Transforming trees

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

SIRT
Strategic Integrated Research in Timber

Institute for Sustainable Construction

Adding value to the Forest through research

Dan Ridley-Ellis
SIRT Network

Edinburgh Napier UNIVERSITY

SIRT

Since 2003 (SHEFC SRDG)

Institute for Sustainable Construction

	Region
km	Forest
	Stand
	Tree
m	Log
	Sawn timber
cm	Clear wood
mm	Growth layer
	Wood anatomy
	Cell
µm	Cell wall
	Cell wall layers
	Microfibril clusters
nm	Molecular

Forest Research.
Forestry Commission.
Aberdeen University.
Growers.

Edinburgh Napier University.
Processors.

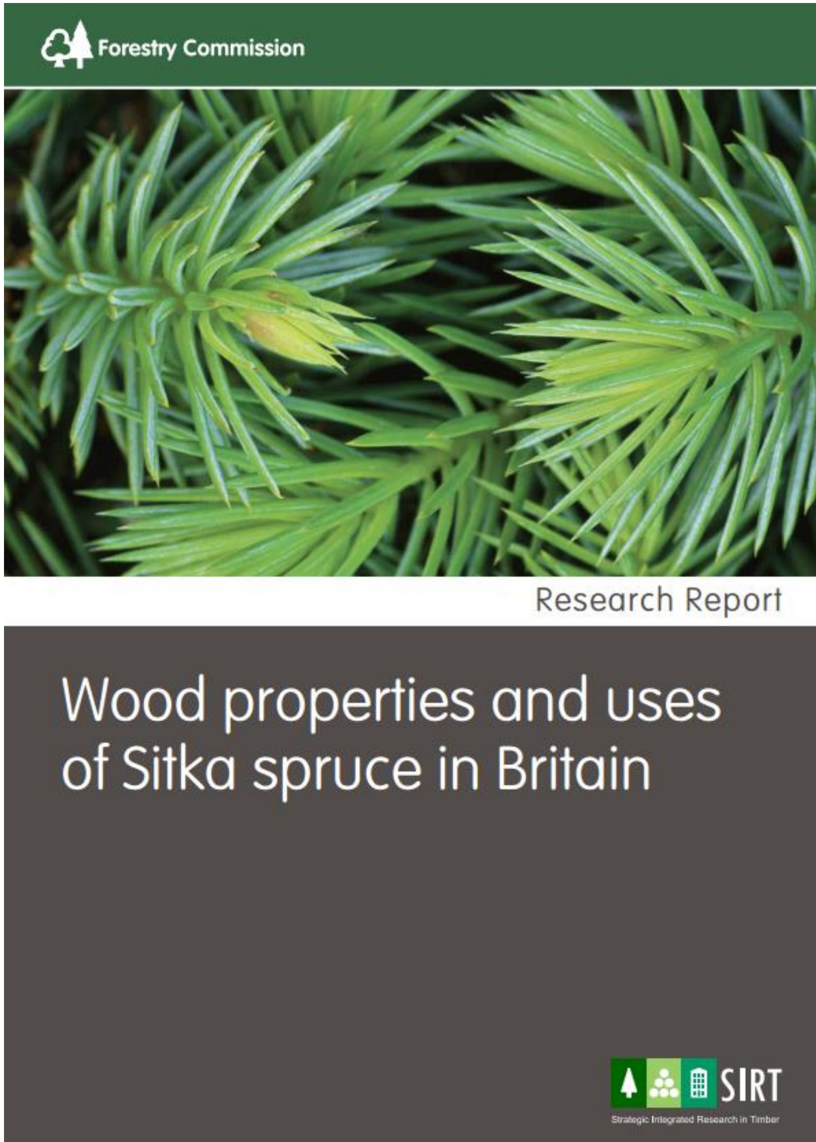
	Building
m	Assembly
	Sawn timber
cm	Details

The University of Glasgow.

Primary focus: UK-grown Sitka spruce

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Edinburgh Napier UNIVERSITY



What we knew about the UK's Sitka spruce resource.

