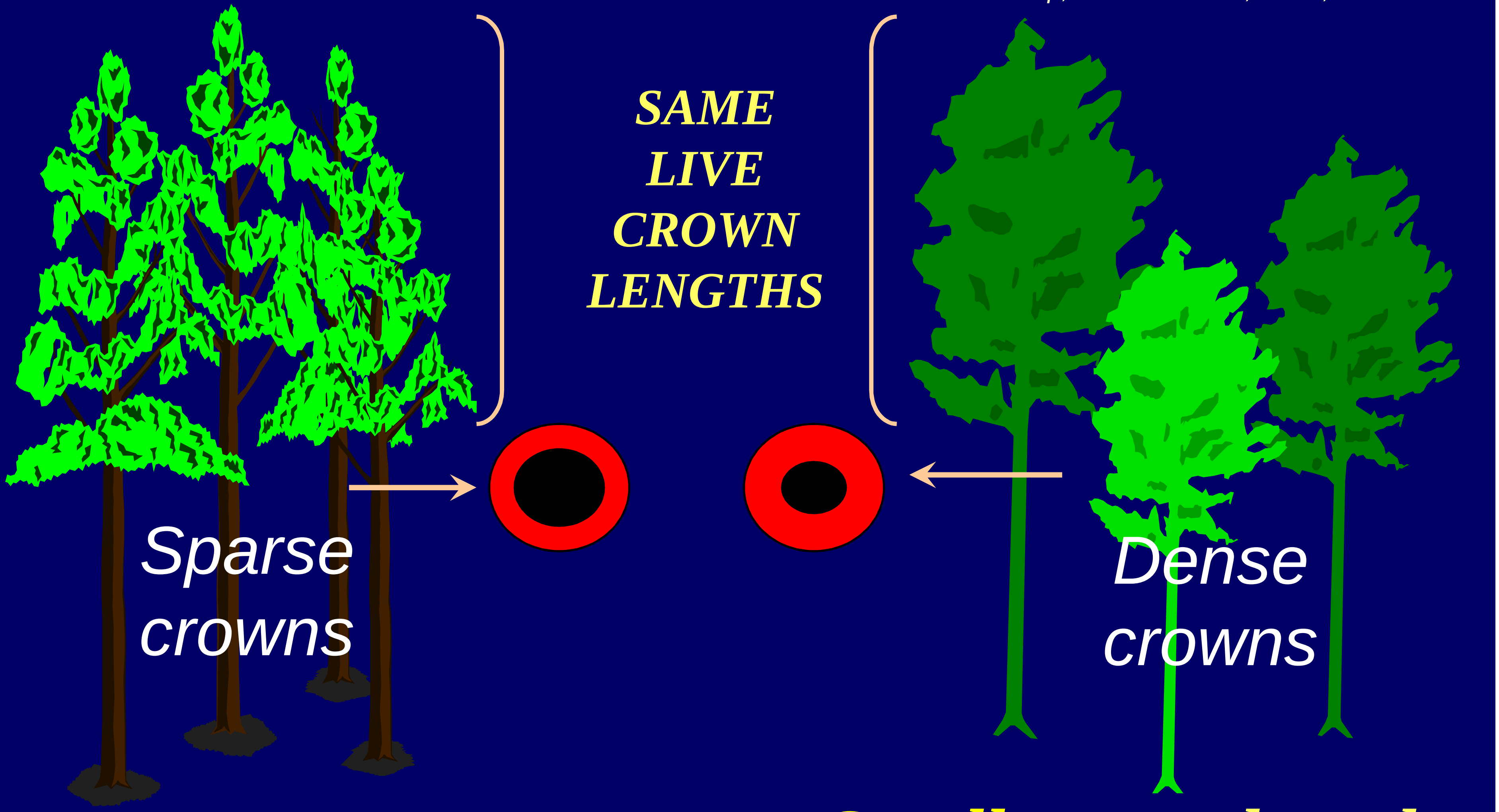
Amount of foliage in different age classes (area under curves at right)

Vertical distribution of foliage by age class



DYNAMIC EQUILIBRIUM (with tree growth or under defoliation)





SAME LIVE CROWN LENGTHS

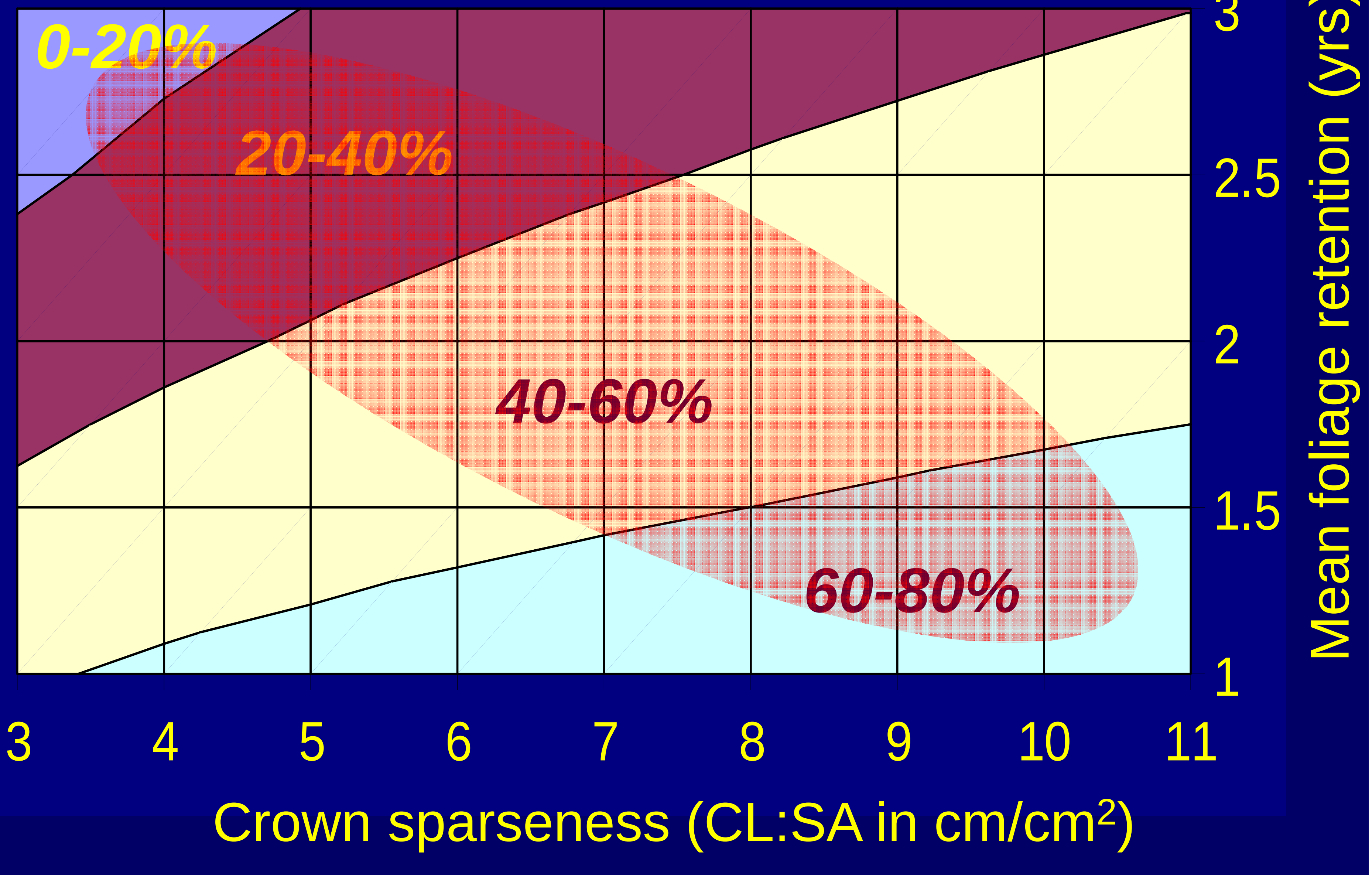
Sparse crowns

Dense crowns

Large crown length to sapwood area ratio

Small crown length to sapwood area ratio

Cubic volume growth loss by foliage retention and crown sparseness



Growth impacts and silvicultural mitigation

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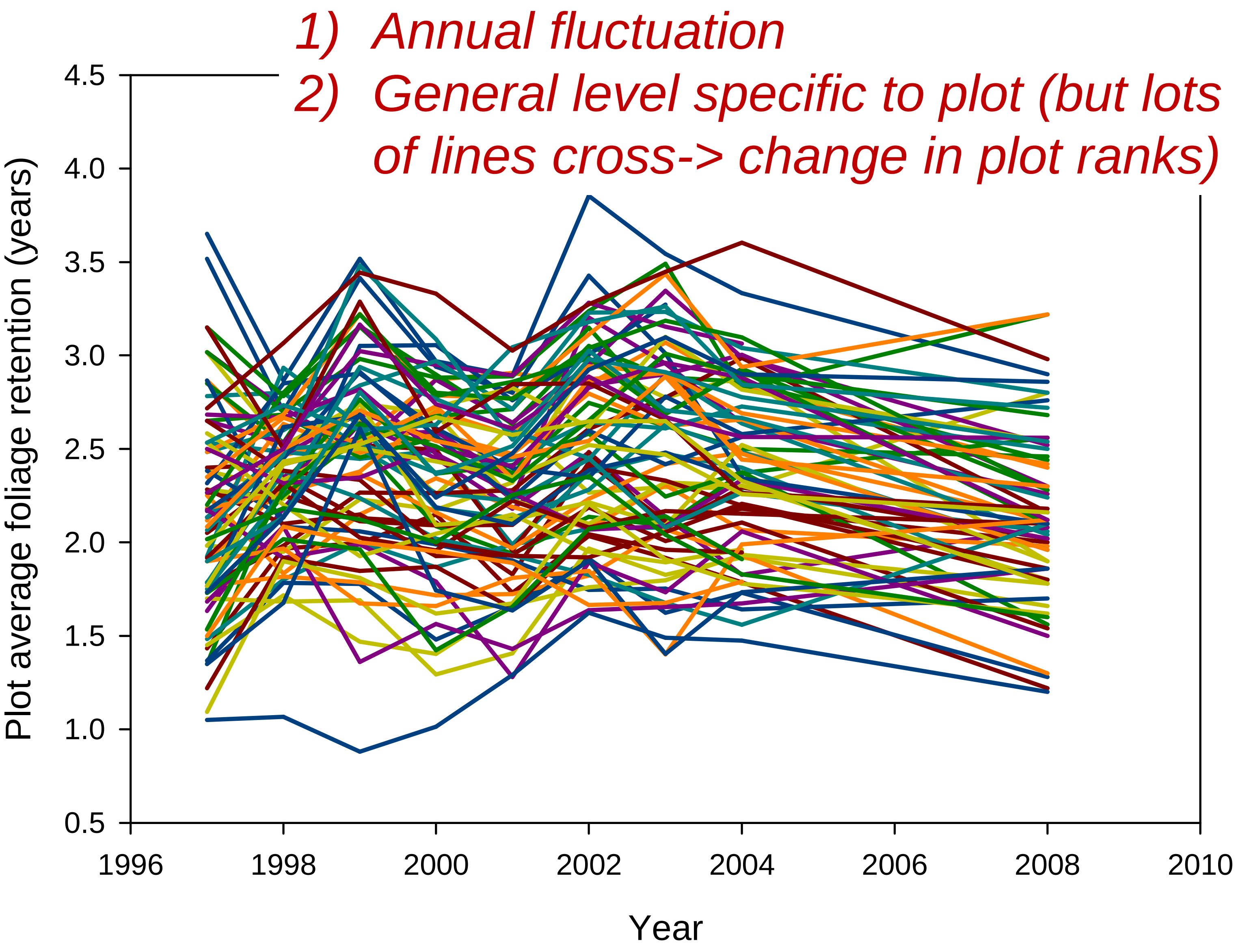
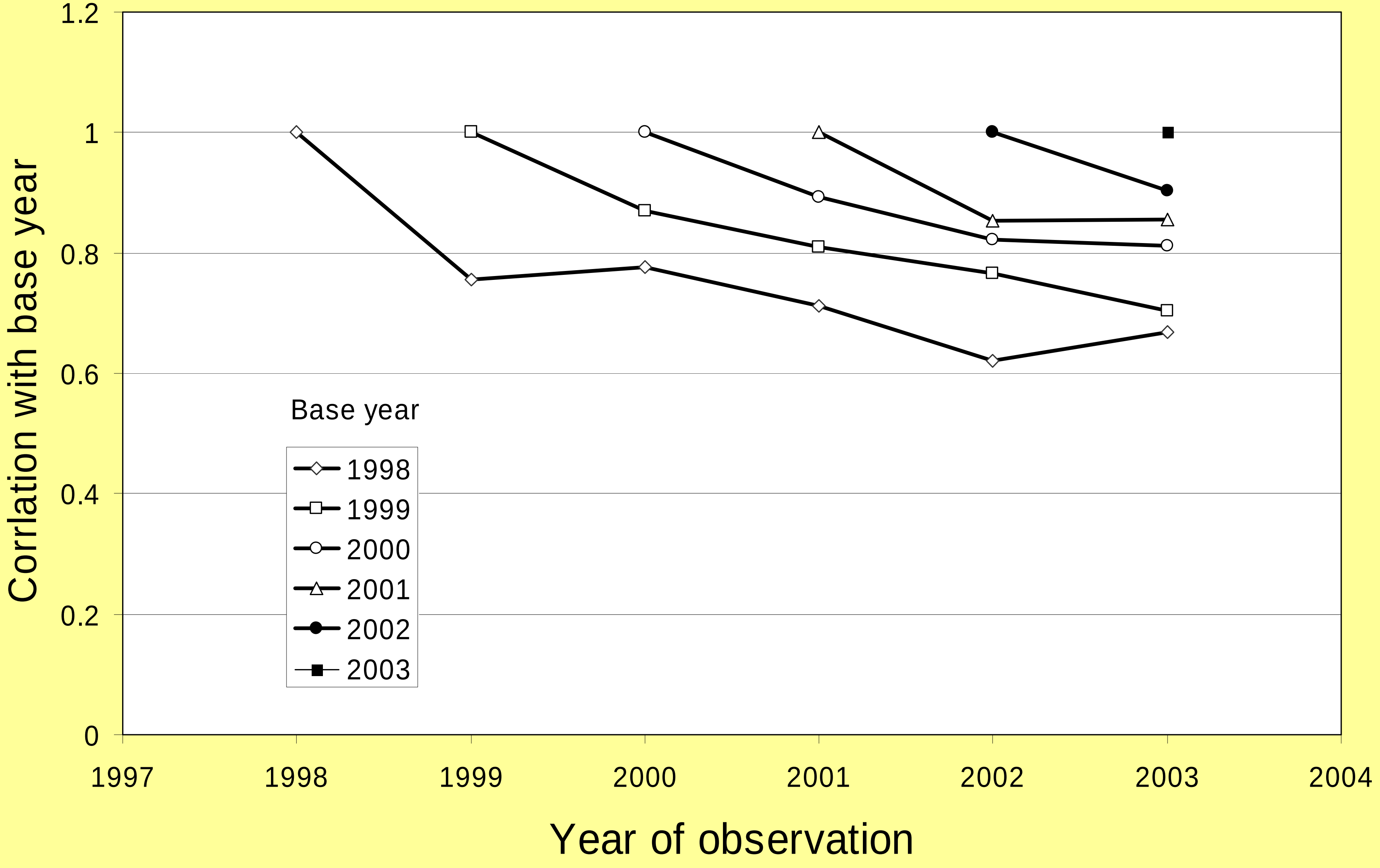
Trend foliage retention for each GIS plot from 1997-2008

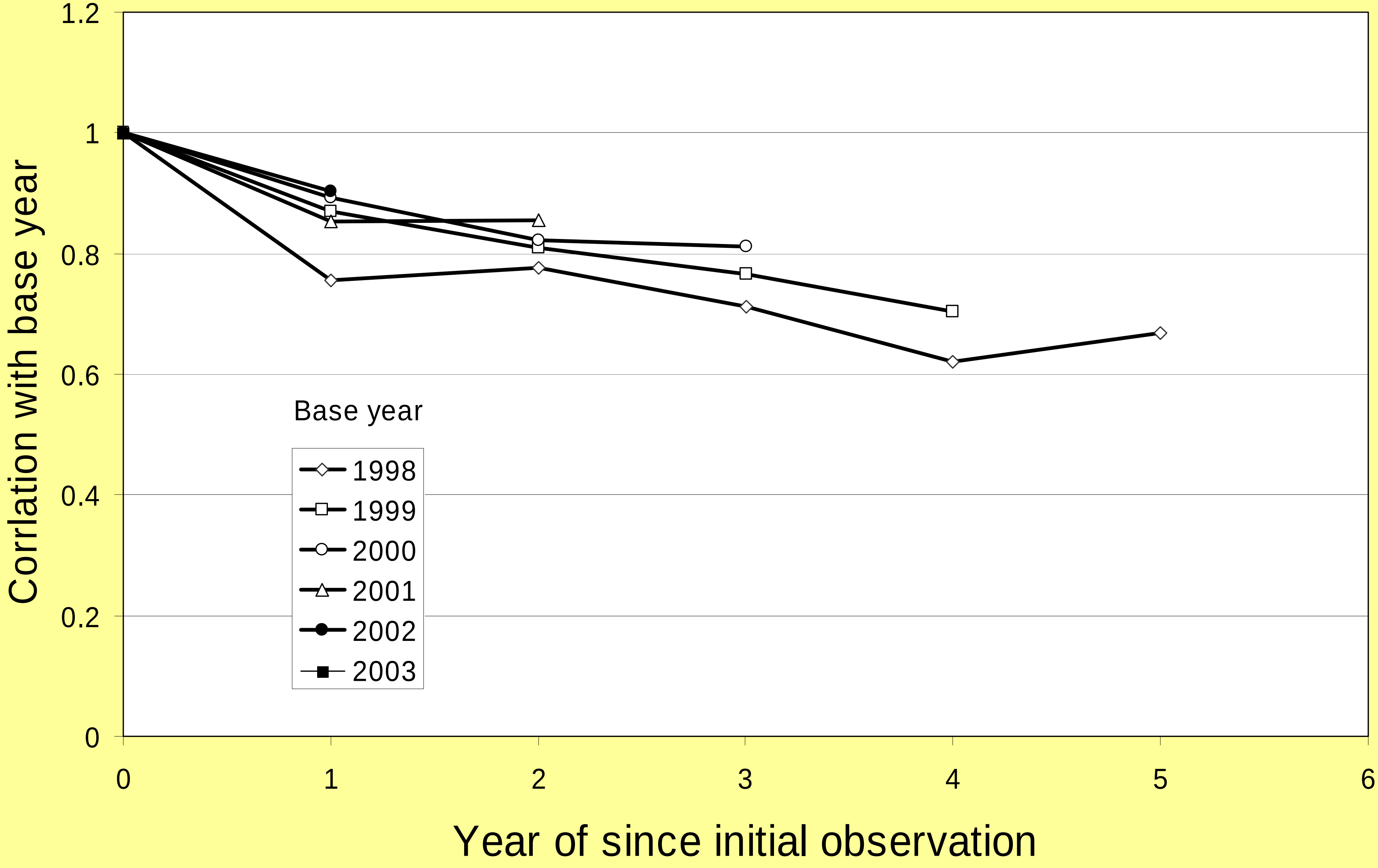


1) *Annual fluctuation*
2) *General level specific to plot (but lots of lines cross-> change in plot ranks)*

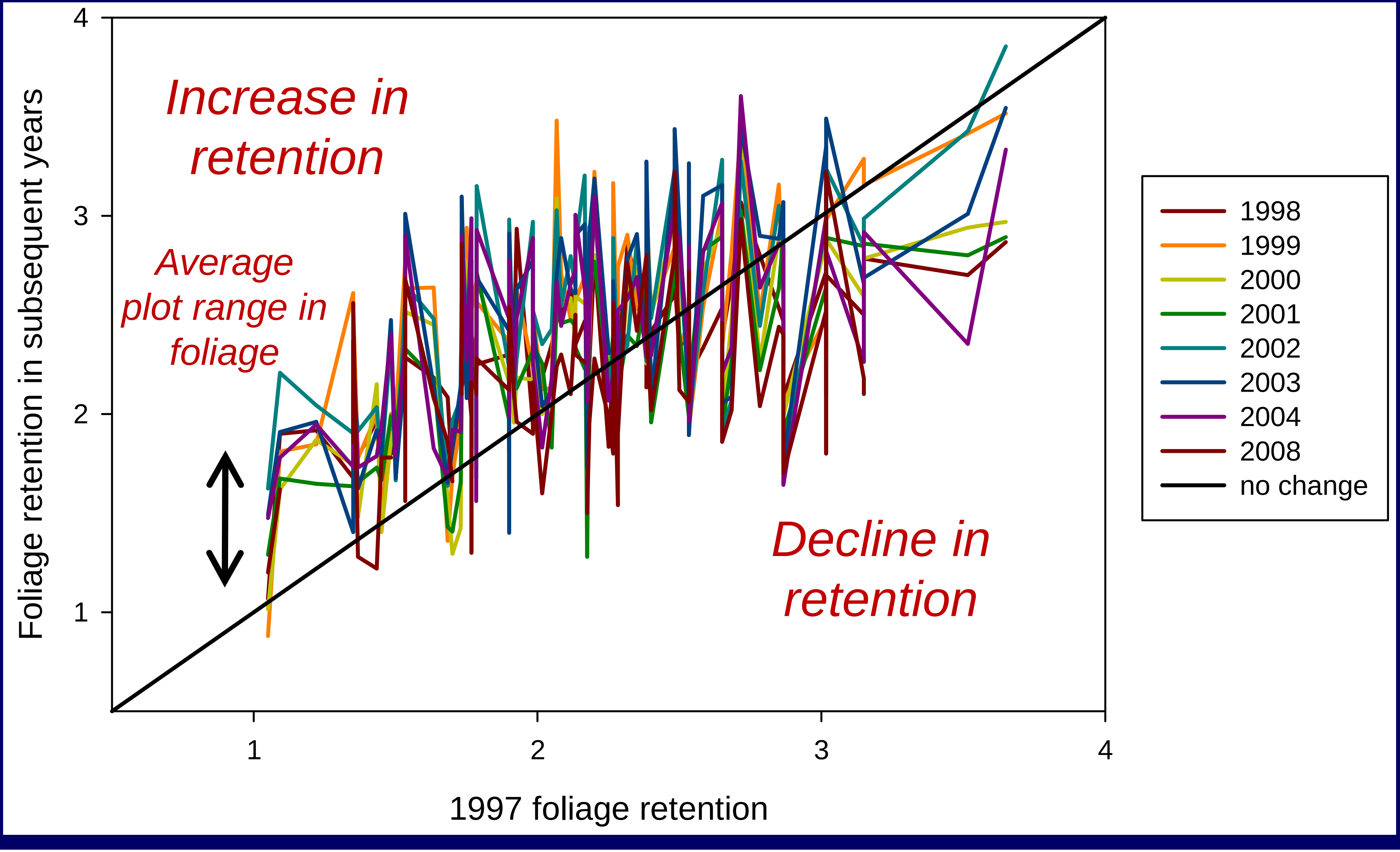
Foliage retention rank correlations



Foliage retention rank correlations



- Plot rank in disease severity changes over time.
- Foliage retention exhibits annual fluctuations, but all plots do not vary in same direction or amount each year.



Growth impacts and silvicultural mitigation

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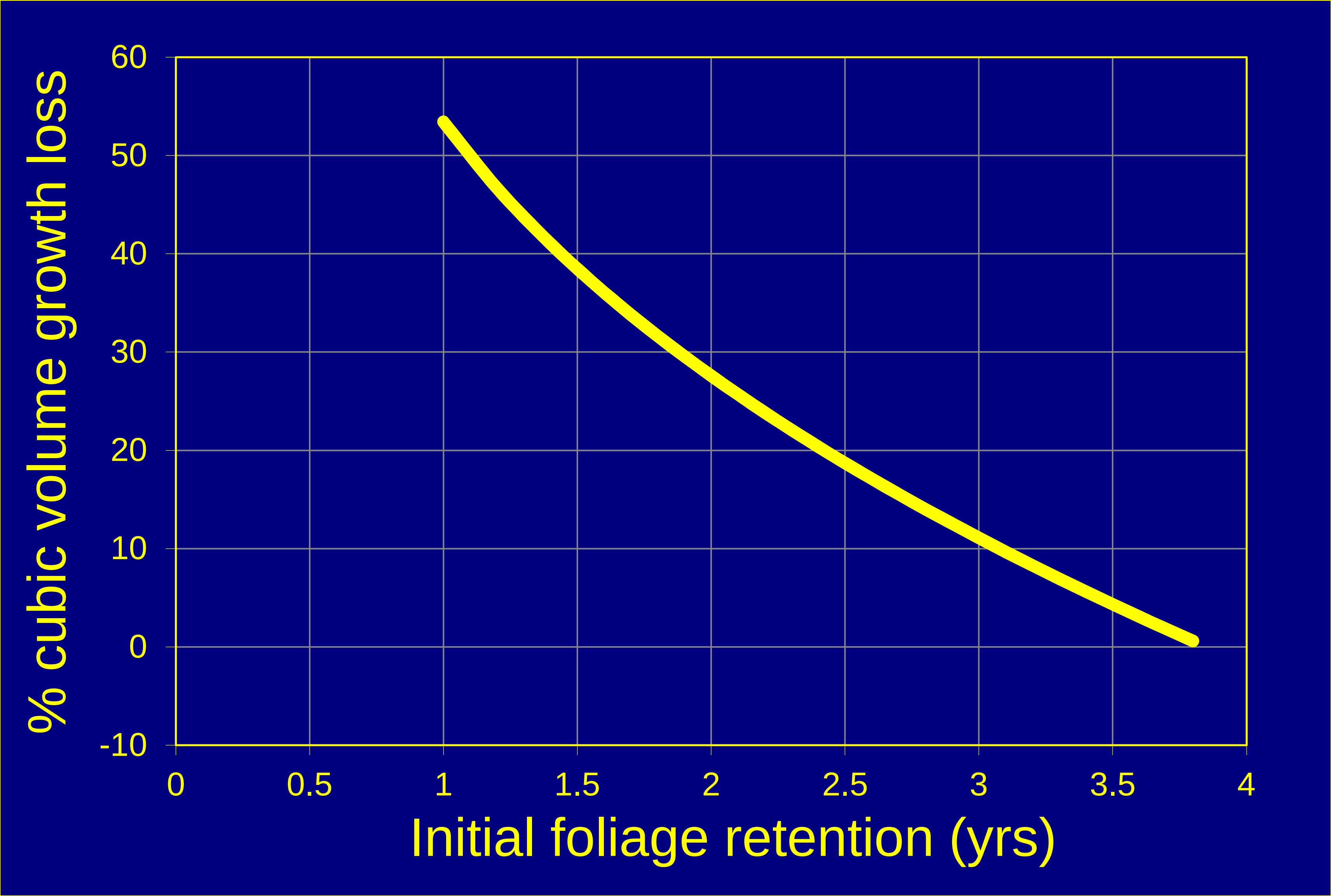
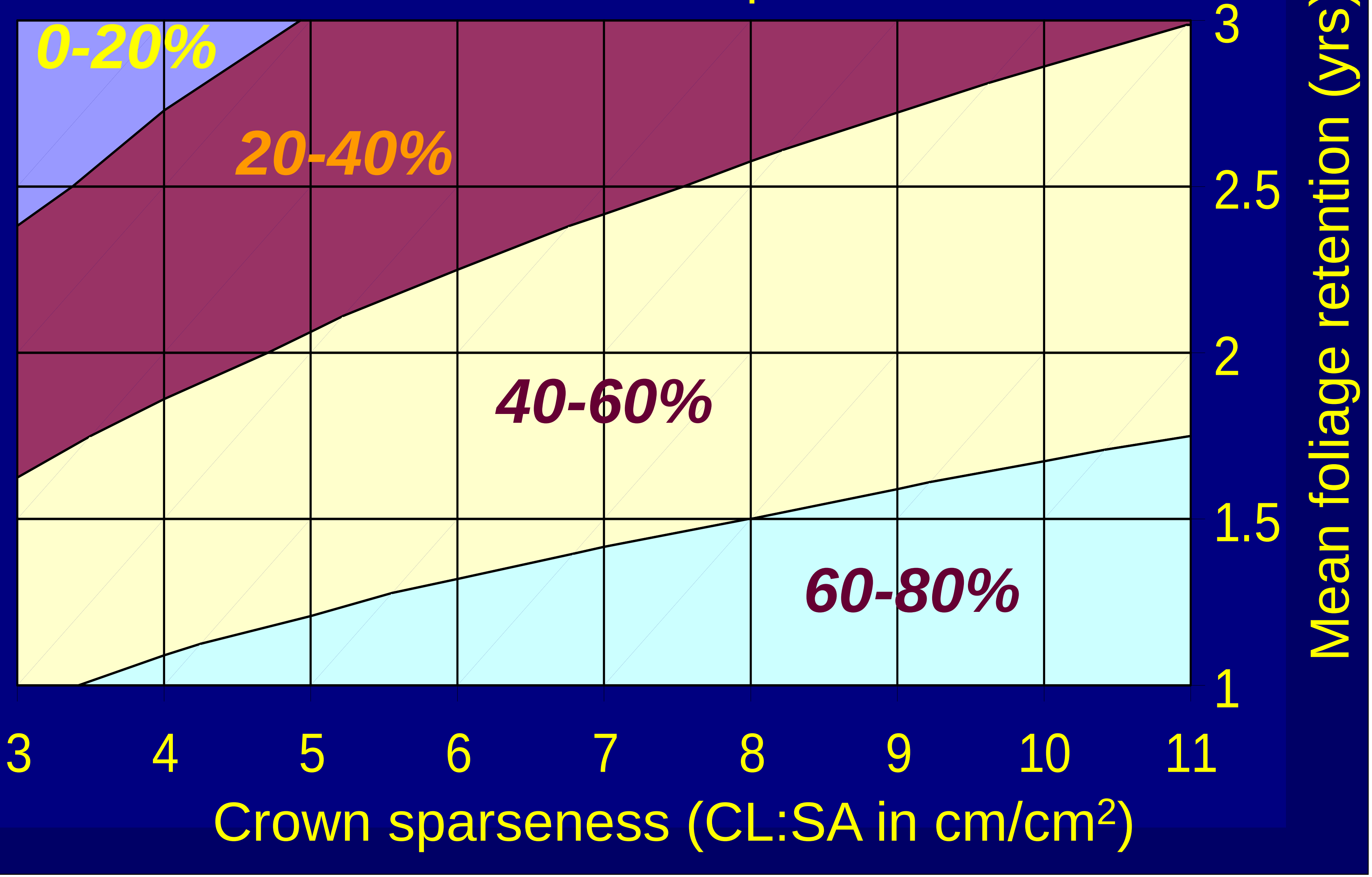
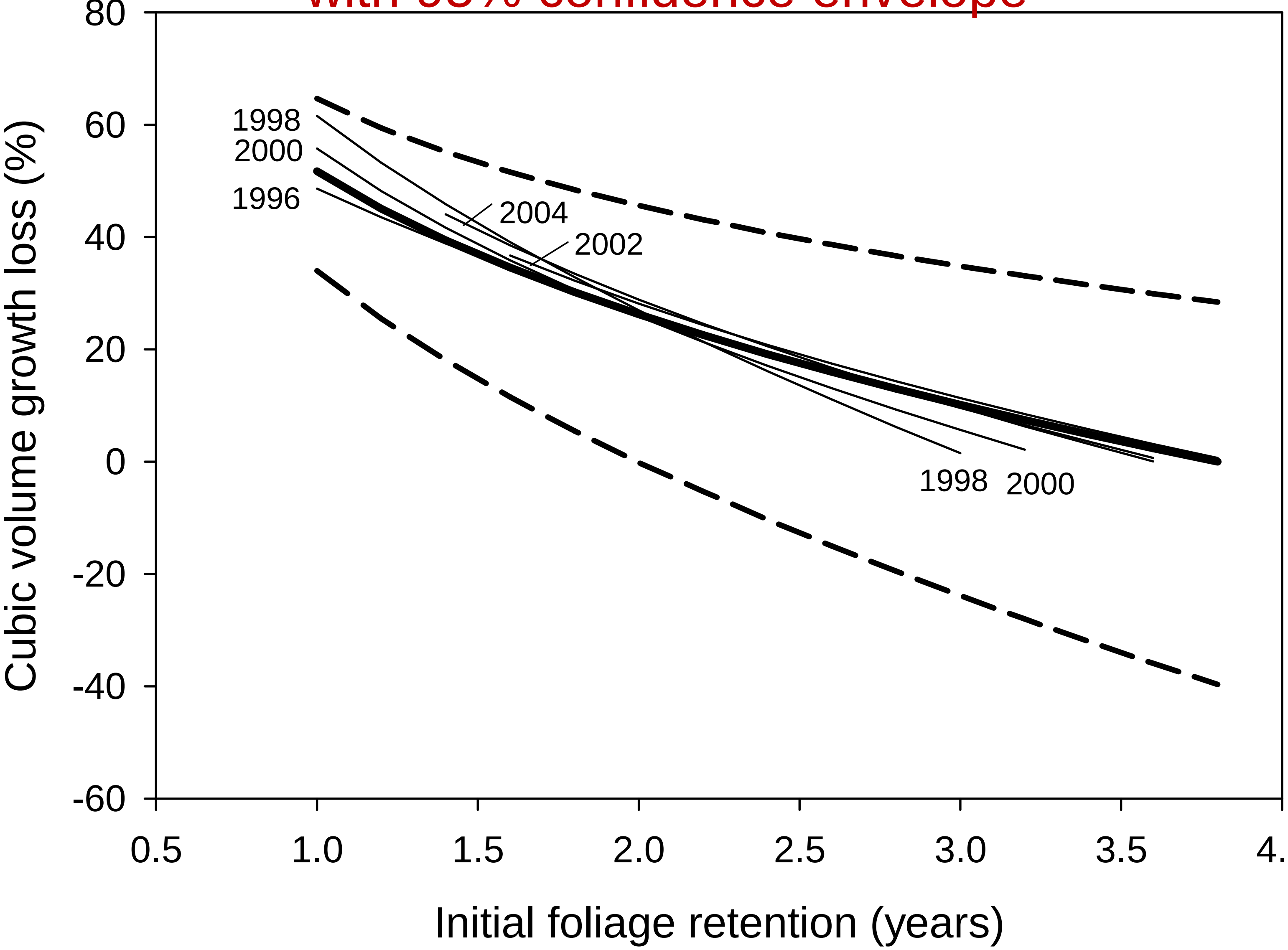
Average growth loss by initial foliage retention, 1998-2008



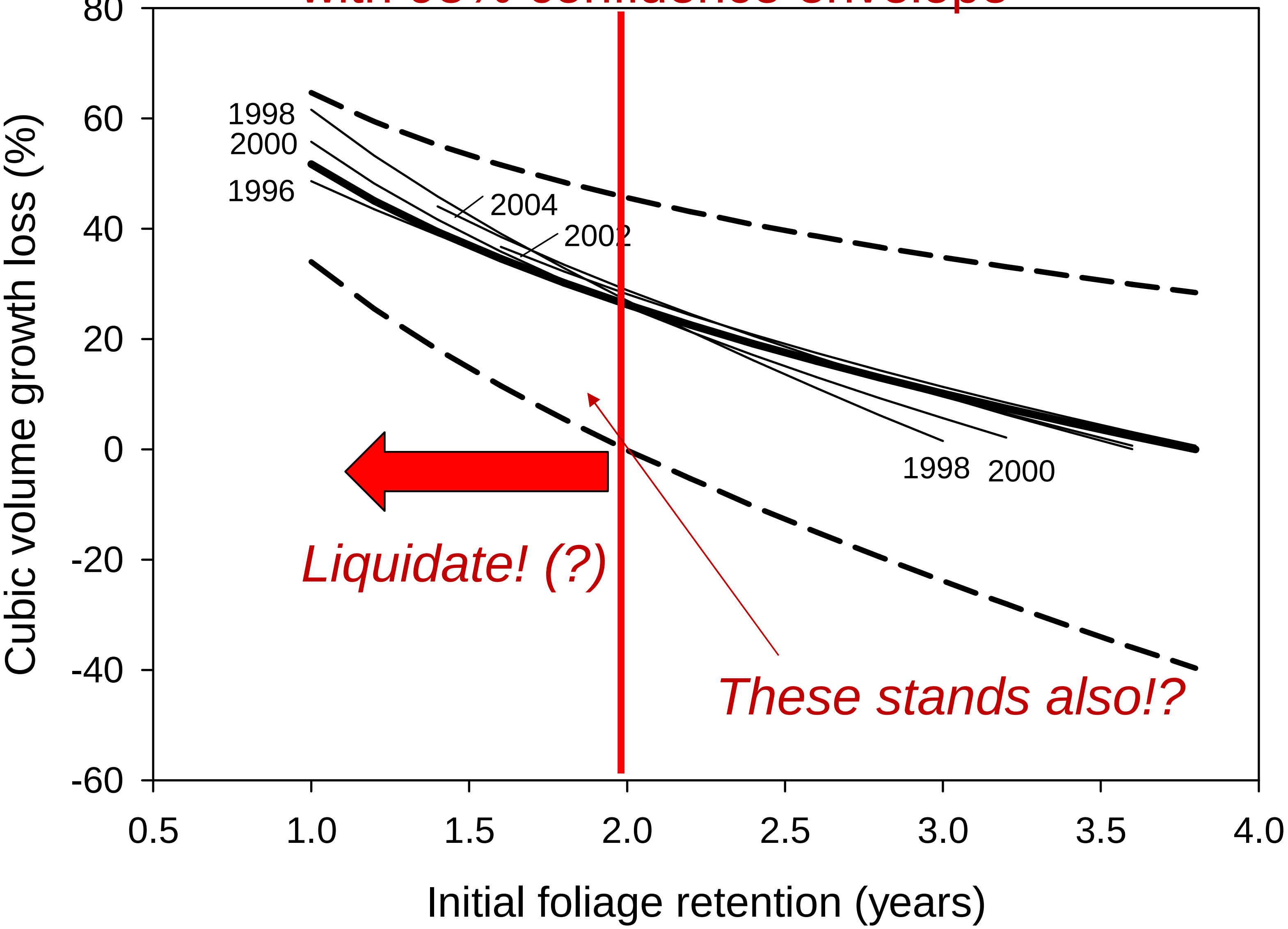
Cubic volume growth loss by foliage retention and crown sparseness



Cubic volume growth loss estimates with 95% confidence envelope



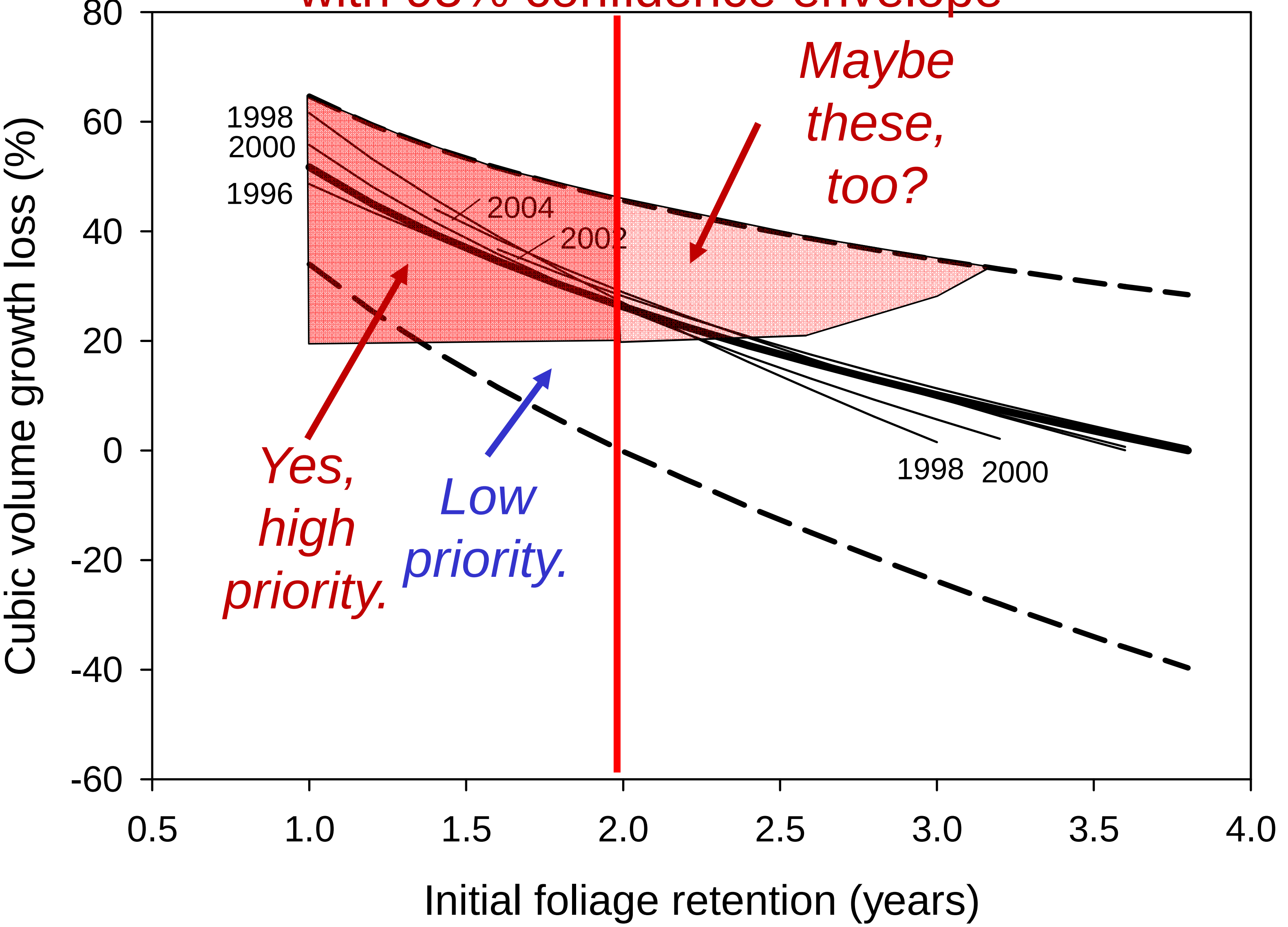
Cubic volume growth loss estimates with 95% confidence envelope



Liquidate! (?)

These stands also!?

Cubic volume growth loss estimates with 95% confidence envelope

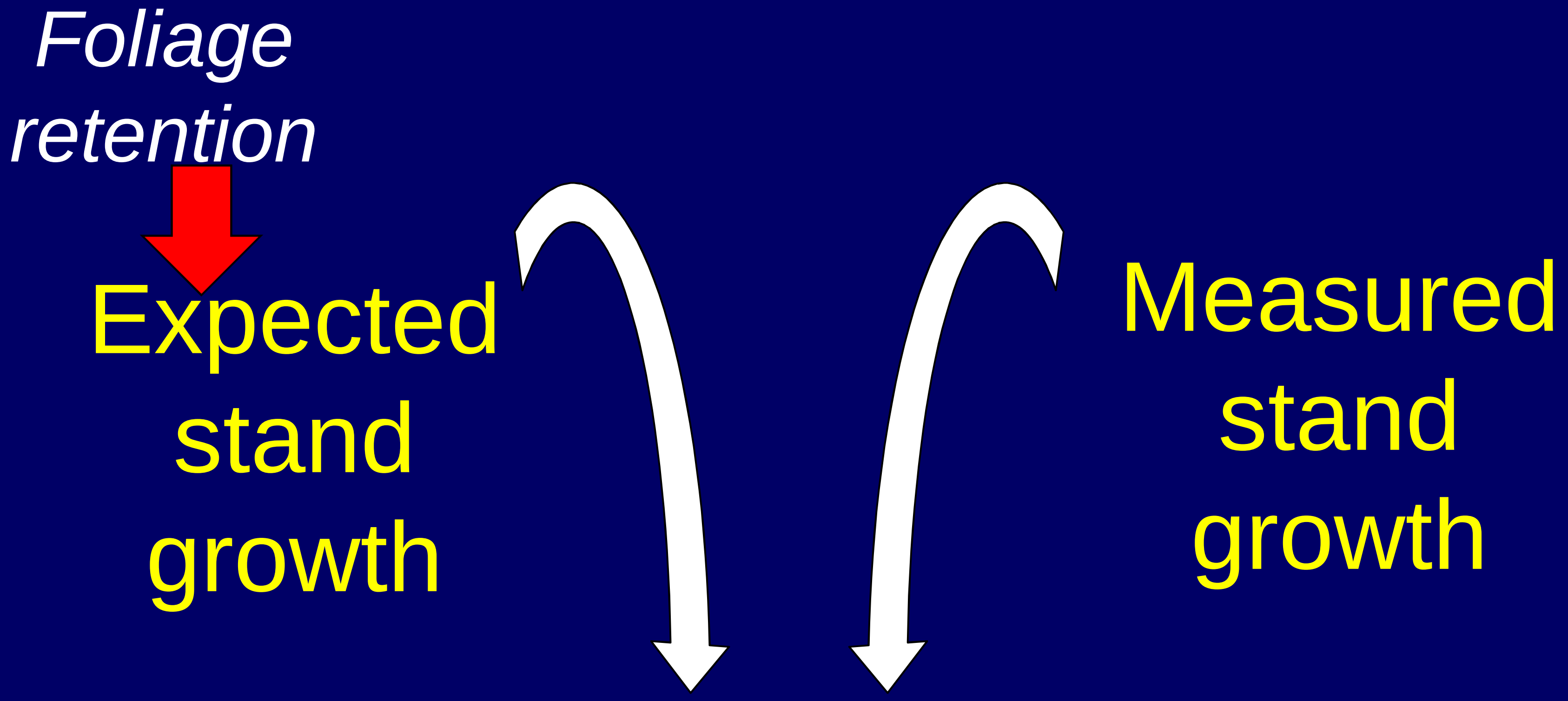


Maybe these, too?

Yes, high priority.

Low priority.