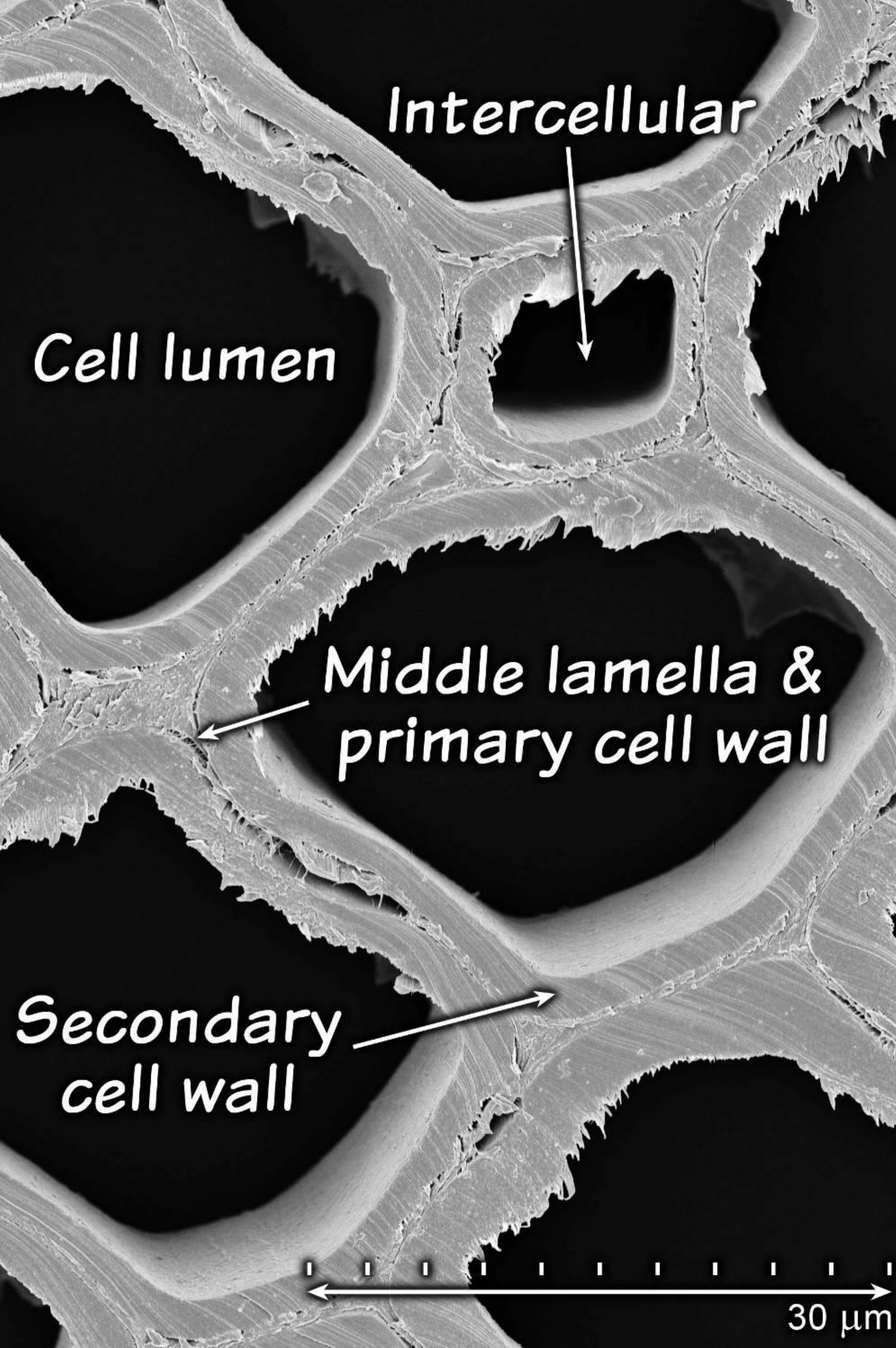
…At the time published in 2011

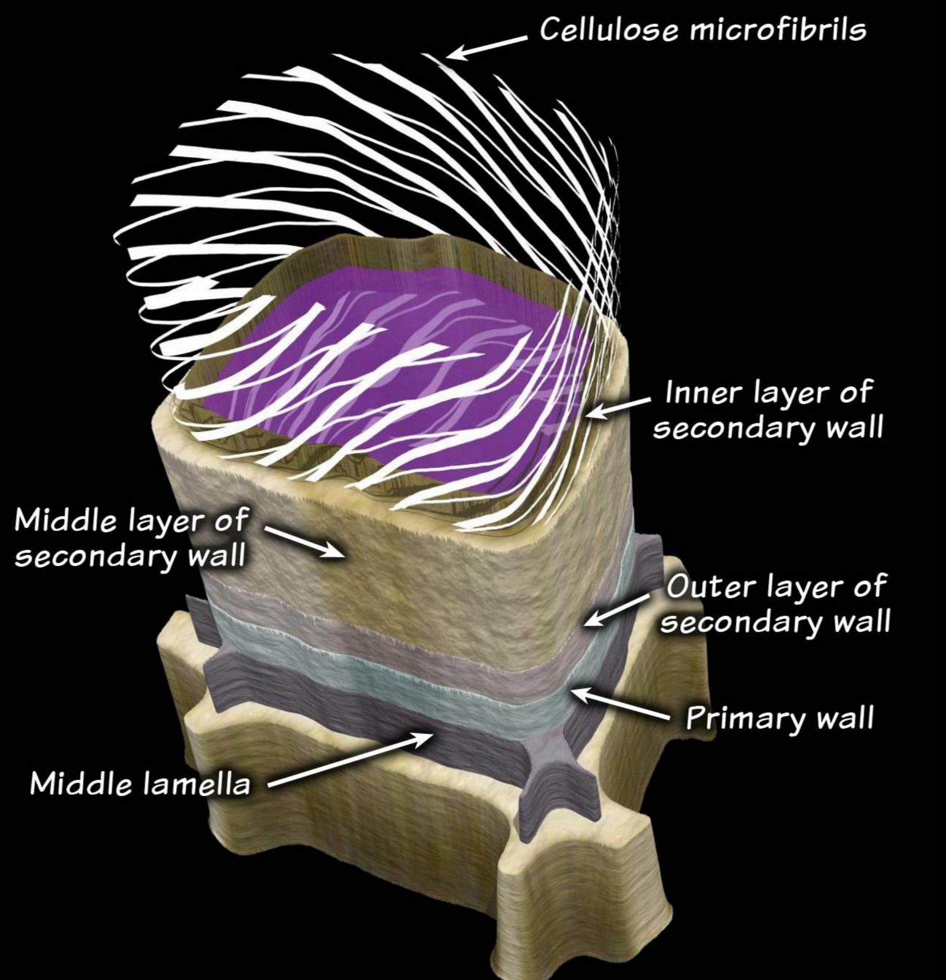
EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

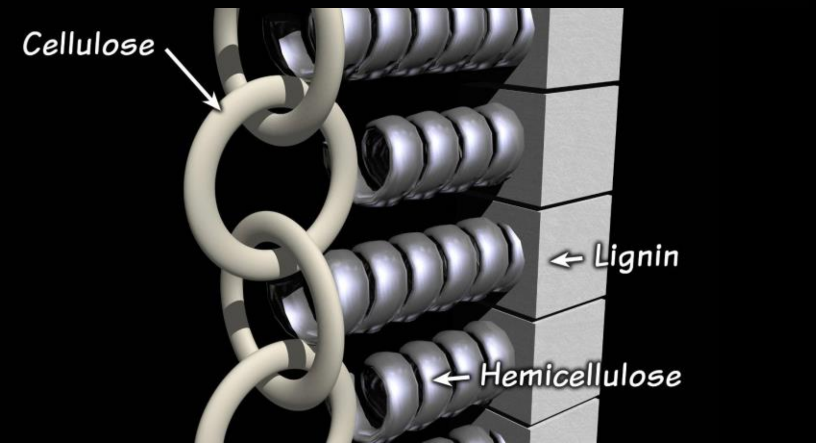
Mechanical properties

- Amount of cell wall material
  - Wood density
- How that cell wall material is arranged
  - Grain, earlywood, latewood
- How that cell wall material is made up
  - Cellulose : lignin
  - Microfibril angle

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

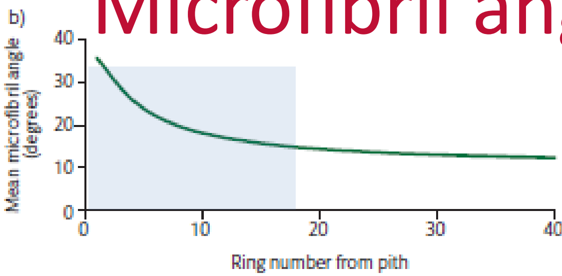

Intercellular
Cell lumen
Middle lamella &
primary cell wall
Secondary
cell wall
30 μm


Cellulose microfibrils
Inner layer of
secondary wall
Middle layer of
secondary wall
Outer layer of
secondary wall
Primary wall
Middle lamella


Cellulose
Lignin
Hemicellulose

Juvenile core

Microfibril angle



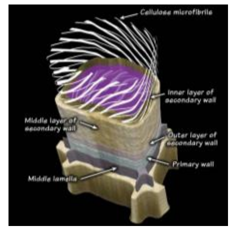
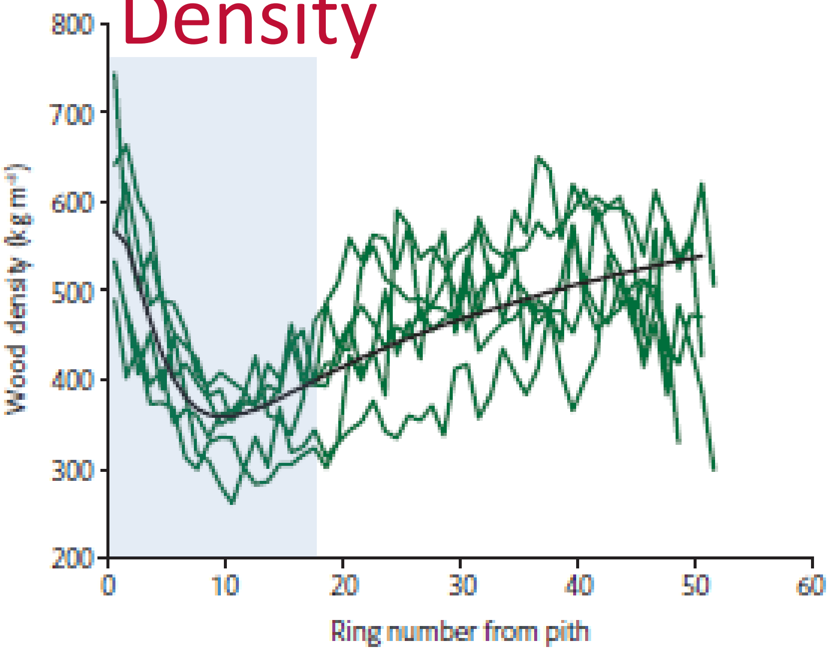