Stand Growth Assessment Tool



Foliage retention

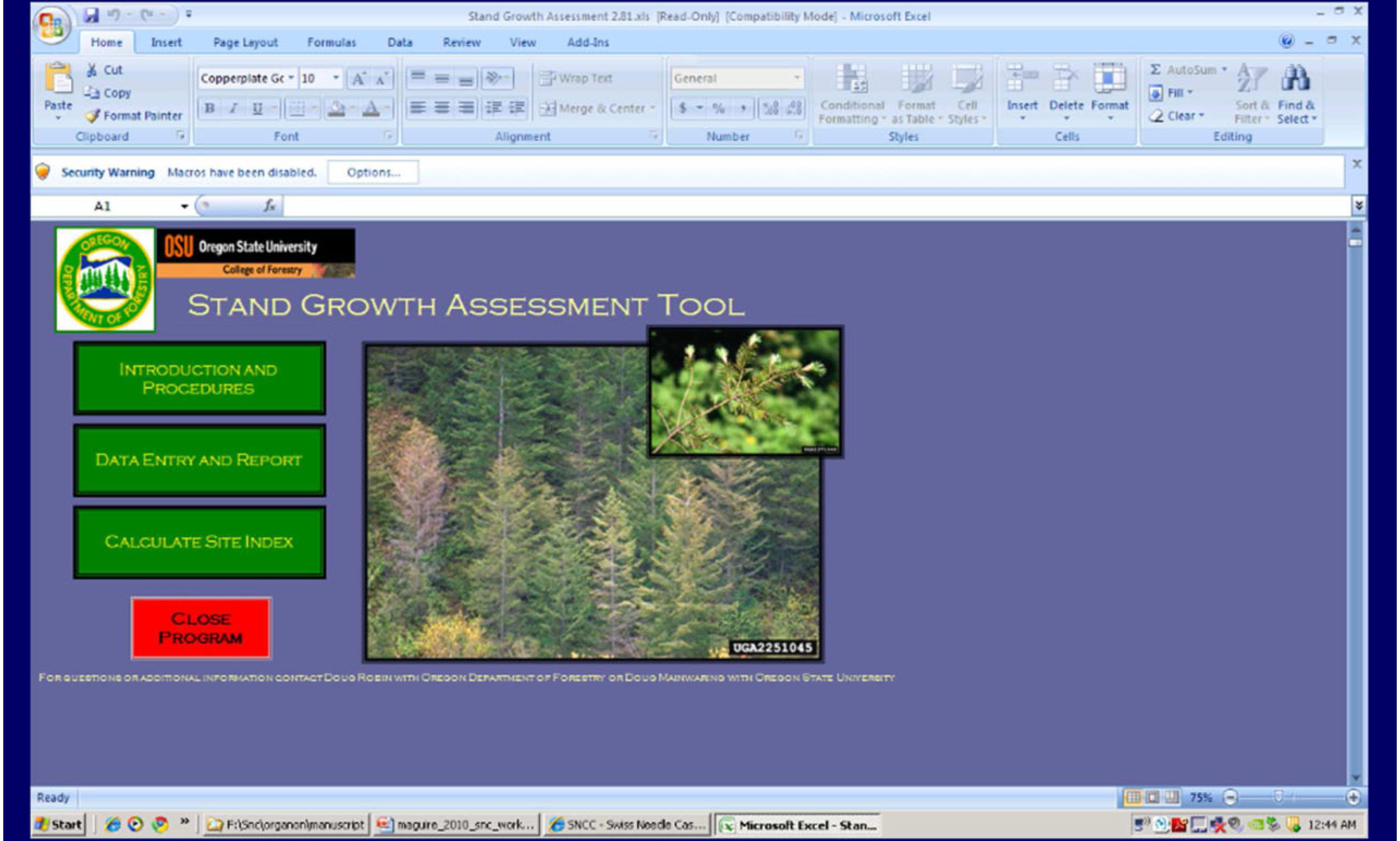
Expected stand growth

Measured stand growth

Diagnostic:

- Severity of SNC
- Relative priority for treatment

Stand Growth Assessment Tool



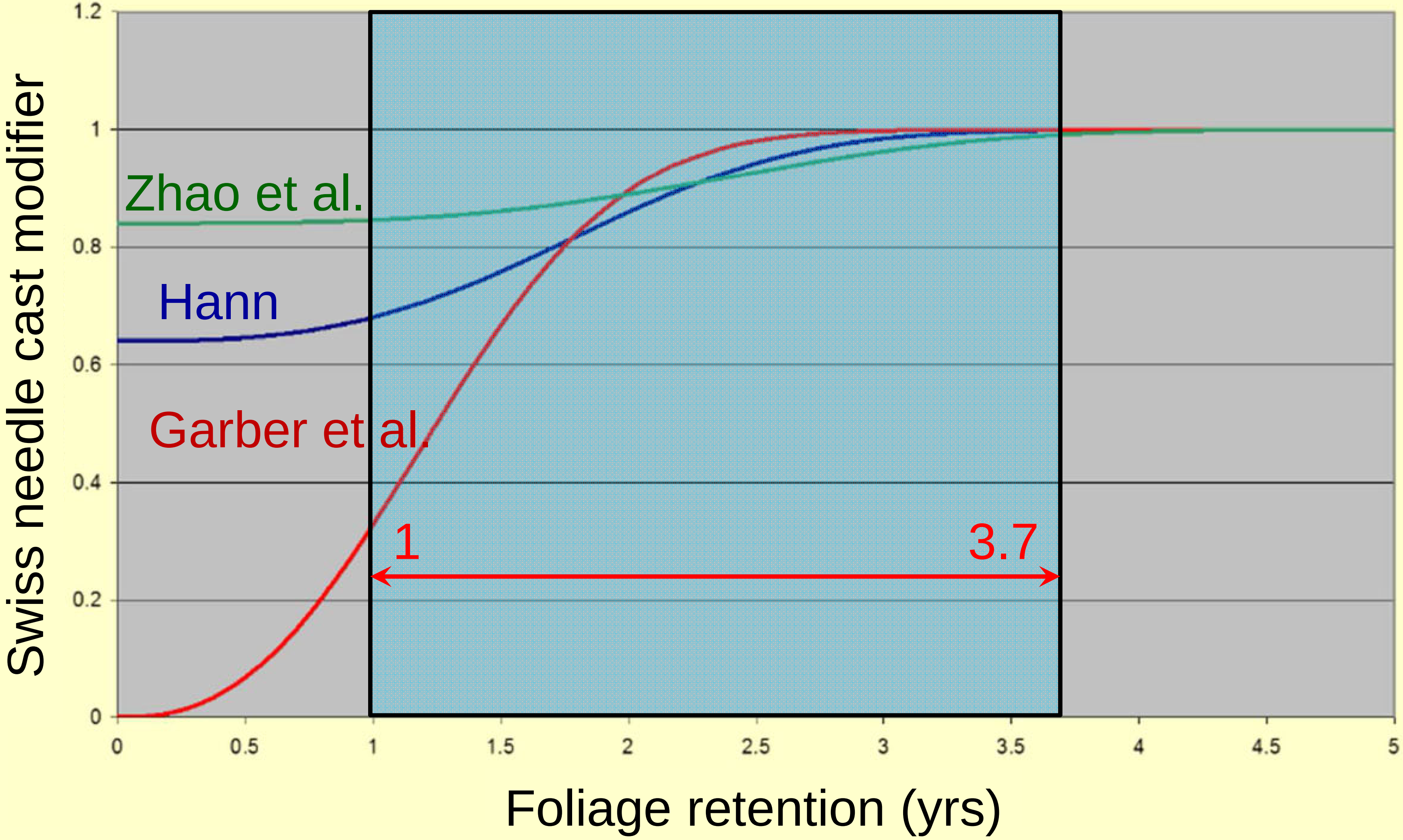
Stand Growth Assessment 2.81.xls [Read-Only] [Compatibility Mode] - Microsoft Excel

Security Warning Macros have been disabled.

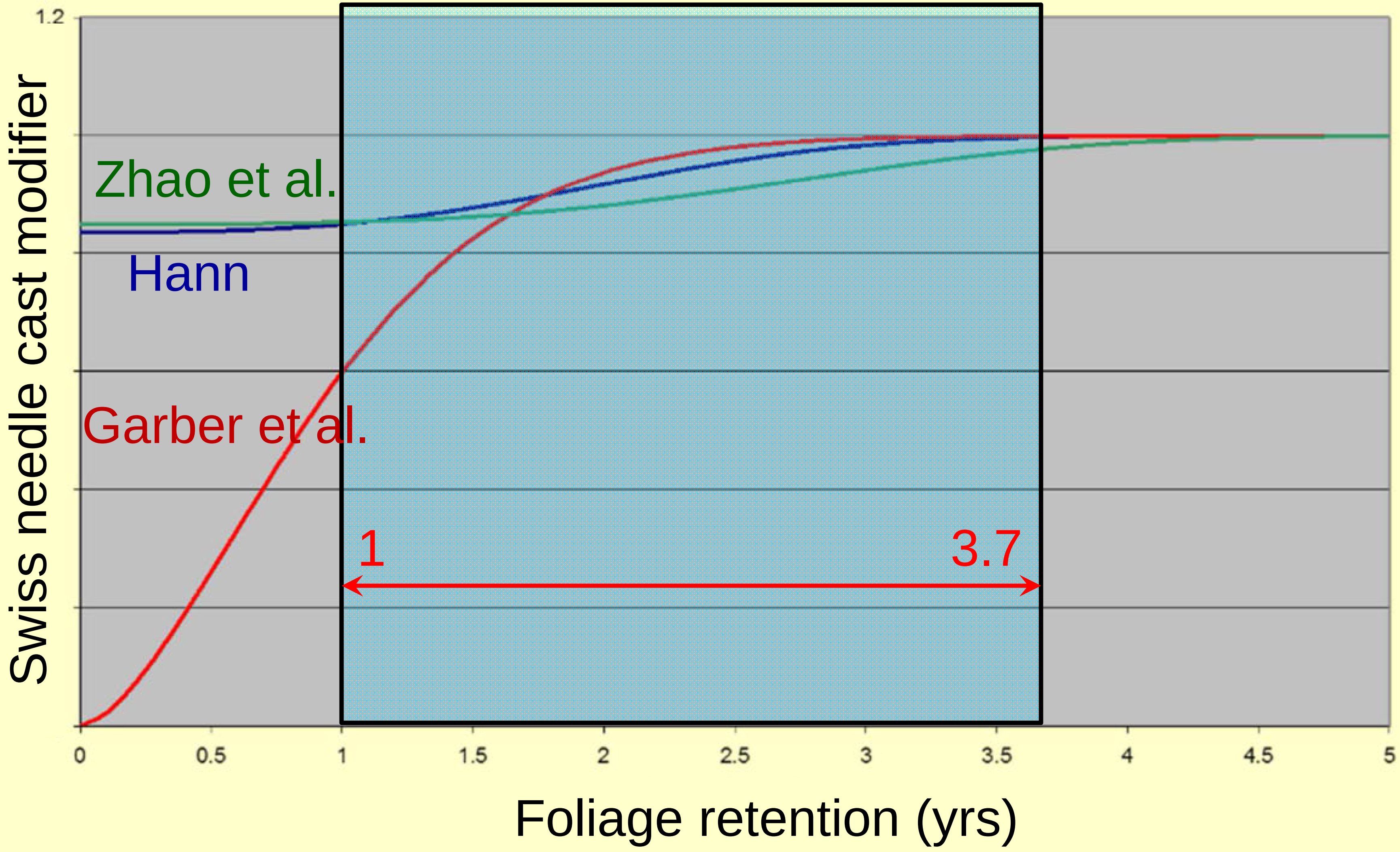
STAND GROWTH ASSESSMENT TOOL

FOR QUESTIONS OR ADDITIONAL INFORMATION CONTACT DOUG ROBIN WITH OREGON DEPARTMENT OF FORESTRY OR DOUG MAINWARING WITH OREGON STATE UNIVERSITY

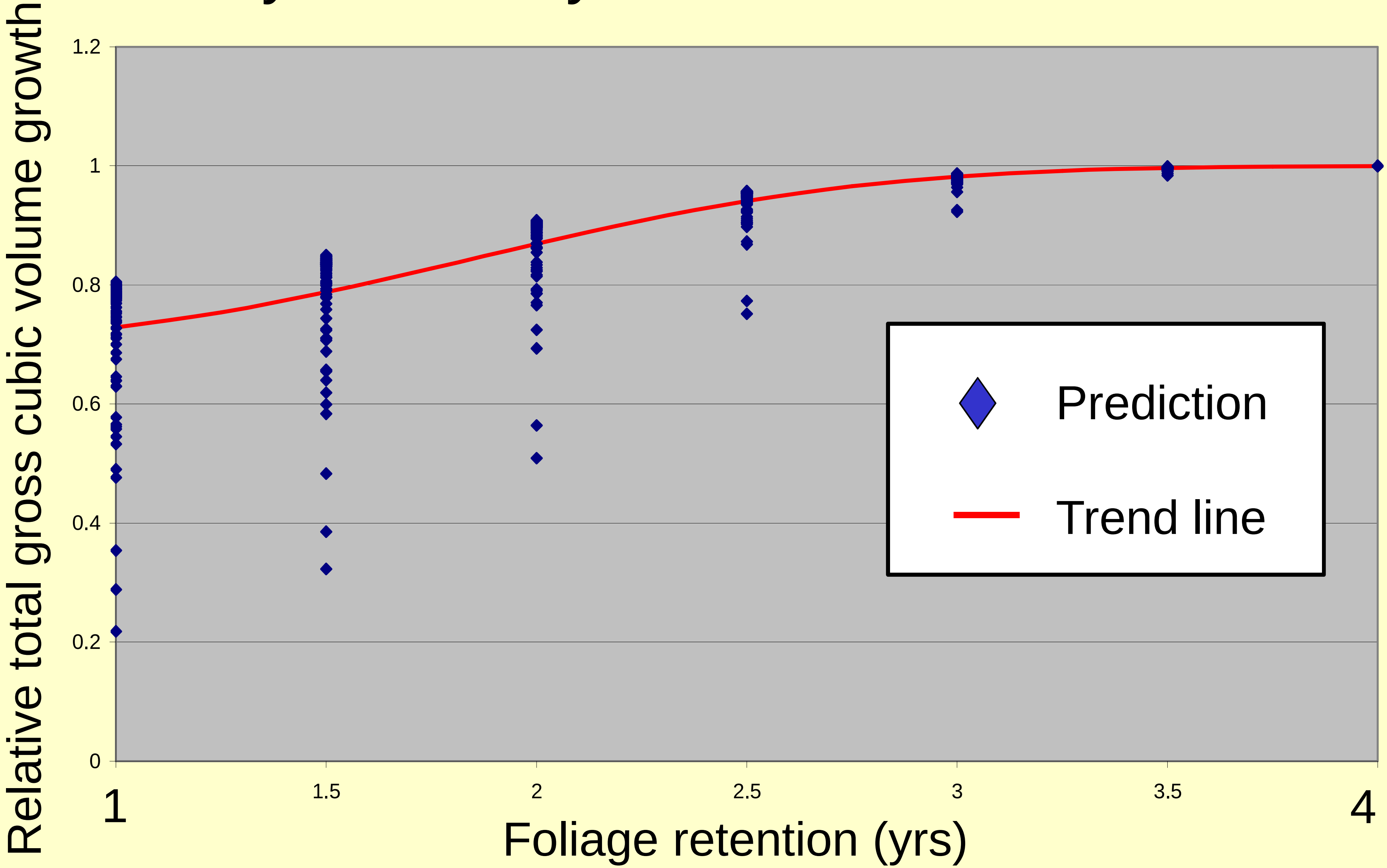
Stand-level diameter growth rate modifiers for ORGANON



Stand-level
height growth rate modifiers for ORGANON



Last year of 30-year ORGANON simulation



Growth impacts and silvicultural mitigation

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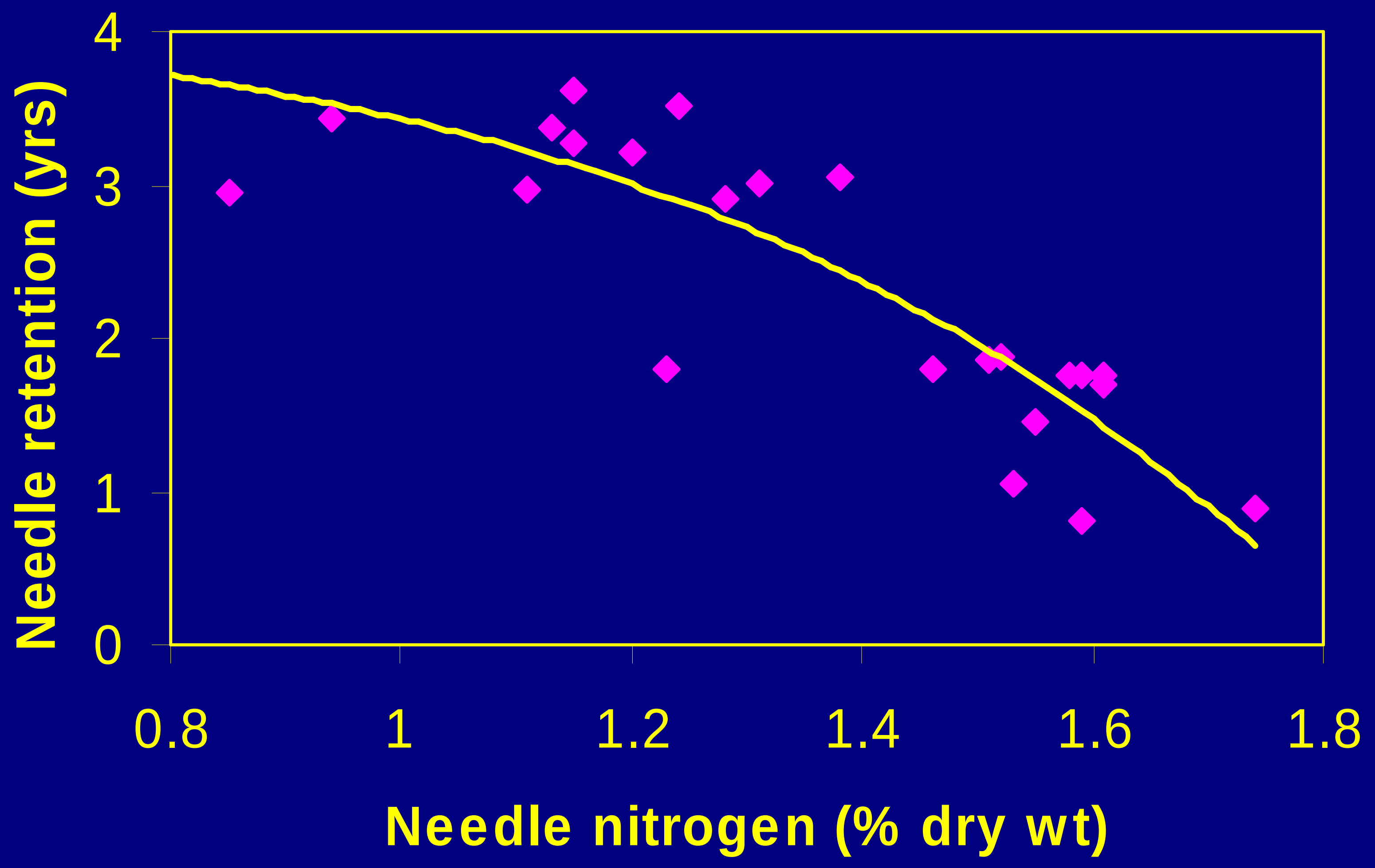
- What tools are available for estimating SNC growth impacts?
- Are there predisposing conditions that suggest mitigation measures?

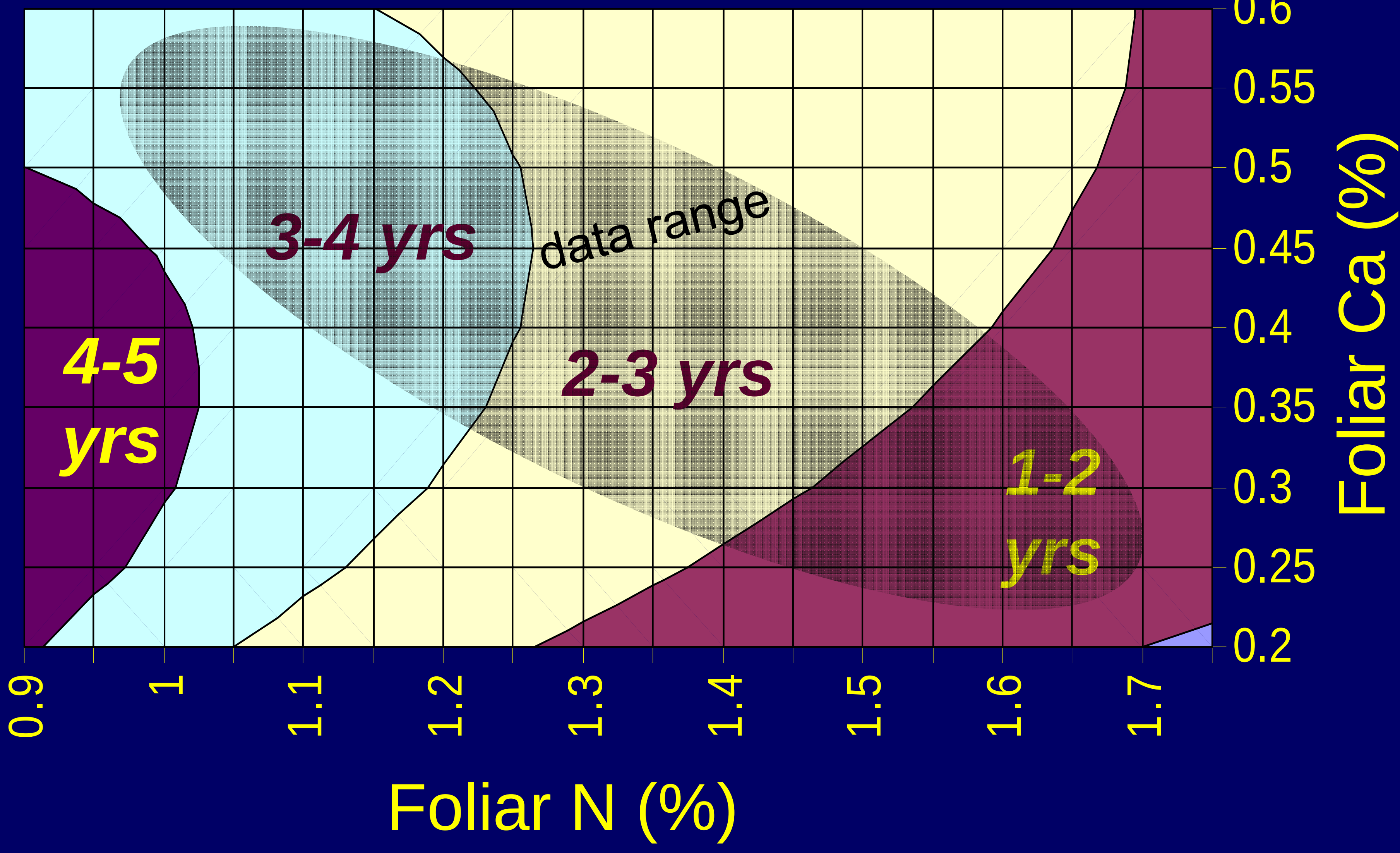
Growth impacts and silvicultural mitigation

- Are there predisposing conditions that suggest mitigation measures?
  - Influence of GENETICS and genetics
  - Nutritional imbalance
  - Climatic fluctuations and directional change

Needle Retention as a Function of Needle N Concentration



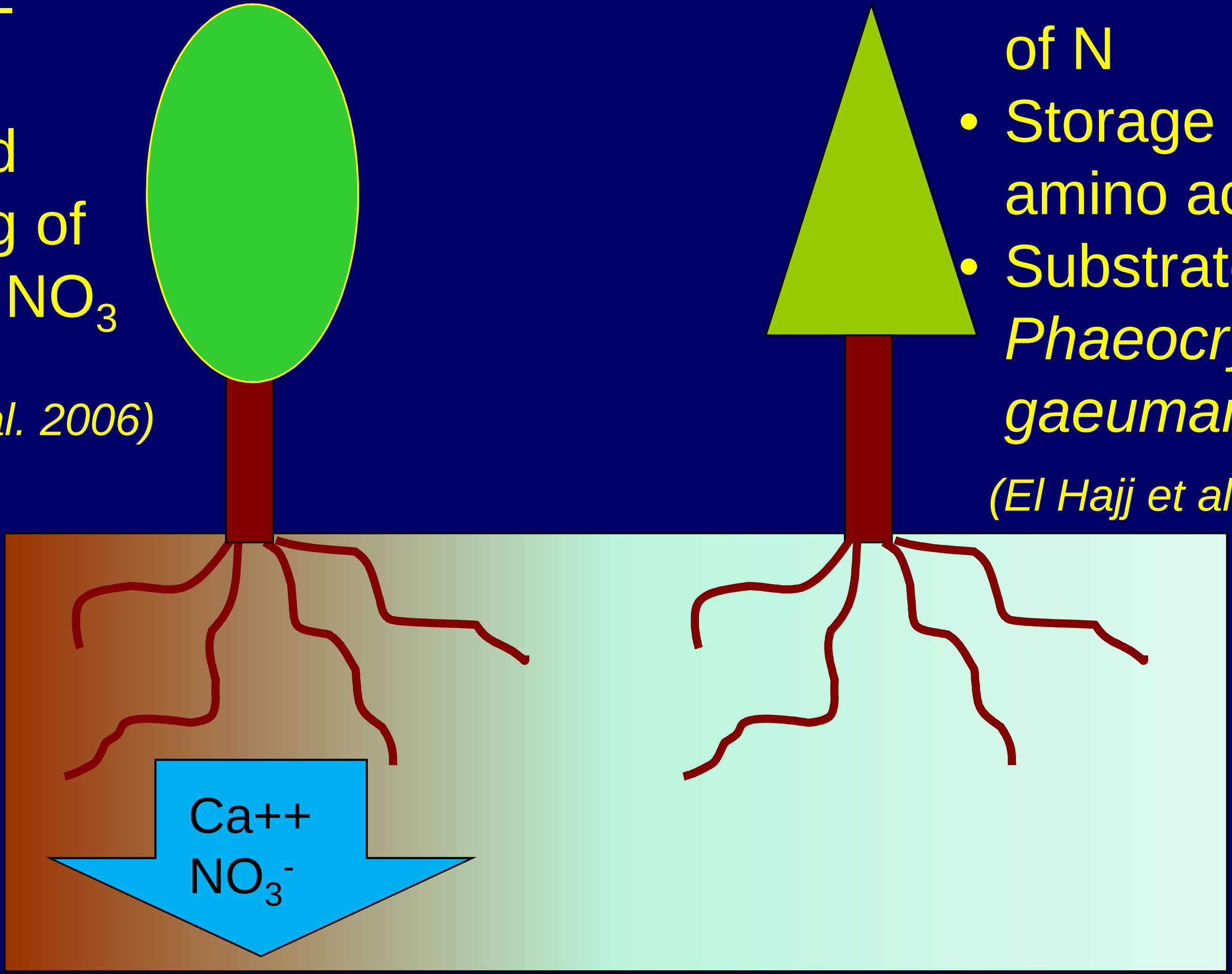
Needle retention by foliar N and Ca



Growth Impact of Swiss needle cast

- ***S and NO_3 have consistently negative relationship to foliage retention***
- ***Ca has consistently positive relationship to foliage retention***
- Foliar S, foliar (or soil) Ca, and soil NO_3 “explain” 91% of the variation in foliage retention

One hypothesis



- Alder N-fixation
- Coupled leaching of Ca and NO_3

(Perakis et al. 2006)

- Relative excess of N
- Storage as free amino acids
- Substrate for *Phaeocryptopus gaeumannii*

(El Hajj et al. 2004)

Climatic influences

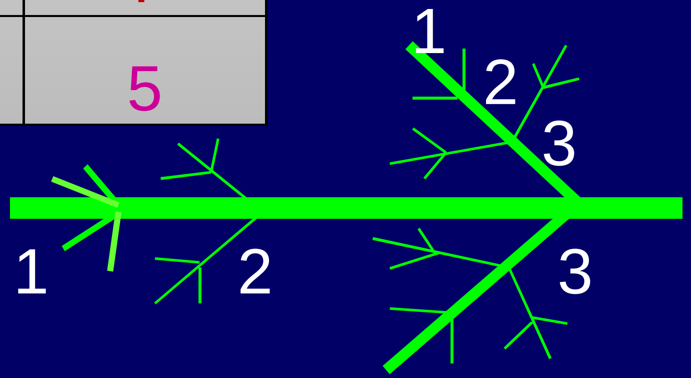
Climatic influences on foliage retention

- Geographic variation: Risk defined by local climatic factors (Rosso, Hansen, Coop, Stone, Latta)
- Annual variation: Driven by long-term site average and annual fluctuations in climatic conditions (Zhao)
  - Lagged climatic variables:
    - Winter temperature
    - Spring/summer wetness
    - Late summer heat
- Dynamics of individual needle cohorts that contribute to foliage retention (Zhao)

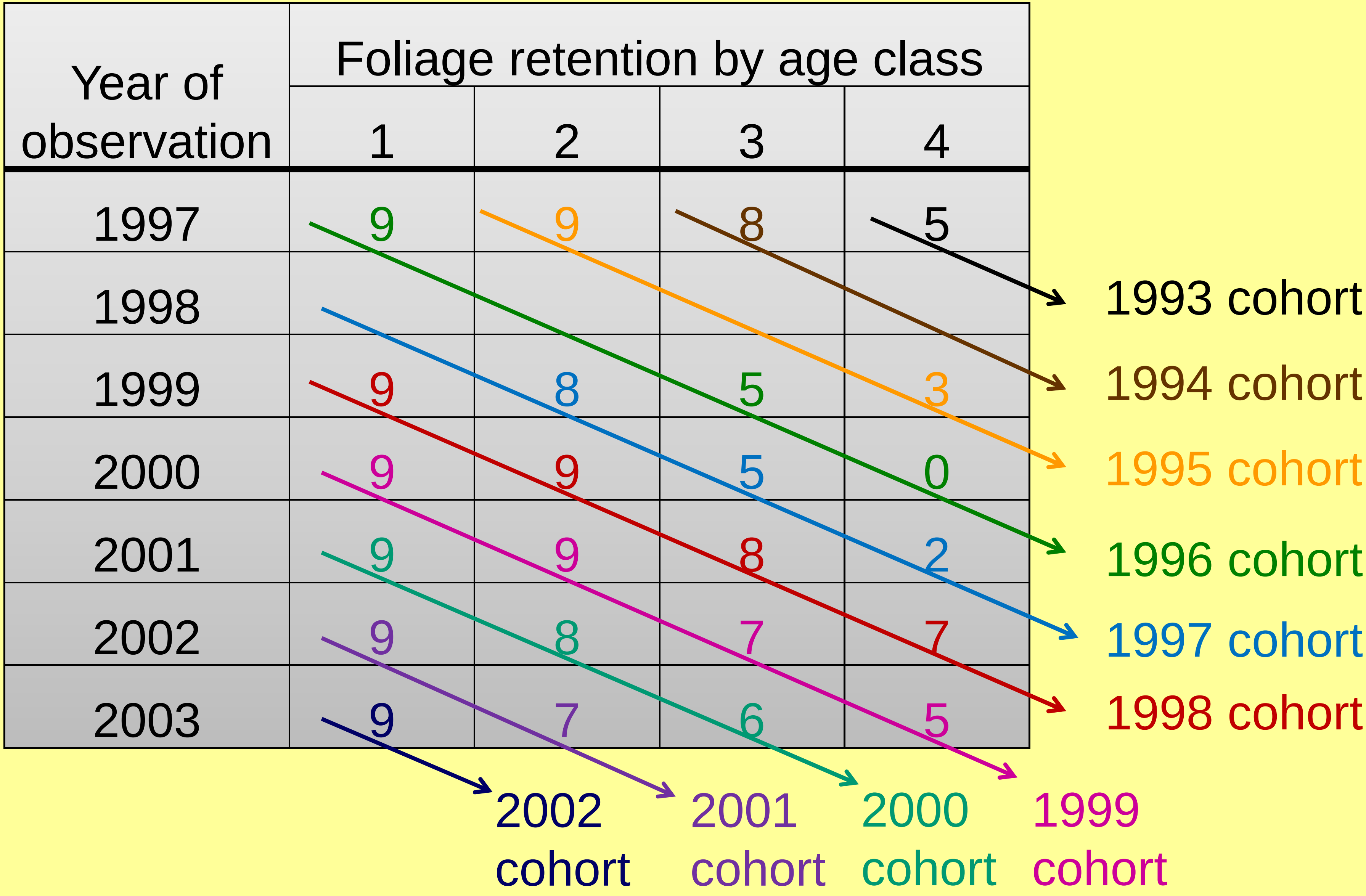
Foliage retention by age class or cohort

Year of observation	Foliage retention by age class			
	1	2	3	4
1997	9	9	8	5
1998				
1999	9	8	5	3
2000	9	9	5	0
2001	9	9	8	2
2002	9	8	7	7
2003	9	7	6	5

9 -> 90-100%
8 -> 80-89%
.
.
.
0 -> 0-9%



Foliage retention by age class or cohort



Year of observation	Foliage retention by age class			
	1	2	3	4
1997	9	9	8	5
1998				
1999	9	8	5	3
2000	9	9	5	0
2001	9	9	8	2
2002	9	8	7	7
2003	9	7	6	5

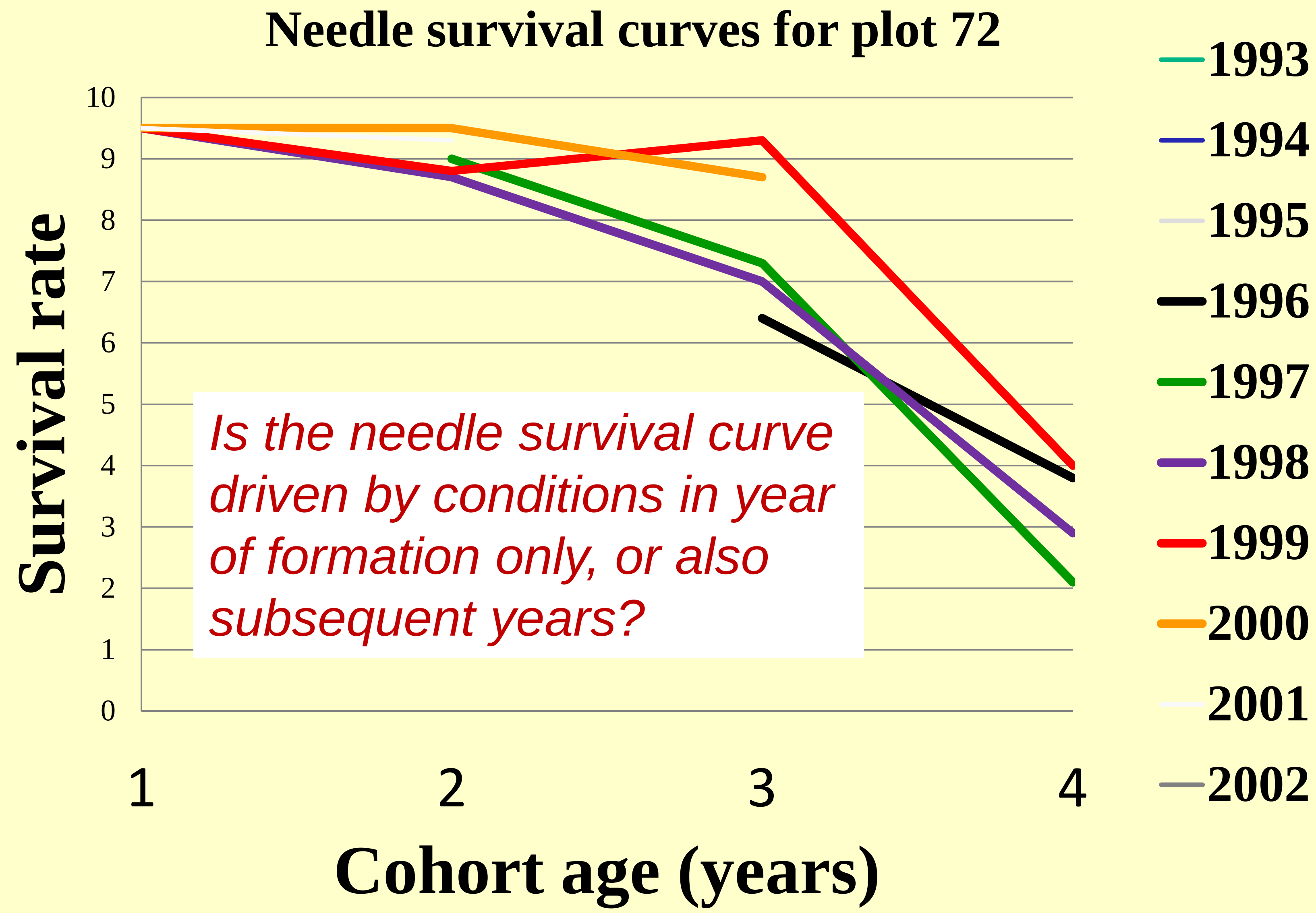
System of equations

Foliage retention by age class as function of climatic variables with differing lag times

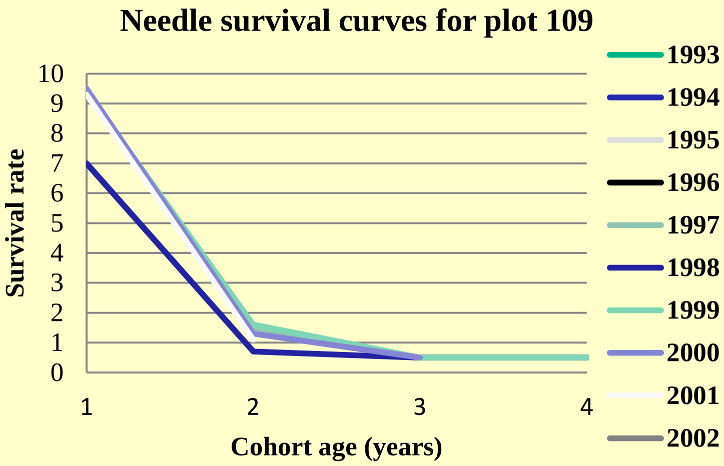
$$FR1_t = \beta_{10} + \beta_{11}SW_{t-1} + \beta_{12}WT_t + \beta_{13}SH_{t-1} + \varepsilon_1$$
$$FR2_t = \beta_{20} + \beta_{21}SW_{t-2} + \beta_{22}WT_{t-1} + \beta_{23}SH_{t-2} + \varepsilon_2$$
$$FR3_t = \beta_{30} + \beta_{31}SW_{t-3} + \beta_{32}WT_{t-2} + \beta_{33}SH_{t-3} + \varepsilon_3$$
$$FR4_t = \beta_{40} + \beta_{41}SW_{t-4} + \beta_{42}WT_{t-3} + \beta_{43}SH_{t-4} + \varepsilon_4$$

FRk_t = Foliage retention of k-yr-old foliage at time *t*
β_k = Parameter to be estimated from the data
SW_t = Spring/summer wetness at time *t*
WT_t = Winter temperature at time *t*
SH_{t-1} = Summer heat at time *t*
ε_1 = *Error term for equation k, assumed correlated with error term from other equations*

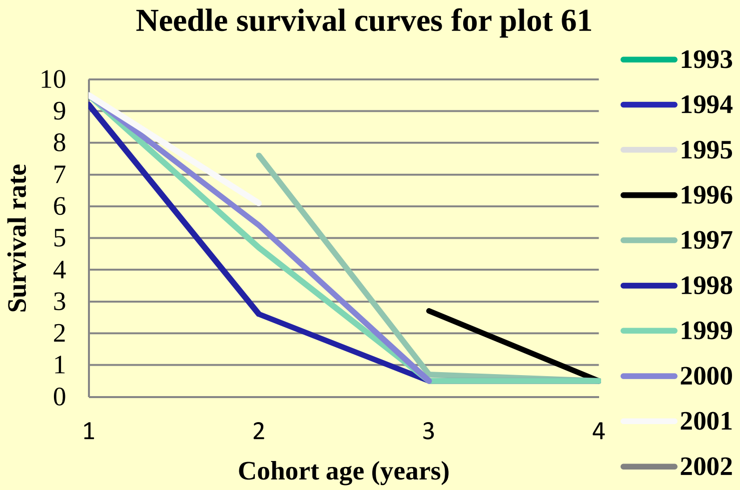
Needle survivorship models



Is the needle survival curve driven by conditions in year of formation only, or also subsequent years?