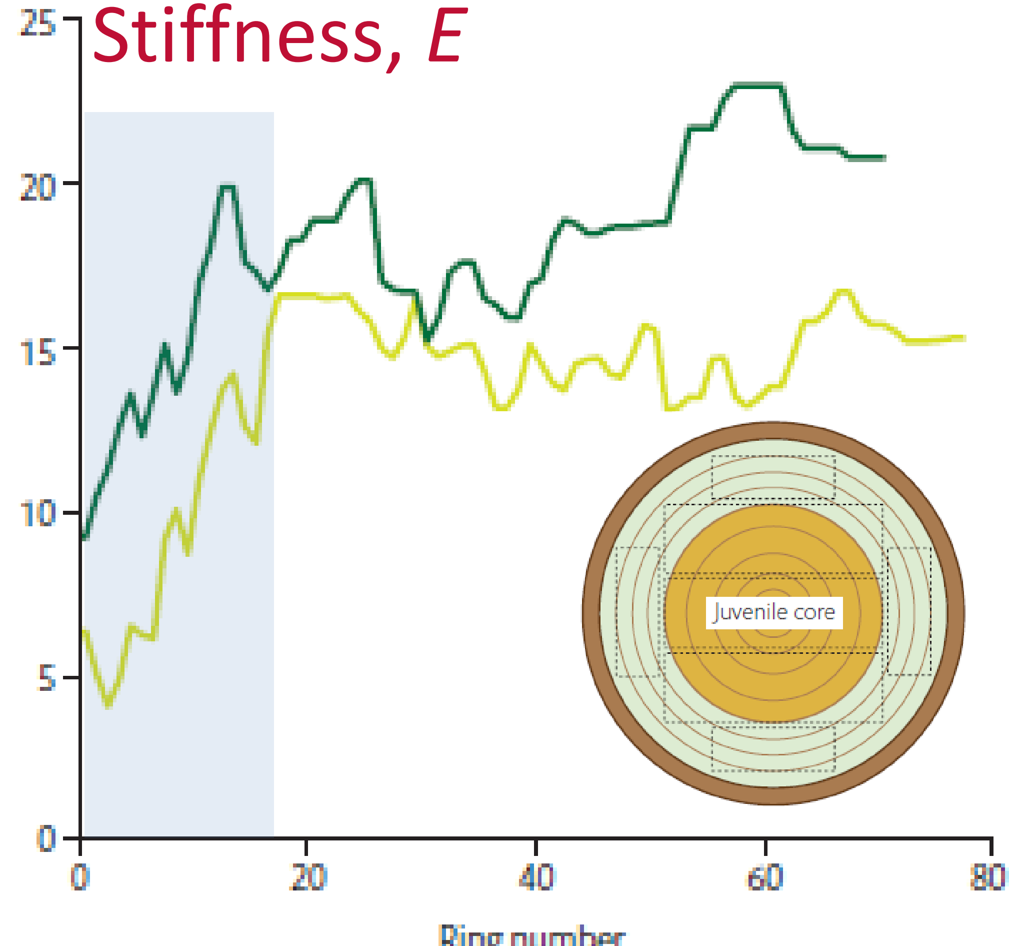
Figure 2.20 Example of the radial variation in modulus of elasticity for two specimens of Sitka spruce wood. Modulus of elasticity was estimated from data on density and microfibril angle obtained from SilviScan-3.

Figure 2.15 Radial profile of Sitka spruce wood density. The green lines show profiles for five individual trees sampled at Baronscourt in Northern Ireland, while the black line represents a model fitted to these data.

Density

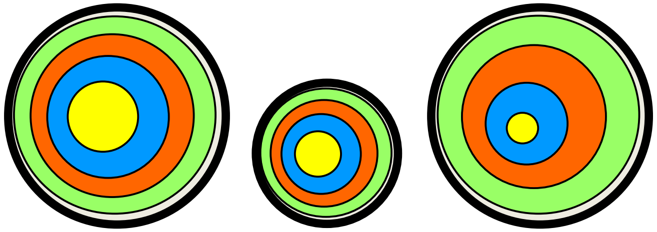


Stiffness, E



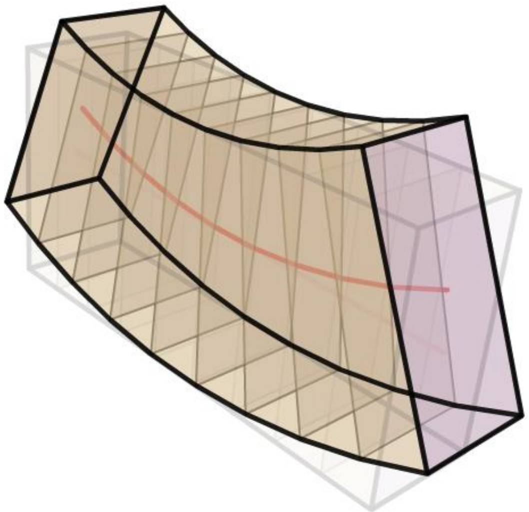
Factors affecting softwood quality

- Position within the tree
  - Radially & vertically
- Silviculture
  - Spacing, thinning, rotation length etc
- Site
  - Exposure, temperature, rainfall, soil type etc
- Genetics
  - Species, variety and individual



EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Grade-determining properties



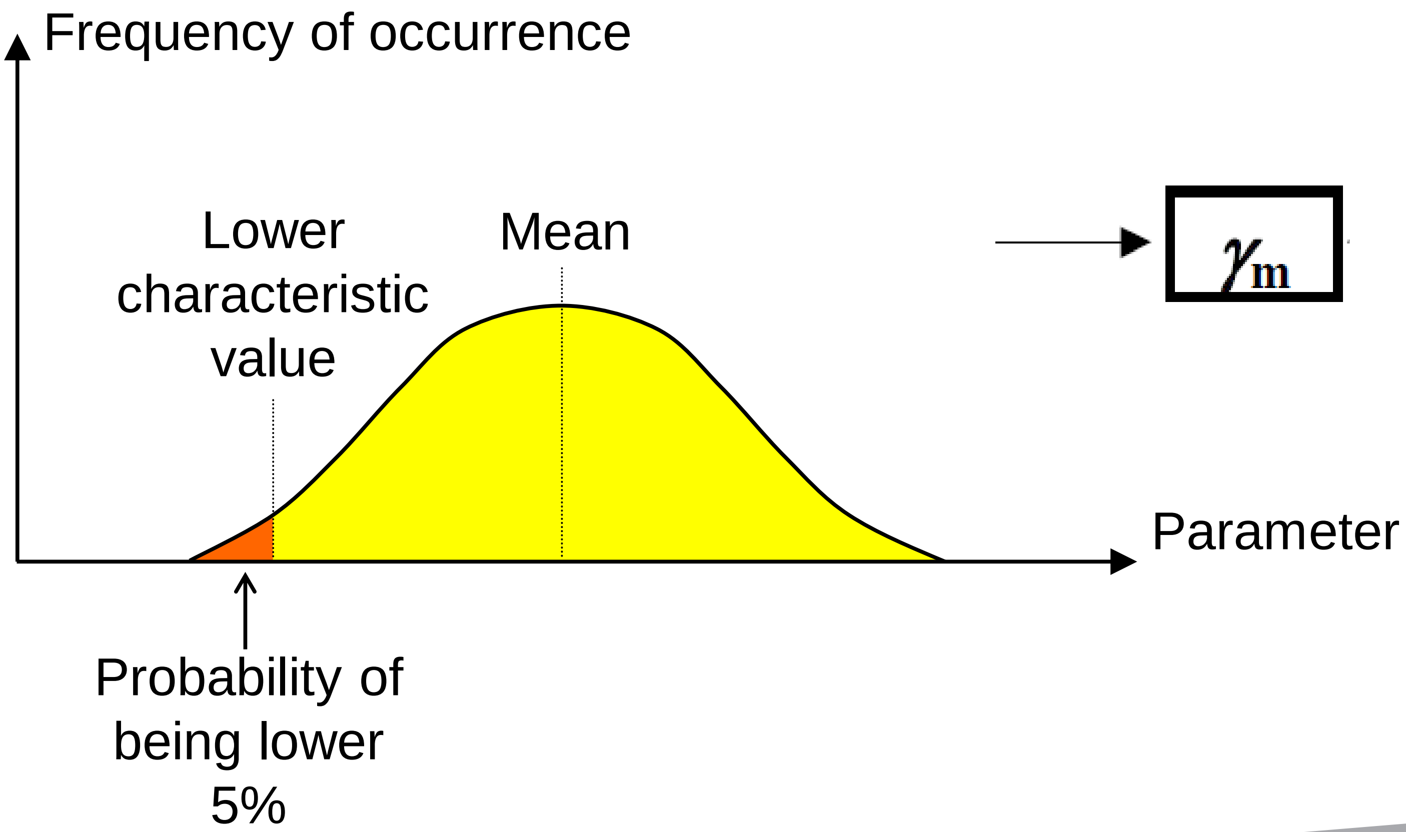
- Strength at 12% MC
  - Major axis bending strength
- Stiffness at 12% MC
  - Major axis bending stiffness
- Density at 12% MC
  - Also an indirect measure of strength in some elements of timber design
- (All other properties are derived from these 3 properties)