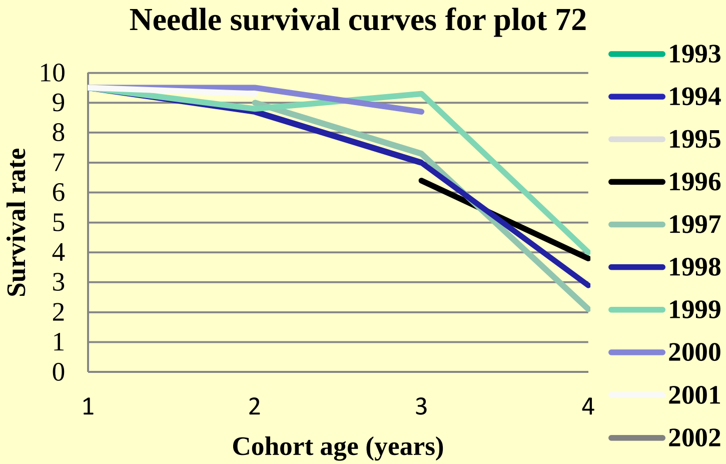


Needle survival curves for plot 109

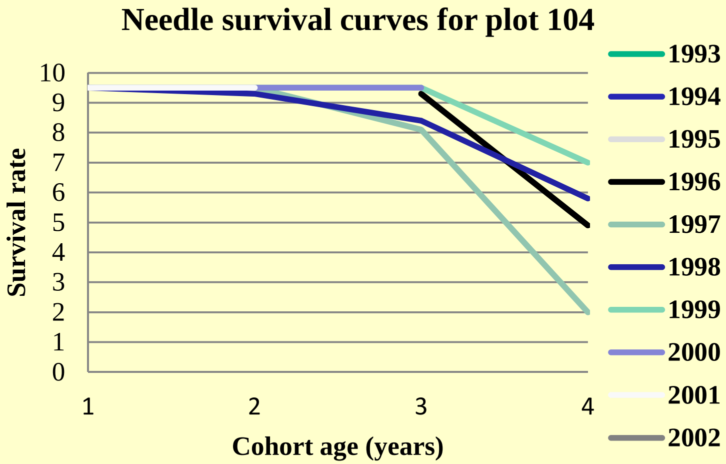


Needle survival curves for plot 61

Plot to plot variation in survival curves consistent with foliate retention



Needle survival curves for plot 72



Needle survival curves for plot 104

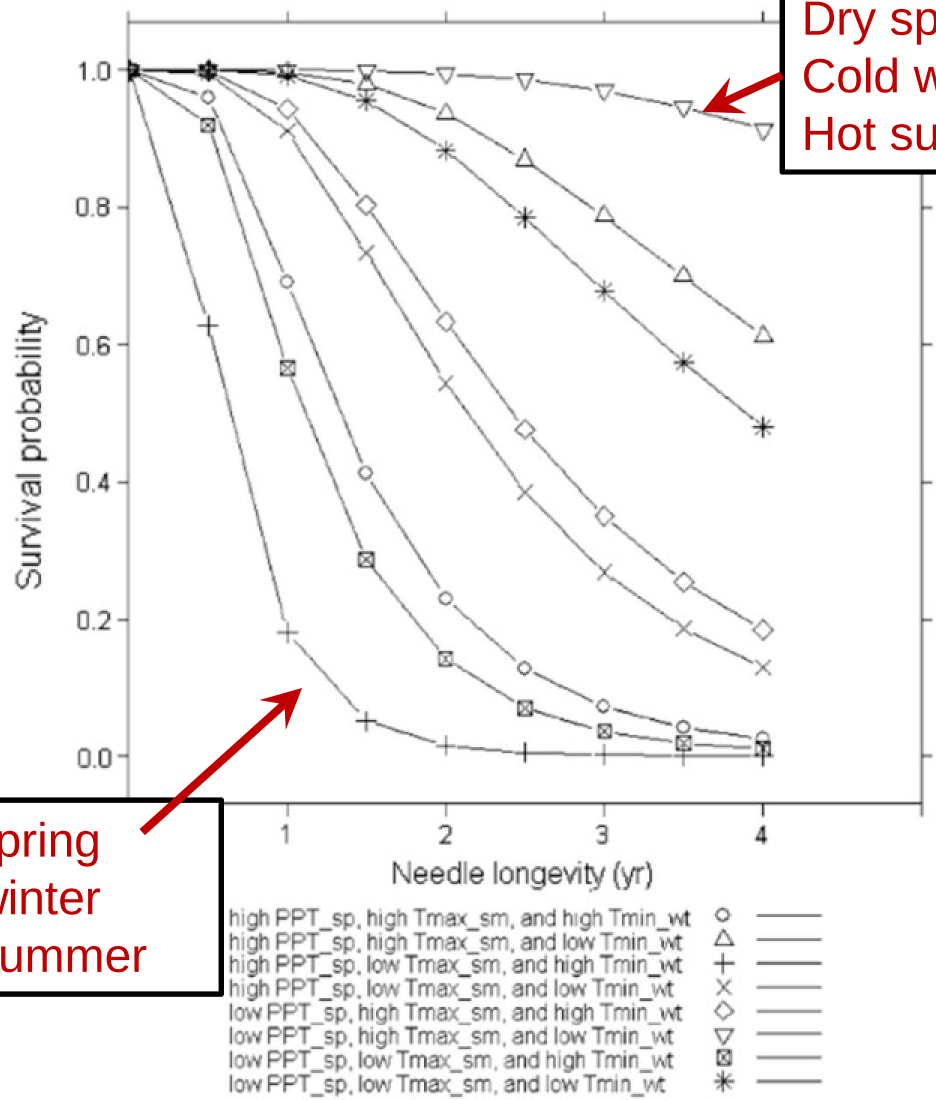


Fig. 5 Predicted survival curves for Douglas-fir needles initiated under different climatic conditions (high and low PPT_sp = 1,281 and 275 mm, respectively; high and low Tmax_sm = 25.6 and 17.1 °C, respectively; and high and low Tmin_wt = 5.8 and −2.2 °C, respectively)

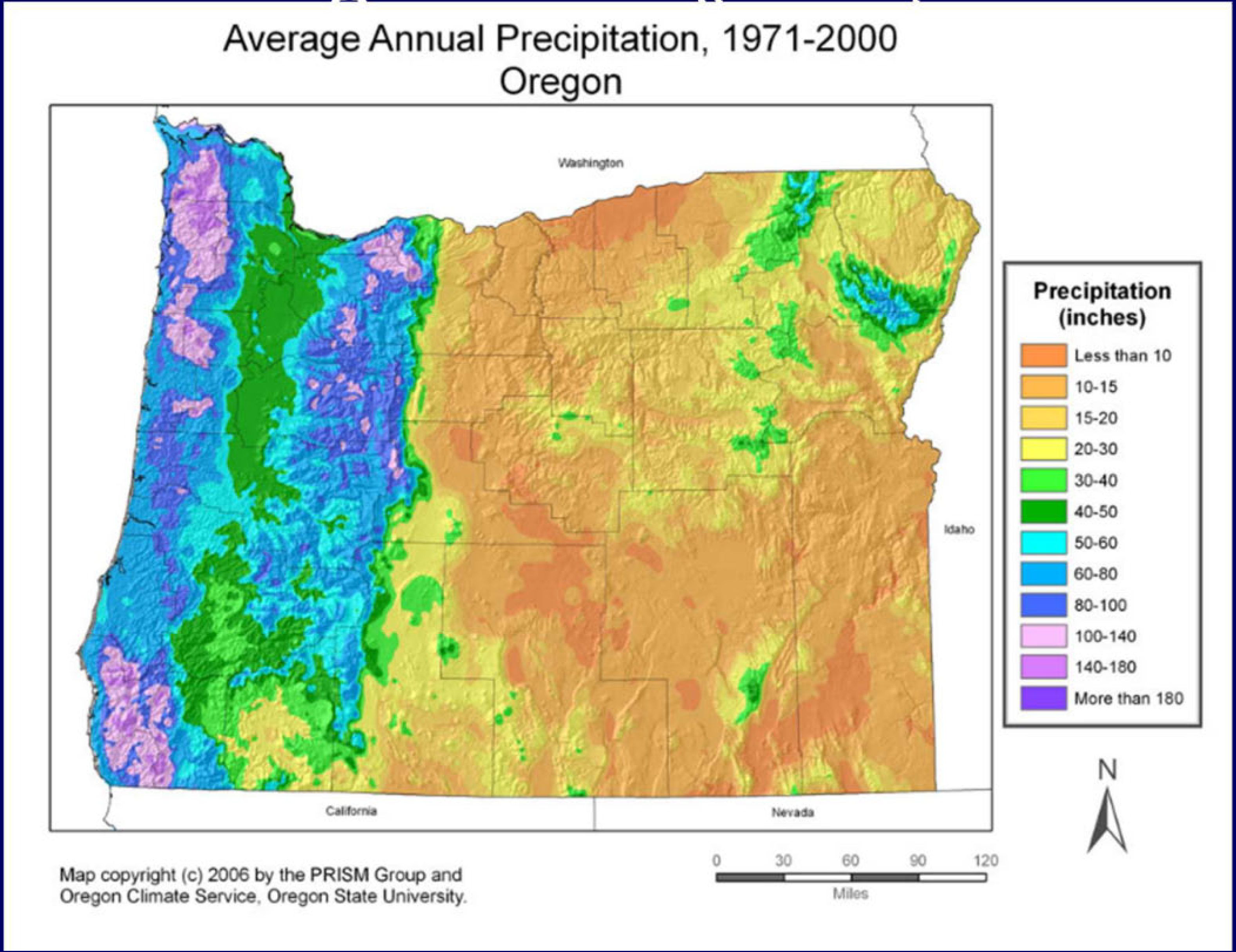
Dry spring
Cold winter
Hot summer

Wet spring
Mild winter
Mild summer

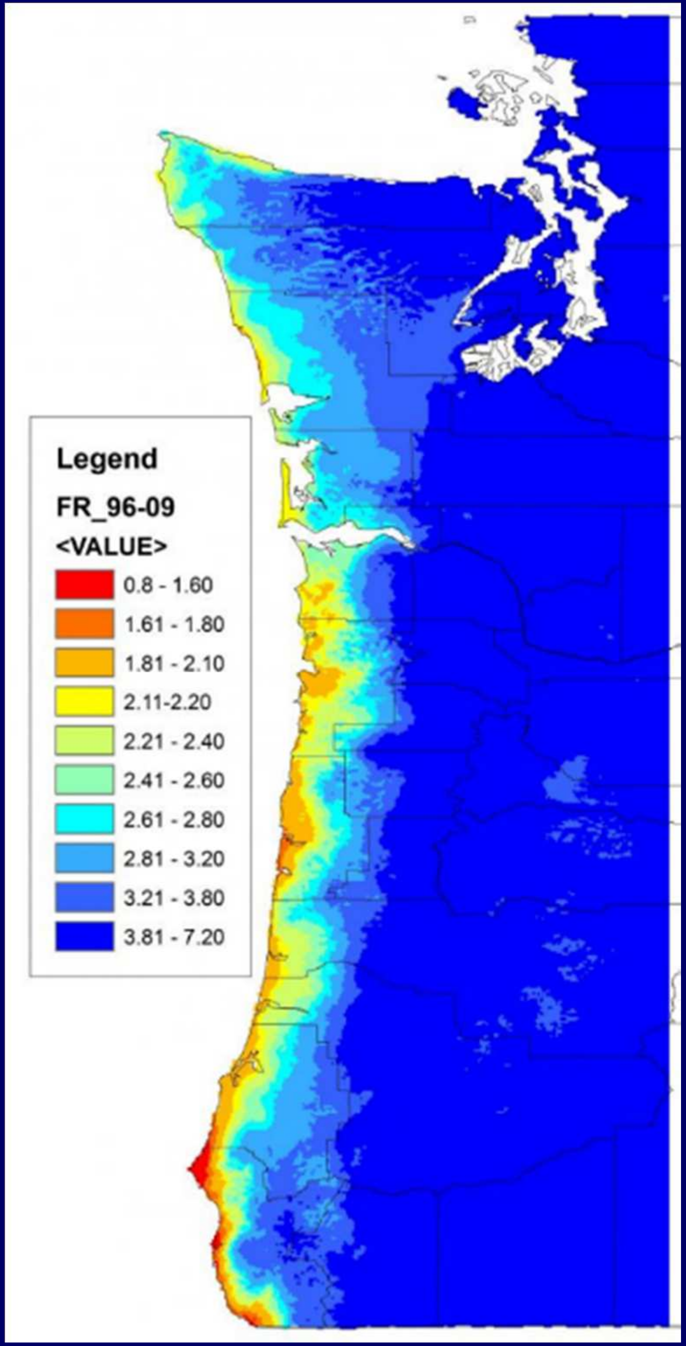
Predicted needle survival curves under different climatic conditions during year of cohort emergence:

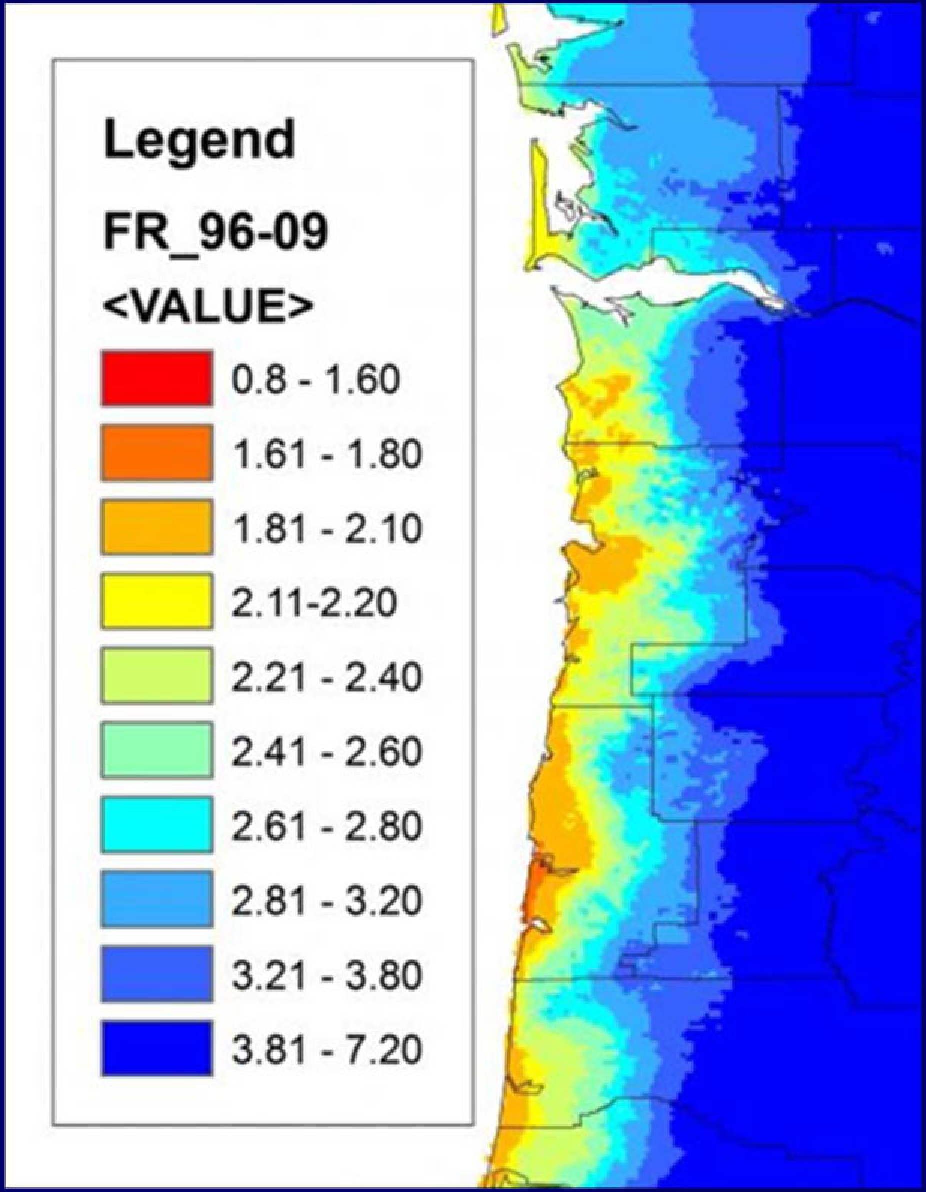
- High and low spring precipitation
- High and low winter temperature
- High and low later summer temperature

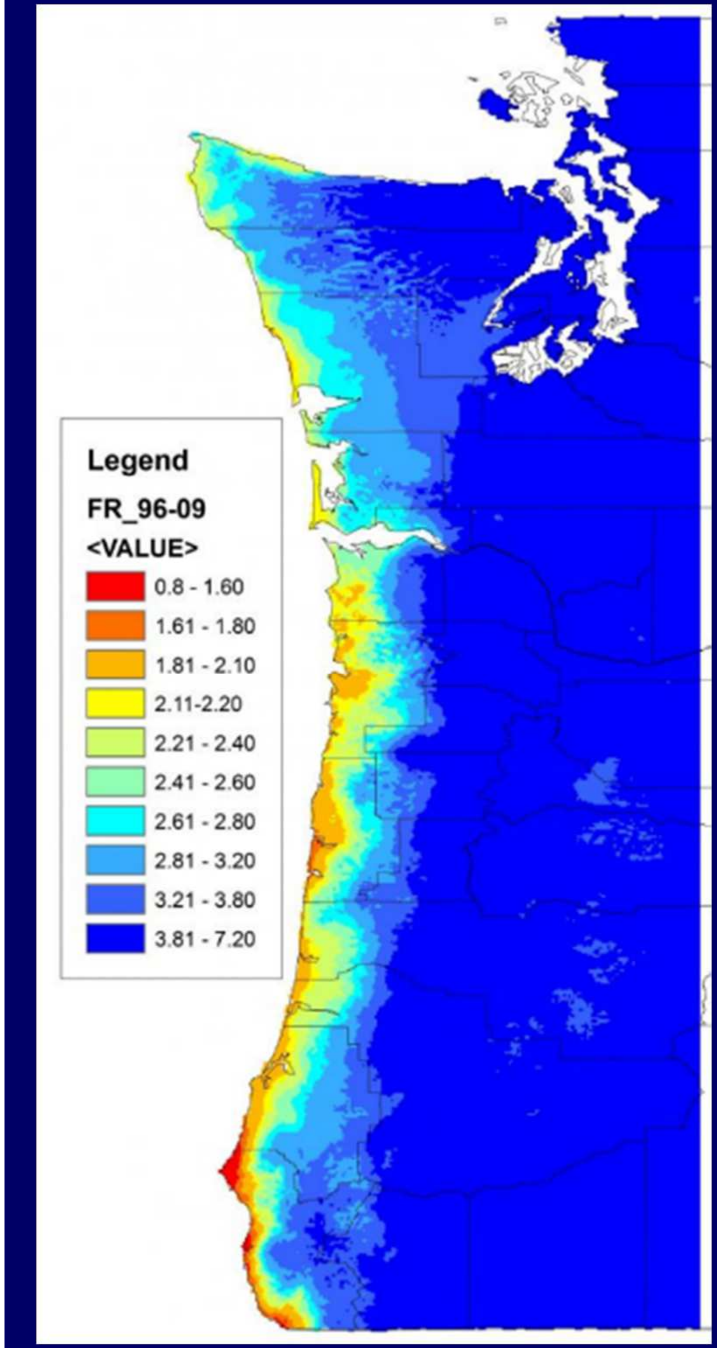
Douglas-fir silviculture in the presence of



Map copyright (c) 2006 by the PRISM Group and Oregon Climate Service, Oregon State University.


Legend
FR_96-09
<VALUE>
0.8 - 1.60
1.61 - 1.80
1.81 - 2.10
2.11-2.20
2.21 - 2.40
2.41 - 2.60
2.61 - 2.80
2.81 - 3.20
3.21 - 3.80
3.81 - 7.20


Legend
FR_96-09
<VALUE>
0.8 - 1.60
1.61 - 1.80
1.81 - 2.10
2.11-2.20
2.21 - 2.40
2.41 - 2.60
2.61 - 2.80
2.81 - 3.20
3.21 - 3.80
3.81 - 7.20



Zhao et al. (2011) Regional and annual trends in Douglas-fir foliage retention: Correlations with climatic variables. For. Ecol. Manage. 262:1872-1886.

Annual weather variables

$FR = b_0 - b_1 MAP\_1$ *Mean annual precip*

$+ b_2 TD\_2$ *Continentality*

$+ b_3 DD0\_4$ *Degree-days <0°C*

Monthly weather variables

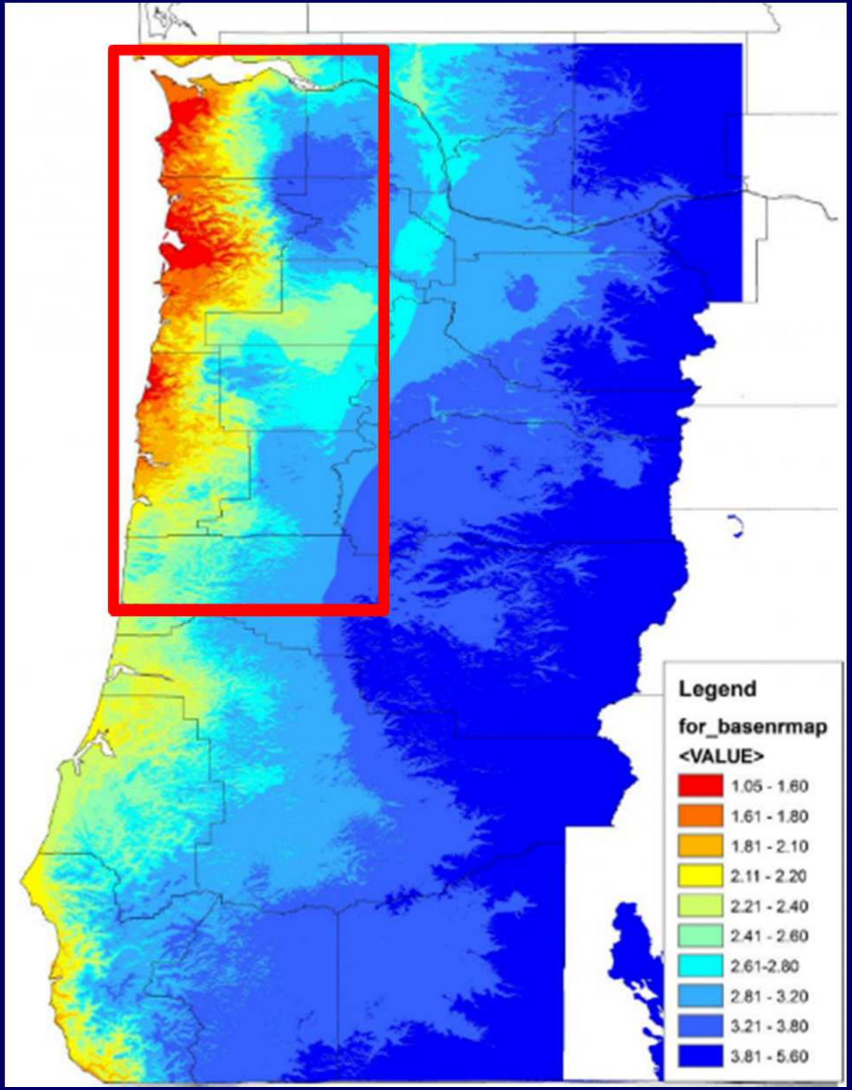
$FR = b_0 - b_1 TMAX\_04\_3$ *April max T*

$+ b_2 TMAX\_07\_3$ *July max T*

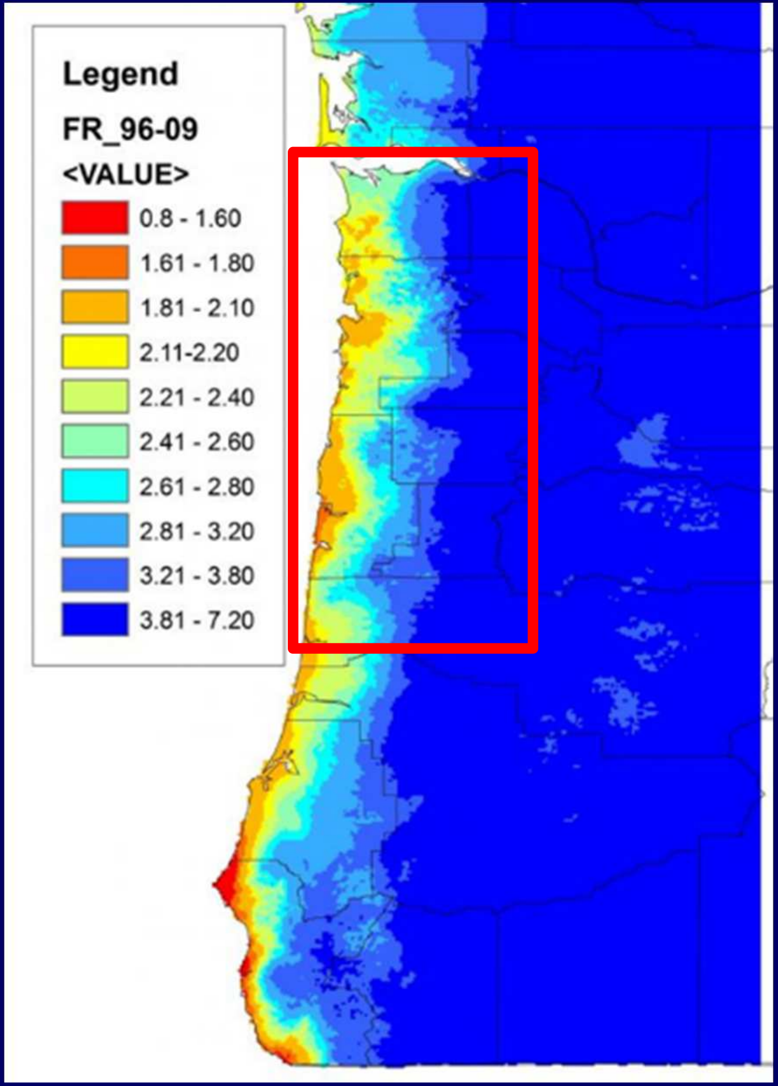
$- b_3 TMIN\_01\_3$ *Jan min T*

$- b_4 {*} PPT\_04\_3$ *April precip*

Alternative models with similar results for estimating foliage retention as a function of climatic variables



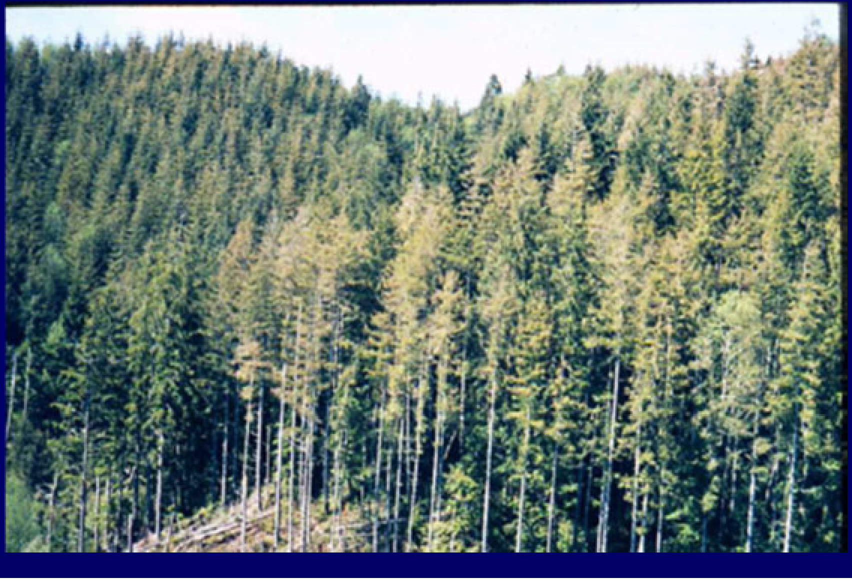
Latta



Zhao et al.

Growth impacts and silvicultural mitigation

- Growth impacts
  - Growth and mortality
  - Foliage dynamics and measures of SNC severity
- Predisposing factors
  - Soil and foliar chemistry
  - Weather/climate
- Silvicultural mitigation
  - Thinning effects
  - Fertilization
  - Fungicides

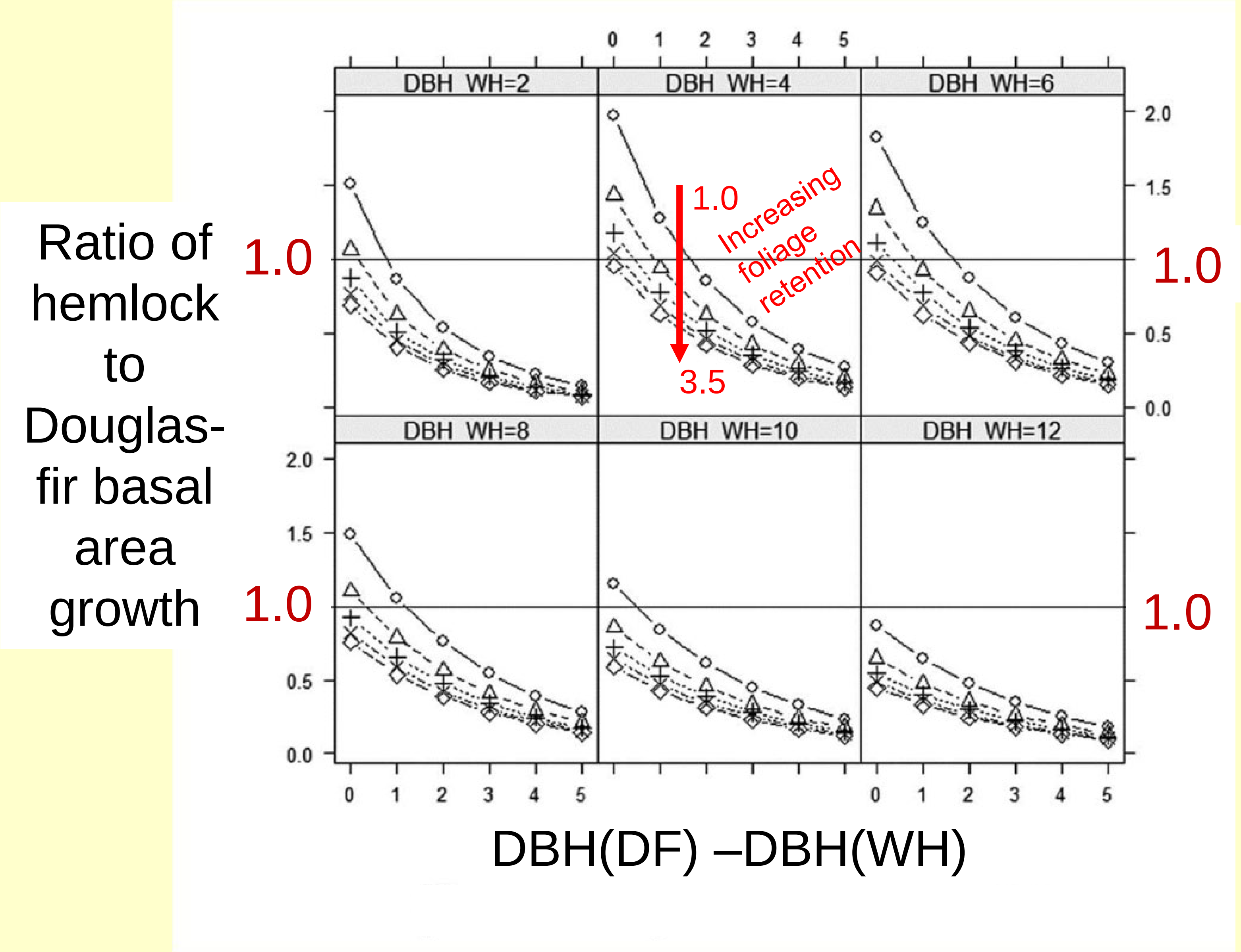


Growth impacts and silvicultural mitigation

Thinning in mixed Douglas-fir / western hemlock

Thinning in pure Douglas-fir stands

Thinning rules for favoring western hemlock or Douglas-fir

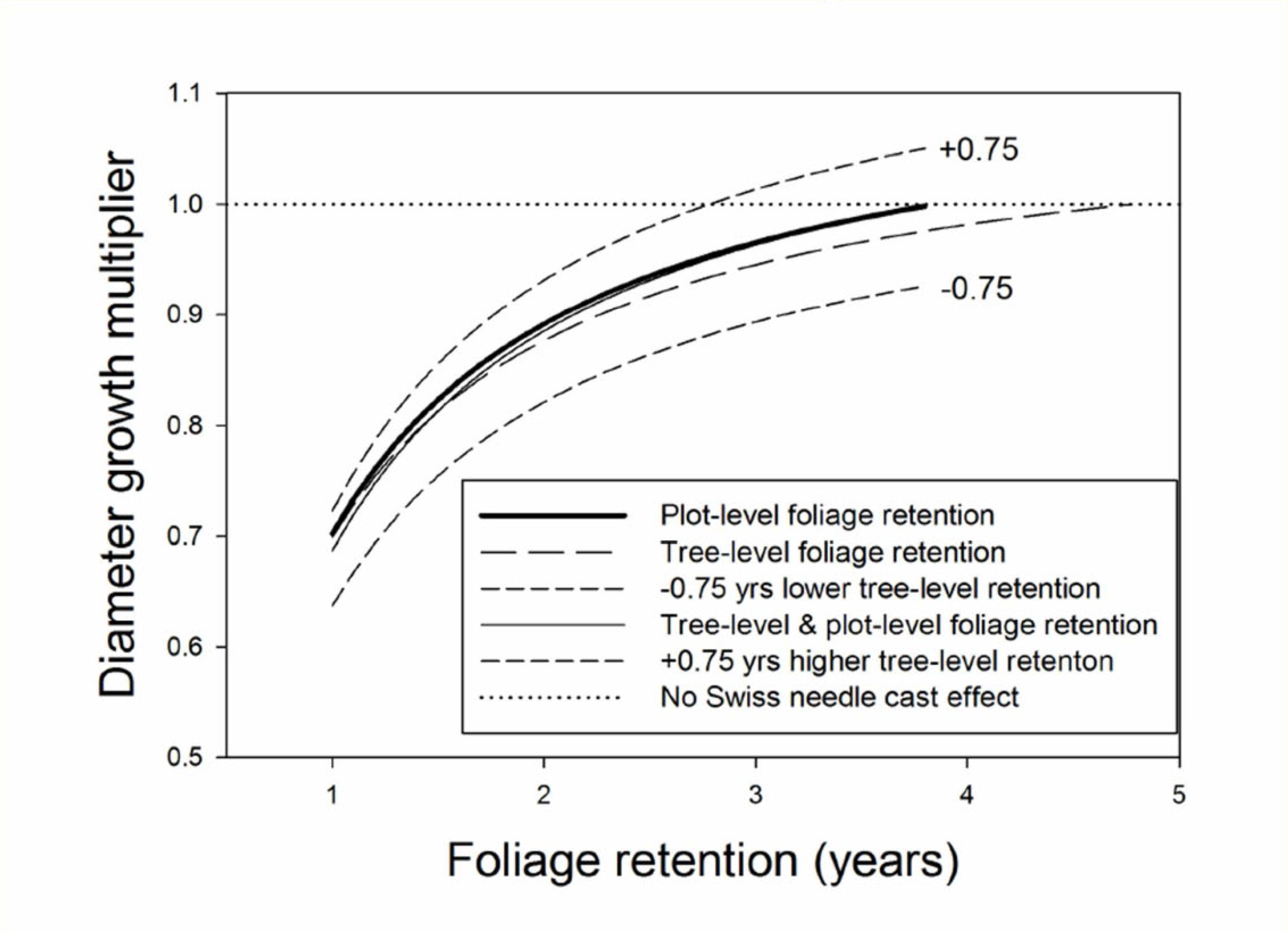


Growth impacts and silvicultural mitigation

Thinning in pure Douglas-fir stands

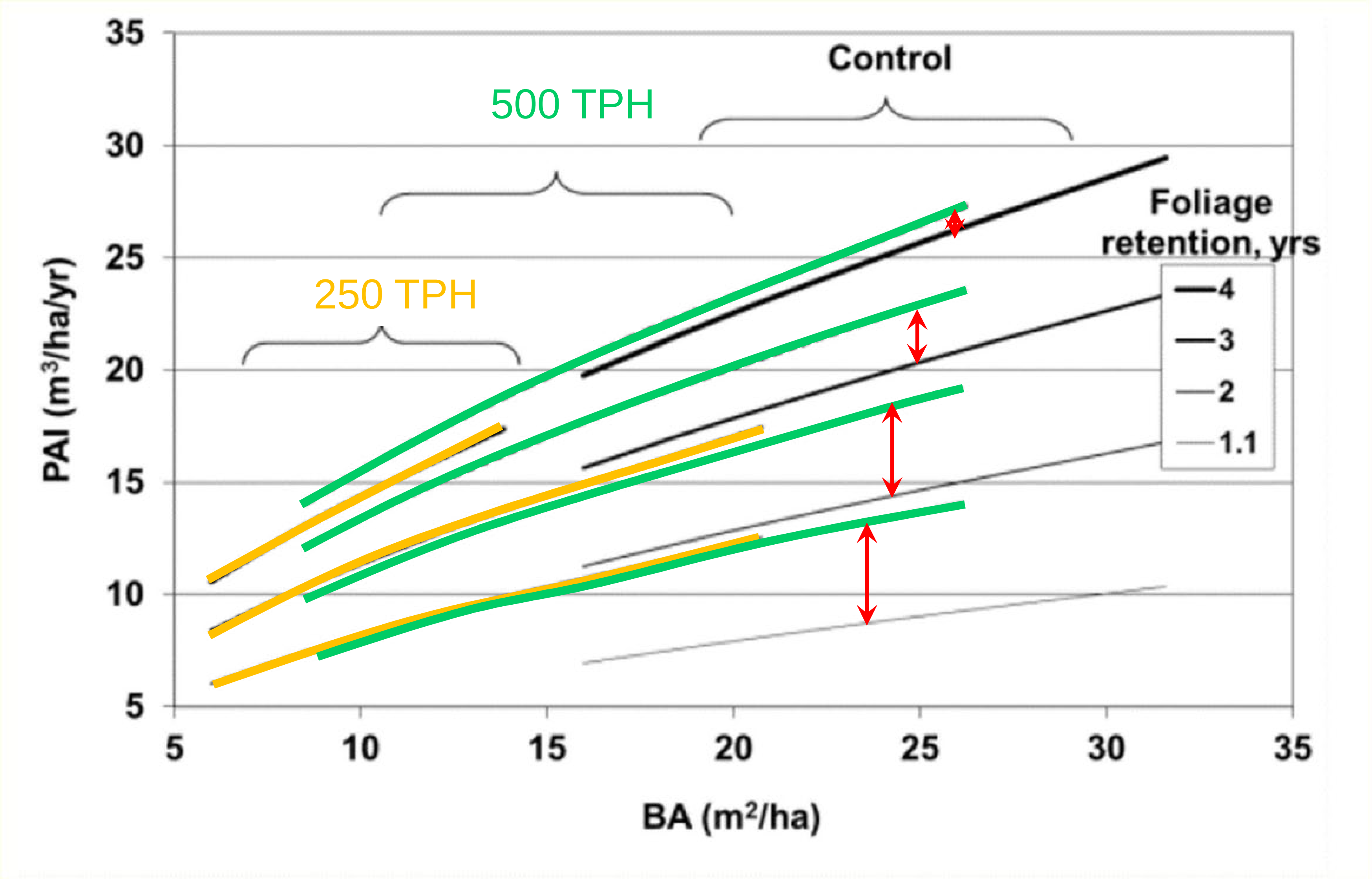
- Usual potential eugenic effect of thinning from below
- Variation in foliage retention => implies variation in SNC tolerance and growth
- Potential for improving stand tolerance of SNC and minimizing growth impact

Plot-level versus tree-level foliage retention

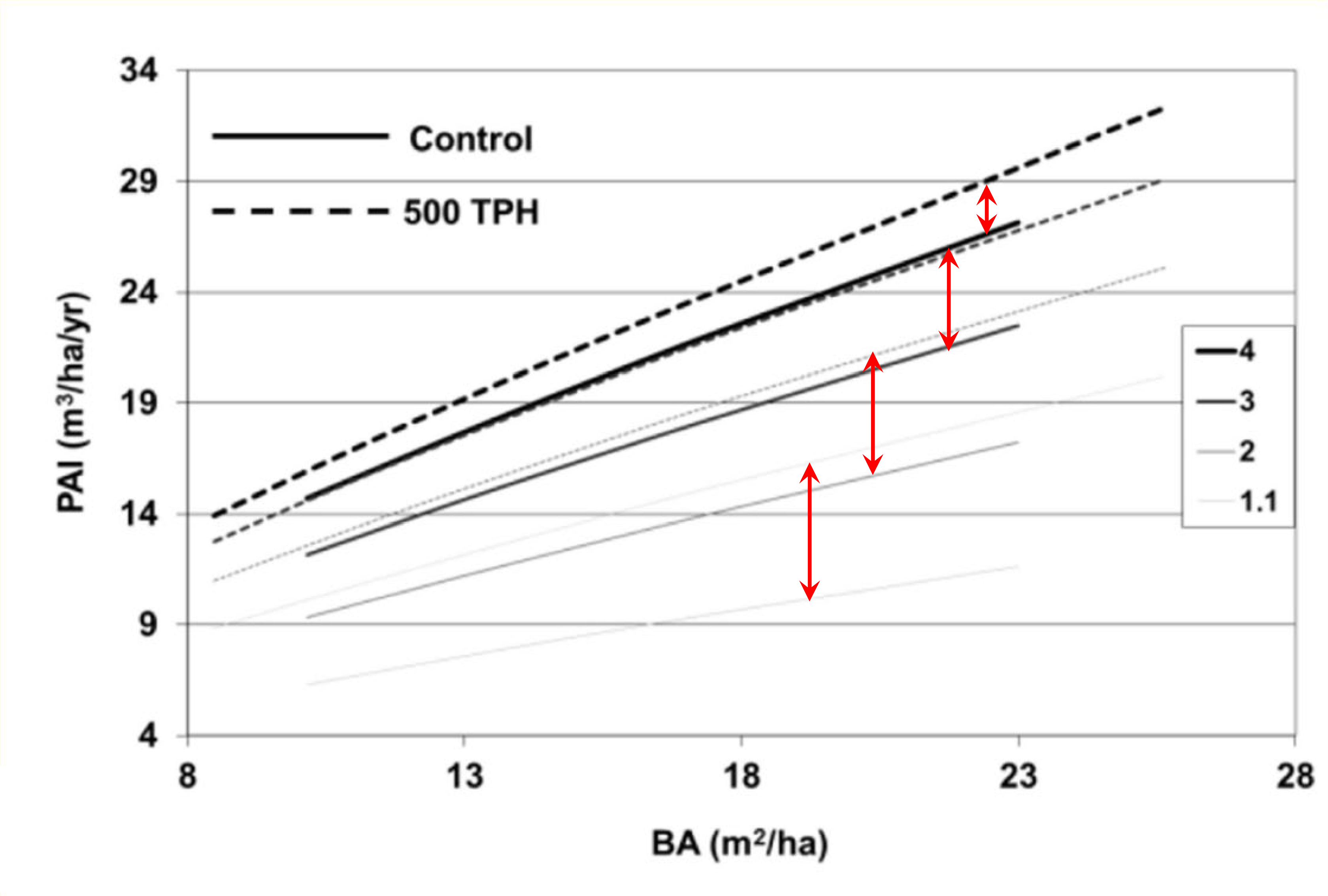


Zhao et al. (2015) For Ecol Manage

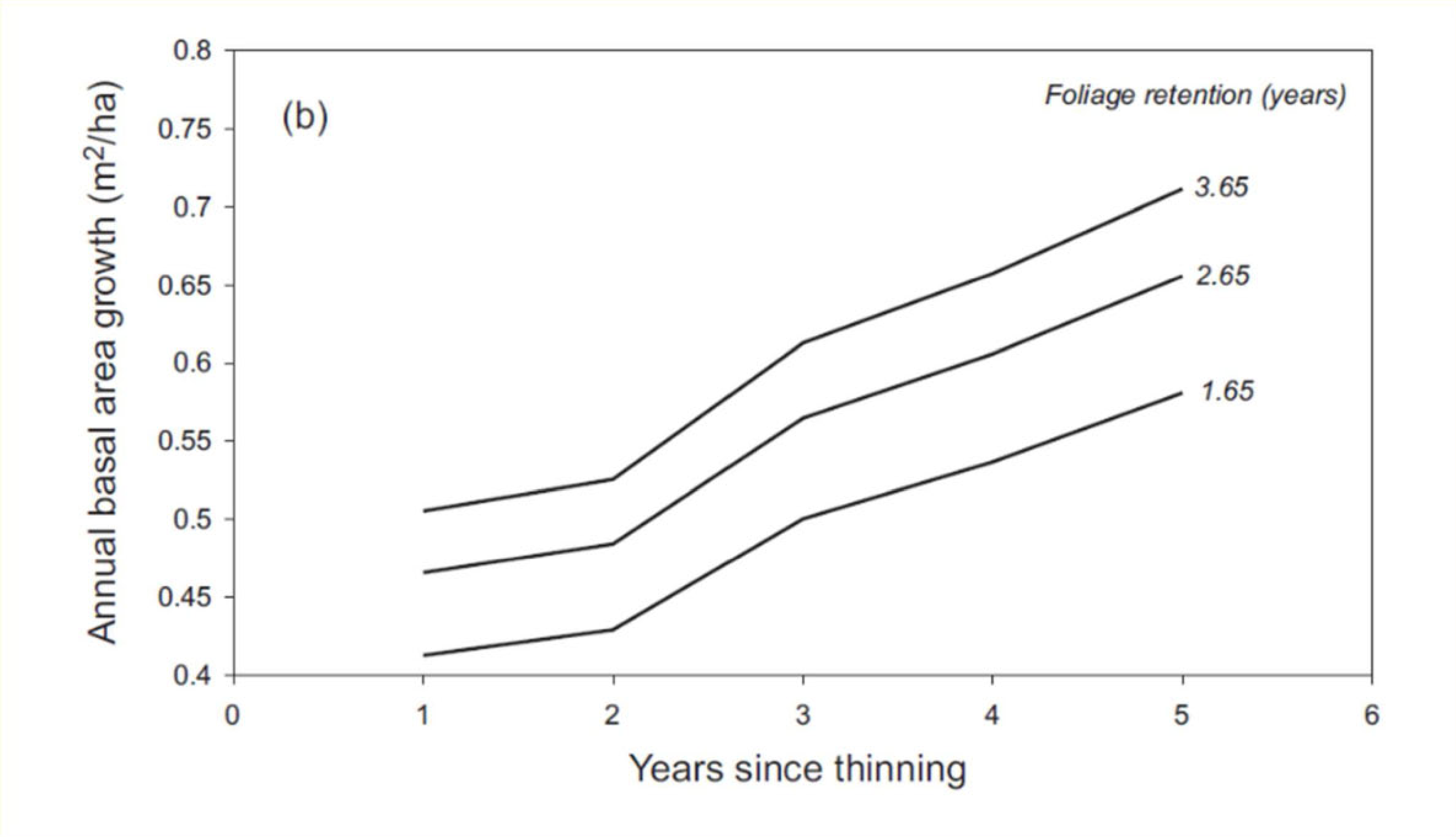
SNCC pre-commercial thinning study



SNCC pre-commercial thinning study
500 largest TPH only



SNCC retrospective commercial thinning study
Average basal area growth under differing initial SNC severity



“Beyond N fertilization trials

16 sites, 5 or 7 treatments

Treatment	Form	Amount	Reason for inclusion
Control	- -	- -	Statistical reference for treatments
N	Urea	224 kg N/ha	Industry standard
Lime	$CaCO_3$	1000 kg Ca/ha	Elevates pH, reduces Al, adds Ca
Ca	$CaCl_2$	100 kg Ca/ha	Add Ca without change in pH
P	Na_3PO_4	500 kg P/ha	P-fixing soils in Coast Range
Kinsey	Blend	Site specific	Agricultural regime to “feed” soil
Fenn	Blend	Site specific	Optimal ratios of foliar nutrients

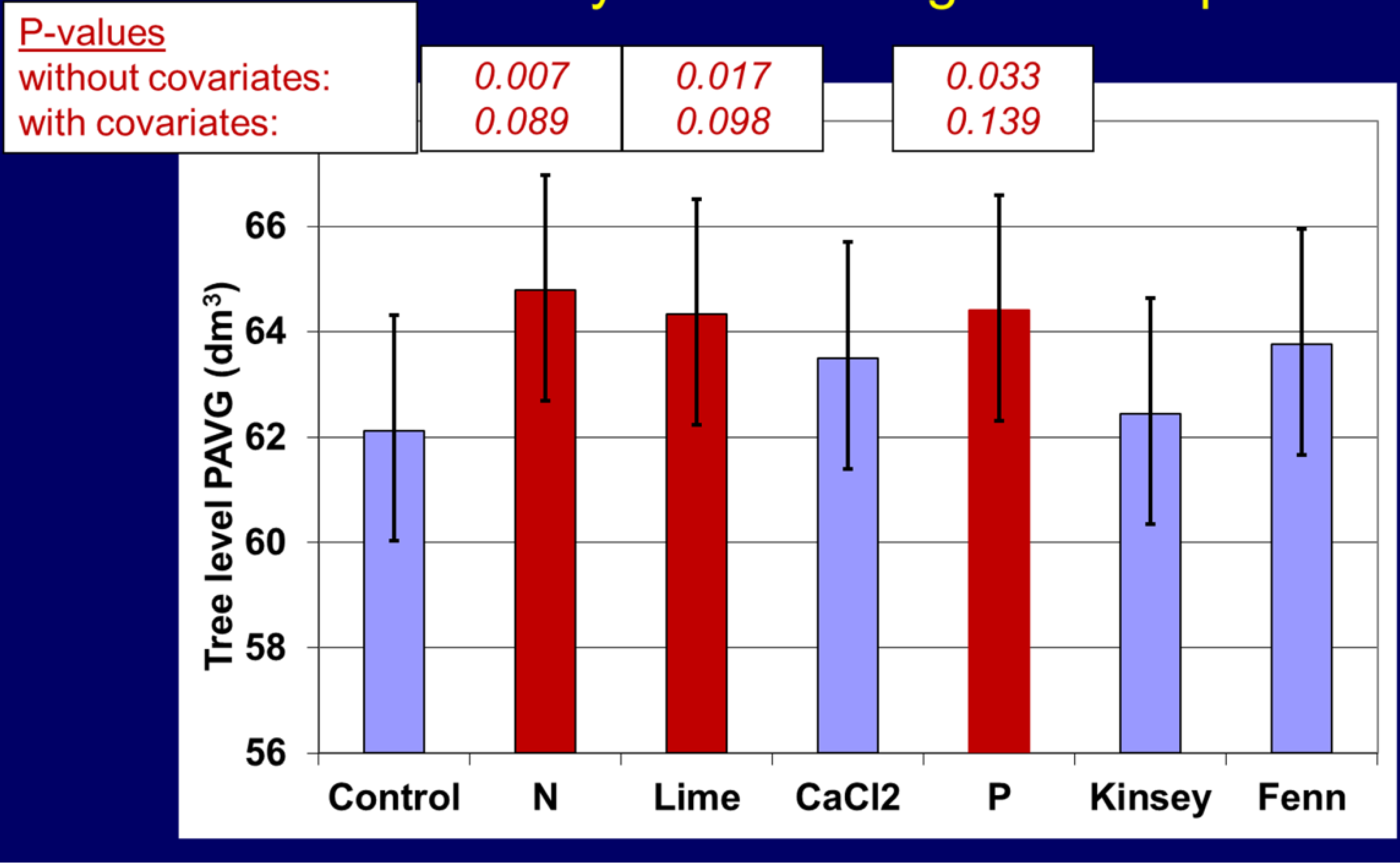
“Beyond N fertilization trials

16 sites, 5 or 7 treatments

"Beyond N fertilization trials

16 sites, 5 or 7 treatments

Three-year volume growth response



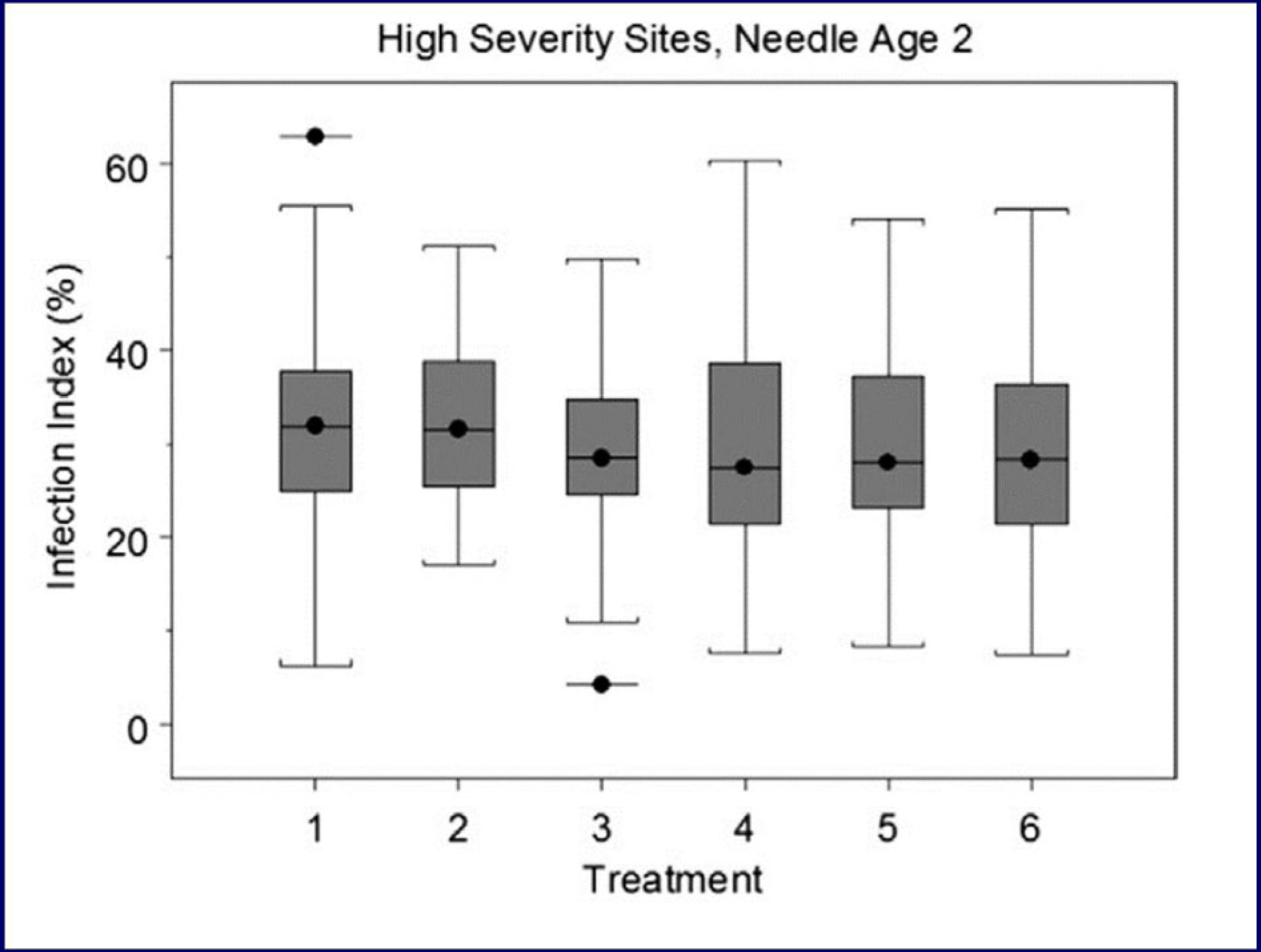
P-values
without covariates: *0.007* *0.017* *0.033*
with covariates: *0.089* *0.098* *0.139*

"Beyond N fertilization trials

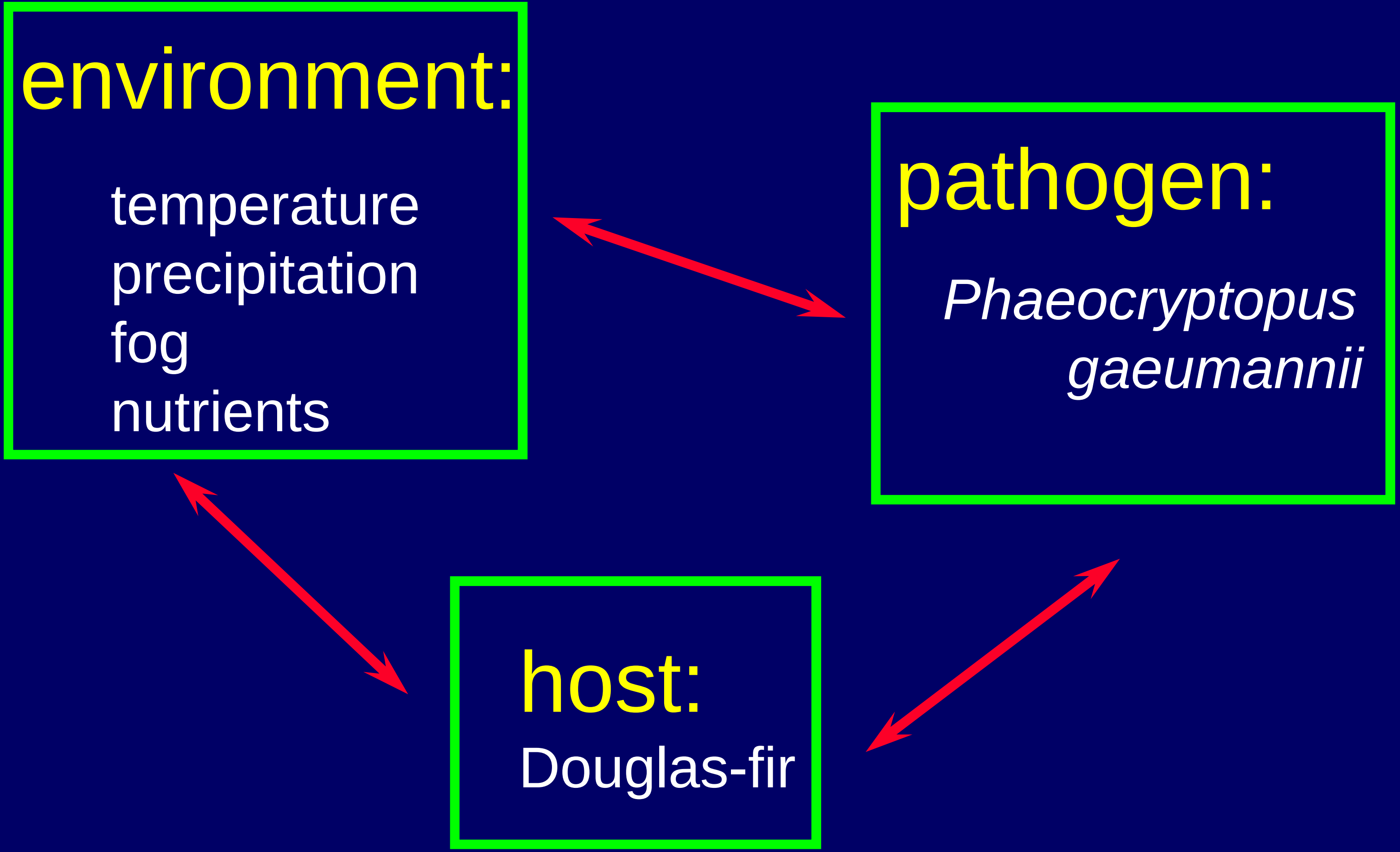
16 sites, 5 or 7 treatments

Infection index =

infection frequency
x
conditional pseudothecia count



Disease triangle !



environment:

temperature
precipitation
fog
nutrients

pathogen:

Phaeocryptopus gaeumannii

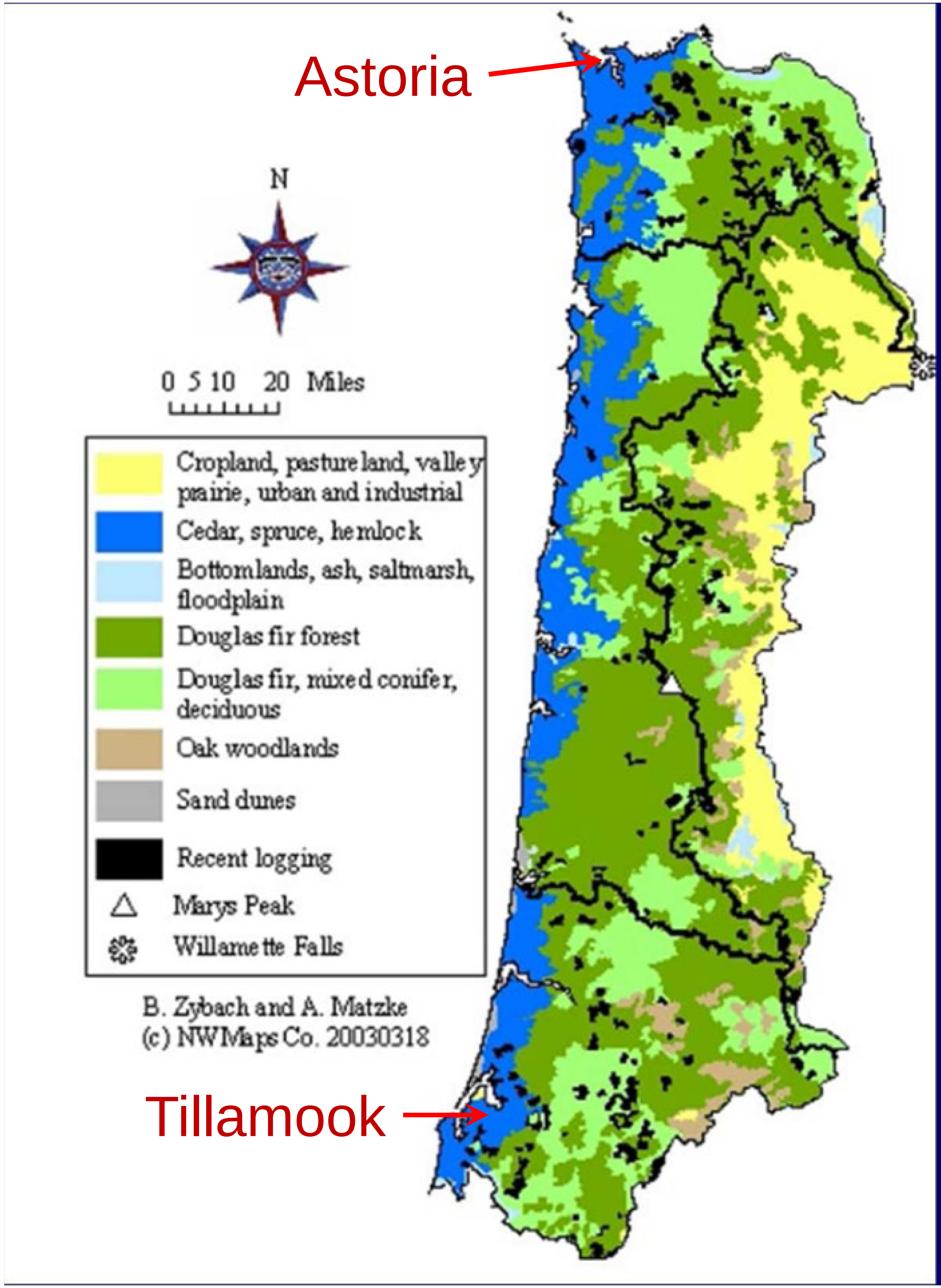
host:

Douglas-fir

Douglas-fir silviculture in the presence of Swiss needle cast:

Relative merits of designing effective management tactics and conceding to environmental limitations

1. Relative low mix of Douglas-fir in plantations within sitka spruce or “fog” belt along coast (severe SNC zone).
2. Seed from tolerant Douglas-fir families identified in progeny tests in middle of Coast Range (moderate to light SNC zone).
3. Thinning to maintain tree vigor in moderate SNC zone.
4. Beware of sites previously occupied by red alder for long time (age or successive stands).



Blue zone delineates sitka spruce zone or fog belt.

Dark green delineates Douglas-fir forest in middle of Coast Range and higher elevations near coast.

Light green largely delineates admixture of red alder.

Thanks for your attention

Chlorothalonil applications 1996-2000

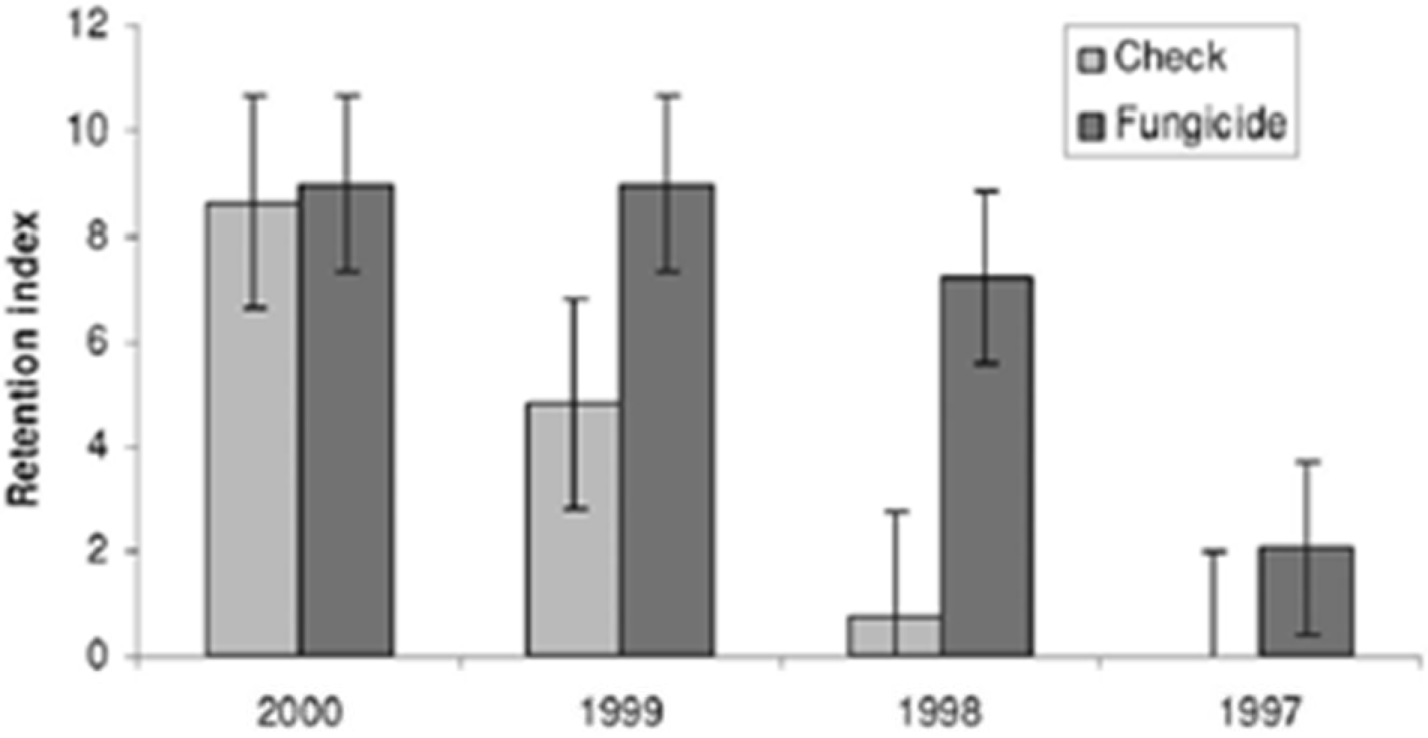


Figure 1. Average foliage retention ratings by needle cohort for fungicide-treated versus untreated units after 5 consecutive years of fungicide applications. Bars denote SE.

Stone et al. 2007

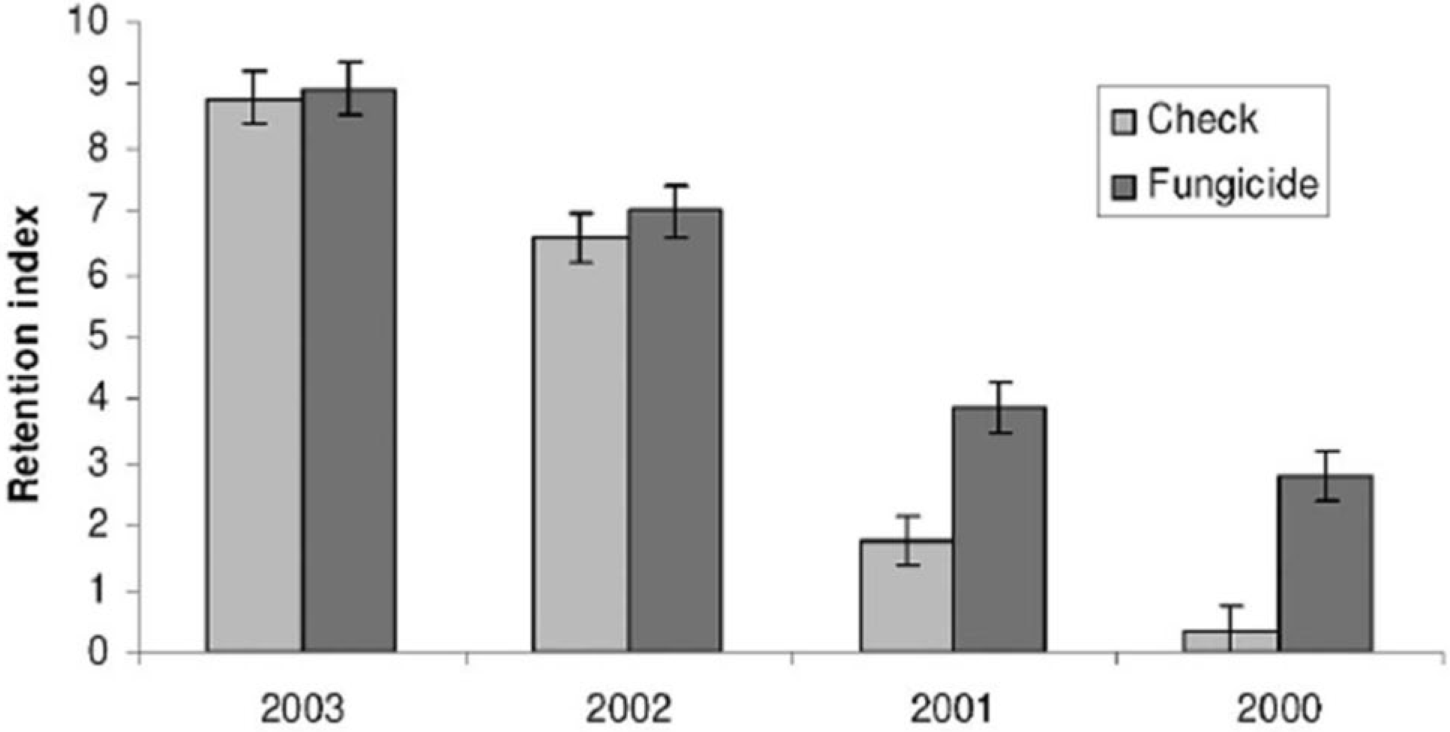


Figure 2. Average foliage retention ratings by needle cohort for fungicide-treated versus untreated units sampled at 4 years after the final fungicide application (2004). Bars denote SE.

Stone et al. 2007

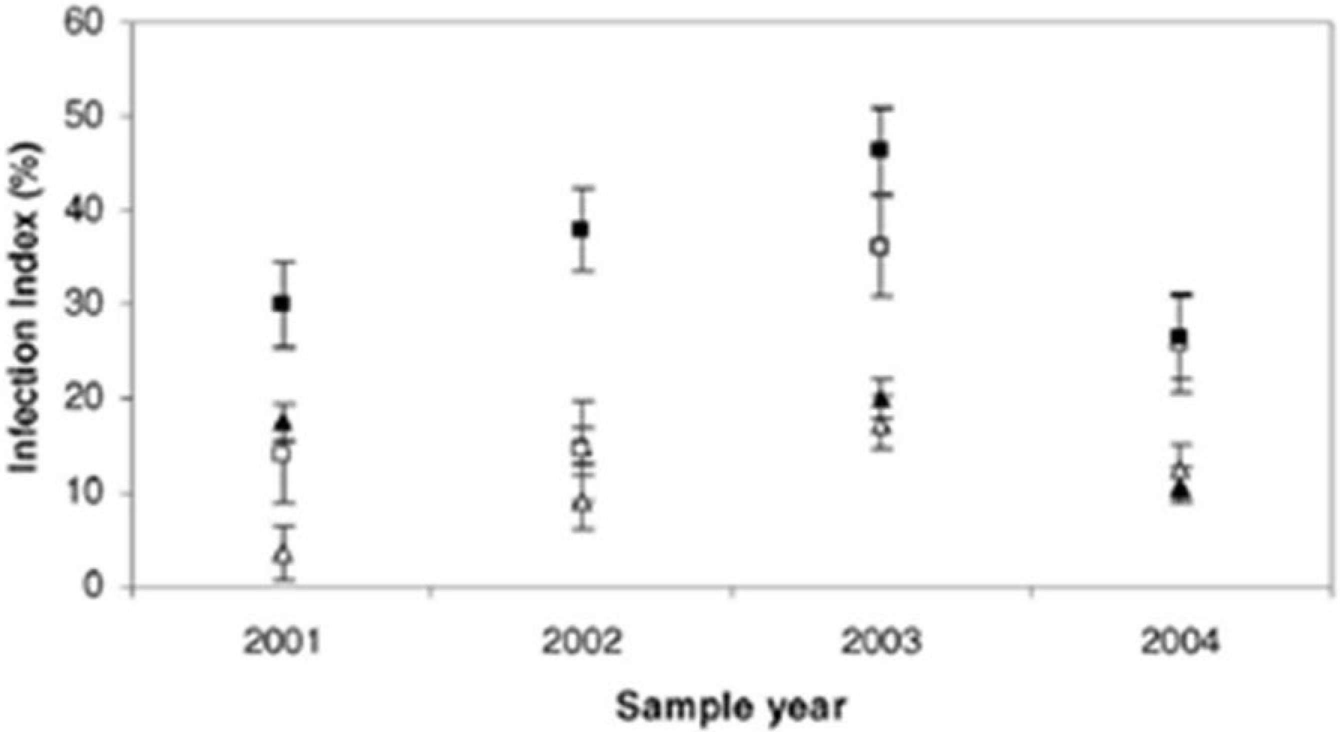
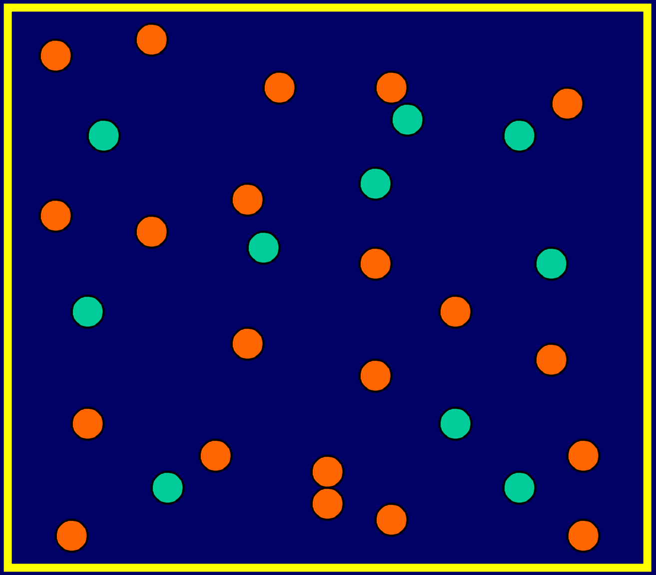


Figure 3. Change in infection index over 4 years following cessation of fungicide application. △, 1-year-old needles, fungicide-treated; ▲, 1-year-old needles, check; □, 2-year-old needles, fungicide-treated; ■, 2-year-old needles, check. Bars denote SE.

Stone et al. 2007

SNCC Growth Impact Study

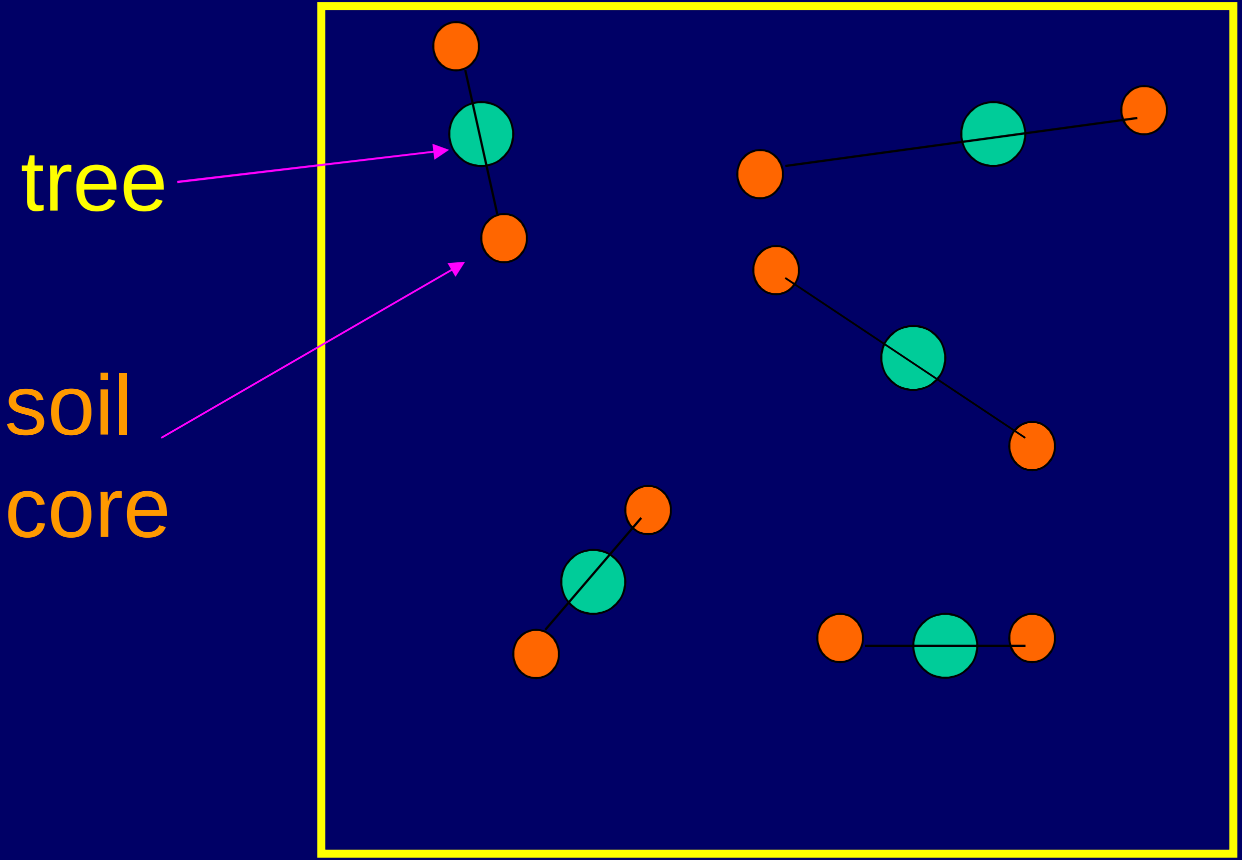
- Dbh on all trees >1.37m in height
- Tagged all trees with dbh>6cm (●)
- 40-tree height sample for Douglas-fir
- SNC ratings on 10 dominant or codominant DF trees per plot (●):
  - foliage retention
  - color
  - crown density
  - crown transparency



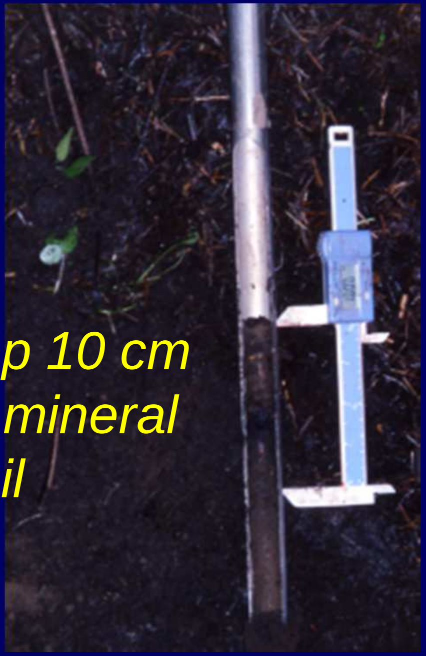
Soil and Foliar Chemistry

25 sites, half at each SNC extreme, early 2000

Soil cores located relative to 5 random SNC-rated trees:



Random distance and azimuth from tree

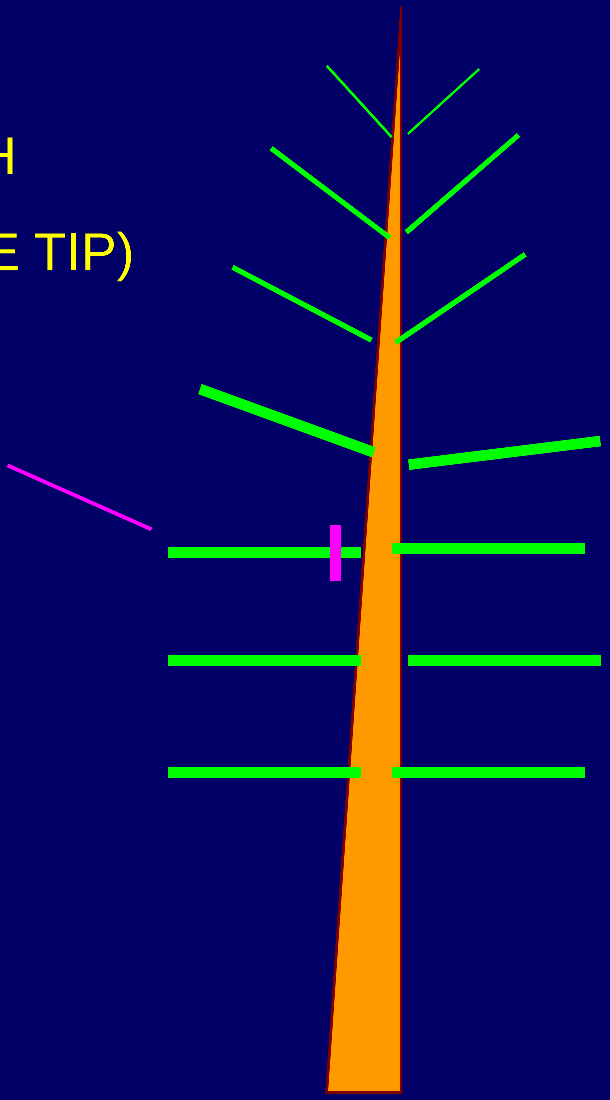


Top 10 cm of mineral soil

Sampling for foliar chemistry

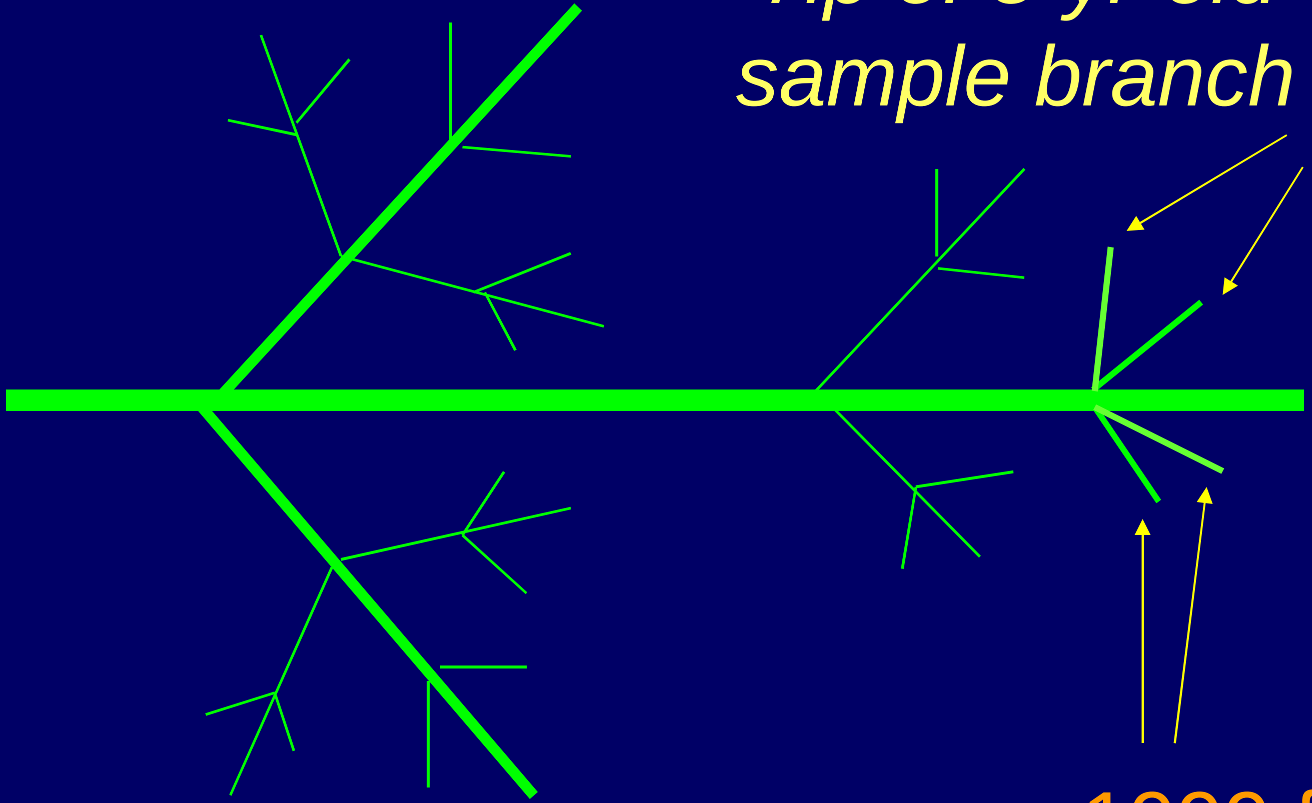
5-YR-OLD SAMPLE BRANCH

(5TH WHORL DOWN FROM TREE TIP)



SAMPLE BRANCH

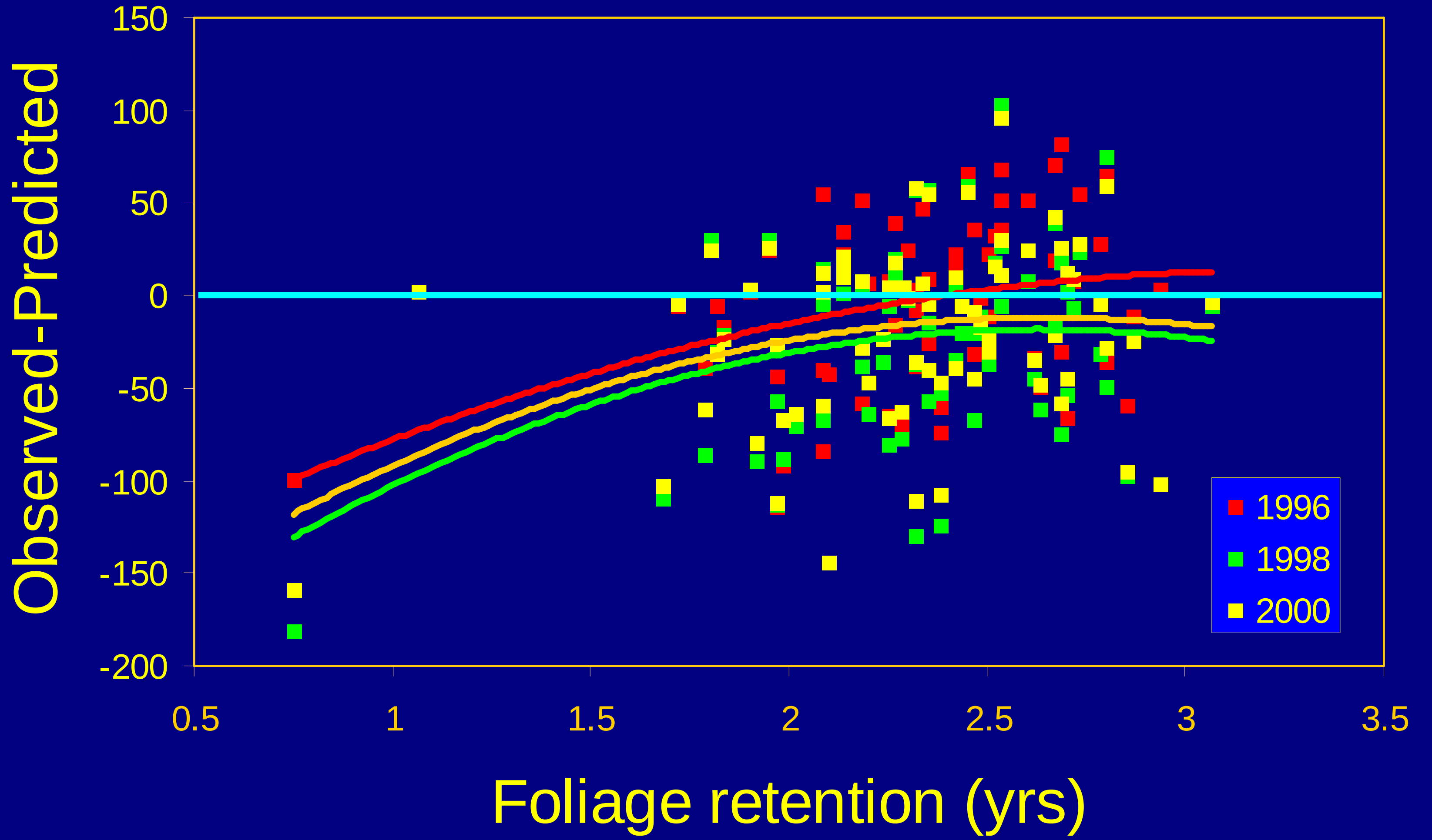
Sampling for foliar chemistry



Tip of 5-yr-old sample branch

1999 foliage sample

Comparison of observed PAIs to ORGANON predictions



Growth does not meet expectation under severe SNC

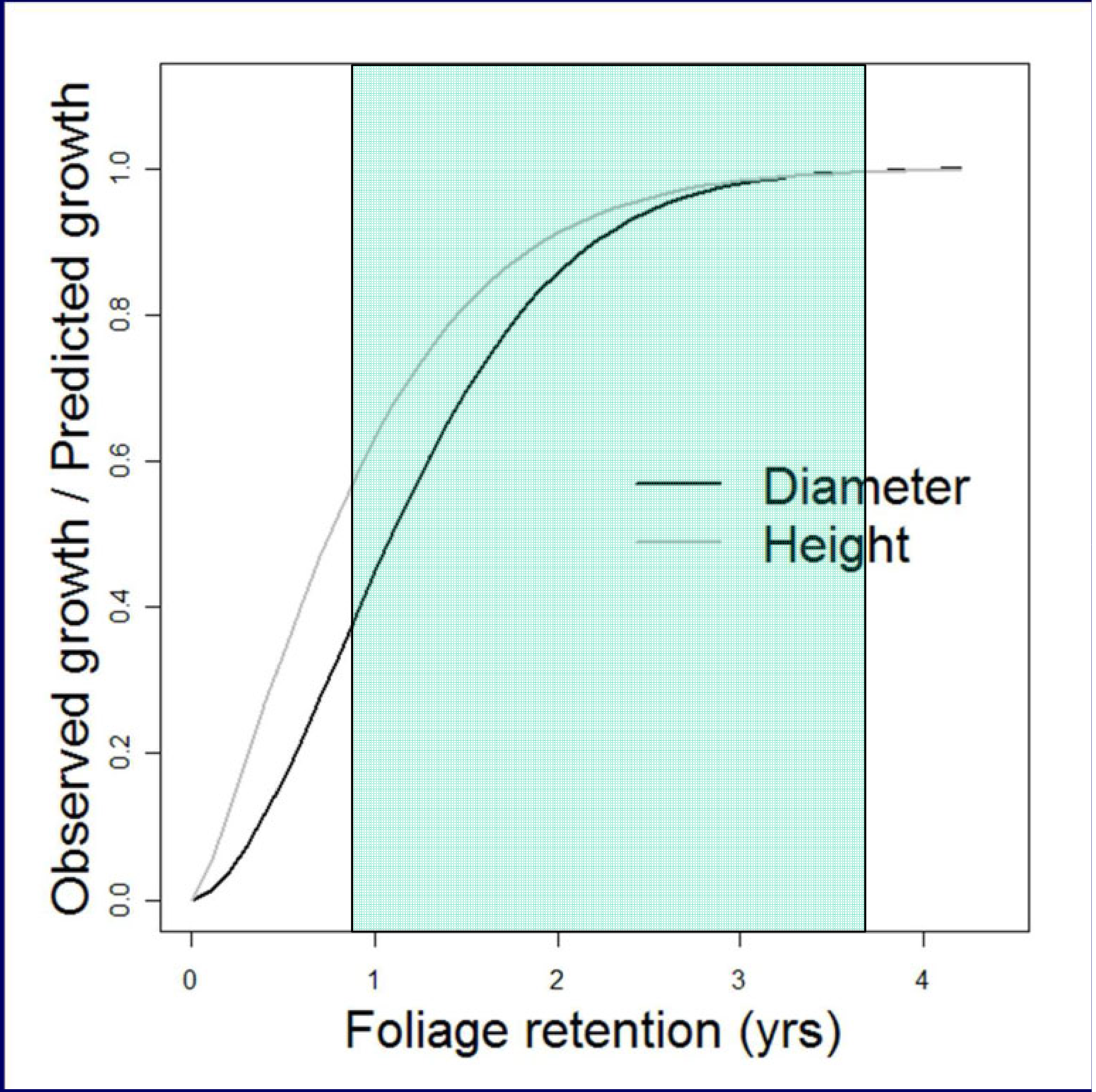
Growth multiplier for diameter and height growth in the SMC variant of ORGANON.