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

EN 338

		Softwood species											
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
Strength properties (in N/mm²)													
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30
Tension perpendicular	$f_{t,90,k}$	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2
Shear	$f_{v,k}$	3,0	3,2	3,4	3,6	3,8	4,0	4,0	4,0	4,0	4,0	4,0	4,0
Stiffness properties (in kN/mm²)													
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16
5 % modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7
Mean modulus of elasticity perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00
Density (in kg/m³)													
Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440	460
Mean density	ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520	550

Characteristic values



Critical property

- Grades are defined by characteristic
  - Strength (lower 5^{th} percentile)
  - Stiffness (mean)
  - Density (lower 5^{th} percentile)
- The limits are general across species
  - Softwoods (C classes...major axis bending)
  - Hardwoods (D classes...major axis bending)
  - Density (lower 5^{th} percentile)

Critical property

- To comply with the grade, characteristic values must be met (at least)
- For a species and grade combination usually one property is limiting
  - Strength
  - Stiffness
  - Density
- So strength grading isn't *always* about predicting strength

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Critical property for UK spruce

British spruce: Sitka spruce and Norway spruce combined from UK and Ireland

SIRT benchmarking validation, 957 pieces

British spruce			C14	**C16**	C18	C20	C22
Strength	20.9	N/mm^2	14	16	18	20	22
Stiffness	8.2	kN/mm^2	7	8	9	9.5	10
Density	338	kg/m^3	290	310	320	330	340

It isn’t density that is limiting

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Actually…more correctly

SIRT benchmarking validation, 957 pieces

British spruce			C14	**C16**	C18	C20	C22
Strength	20.9	N/mm^2	12.50	14.29	16.07	17.86	19.64
Stiffness	8.2	kN/mm^2	6.65	7.60	8.55	9.03	9.50
Density	338	kg/m^3	290	310	320	330	340

For machine grading (EN14081 & EN384):

The mean stiffness requirement is reduced to 95% of the figure in EN338

The 5th %ile strength requirement is reduced by a factor of 1.12 for grades less than C30 (k_v)

Approximate yields

(with a perfect grading machine)

The other 74% is C16

(Single grade / reject)

C14	C16	C18	C20	C22	C24
100%	100%	90%	73%	55%	26%

For higher grades, density becomes critical. Yield of C27 ~ 9%

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Other species

SIRT benchmarking validation, 957 pieces

British spruce		C14	**C16**	C18	C20	C22	C24	C27	C30	C35	C40
Strength	20.9 N/mm^2	14	16	18	20	22	24	27	30	35	40
Stiffness	8.2 kN/mm^2	7	8	9	9.5	10	11	11.5	12	13	14
Density	338 kg/m^3	290	310	320	330	340	350	370	380	400	420

James Ramsay PhD, 166 pieces

Scottish larch		C14	C16	**C18**	C20	C22	C24	C27	C30	C35	C40
Strength	23.8 N/mm^2	14	16	18	20	22	24	27	30	35	40
Stiffness	9.4 kN/mm^2	7	8	9	9.5	10	11	11.5	12	13	14
Density	407 kg/m^3	290	310	320	330	340	350	370	380	400	420