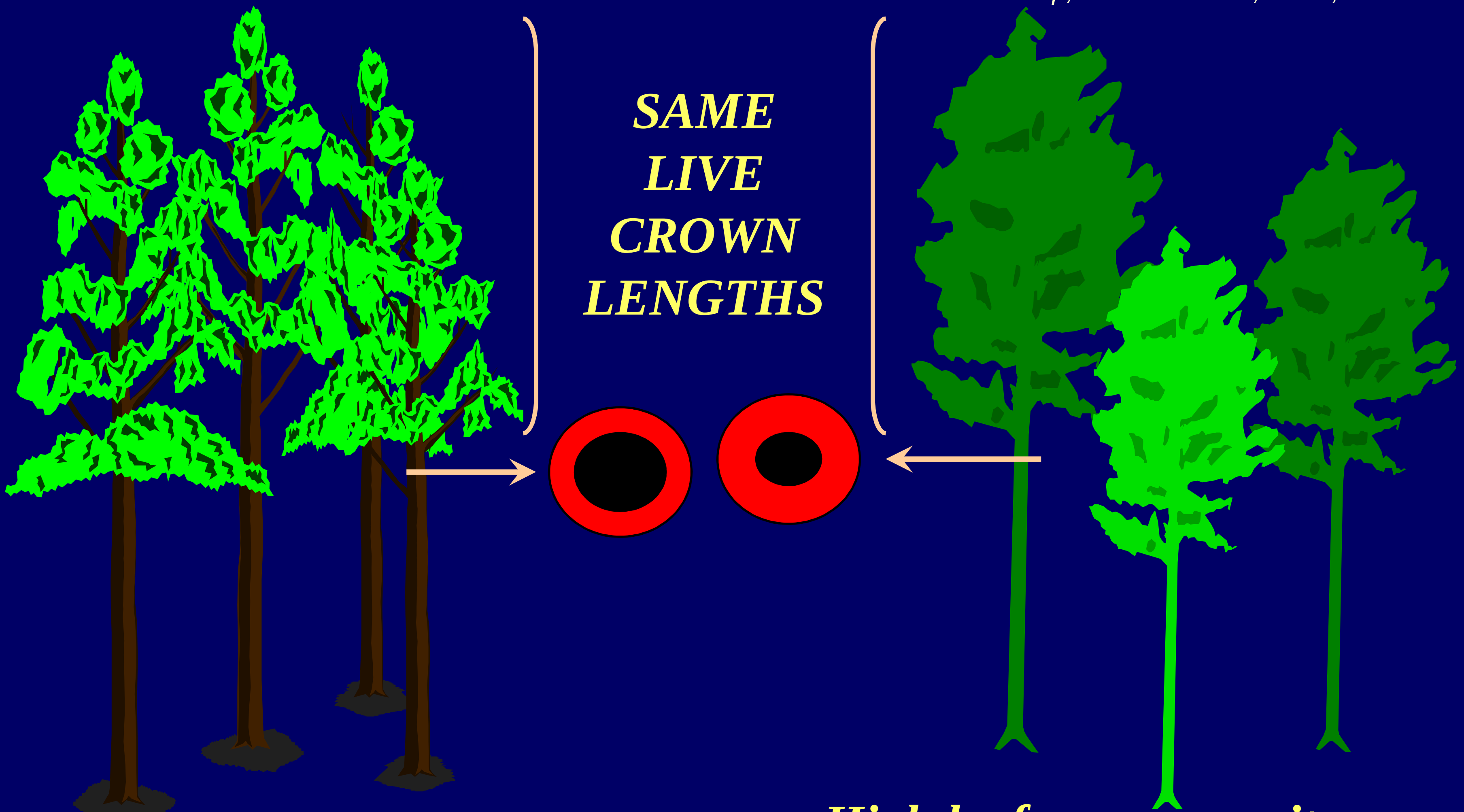
Diameter:

$1\text{-exp}(0.5952FR^{1.7121})$

Height:

$1\text{-exp}(1.0021FR^{1.2802})$





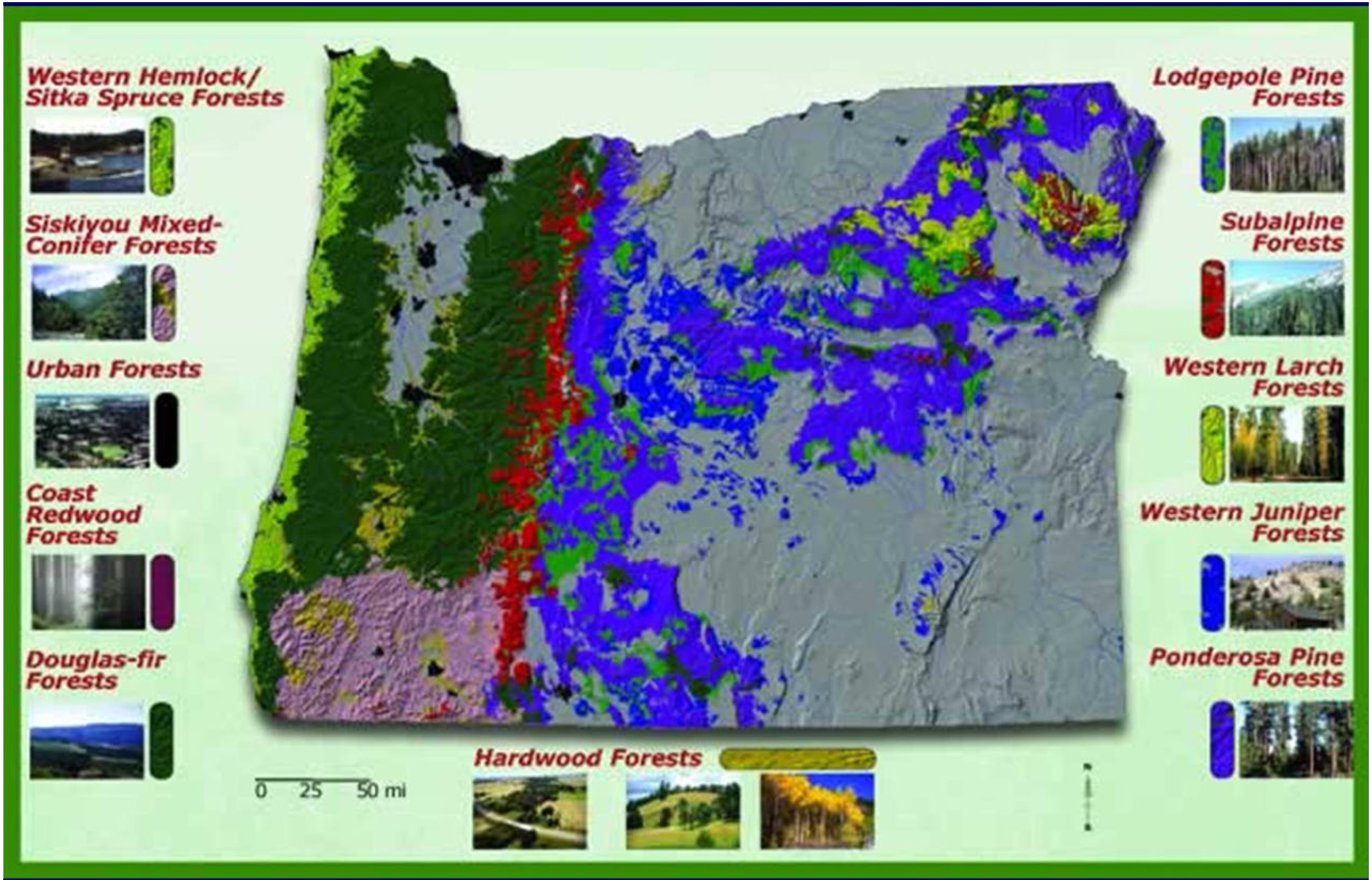
SAME LIVE CROWN LENGTHS

Low leaf area per unit crown length

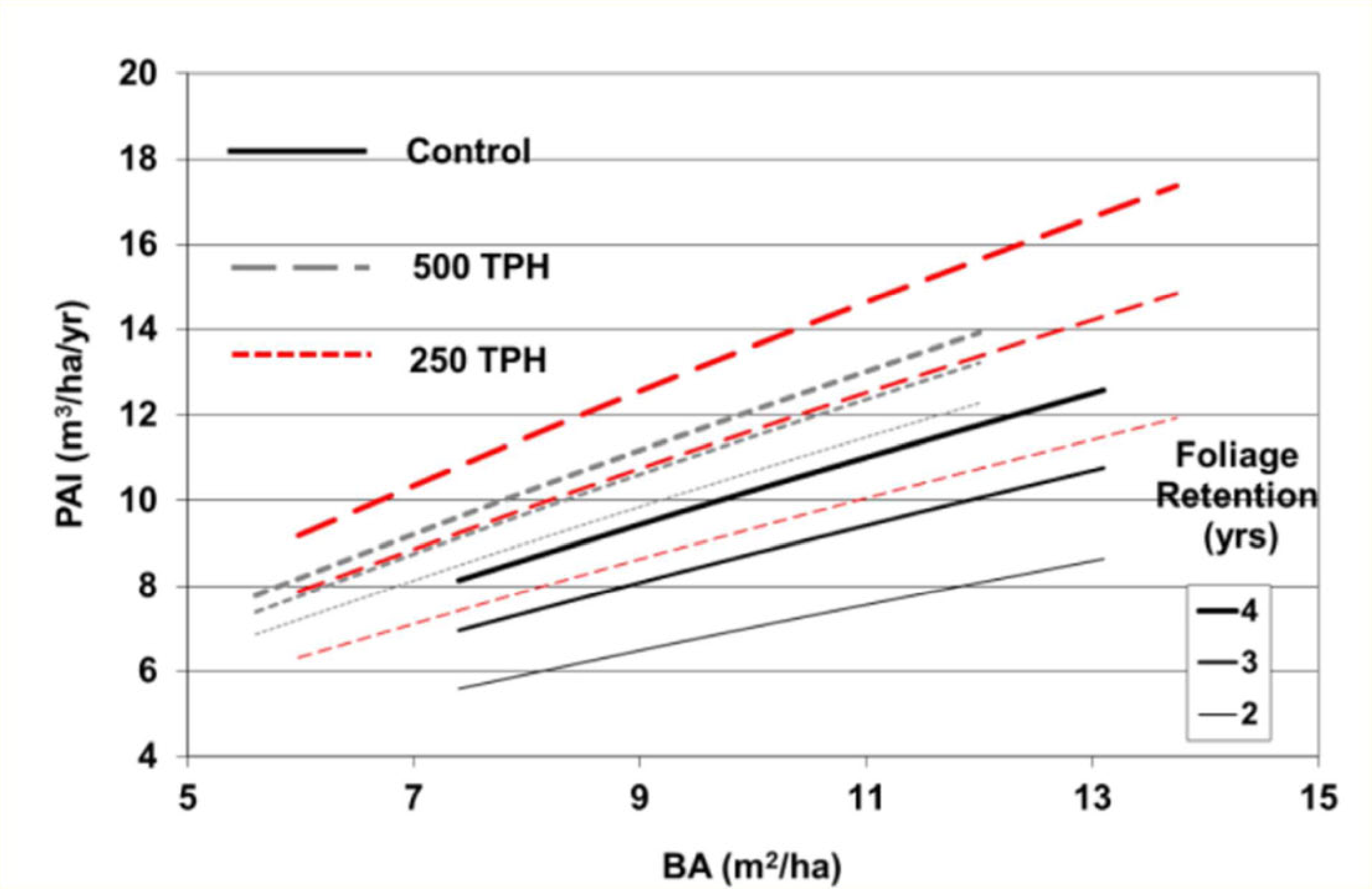
→ Relatively small sapwood area at crown base

High leaf area per unit crown length

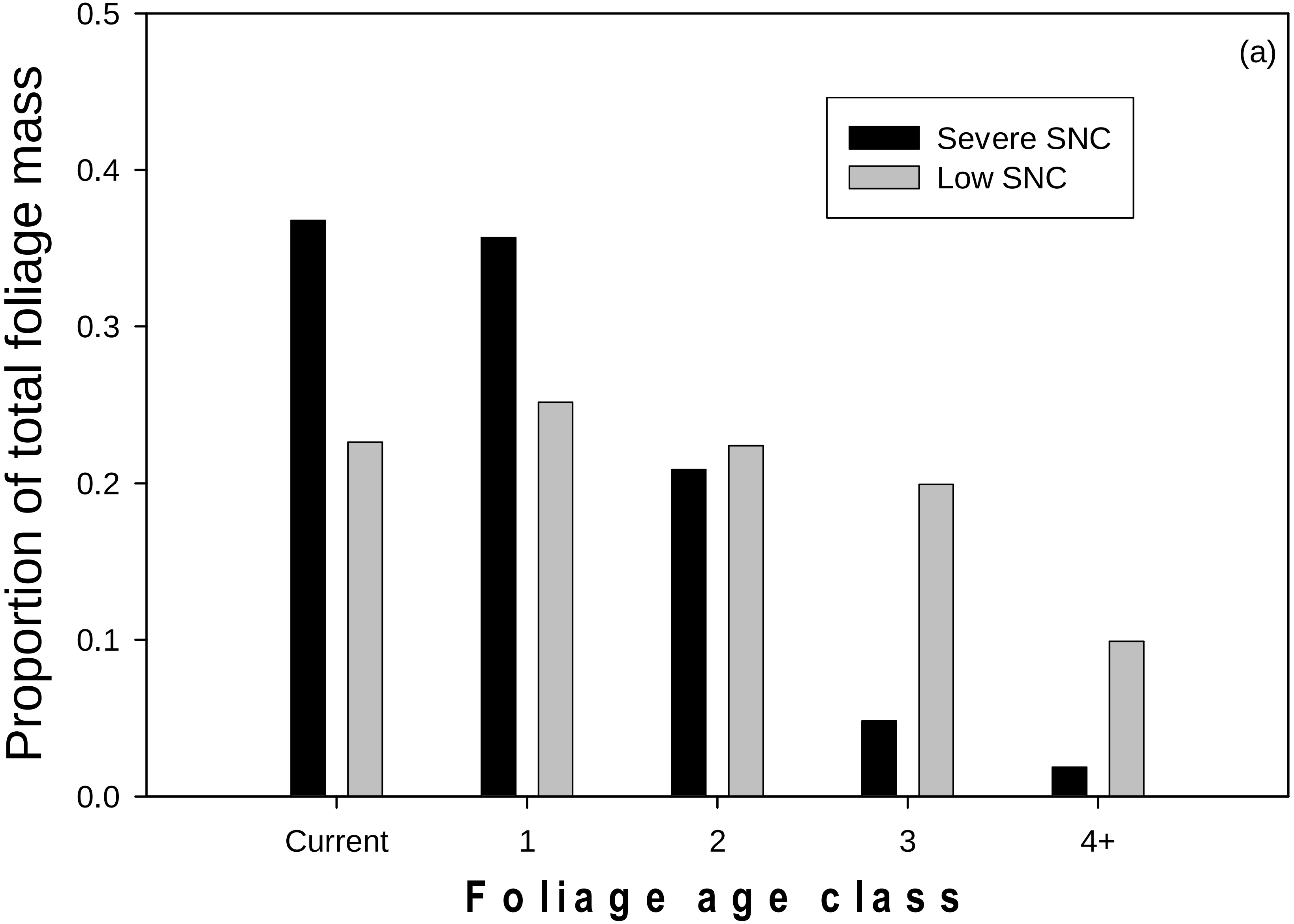
→ Relatively large sapwood area at crown base


Western Hemlock/ Sitka Spruce Forests
Siskiyou Mixed-Conifer Forests
Urban Forests
Coast Redwood Forests
Douglas-fir Forests
Lodgepole Pine Forests
Subalpine Forests
Western Larch Forests
Western Juniper Forests
Ponderosa Pine Forests
Hardwood Forests
0 25 50 mi

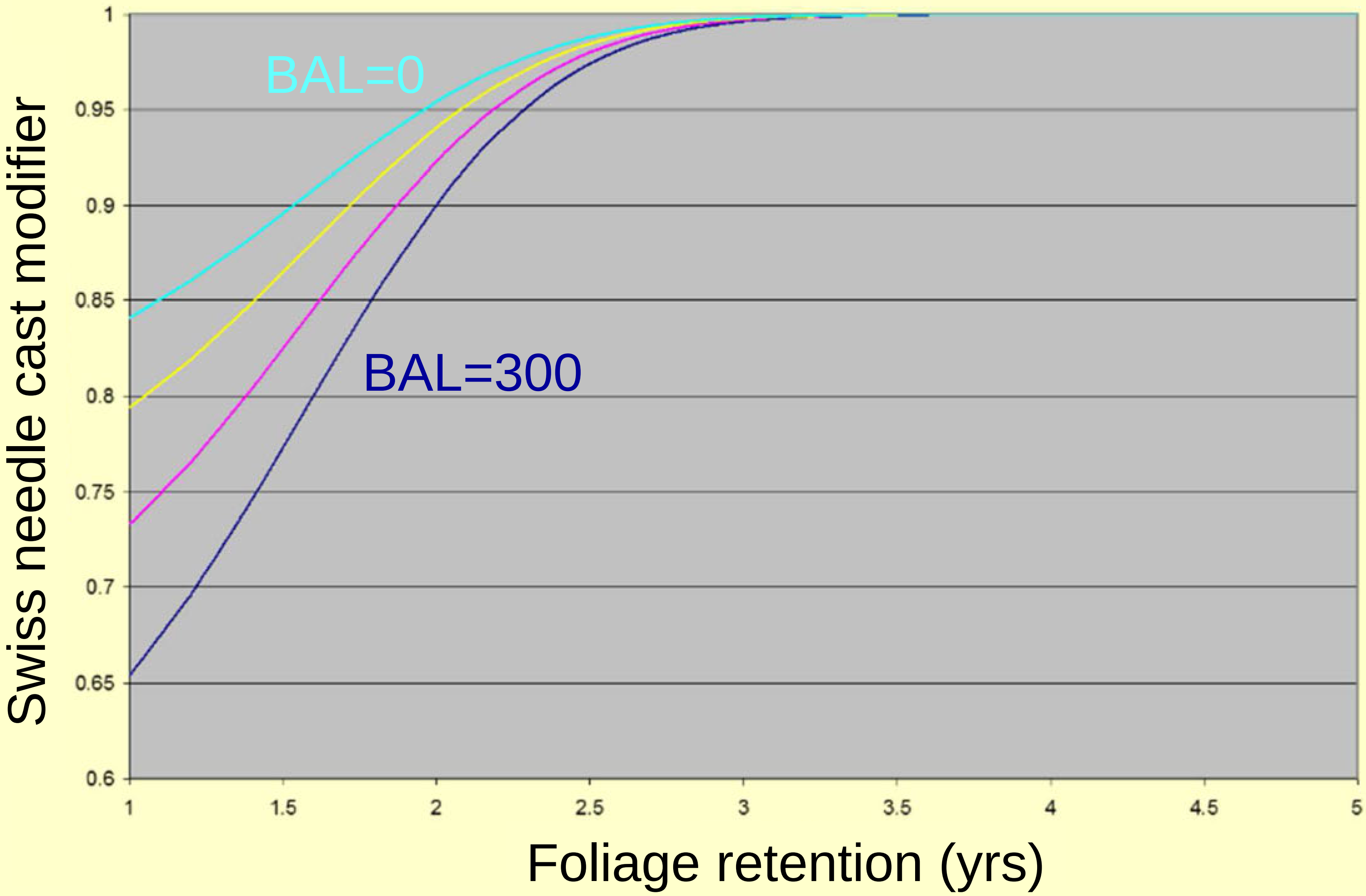
SNCC pre-commercial thinning study
250 largest TPH only



Aaron Weiskittel M.S. Thesis

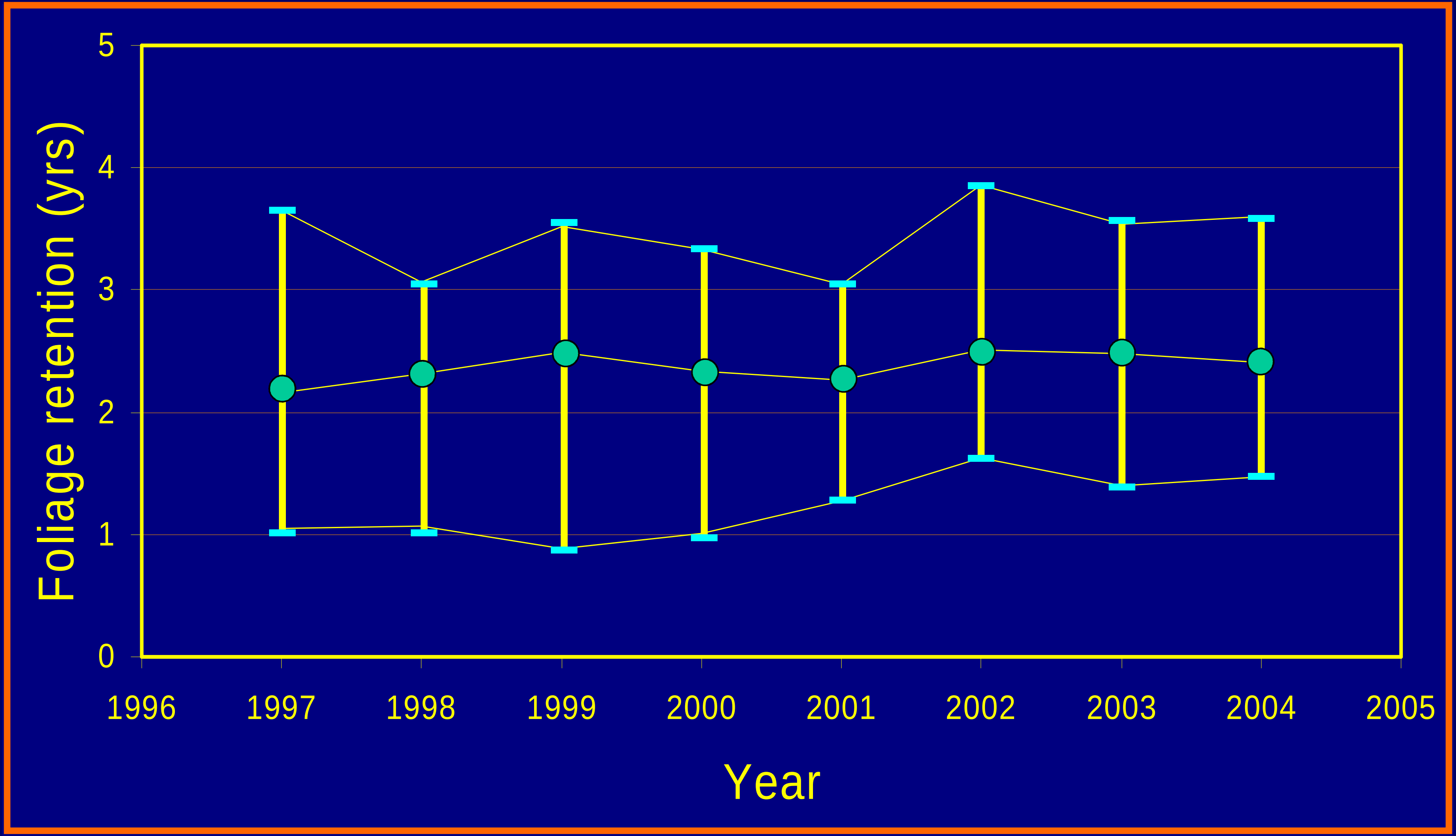


Tree-level diameter growth rate modifiers



Growth Impact of Swiss needle cast

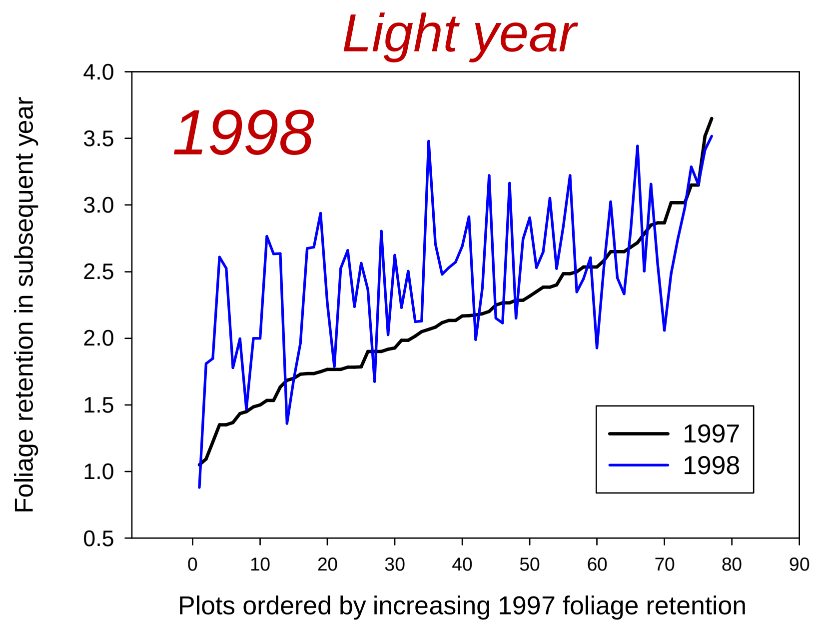
- What is the range in SNC severity?



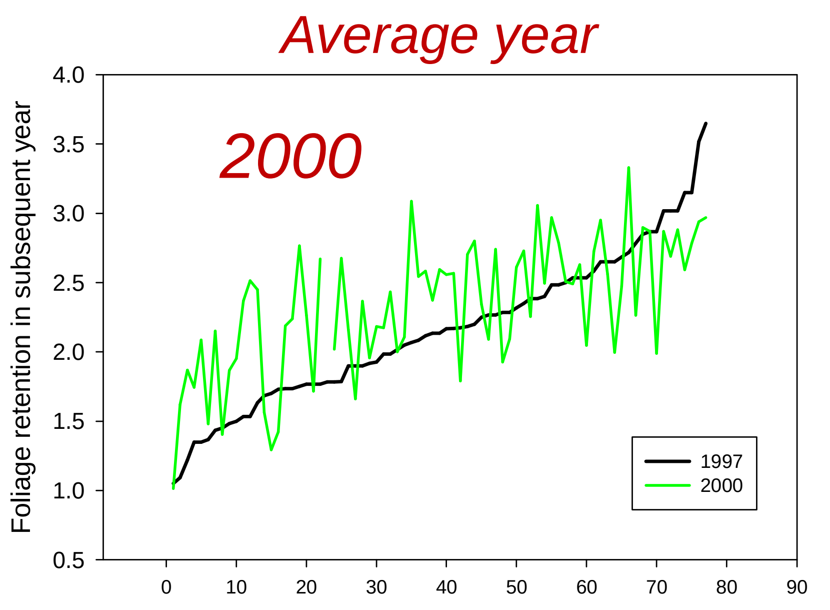
In general:

Plots of high SNC severity became slightly better, SNC;

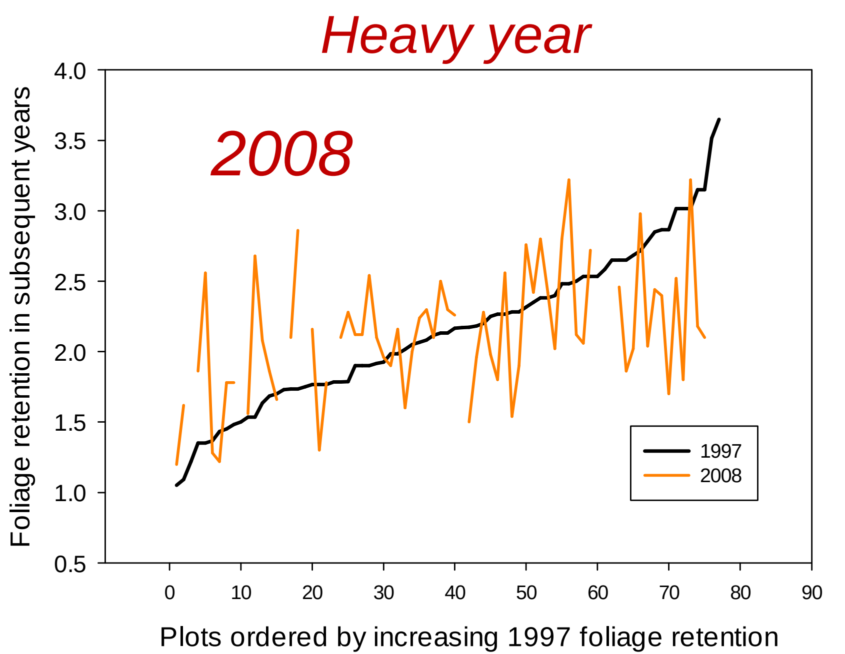
Plots with low SNC severity became slightly worse



Light year

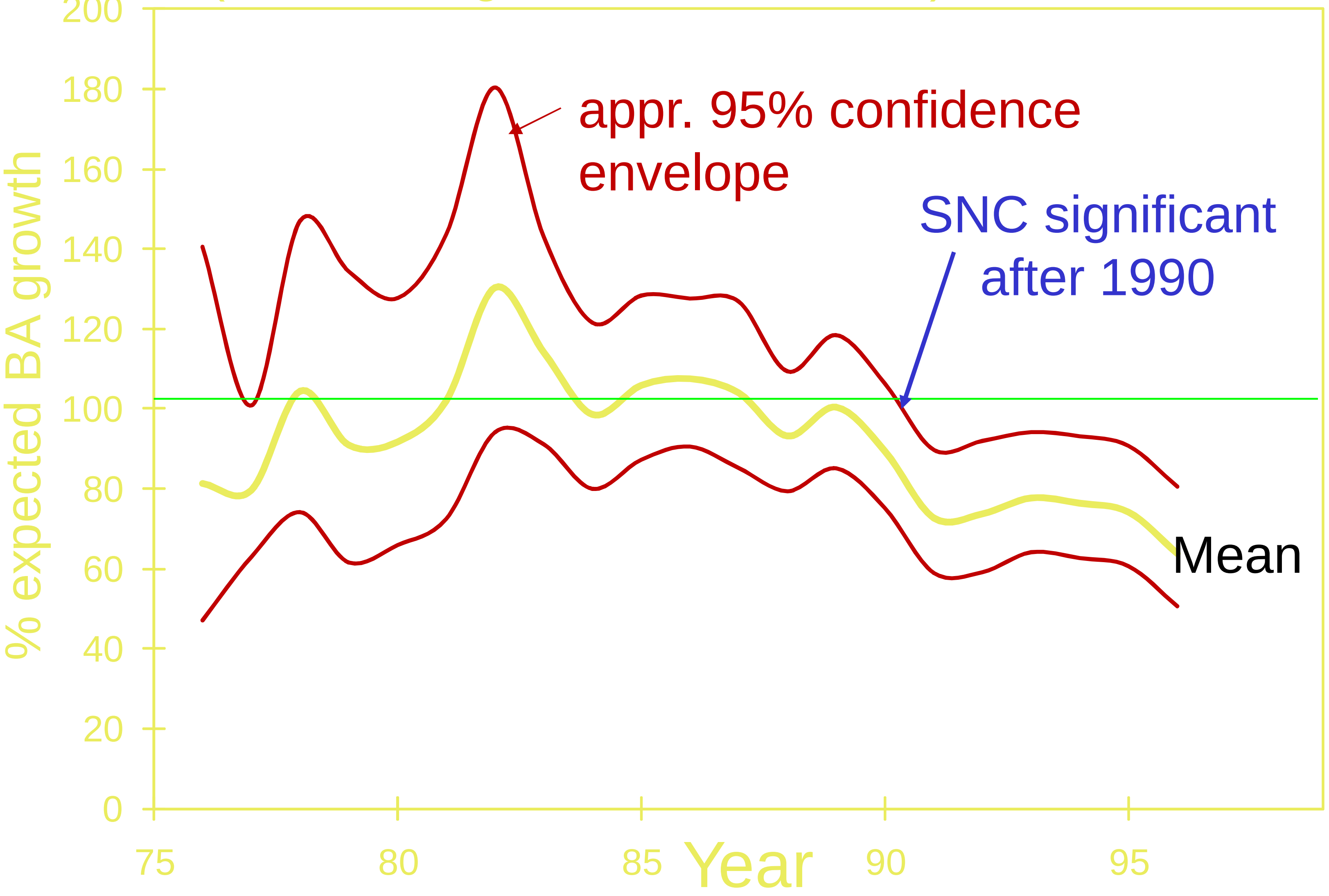


Average year



Heavy year

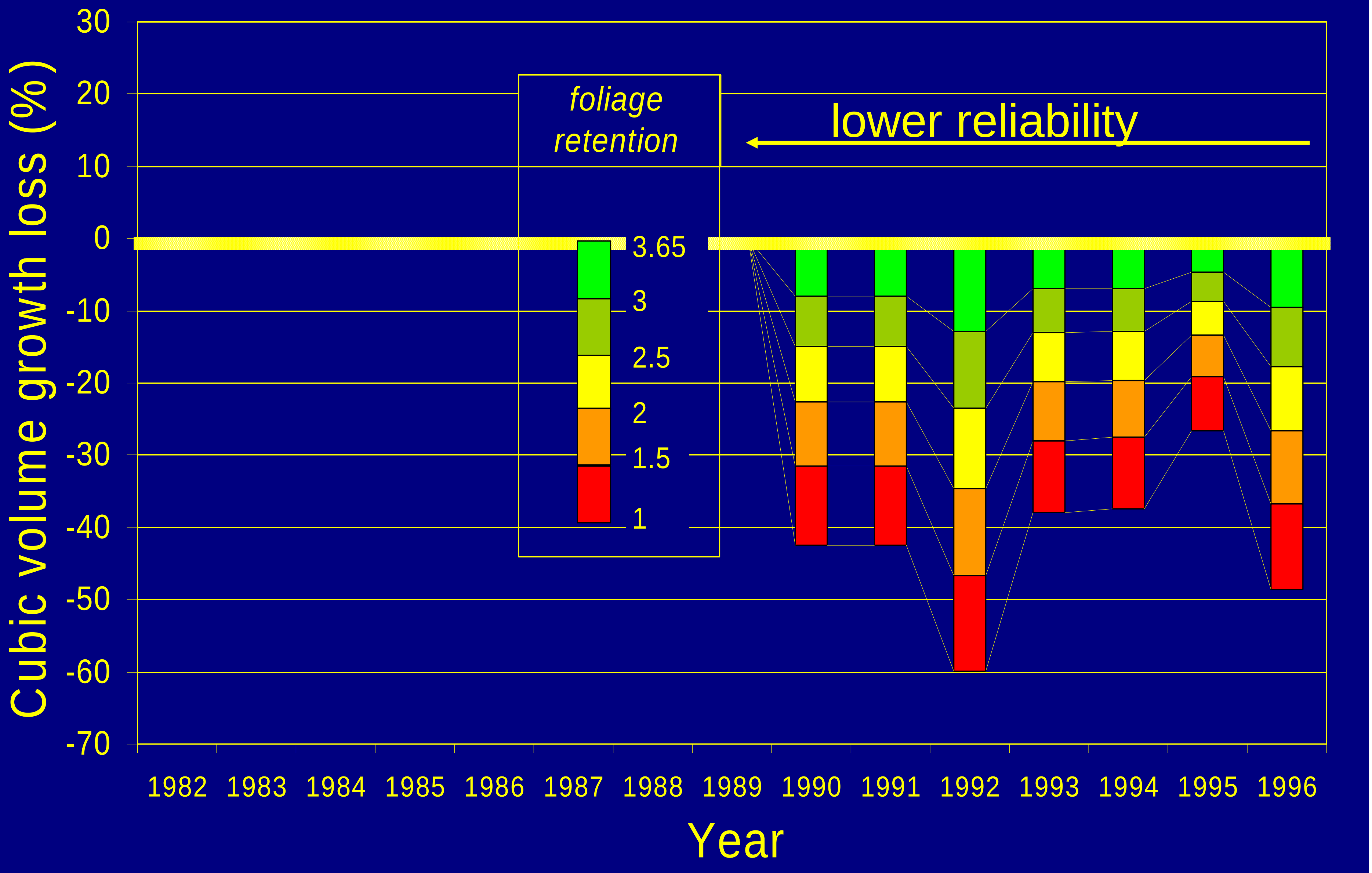
Maximum SNC "effect" on BA growth (lowest foliage retention in 1996)



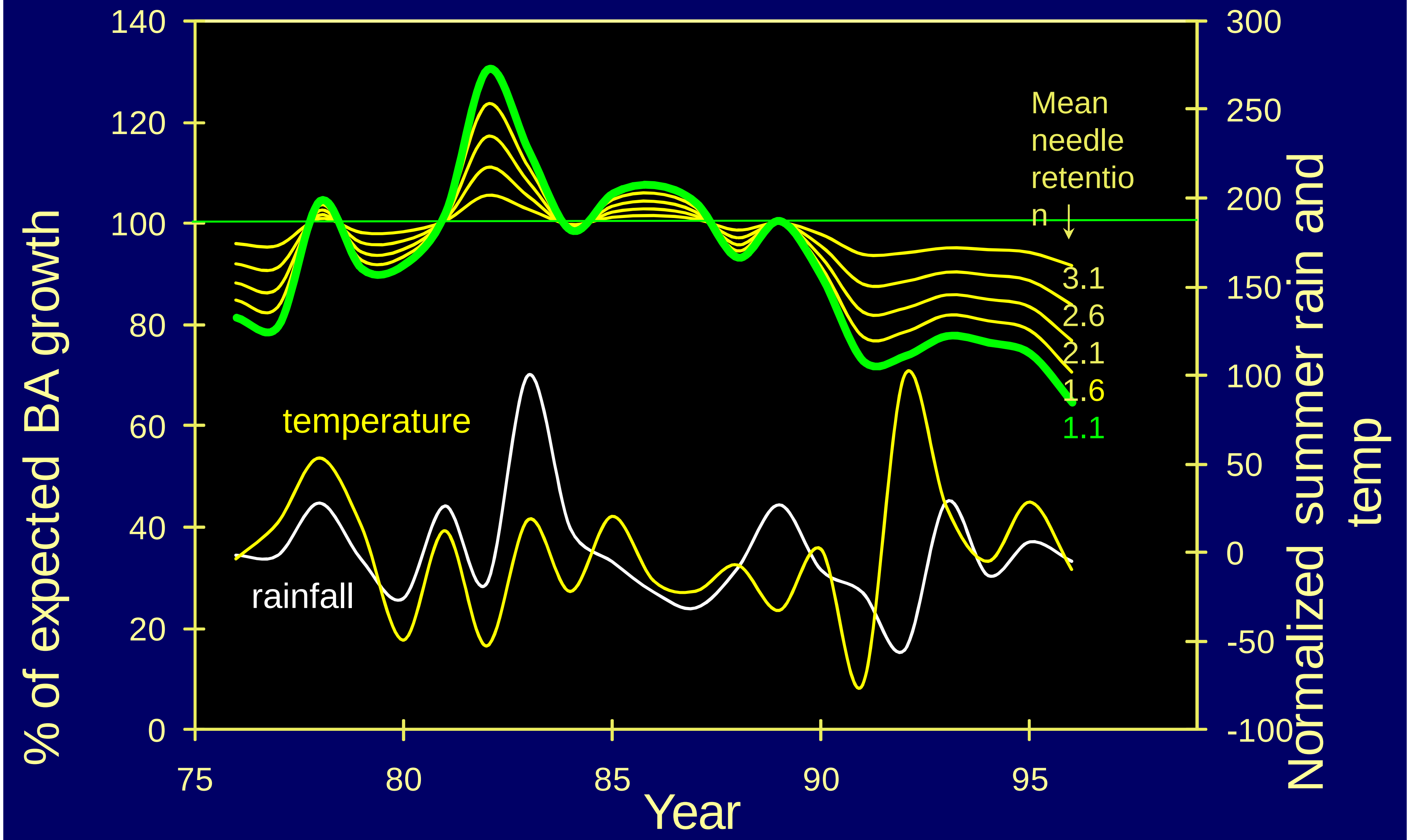
appr. 95% confidence envelope

SNC significant after 1990

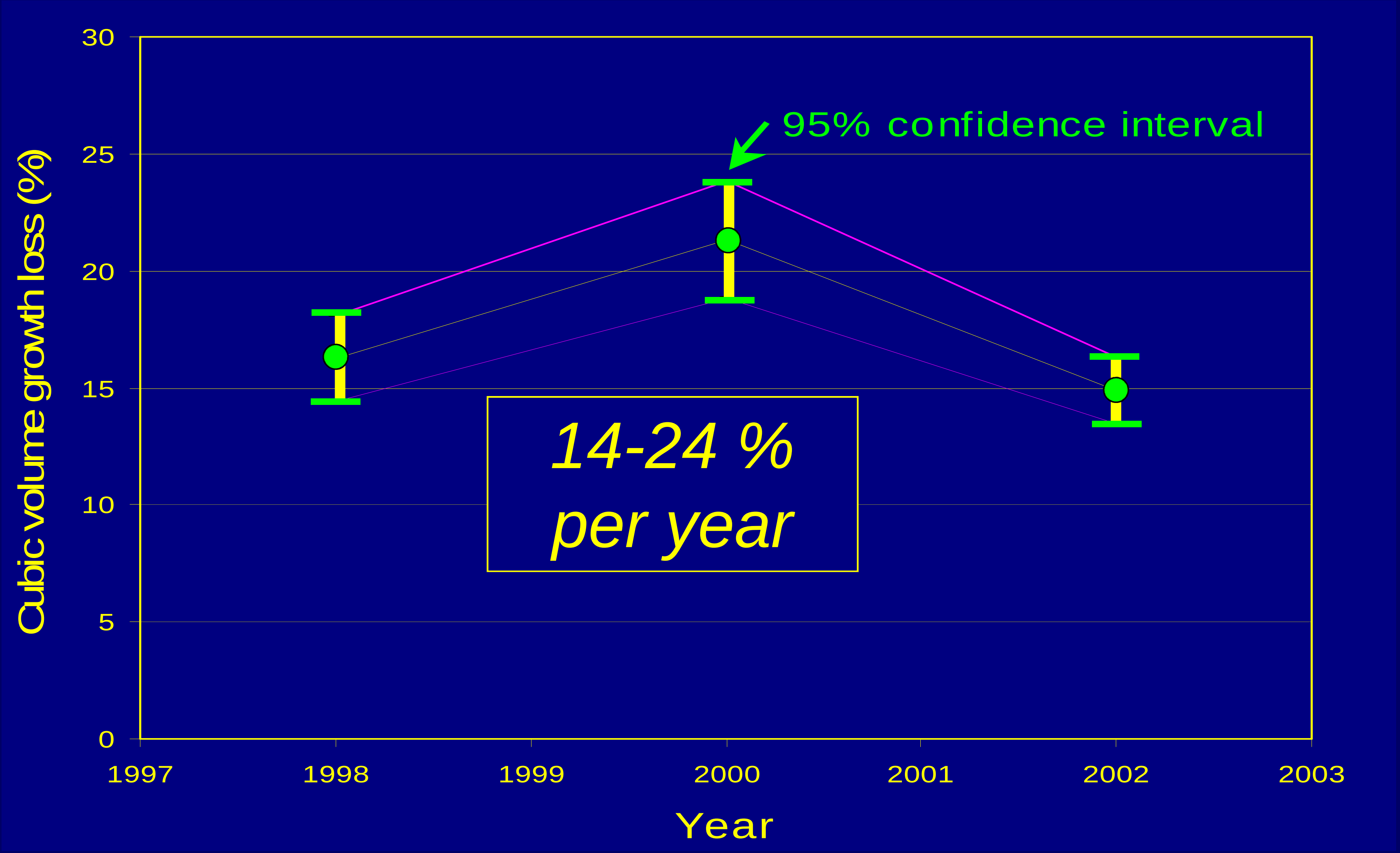
Growth losses estimated from retrospective analysis



Basal area growth and weather trends

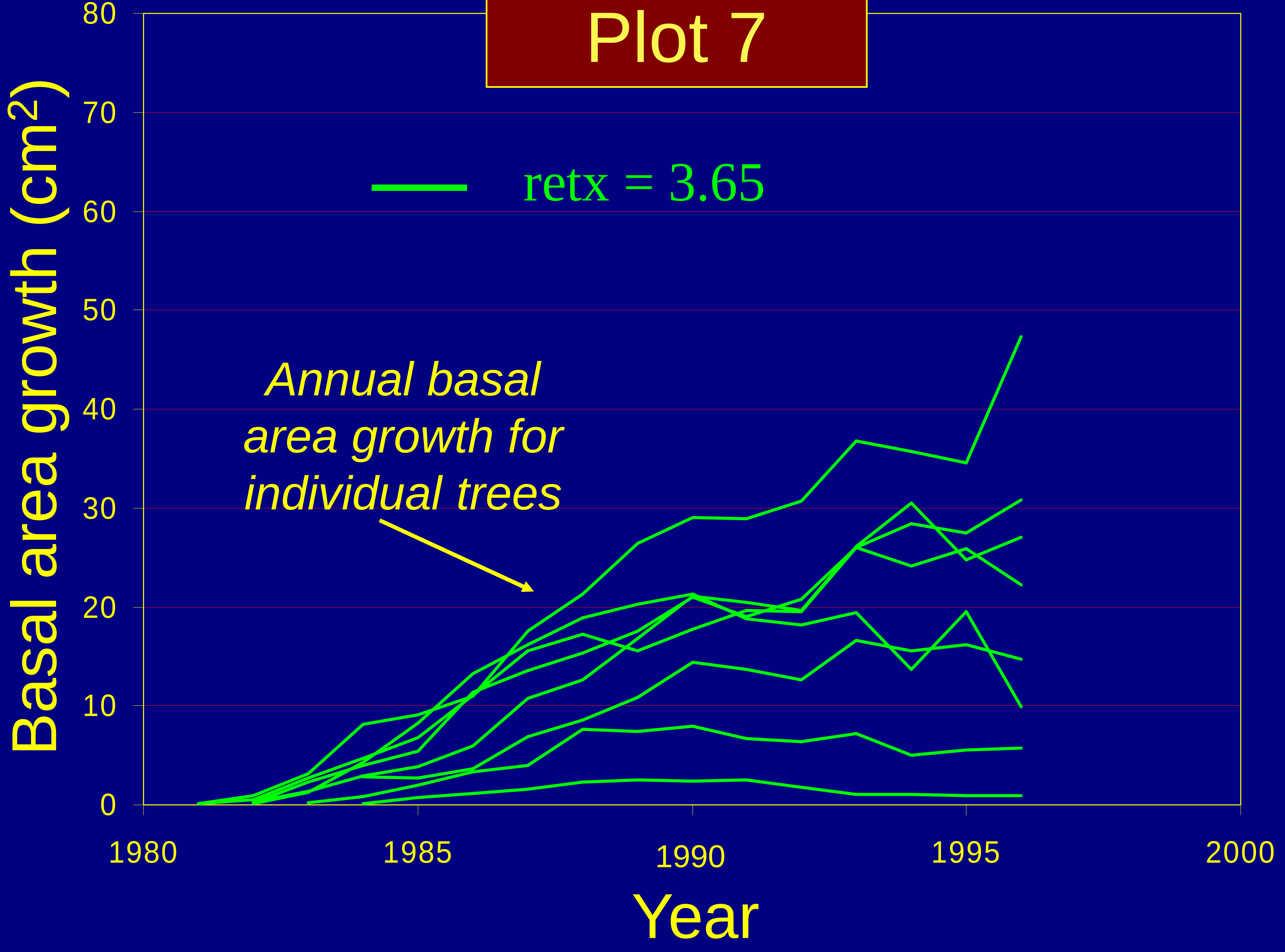


Average growth loss for population of young Douglas-fir plantations



14-24 % per year

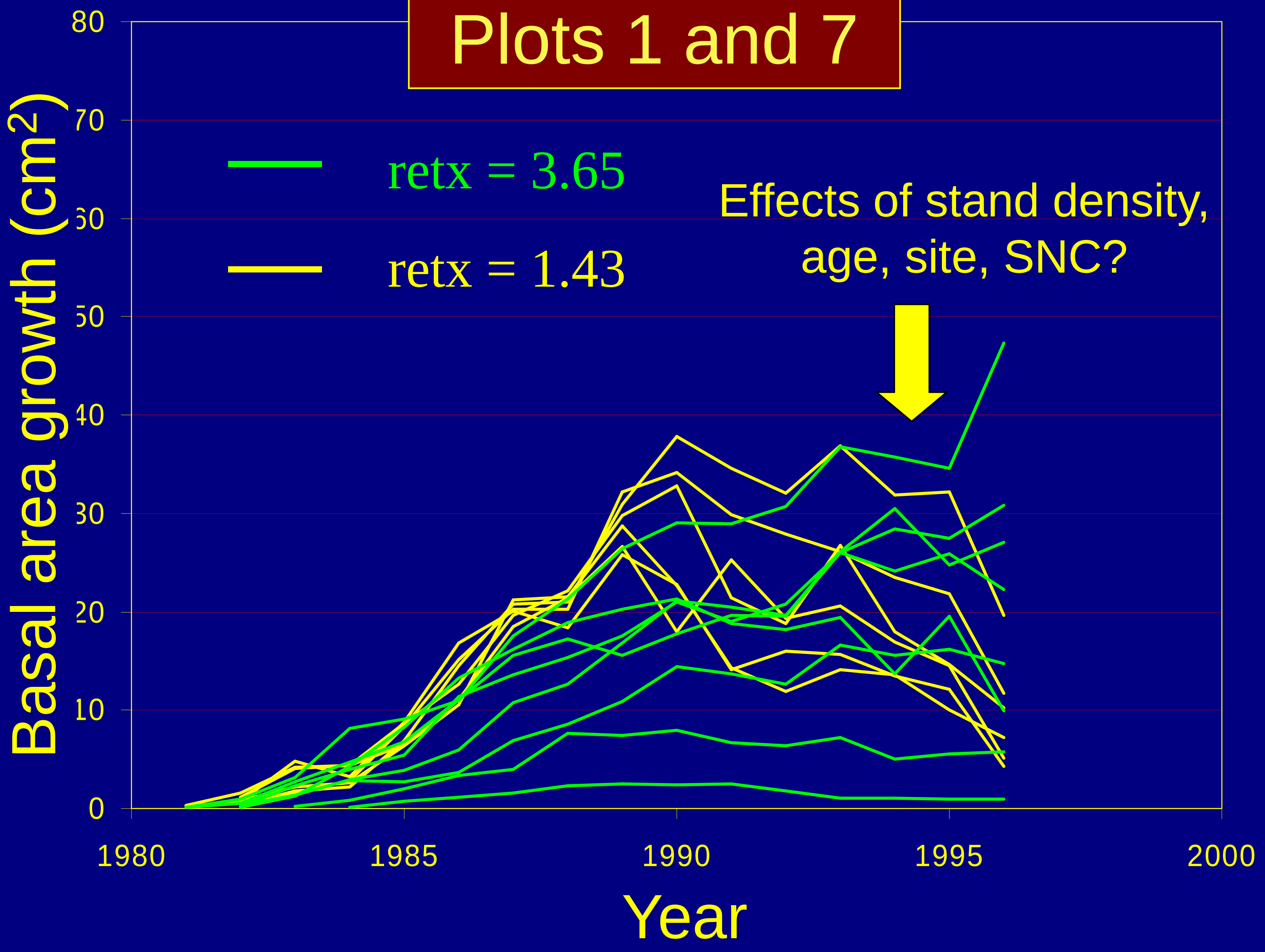
Plot 7


retx = 3.65
Annual basal area growth for individual trees
Basal area growth (cm^2)
0
10
20
30
40
50
60
70
80
1980
1985
1990
1995
2000
Year

Plot 1

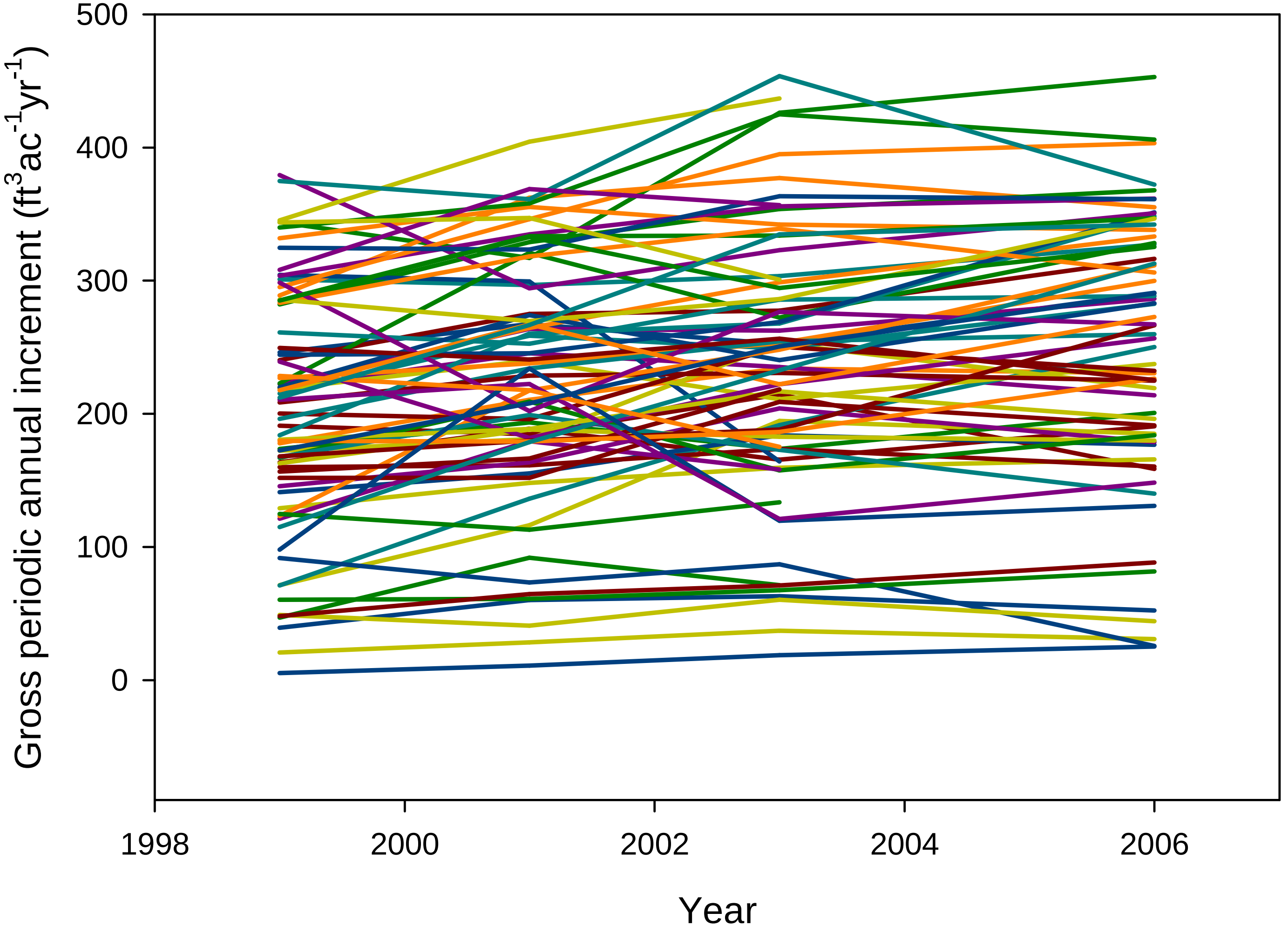

retx = 1.43
Basal area growth (cm²)
80
70
60
50
40
30
20
10
0
1980
1985
1990
1995
2000
Year

Plots 1 and 7

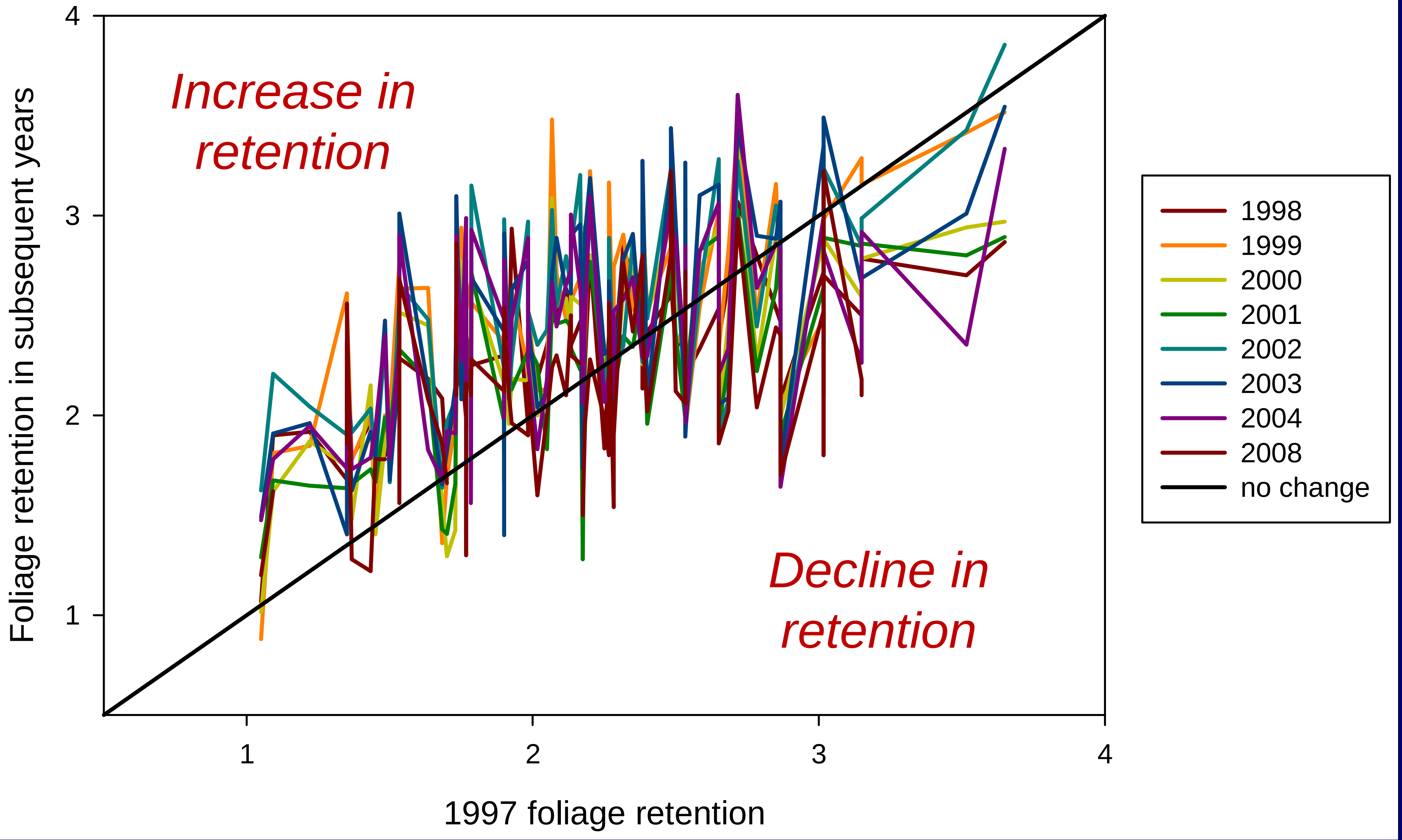


Effects of stand density, age, site, SNC?

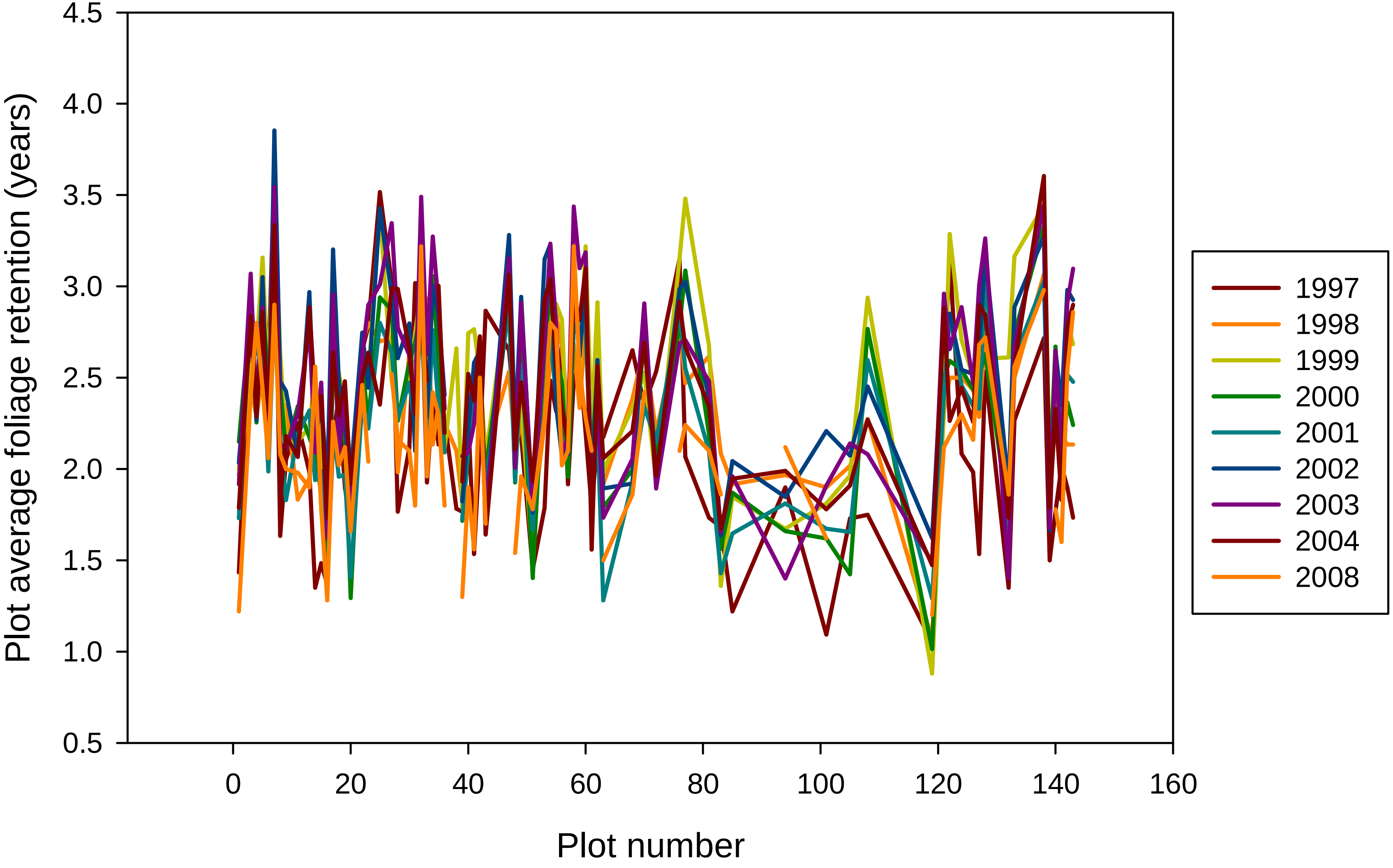
Gross periodic annual increment over year of growth

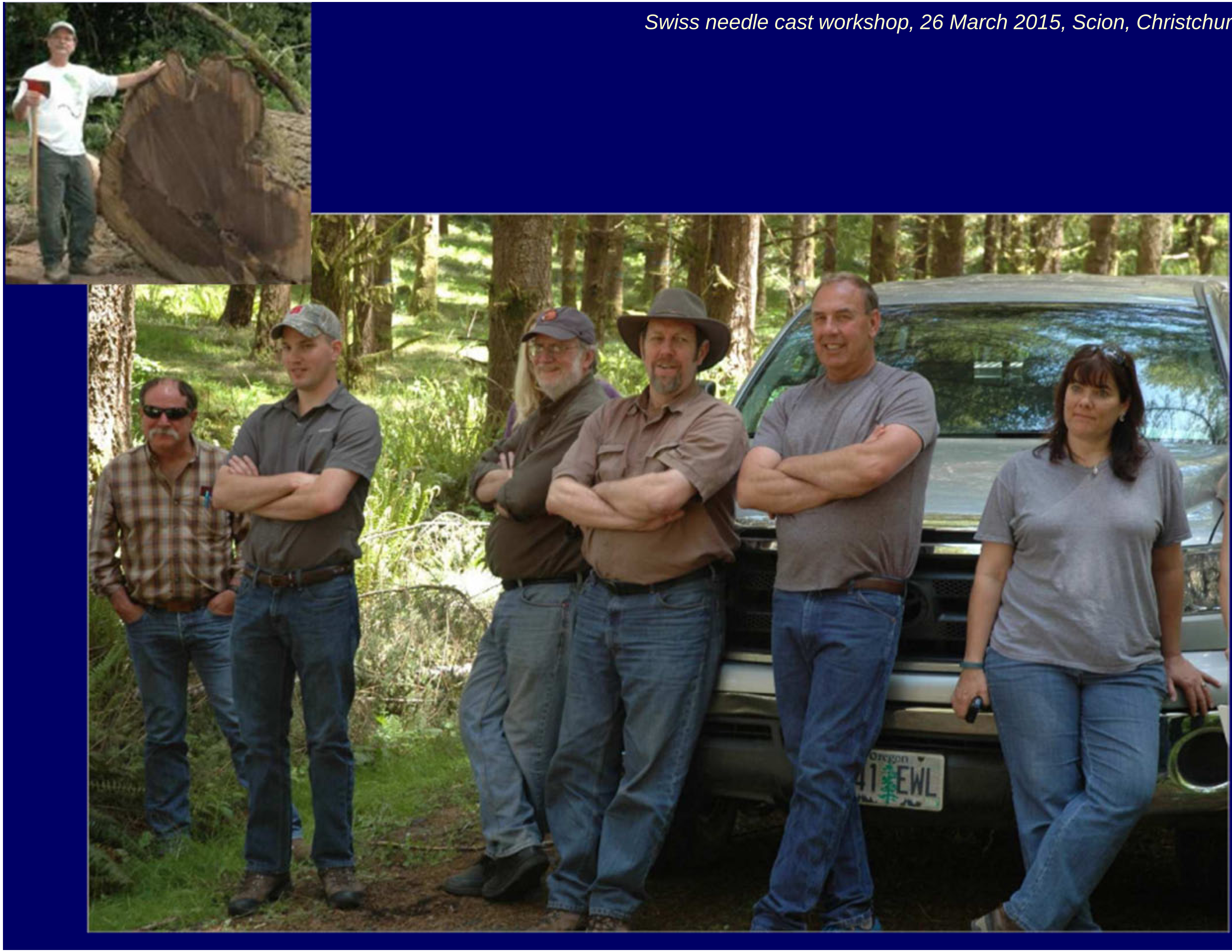


Level of foliage retention among years, ordered plots

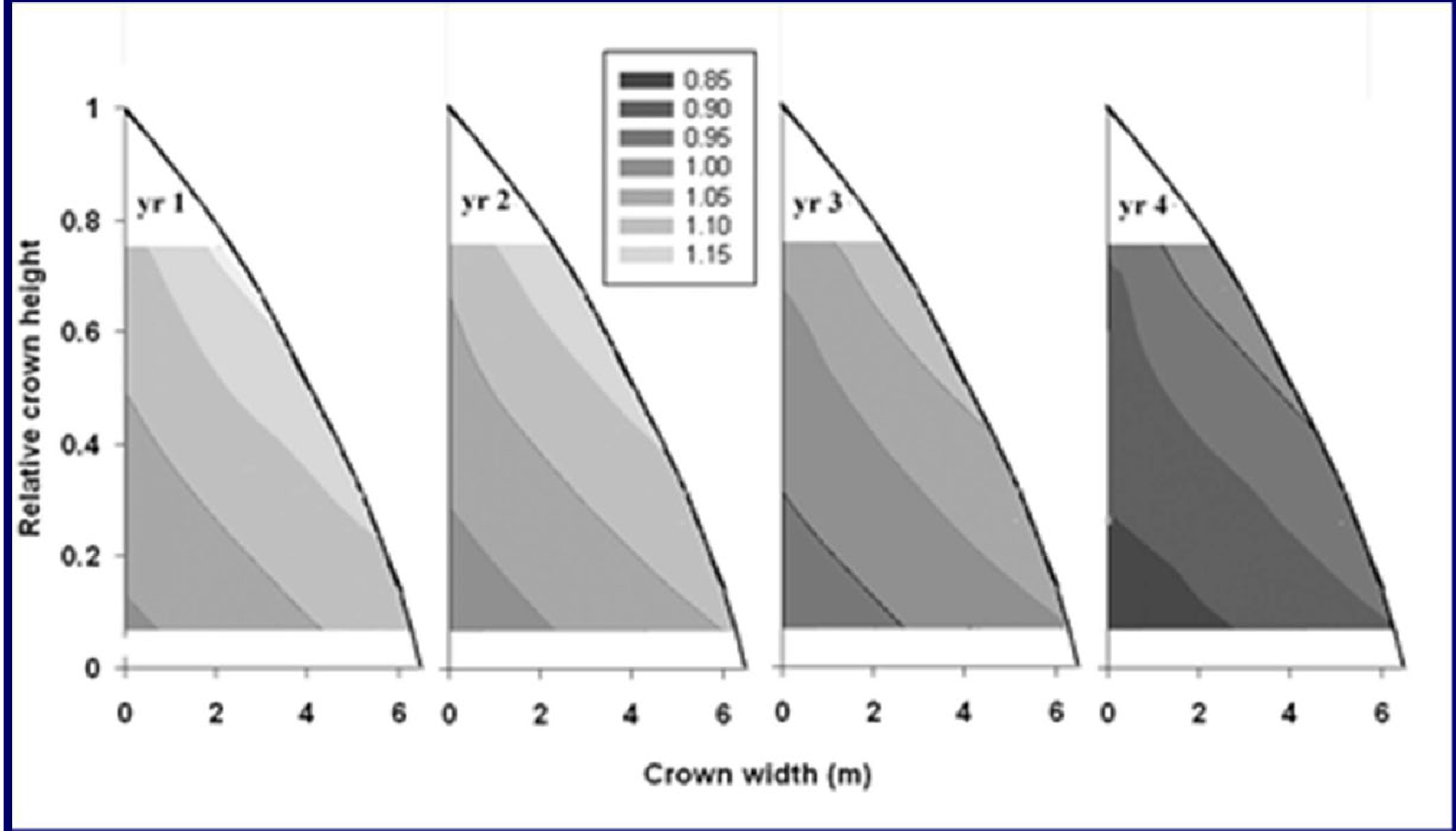


Level of foliage retention among years

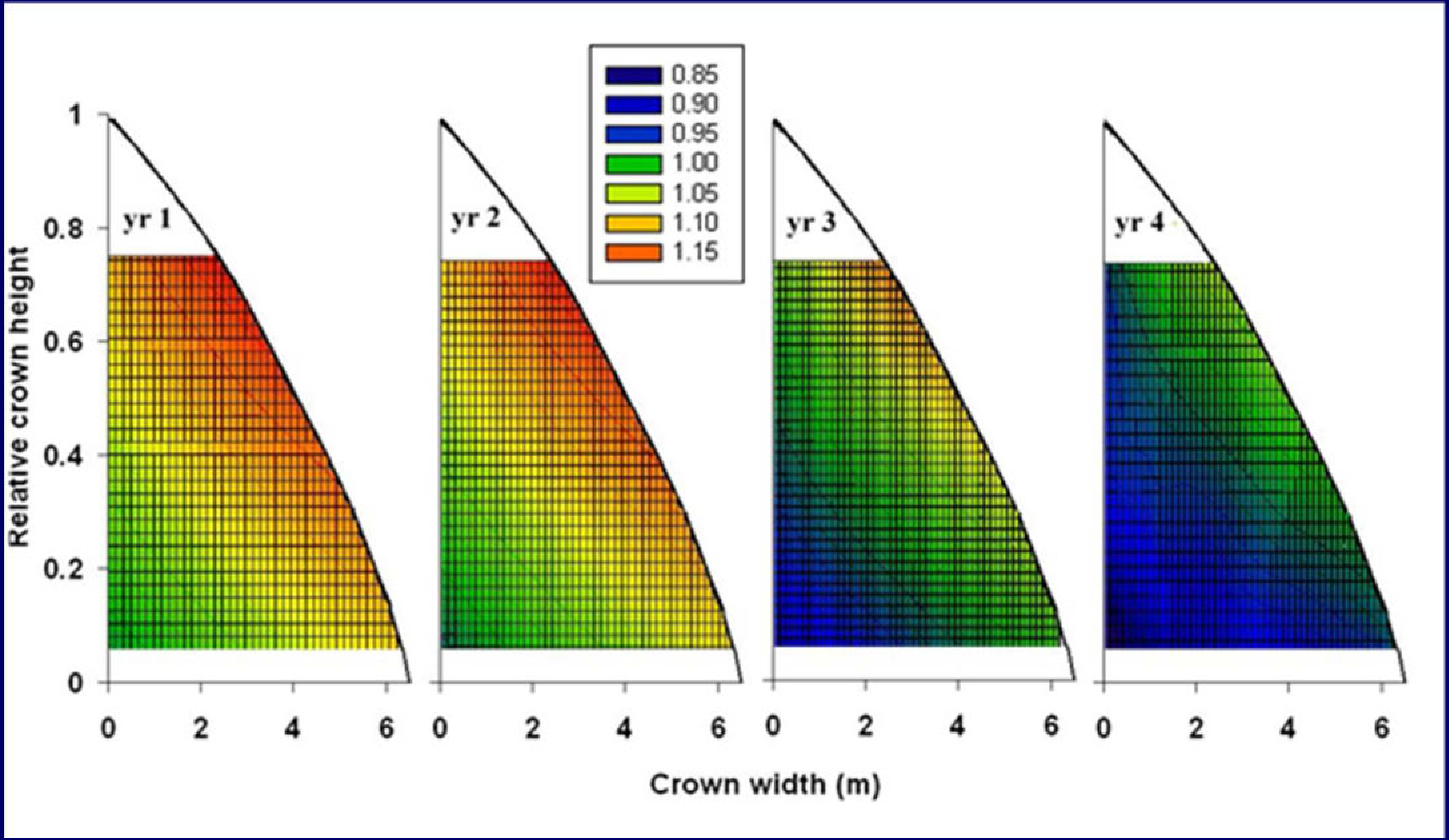




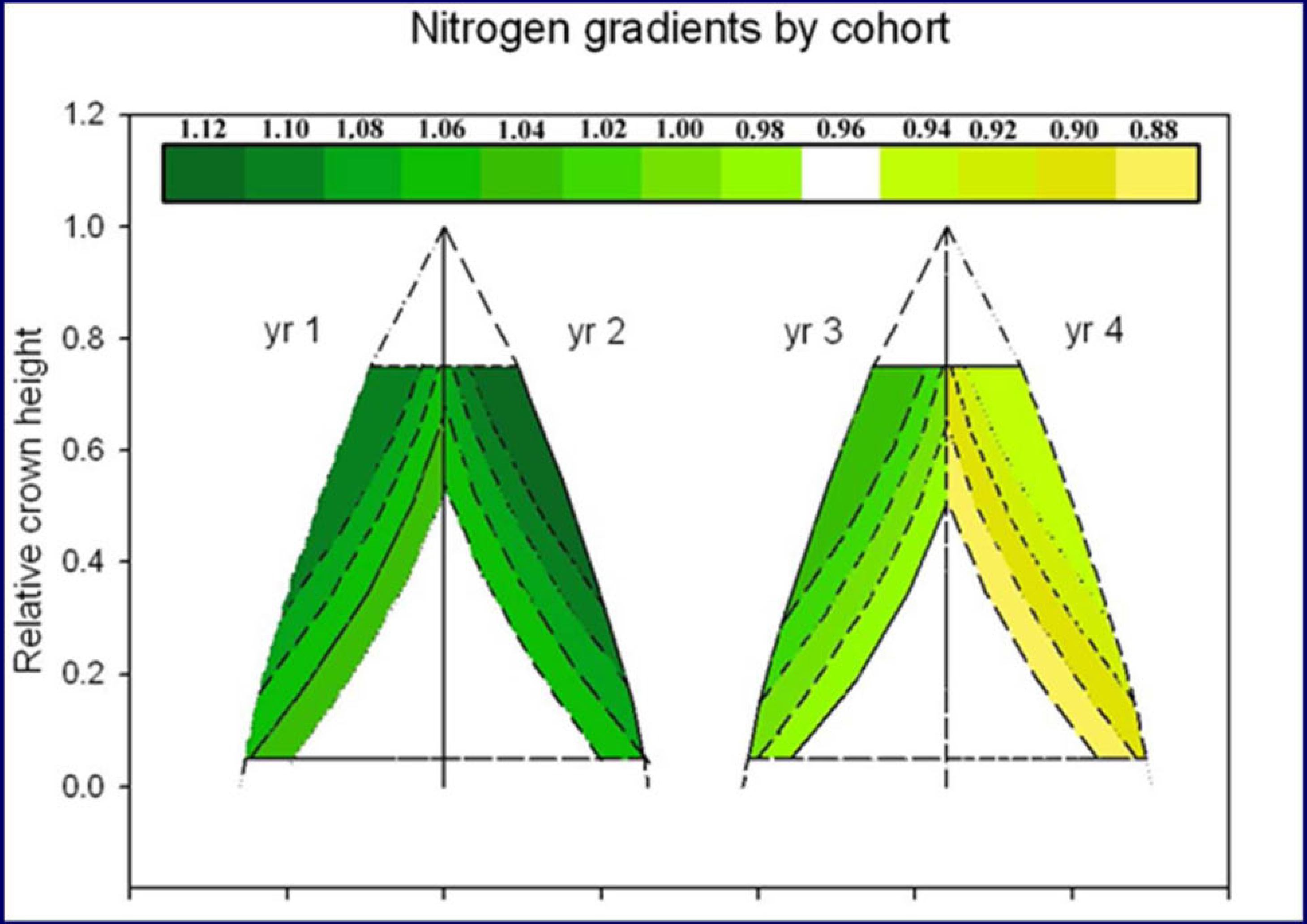
Gradients in Nitrogen concentration in Douglas-fir foliage



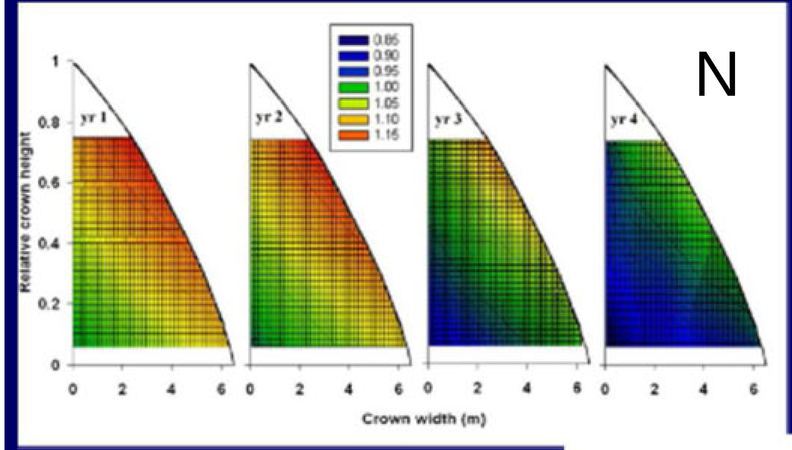
Gradients in Nitrogen concentration in Douglas-fir foliage

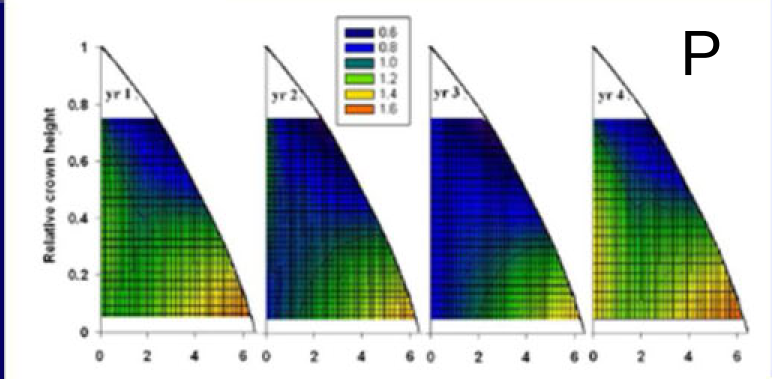


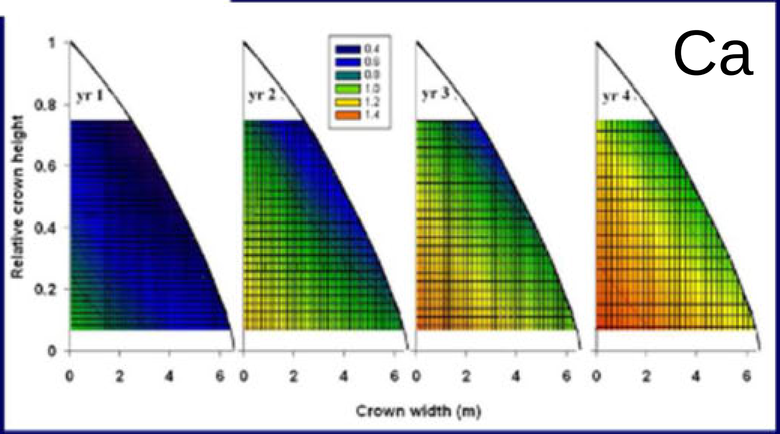
Gradients in Nitrogen concentration in Douglas-fir foliage



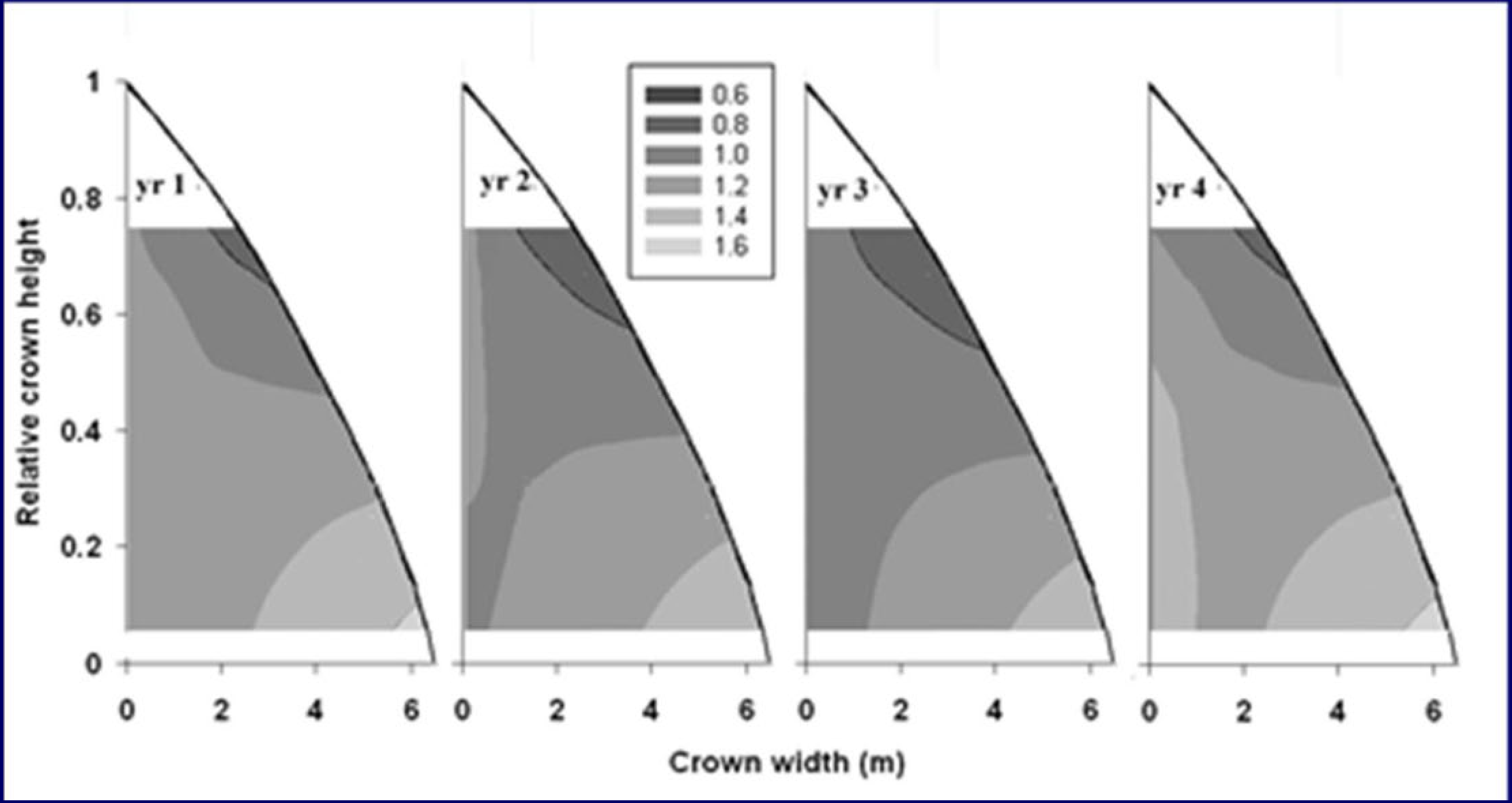
Nutrient concentration gradients in Douglas-fir foliage



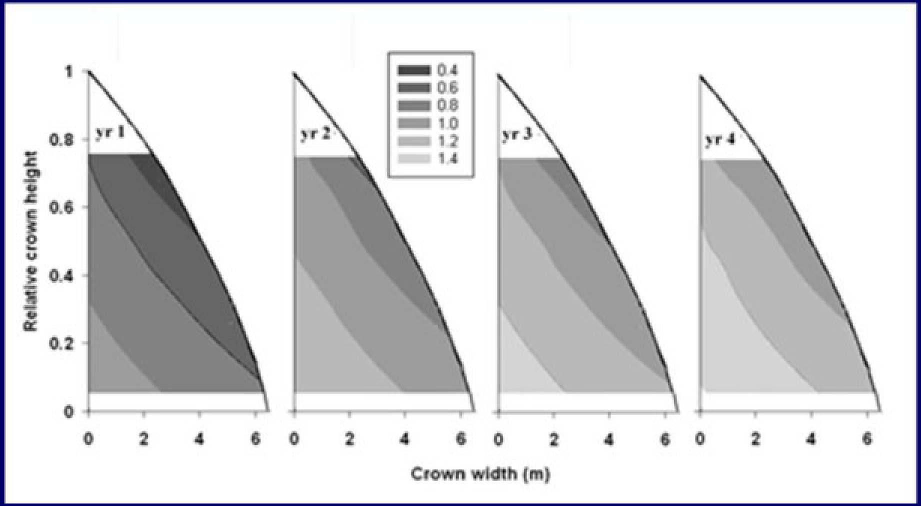


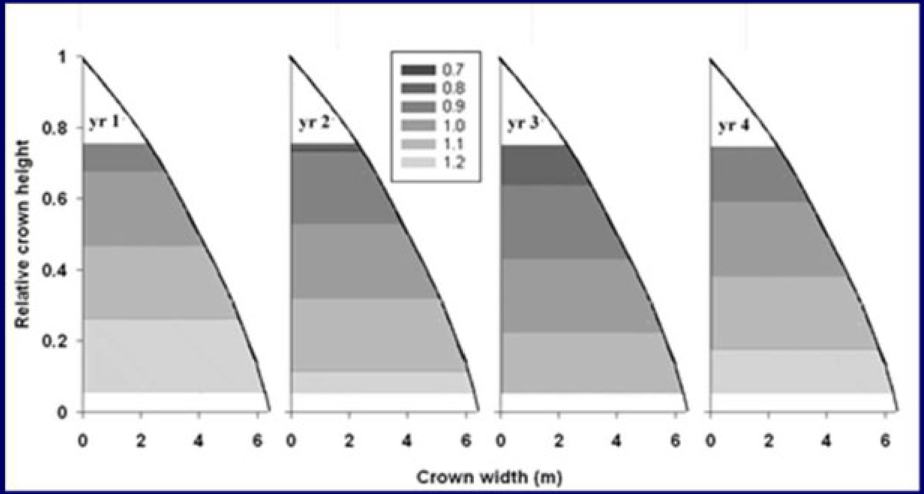


Gradients in Phosphorus concentration in Douglas-fir foliage

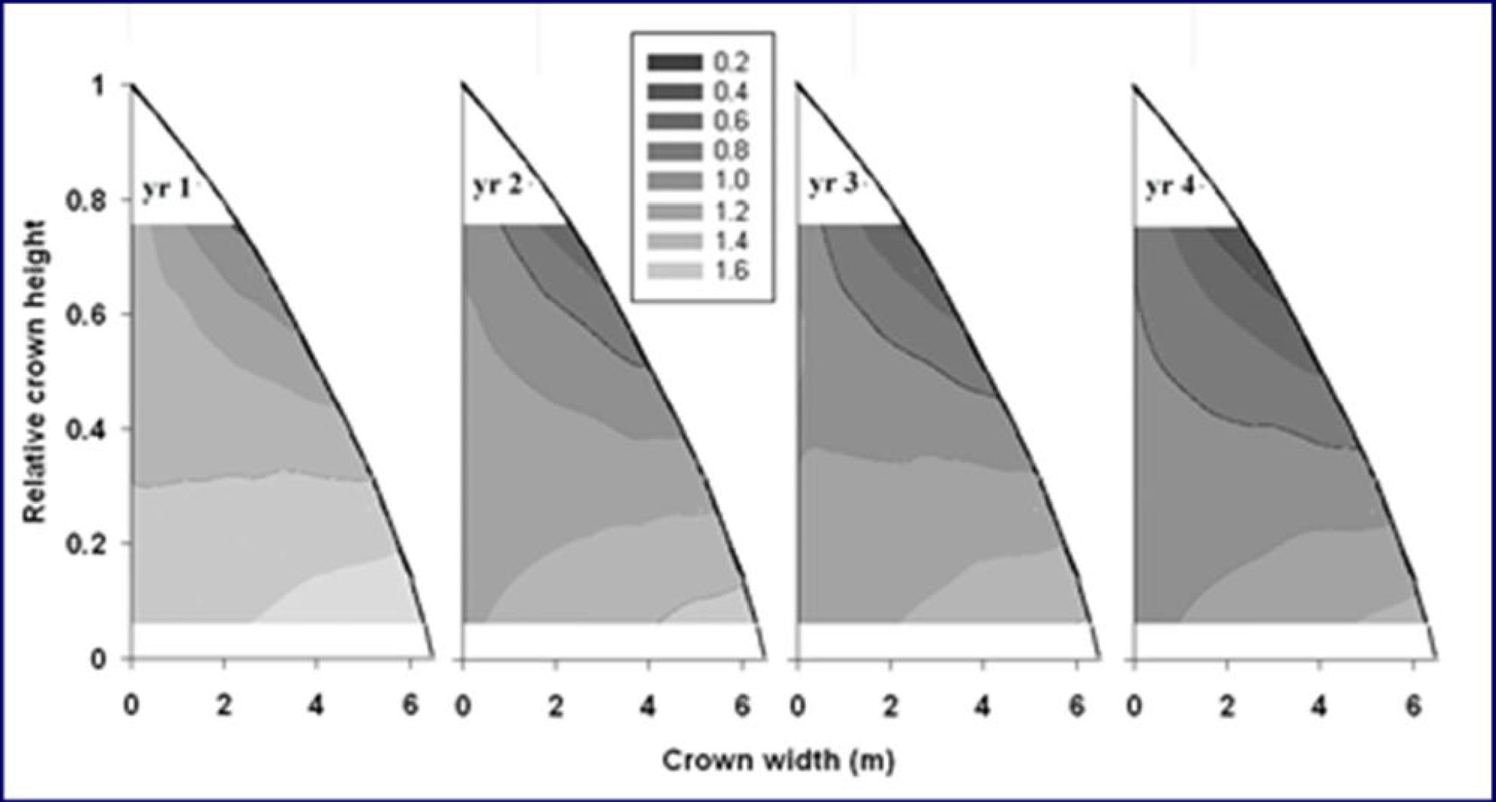


Gradients in Calcium and Magnesium concentrations in Douglas-fir foliage





Gradients in Potassium concentration in Douglas-fir foliage



Swiss Needle Cast Workshop Ernslaw One Ltd experience

ERNSLAW ONE

www.ernslaw.co.nz

Ernslaw One Douglas-fir Estate

- North Island – 600ha

Karioi Forest 300ha, Mangatu 200ha, Rip Forest 100ha

- South Island – 15,500ha

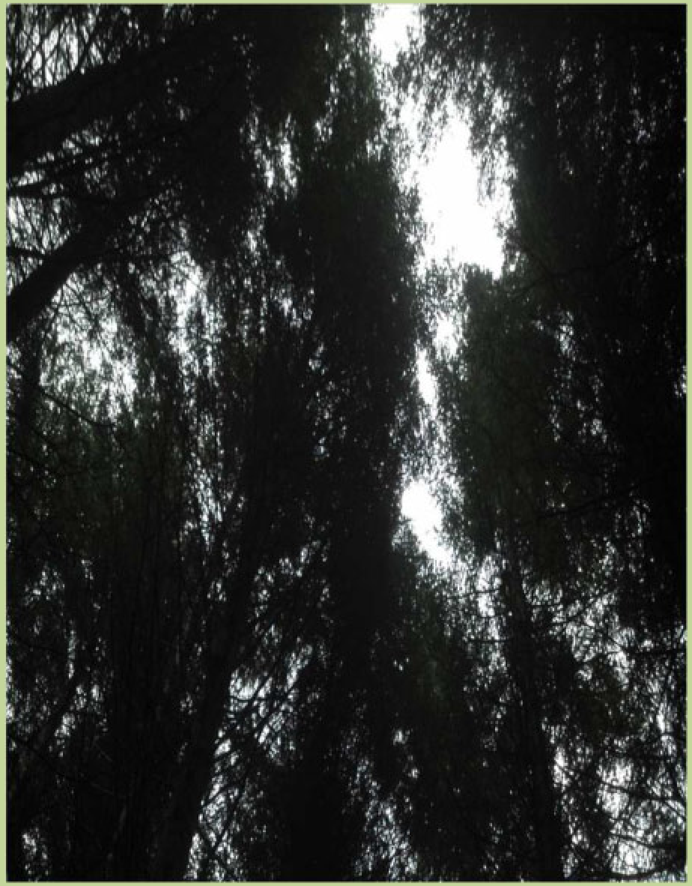
Blue Mountain Forest 5,400ha, Aparima Forest 6,100ha, Clutha Forest 3,300ha, Naseby Forest 700ha

Forest Health Reports

- SNC observed throughout Ernslaw estate
- Old reports describe 5-6 years of needle retention
- Recent reports (last 20 years) average 4 years of needle retention with a variation from 3 to 5
- Defoliation levels related more to drought stress than SNC infection levels

Visual appearance – high levels of foliage retention

Little undergrowth, closed canopy



Karioi Forest 1970s planting showing 4 years plus needle retention.

Response to tree diseases

- NZ forest managers have been spoiled for too long with relatively disease free forests. A disease can be an excuse not to plant a species.
- PNW forest managers have learnt to manage their estates for disease, in many cases simply by matching species to site.

SNC in North Island

- Forest managers often use SNC as the excuse for not planting Douglas-fir in the North Island.
- Ernslaw's experience on our own NI estate is that the disease levels are similar to SI levels.

Reality vs perception

- NI forests have a reputation for SNC infection
- Not all NI forests have SNC at significant levels
- Do we know where the infection hotspots are?
- Do we know how to manage them?

Solutions

- Short term - Managing existing constraints.
- Long term - Breeding

Management – site selection

- Identifying areas with consistently high infection levels – at two levels:
- Large scale mapping showing areas where SNC levels are too high to successfully grow Douglas-fir (< 3 years foliage)
- Detailed mapping by forest managers based on foliage retention in their own estates

Breeding

- Screening our best breeds for SNC resistance.
- Testing these selections across multiple sites.

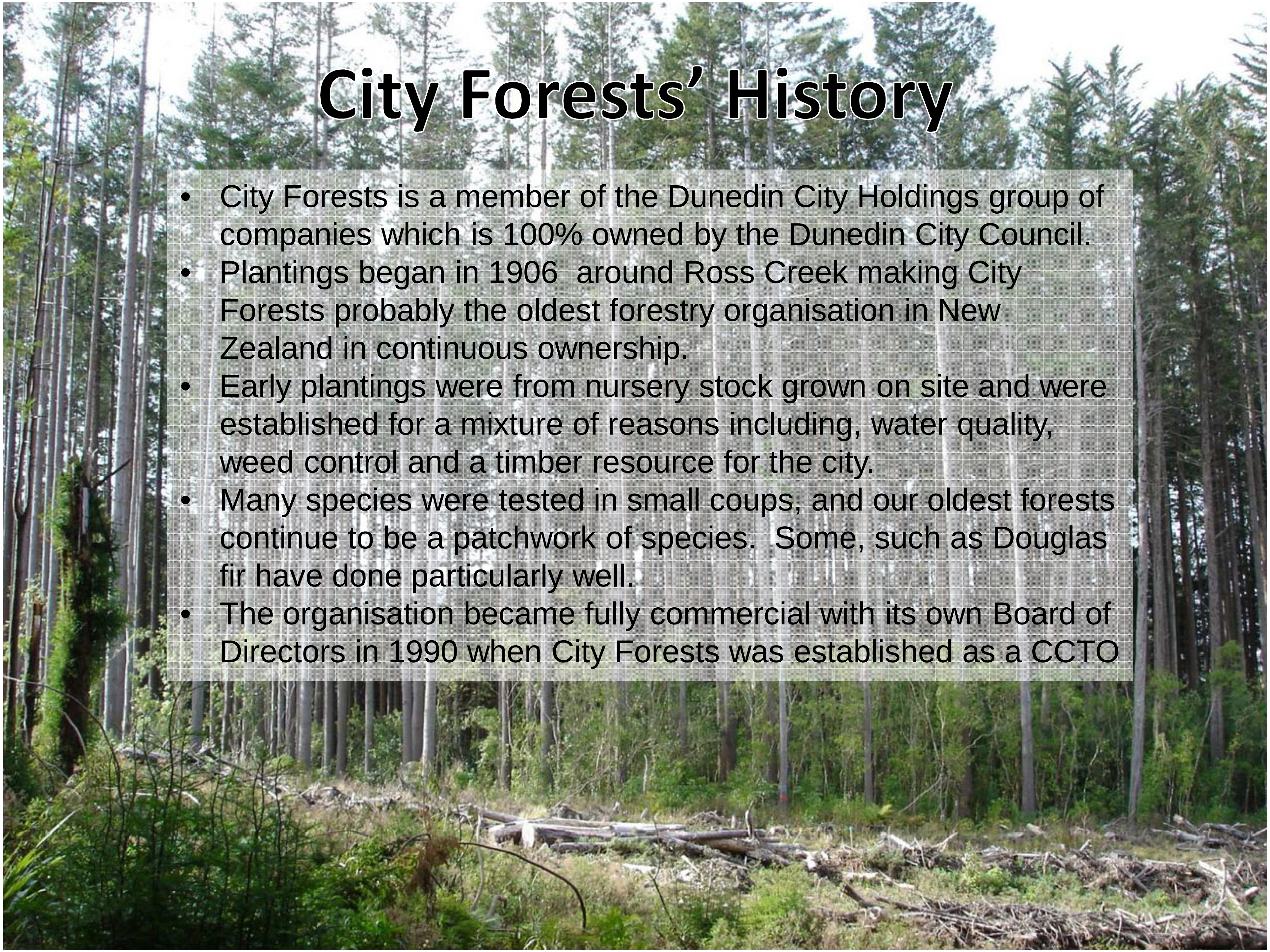
Breeding solutions

Second generation Tramway progeny trial – full sib cross of best parents

SNC Workshop

City Forests' Overview

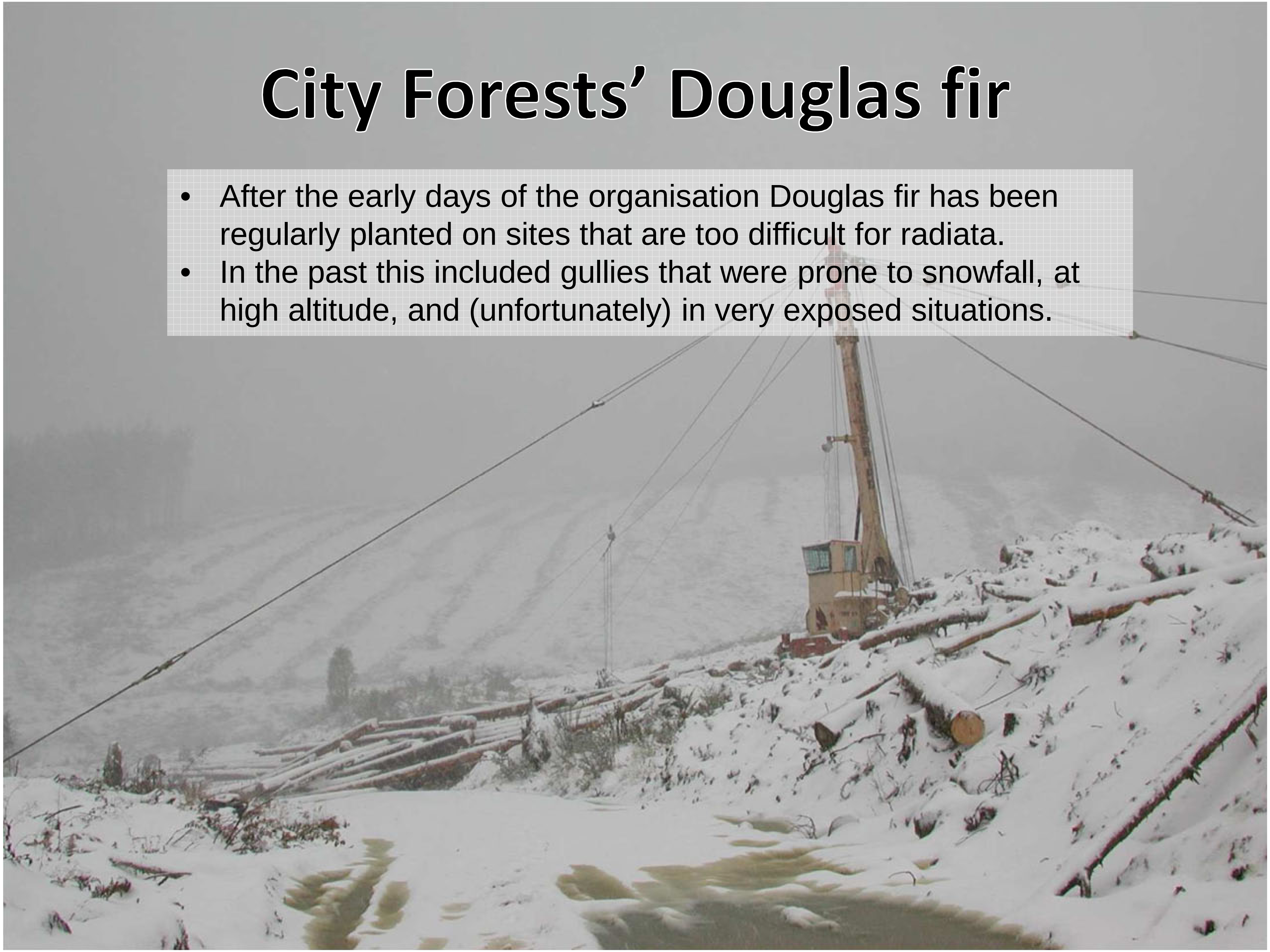
March 2015



City Forests' History

- City Forests is a member of the Dunedin City Holdings group of companies which is 100% owned by the Dunedin City Council.
- Plantings began in 1906 around Ross Creek making City Forests probably the oldest forestry organisation in New Zealand in continuous ownership.
- Early plantings were from nursery stock grown on site and were established for a mixture of reasons including, water quality, weed control and a timber resource for the city.
- Many species were tested in small coups, and our oldest forests continue to be a patchwork of species. Some, such as Douglas fir have done particularly well.
- The organisation became fully commercial with its own Board of Directors in 1990 when City Forests was established as a CCTO

City Forests’ Douglas fir



- After the early days of the organisation Douglas fir has been regularly planted on sites that are too difficult for radiata.
- In the past this included gullies that were prone to snowfall, at high altitude, and (unfortunately) in very exposed situations.

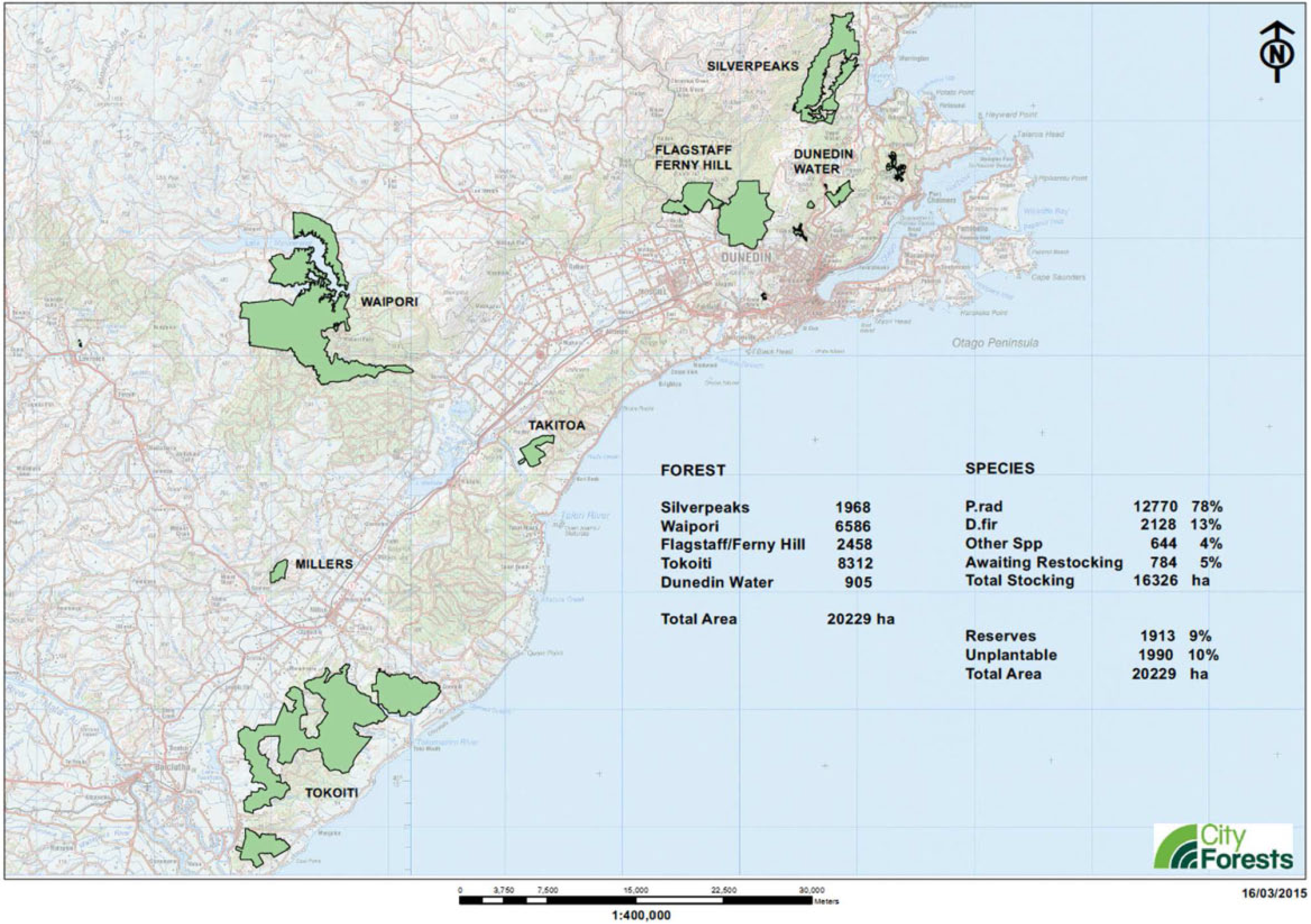
City Forests' Douglas fir

As a consequence, the quality of later Douglas fir was average, and lagged well behind the surrounding radiata.

City Forests' Douglas fir

- In 2003 the company purchased Silverpeaks forest, and with it over 600 hectares of Douglas fir planted between 1970 and 1987. This nearly doubled the company's area of Douglas fir.
- The resource now represents about 13% of the planted area.

City Forests Today



FOREST	
Silverpeaks	1968
Waipori	6586
Flagstaff/Ferny Hill	2458
Tokoiti	8312
Dunedin Water	905
Total Area	20229 ha

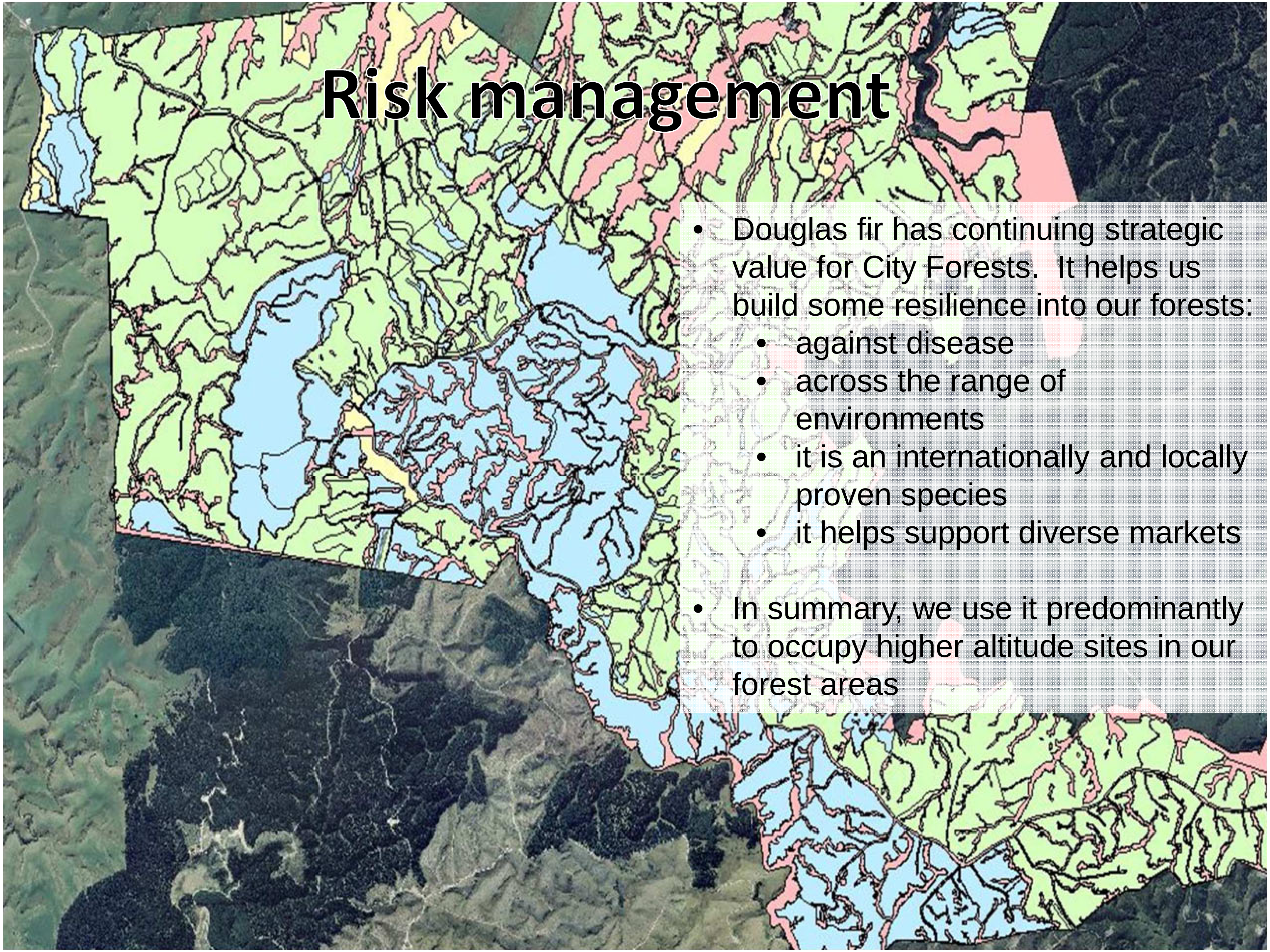
SPECIES		
P.rad	12770	78%
D.fir	2128	13%
Other Spp	644	4%
Awaiting Restocking	784	5%
Total Stocking	16326	ha
Reserves	1913	9%
Unplantable	1990	10%
Total Area	20229	ha

16/03/2015

Swiss Needle Cast today

To the best of our (City Forests') knowledge SNC is not presently causing any significant issues for our Douglas fir.
Our 2014 Forest Health report noted:
"Inspections of older Douglas fir stands revealed low to moderate severity infections levels of SNC, but none of this infection appeared to be in association with any defoliation or yellowing of foliage."

Projections we have seen suggest that in the future, even under climate change scenarios, the majority of our current Douglas fir sites will remain suitable for Douglas fir production. Cool and relatively dry winters look likely to prevail.



Risk management

- Douglas fir has continuing strategic value for City Forests. It helps us build some resilience into our forests:
    - against disease
    - across the range of environments
    - it is an internationally and locally proven species
    - it helps support diverse markets

- In summary, we use it predominantly to occupy higher altitude sites in our forest areas

Swiss Needle Cast and the future

Douglas fir is the only “minor” species that we have experienced consistent success with.

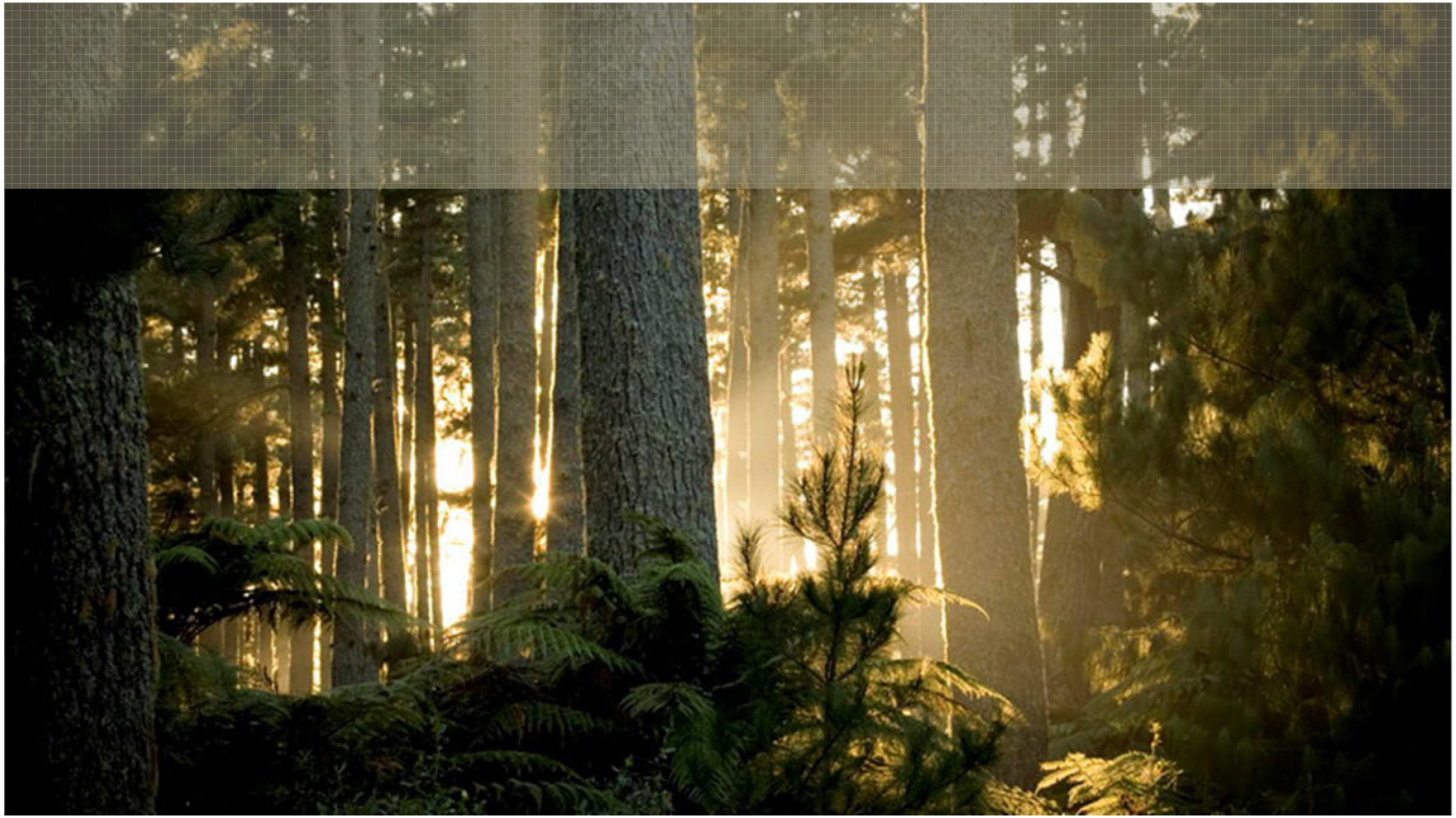
As an economic prospect it struggles to match what we can achieve with radiata on our better sites, although we are achieving some good results where production thinning is possible.

Therefore we will continue to plant small to moderate quantities of Douglas fir to fulfil a strategic niche role in our forests and markets.

It is therefore important that City Forests understands the SNC risks we may face in the future.

Swiss needle cast – pathologist's perspective

Lindsay Bulman



Selecting for resistance or susceptibility

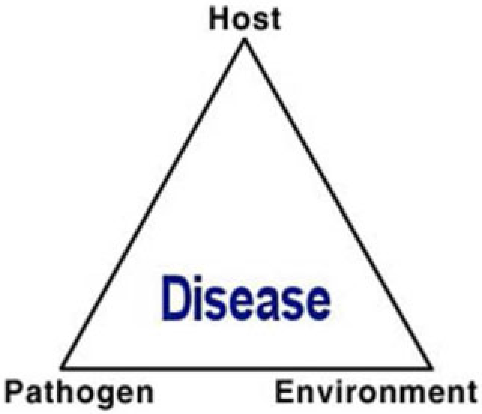
- Simple – assess disease

Selecting for SNC resistance or susceptibility

- Not always simple – Swiss needle cast is not a spectacular disease
- Difficult and time consuming to assess

Selecting for resistance or susceptibility

- Disease triangle (pathologists' version of G x E)



Selecting for SNC resistance or susceptibility

- Could assess fruit body formation on underside of needles

- Disease causes needle loss – assess crown transparency

Selecting for SNC resistance or susceptibility

- Objective crown transparency assessment
- LiDAR
- UAVs
- Individual tree and landscape assessment?
- Done for *P. radiata* in 2009
- Very good relationships between ground assessments, LiDAR, and leaf area index (with SPH)
  - – Transparency $R^2 = 0.79$
  - – Needle retention $R^2 = 0.85$
  - – LiDAR $R^2 = 0.95$

Other options

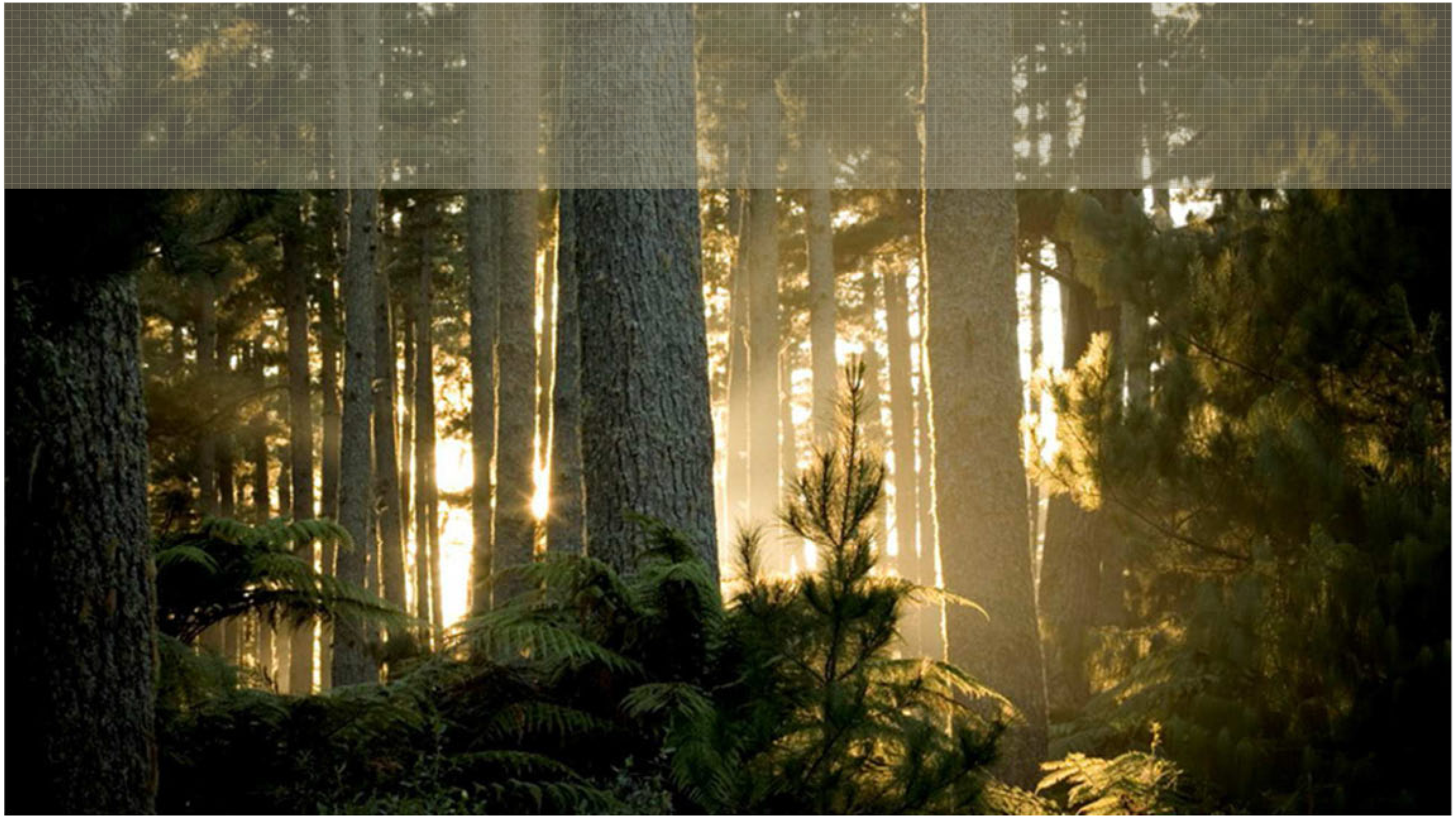
- SNC difficult to assess so may be possible to use metabolomics – but may not be a host response to infection
- Transcriptomics?
- Other molecular/genomic techniques?

Summary

- SNC difficult to assess
- Relying on filed assessment of symptoms is unreliable due to variation in environment
- Objective assessment (counting fruit bodies) very expensive
- Crown transparency – new technologies LiDAR and UAVs show promise
- The “…omics” age is here
- More sophisticated technologies to screen should be considered

Genetic solutions

Mari Suontama, Heidi Dungey, Charlie Low



Outline

- Evidence + potential gains

- Possible solutions

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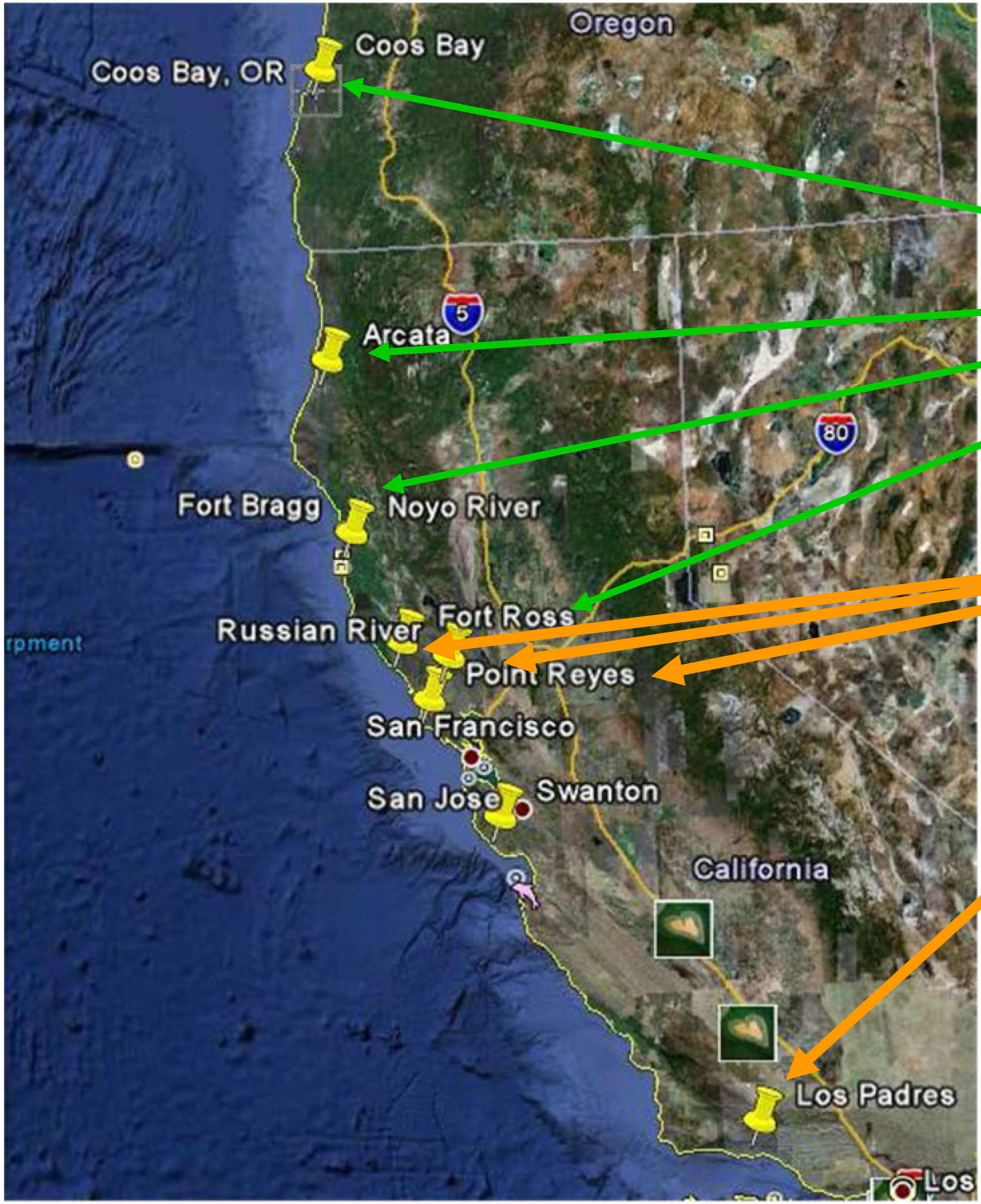

Best needle retention

Worst needle retention

$$h^2 = 0.36 \pm 0.06$$

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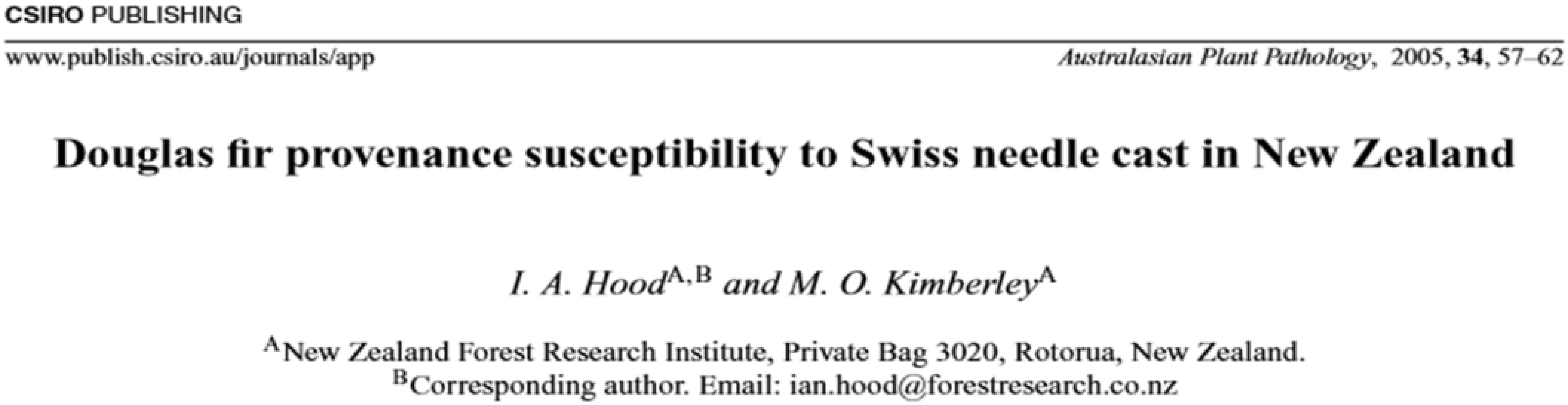


CSIRO PUBLISHING
www.publish.csiro.au/journals/app
Australasian Plant Pathology, 2005, **34**, 57–62

Douglas fir provenance susceptibility to Swiss needle cast in New Zealand

I. A. Hood[A,B] *and M. O. Kimberley*[A]

[A]New Zealand Forest Research Institute, Private Bag 3020, Rotorua, New Zealand.
[B]Corresponding author. Email: ian.hood@forestresearch.co.nz

Oregon provenances had most needle retention
Californian provenances lease needle retention

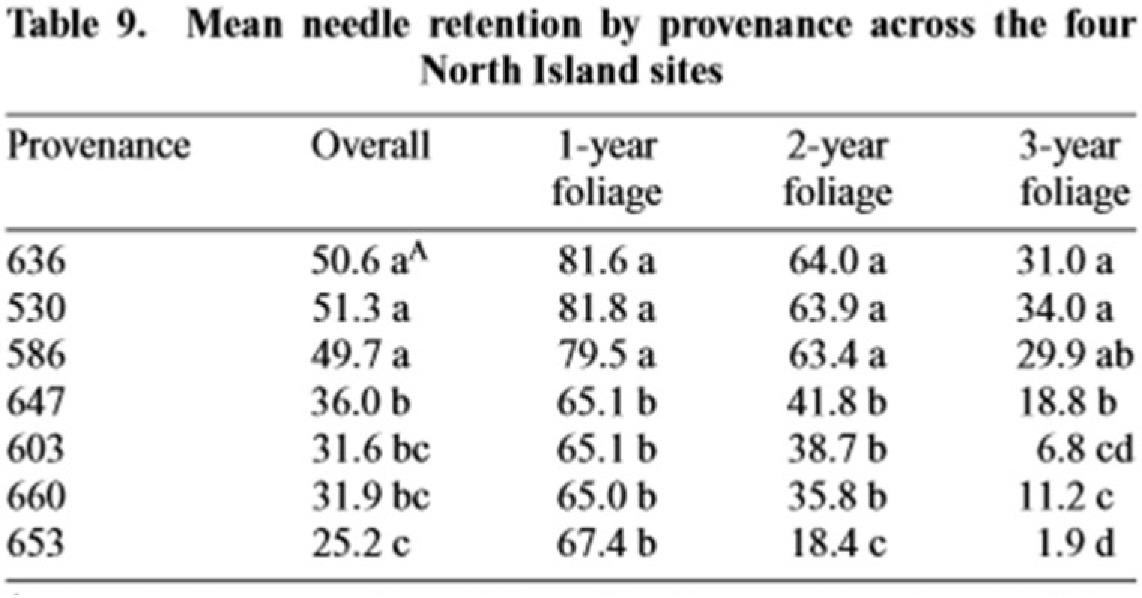


Table 9. Mean needle retention by provenance across the four North Island sites

	Provenance	Overall	1-year foliage	2-year foliage	3-year foliage
Oregon	636	50.6 a[A]	81.6 a	64.0 a	31.0 a
Kaing	530	51.3 a	81.8 a	63.9 a	34.0 a
Washington	586	49.7 a	79.5 a	63.4 a	29.9 ab
California	647	36.0 b	65.1 b	41.8 b	18.8 b
California	603	31.6 bc	65.1 b	38.7 b	6.8 cd
California	660	31.9 bc	65.0 b	35.8 b	11.2 c
California	653	25.2 c	67.4 b	18.4 c	1.9 d

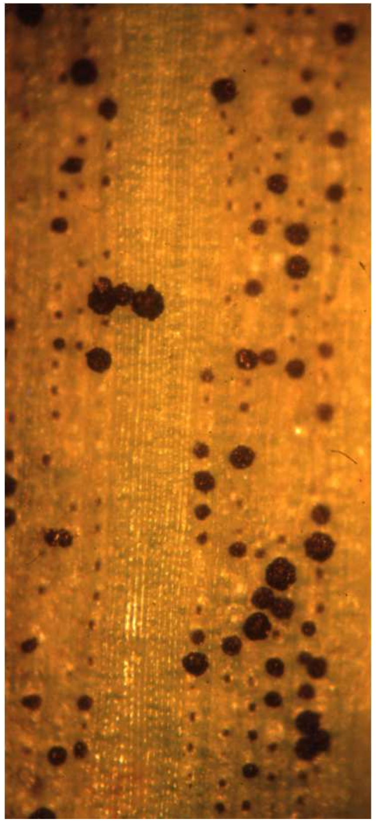
International

Pacific northwest

- Epidemic – 1 million ha
- Average growth reduction 25%
- Douglas-fir now planted where other species were historically more dominant
- Evidence there is a second line of SNC within the outbreak area (Mycologia 2006: 98 Pages 781-791)

- SNC Cooperative http://sncc.forestry.oregonstate.edu/
- Northwest Tree Improvement Cooperative
  - SNC tolerant families
  - http://nwtic2.forestry.oregonstate.edu/

2009-12 report Northwest Tree Improvement Coop



- No known genetic resistance mechanisms, as all foliage and all trees are susceptible given the right conditions
- Fungal infection and needle colonisation occur passively
- Infection requires physical or enzymatic penetration of host tissue that might trigger a host defence response

TI Cooperative

- Tolerance found
- Heritabilities of 0.6 to 0.8 for needle retention, crown density, foliage colour
- Measurement of trials under disease pressure
- 26 new trials will be assessed for SNC

- http://sncc.forestry.oregonstate.edu/sites/default/files/2012%20Jayawickrama_0.pdf

Genetic variation in tolerance of Douglas-fir to Swiss needle cast as assessed by symptom expression

- Crown density and colour -reasonable indicators of disease tolerance & can help screen for families that show tolerance to the disease

- Johnson, G.R. **Silvae Genetica**
- Volume 51, Issue 2-3, 2002, Pages 80-86

Genetic variation in tolerance of Douglas-fir to Swiss needle cast as assessed by symptom expression

- The most useful definition of tolerance to Swiss needle cast is continued tree growth in the presence of increased disease pressure
- Indirect selection for basal-area increment using DBH (age-11) was 92% as efficient as direct selection
- Age-11 height was 72% as efficient
- ***Increasing growth through breeding could offset the 27% reduction in growth***

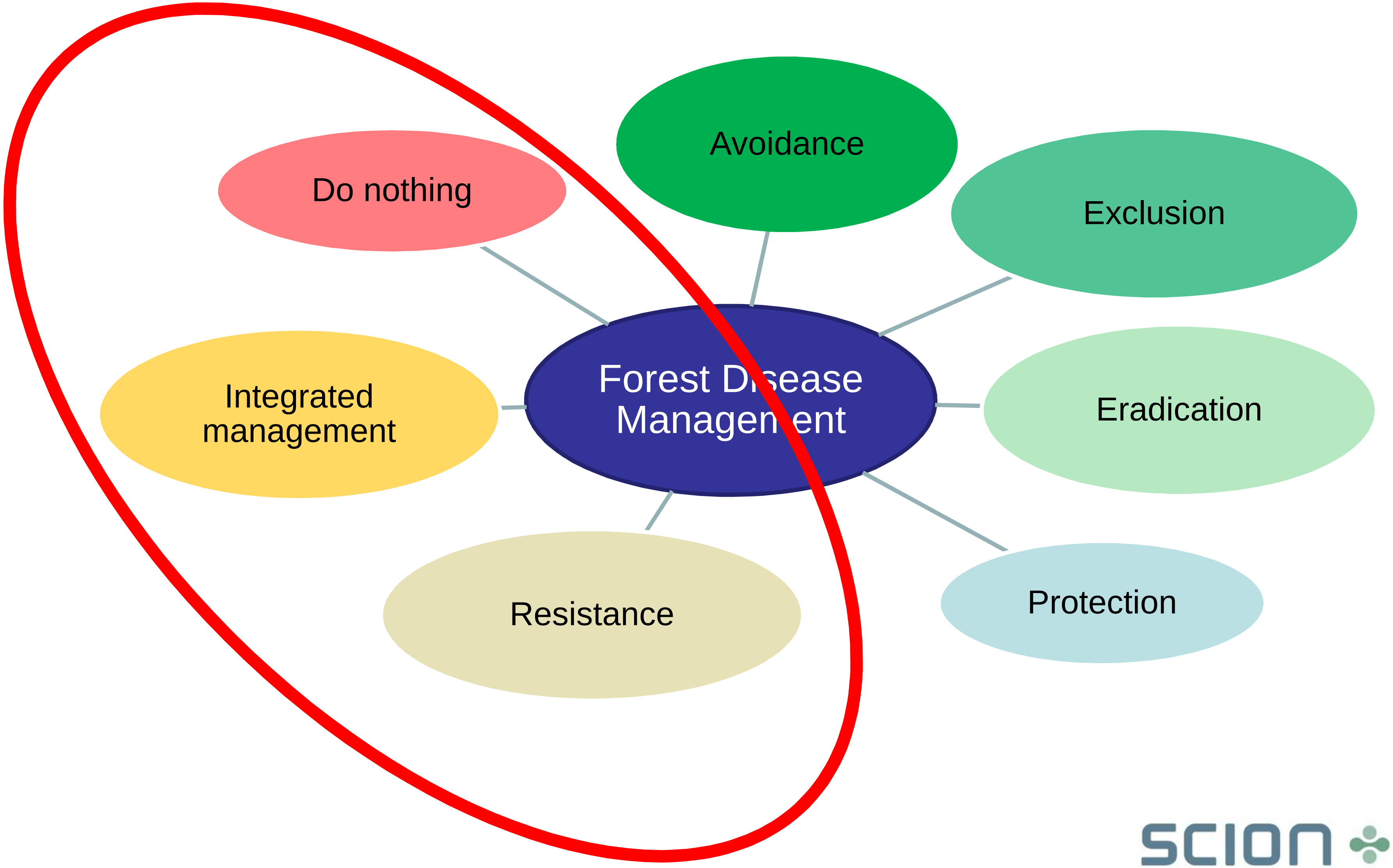
Screening by Temel

- Families differed significantly at both ages for all SNC symptom traits and for PSOP
  - [PSOP-proportion of needle stomata blocked with pseudothecia],
- No difference for amount of fungal DNA.
  - Temel Johnson, Adams (2005). Early genetic testing of coastal Douglas-fir for Swiss needle cast toleranceCanadian Journal of Forest Research 35: 521-529
- Mean $h_i\,^2$ = 0.19, range 0.06-0.37
- Family selection for SNC tolerance at the seedling stage can be very effective in increasing tolerance in older trees

Europe

- Provenances from the coast range have better resistance
- Within the interior range, northern pops are more tolerant than southern pops (Rhabdocline and SNC)
  - Forest Tree Breeding in Europe (Ed: Luc Paques)

Possible solutions



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Breeding – where too from here?

- South Island breed
  - growth and exposure
  - 2 sites
  - 100-120 trees

- North Island breed
  - SNC and growth
  - 2 sites
  - 100-120 trees

- Screen for stiffness

- Forward selection breeding strategy
- Pedigree reconstruction from fingerprinting
- Oregon, Washington and Fort Bragg as controls

Possible solutions

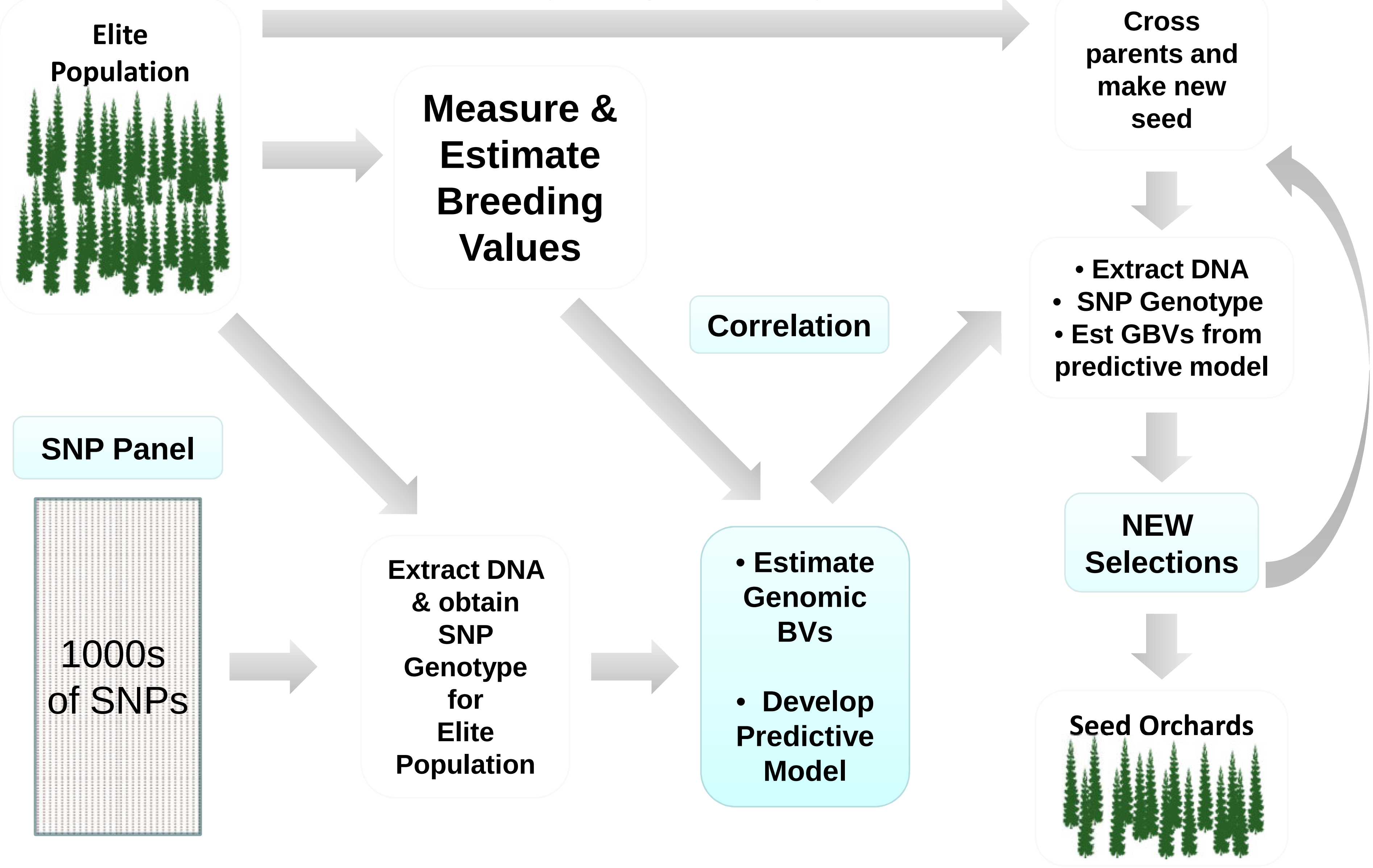
- Determine the parameters for sites where needle loss is too severe
- Genomic selection
- & breeding for resistance/tolerance

- New methods for quantifying needle loss- remote sensing
- Phenotyping systems?

What is a phenotype?

- The physical appearance and measurements of a tree
- An expression of the genotype (or genes) in a given environment
- Based on measurements – e.g. DBH

Genomic Selection
–will double the delivery of genetic gain per unit time



Elite Population

Measure & Estimate Breeding Values

Cross parents and make new seed

Correlation

- Extract DNA
- SNP Genotype
- Est GBVs from predictive model

SNP Panel

1000s of SNPs

Extract DNA & obtain SNP Genotype for Elite Population

- Estimate Genomic BVs
- Develop Predictive Model

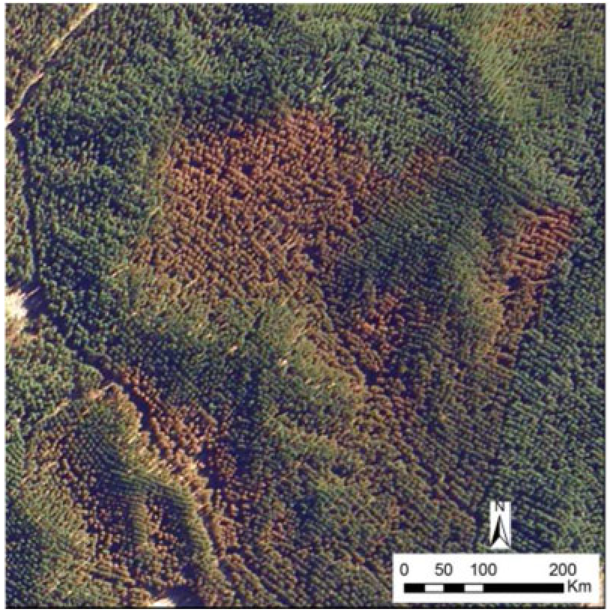
NEW Selections

Seed Orchards

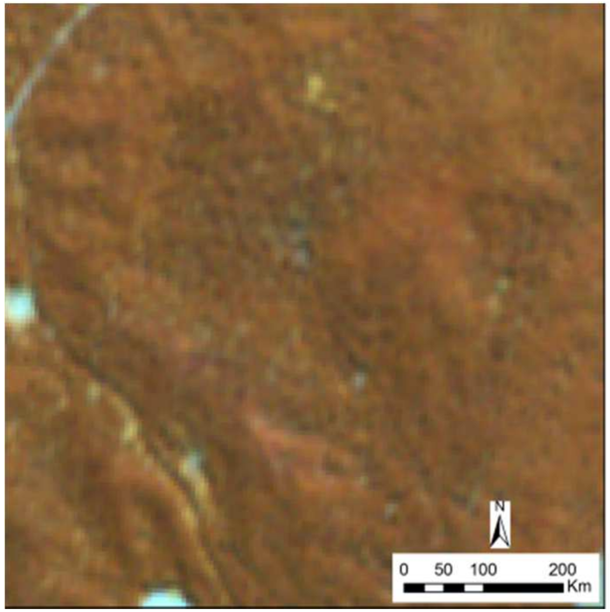
Phenotyping
More accurate phenotyping will deliver results through breeding

- Using subjective assessment of % needle retention
- Count the amount of blocked stomata?
- LAI-meter (very slow not really suitable for genetics)
- LiDAR? Remote sensing?

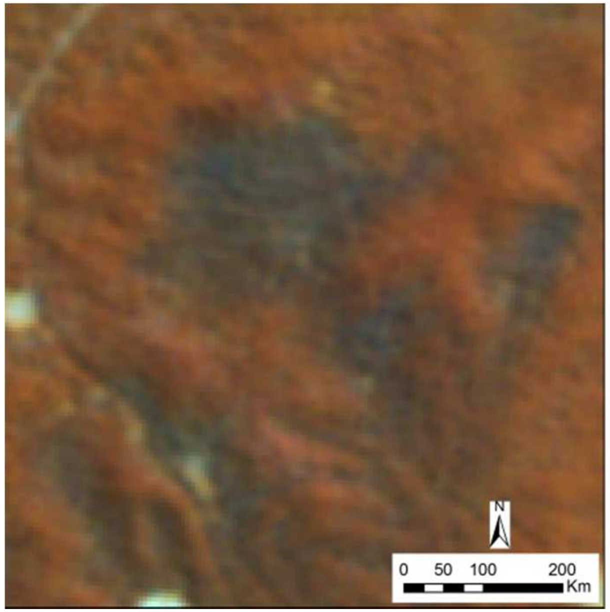
Remote sensing technologies



Aerial photography

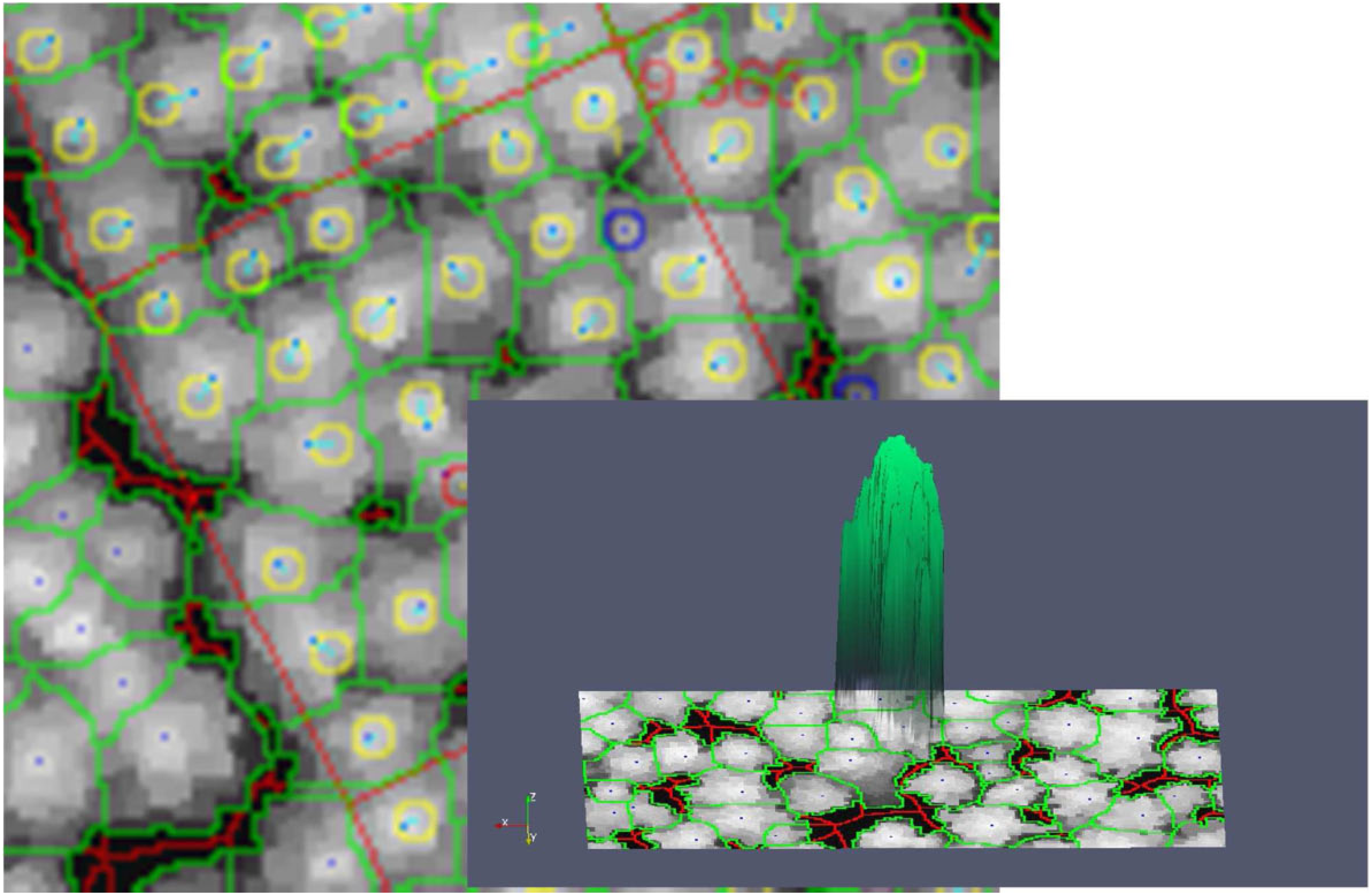


RapidEye before needle cast



RapidEye after needle cast

Methods – Crown metrics



Summary

- SNC resistance appears to be heritable
- We can breed for this
- New technologies – phenotyping and genetics will allow more accurate and faster delivery of improved trees to the forest

- Proof of concept covered in the partnership programme
- Rapid delivery will require further investment or more time

[redacted]

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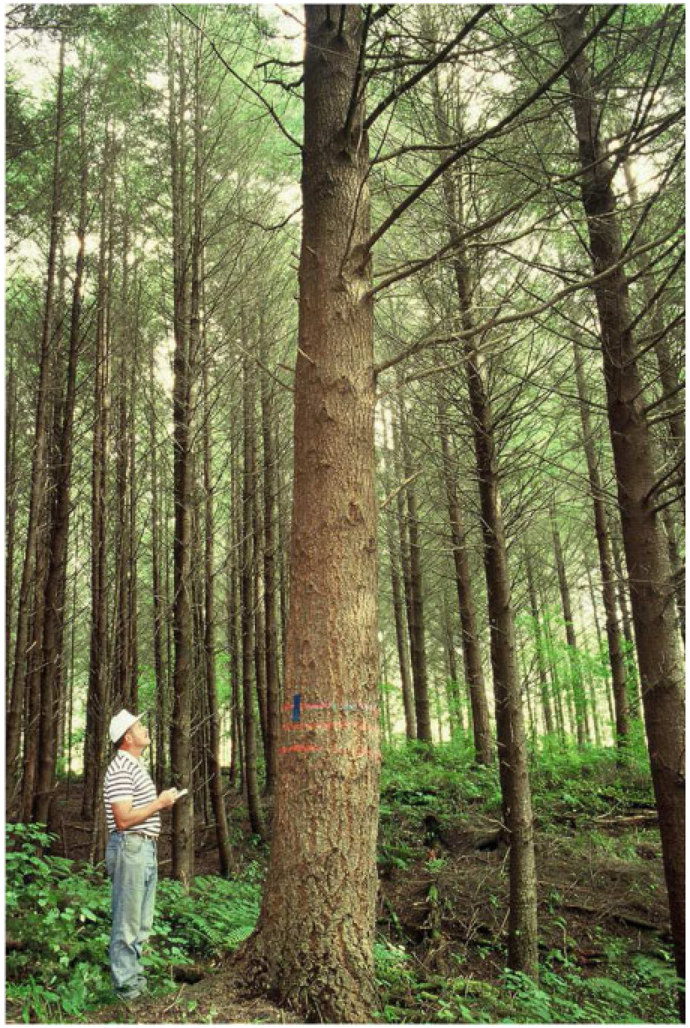
Gains and foliage health from progeny tests

Charlie Low

Douglas-fir 109,000 hectares



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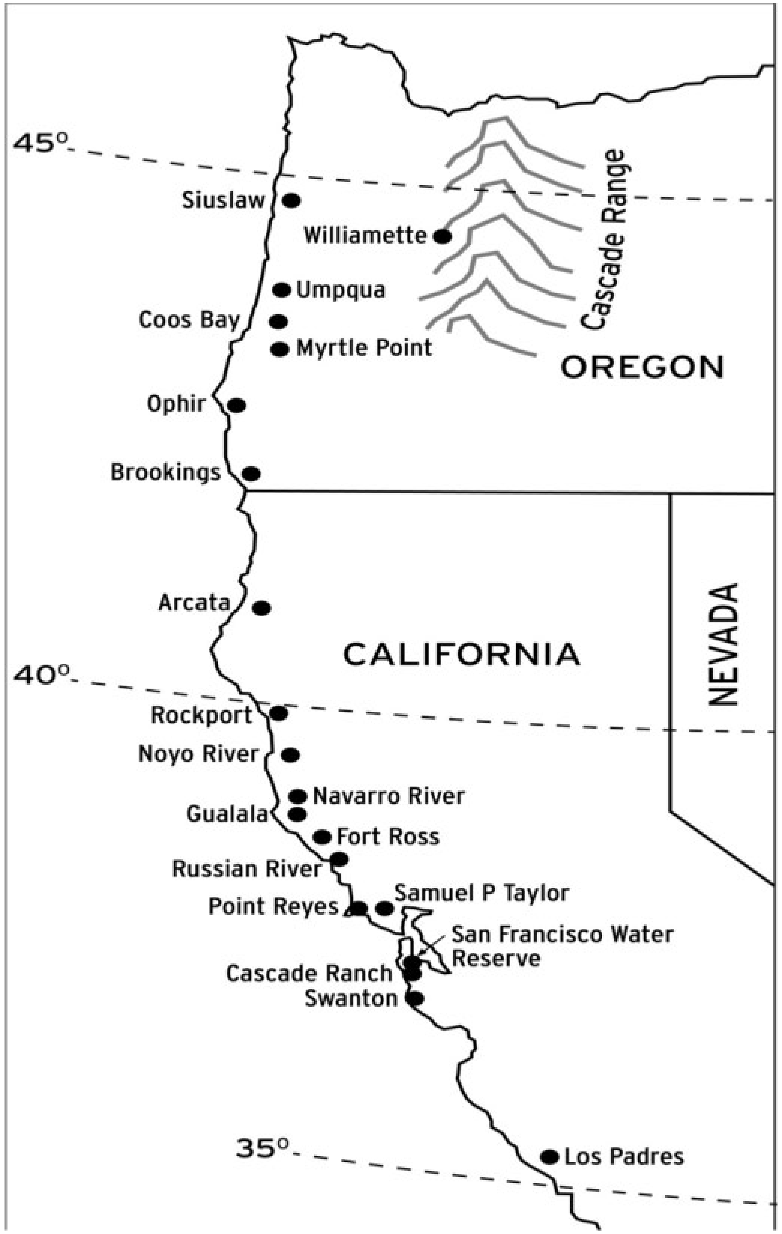
1996 progeny trial

- 20 provenances
- 220 progenies from California and Oregon
- All mother trees growing in the “fog-belt”, except for 10 from Willamette forest
- 6 seedlots from NZ seed stands
- Height measured 2000
- Needle retention assessed 2003
- Diameter measured 2007



Provenances in 1996 trial

Californian provenances

Provenance	Latitude °N	Needle retention
Los Padres	35° 49’	1.44 d
Swanton	37° 06’	1.96 bc
Cascade Ranch	37° 08’	1.96 bc
SF water reserve	37° 27’	2.01 bc
SP Taylor FP	38° 02’	1.91 bc
Point Reyes	38° 04’	2.22 ab
Russian river	38° 21’	1.72 cd
Fort Ross	38° 25’	2.18 ab
Gualala	38° 47’	1.97 bc
Navarro river	39° 11’	2.31 ab
Noyo river	39° 25’	2.27 ab
Rockport	39° 47’	2.00 bc
Arcata	39° 59’	2.30 ab

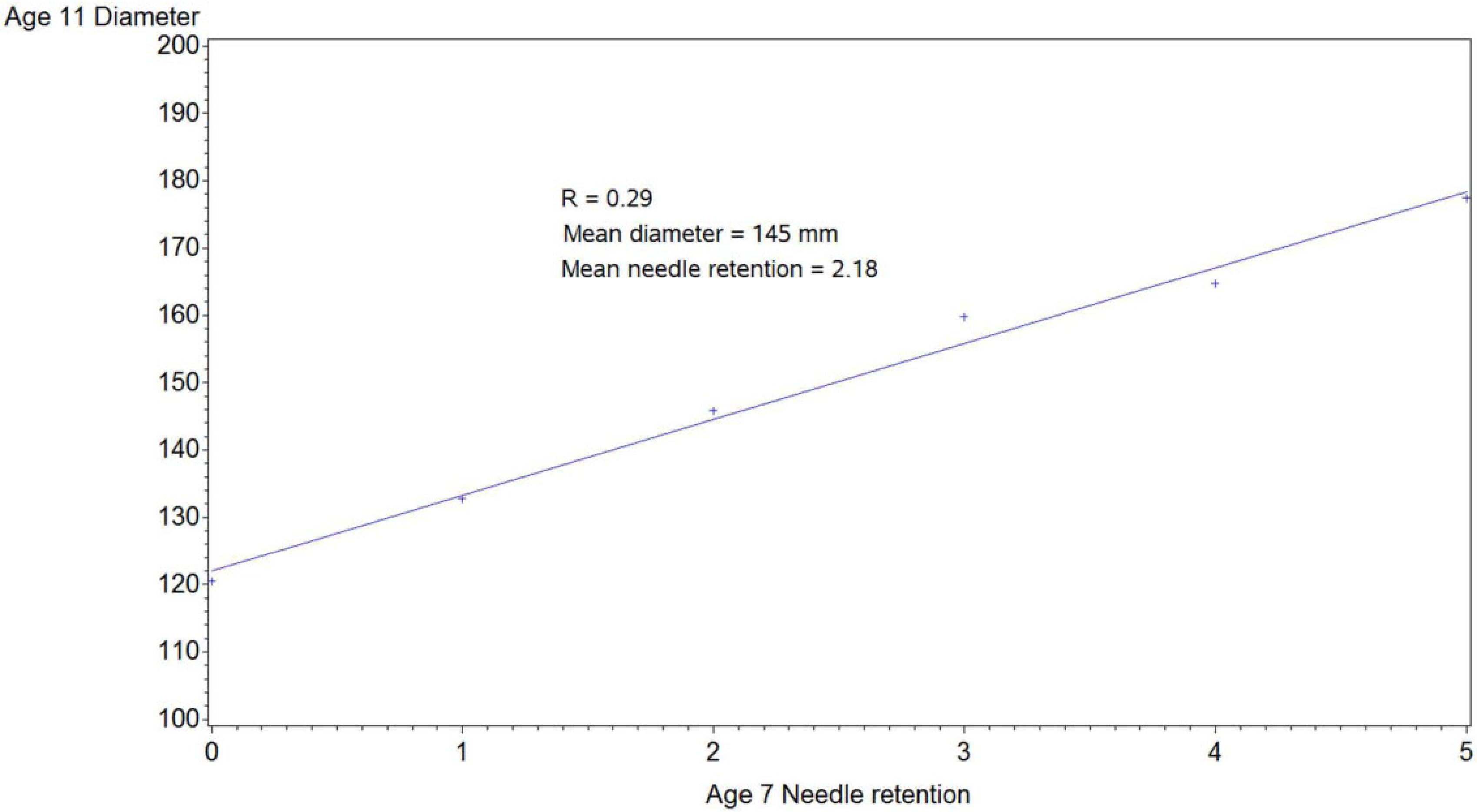
Oregon provenances

Provenance	Latitude °N	Needle retention
Brookings	42° 06’	2.11 abc
Ophir	42° 36’	1.96 bc
Myrtle Point	43° 06’	2.35 ab
Coos Bay	43° 20’	2.49 a
Umpqua river	43° 36’	2.10 abc
Siuslaw forest	44° 10’	2.25 ab
Willamette forest	43° 50’	2.17 abc

New Zealand seed stands

Seedstand	provenance	Needle retention
Rotoehu cpt 55	Fort Bragg, CA	2.66
Kaingaroa cpt 1132	Ft Bragg ex Rotoehu	2.79
Kaingaroa cpt 1061	Washington	2.46
Golden Downs cpt 114	Fort Bragg	2.50
Eyrewell	Oregon	2.45
Mount Thomas	Oregon	2.24
Beaumont	Washington	2.40

Douglas-fir DBH by SNC



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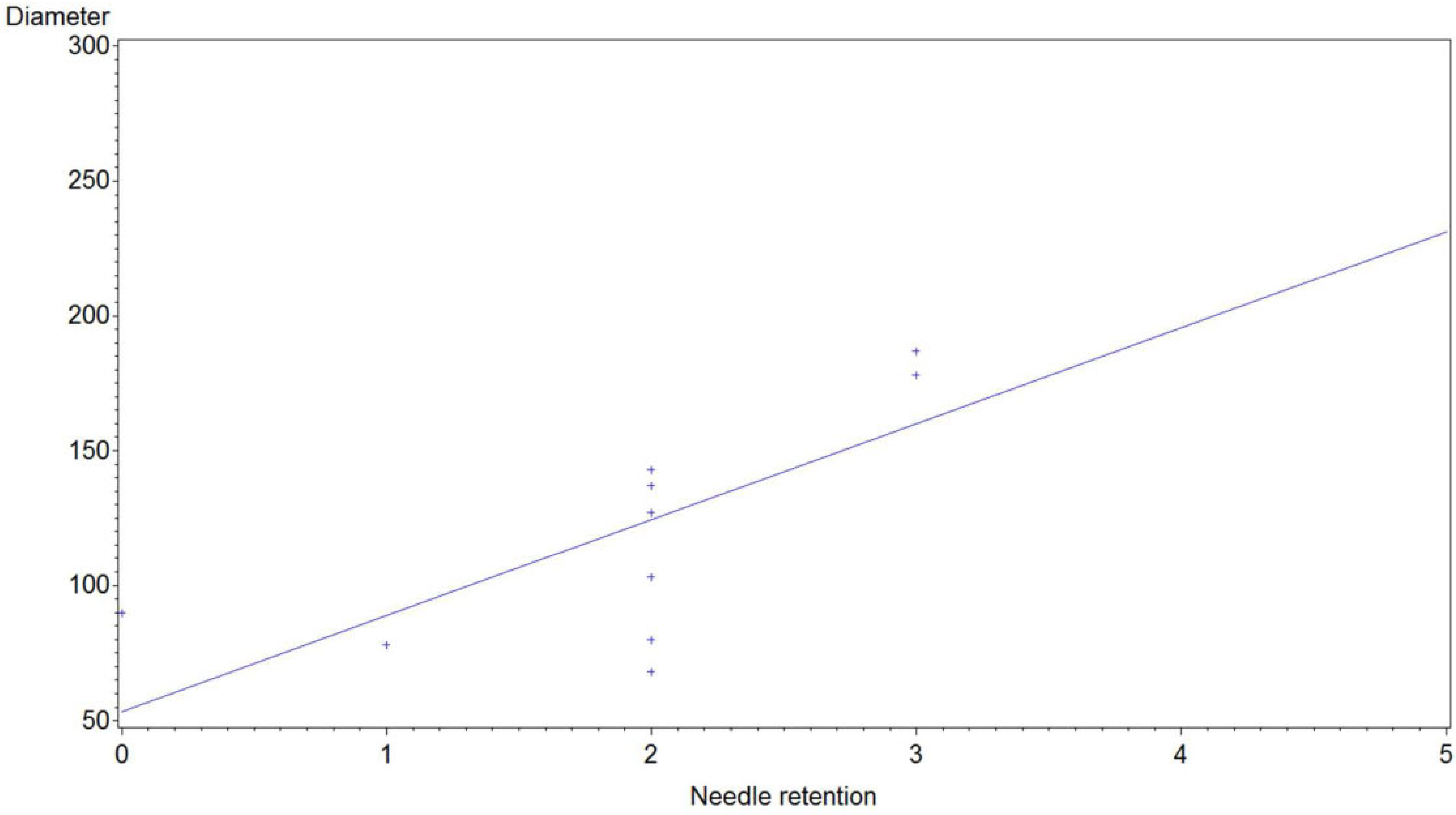
Los Padres



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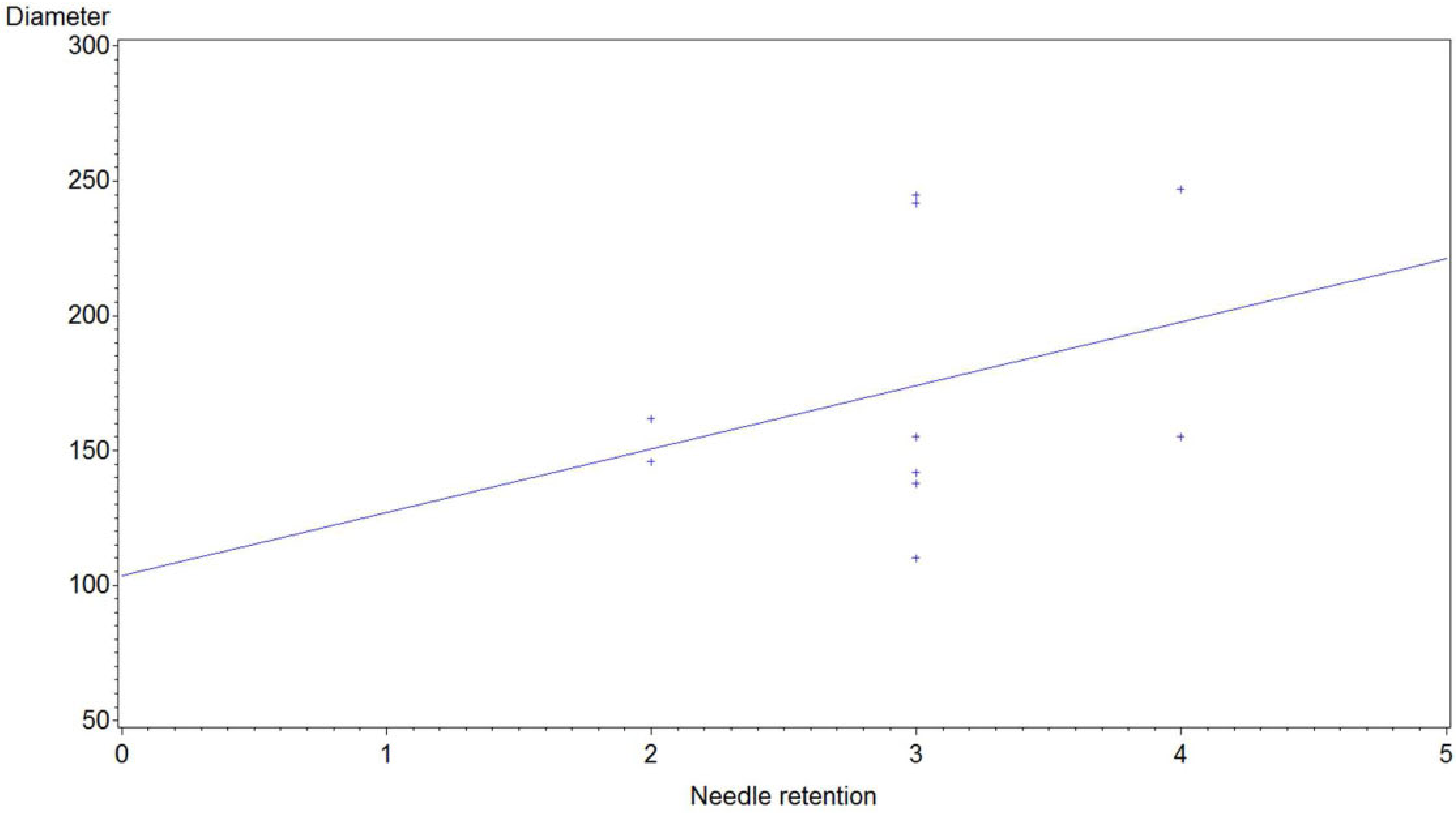
Cascade Ranch, Santa Cruz



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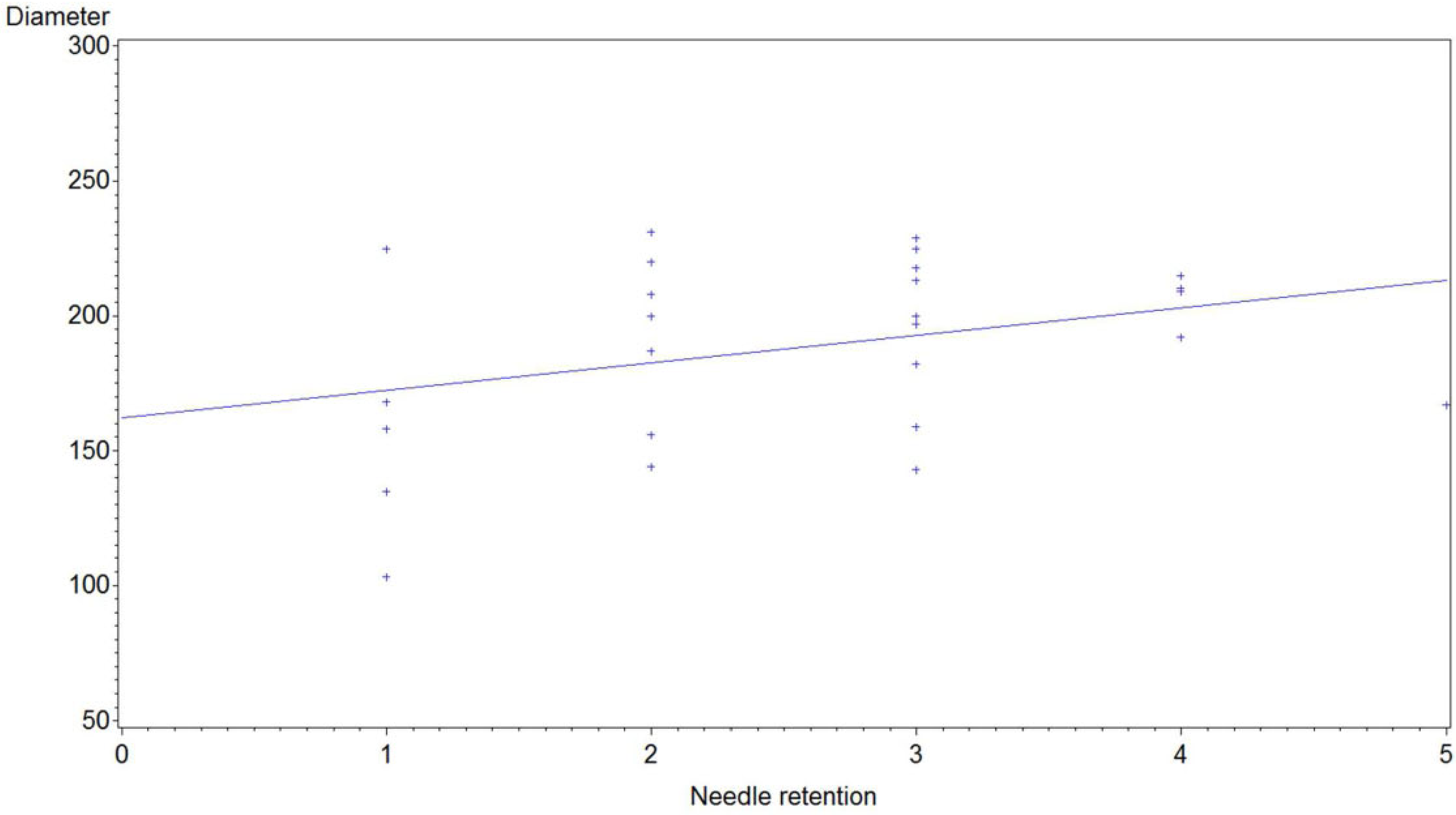
Navarro River



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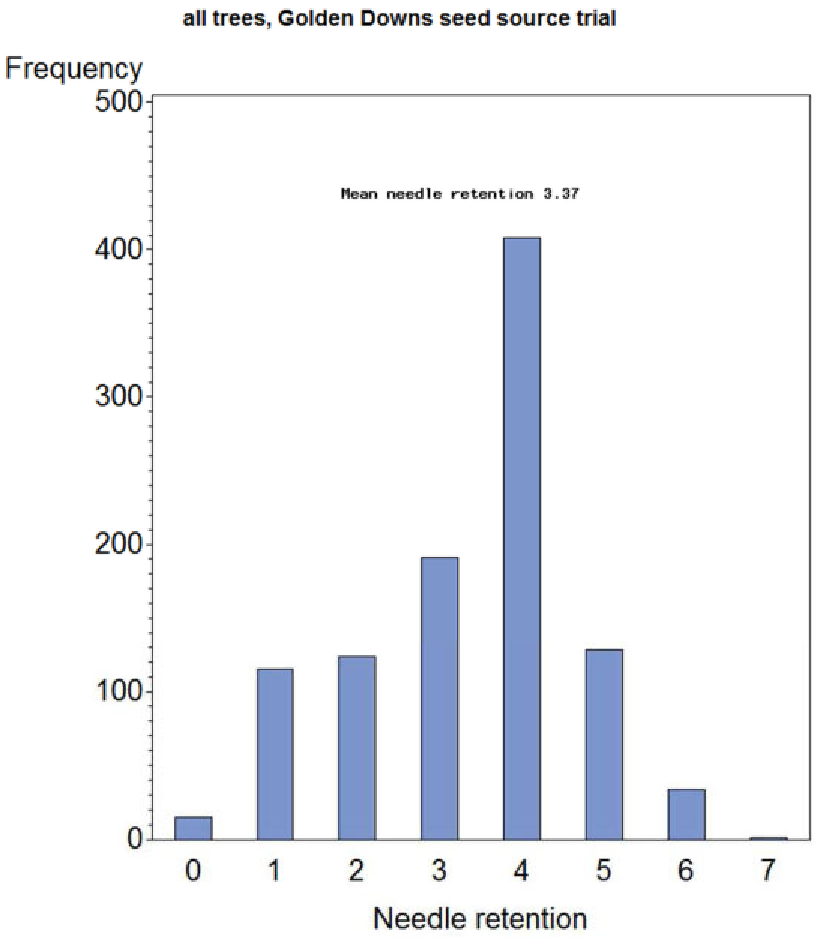
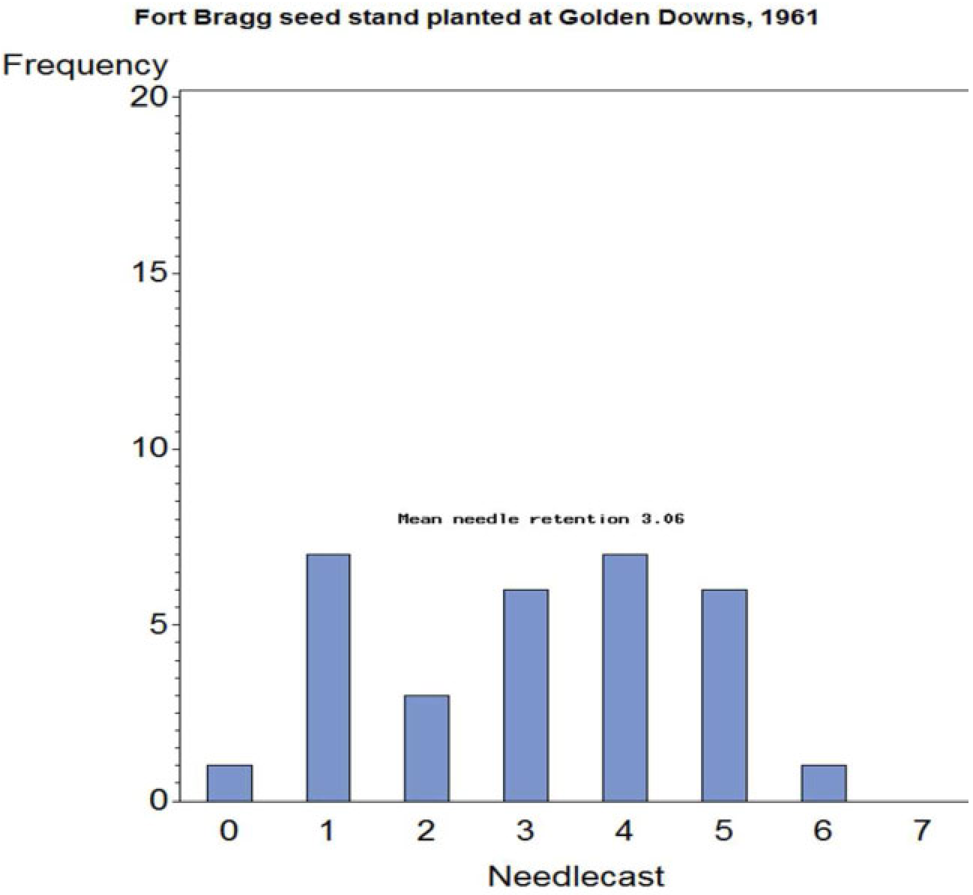
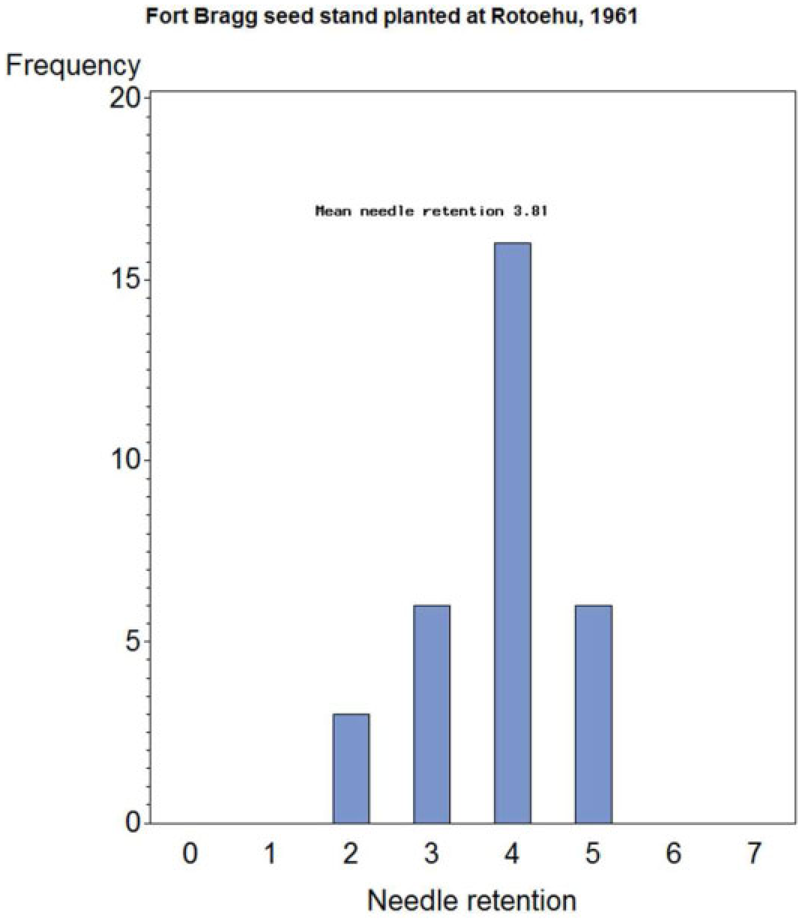
1996 seed source trial, Golden Downs

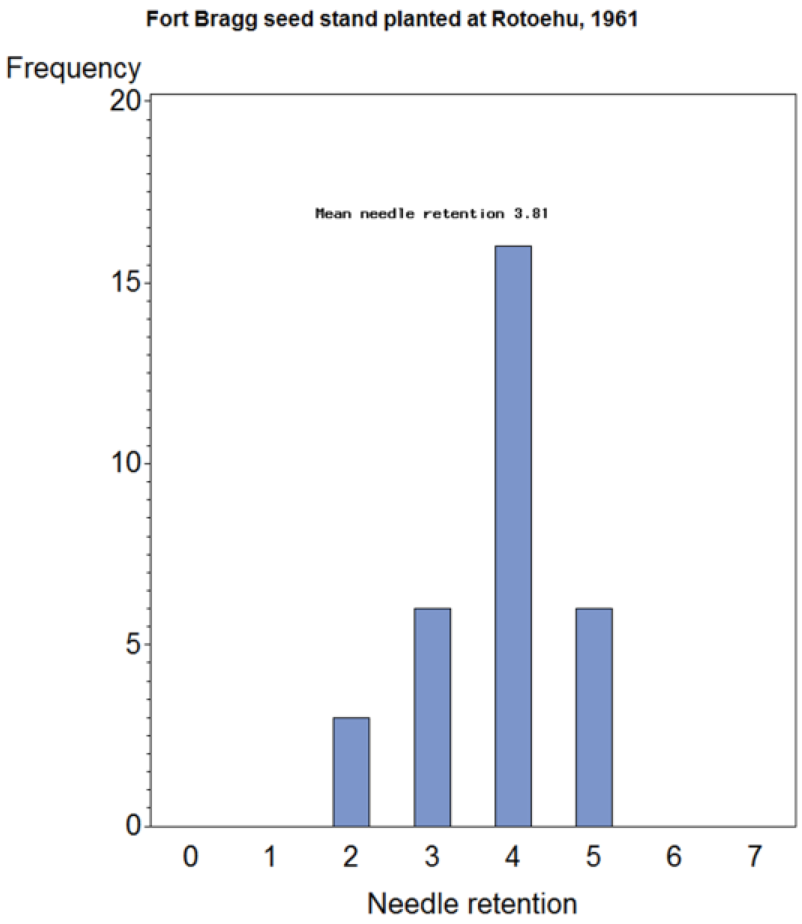


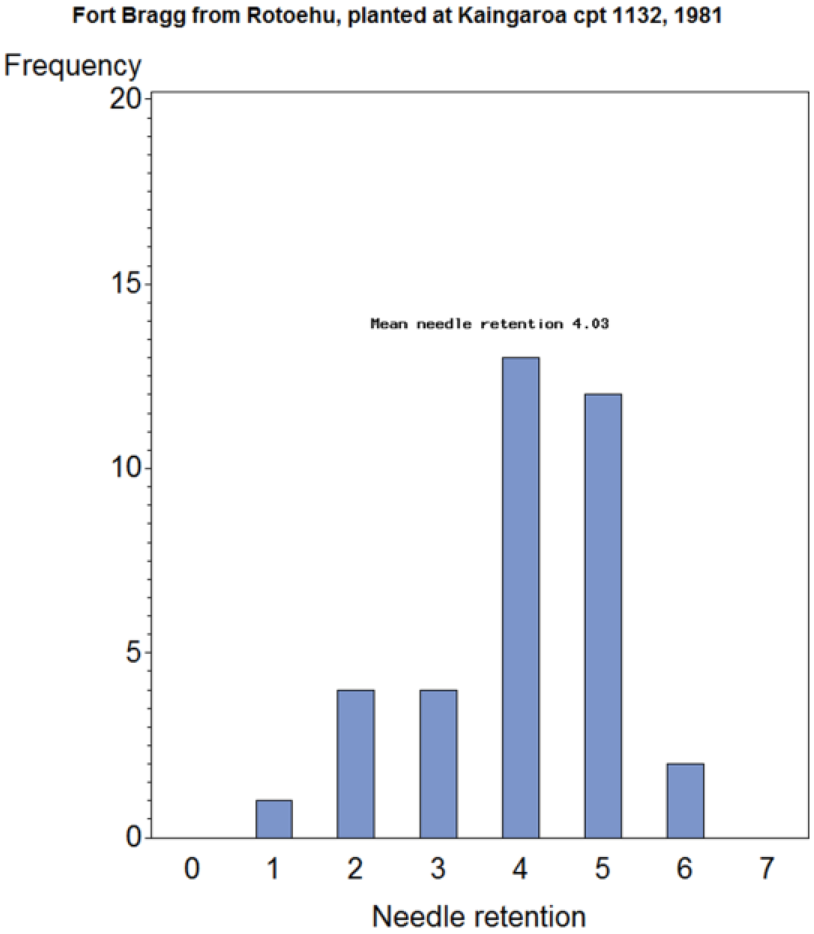
Fort Bragg from different Seed stands


Fort Bragg seed stand planted at Golden Downs, 1961


Fort Bragg seed stand planted at Rotoehu, 1961

First generation, second generation





Conclusions

- Genetics works!
- Exposure to SNC causes natural selection of resistant trees
- Selecting and crossing most resistant trees will speed up the improvement
- Moving average needle retention from 2 to 3 will gain 10% in diameter growth

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