Tom Drewett PhD, 188 pieces

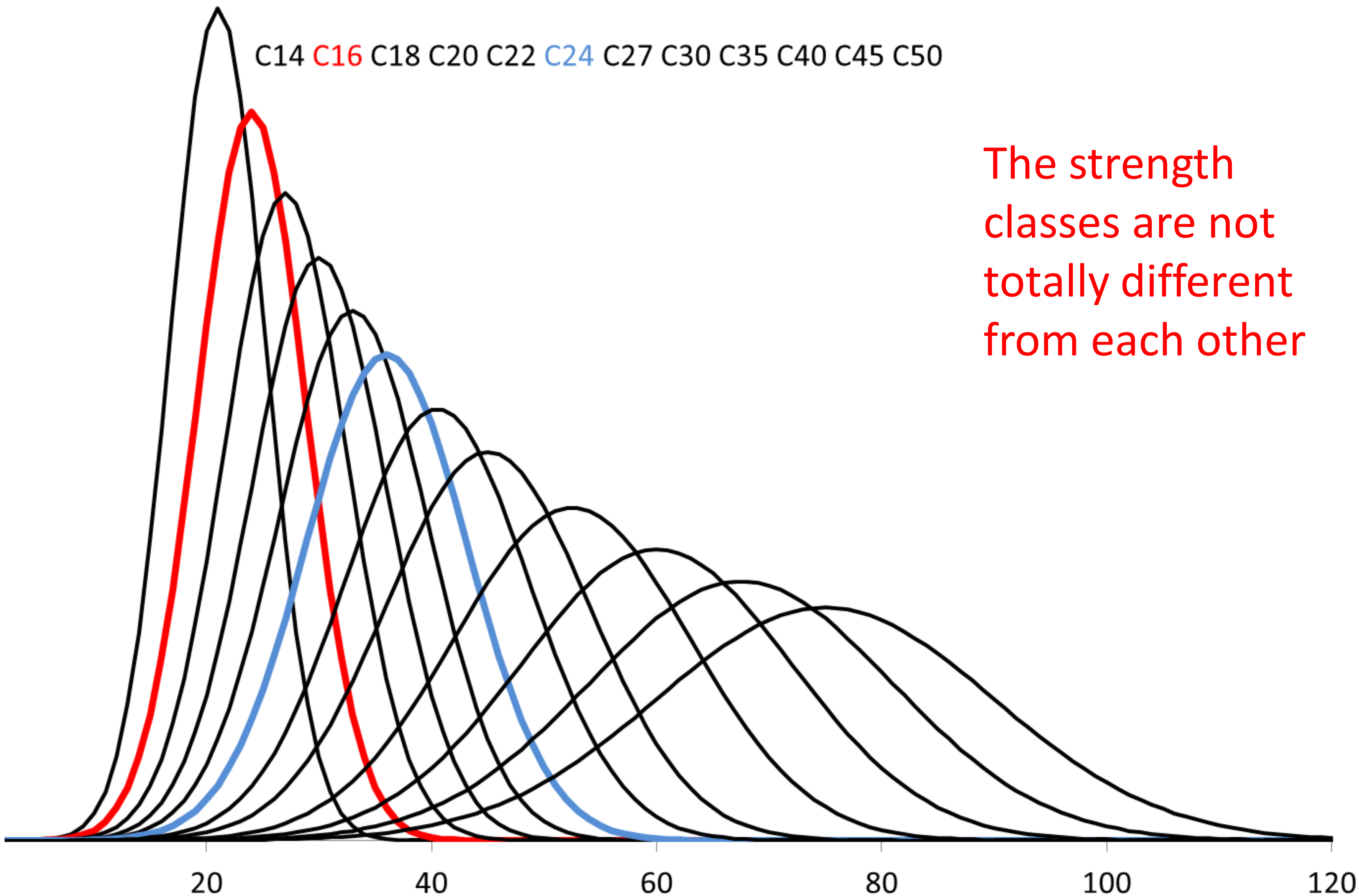
Scottish&Welsh Douglas-fir		C14	C16	**C18**	C20	C22	C24	C27	C30	C35	C40
Strength	18.8 N/mm^2	14	16	18	20	22	24	27	30	35	40
Stiffness	9.2 kN/mm^2	7	8	9	9.5	10	11	11.5	12	13	14
Density	398 kg/m^3	290	310	320	330	340	350	370	380	400	420

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

SIRT

Institute for Sustainable Construction

Bending strength

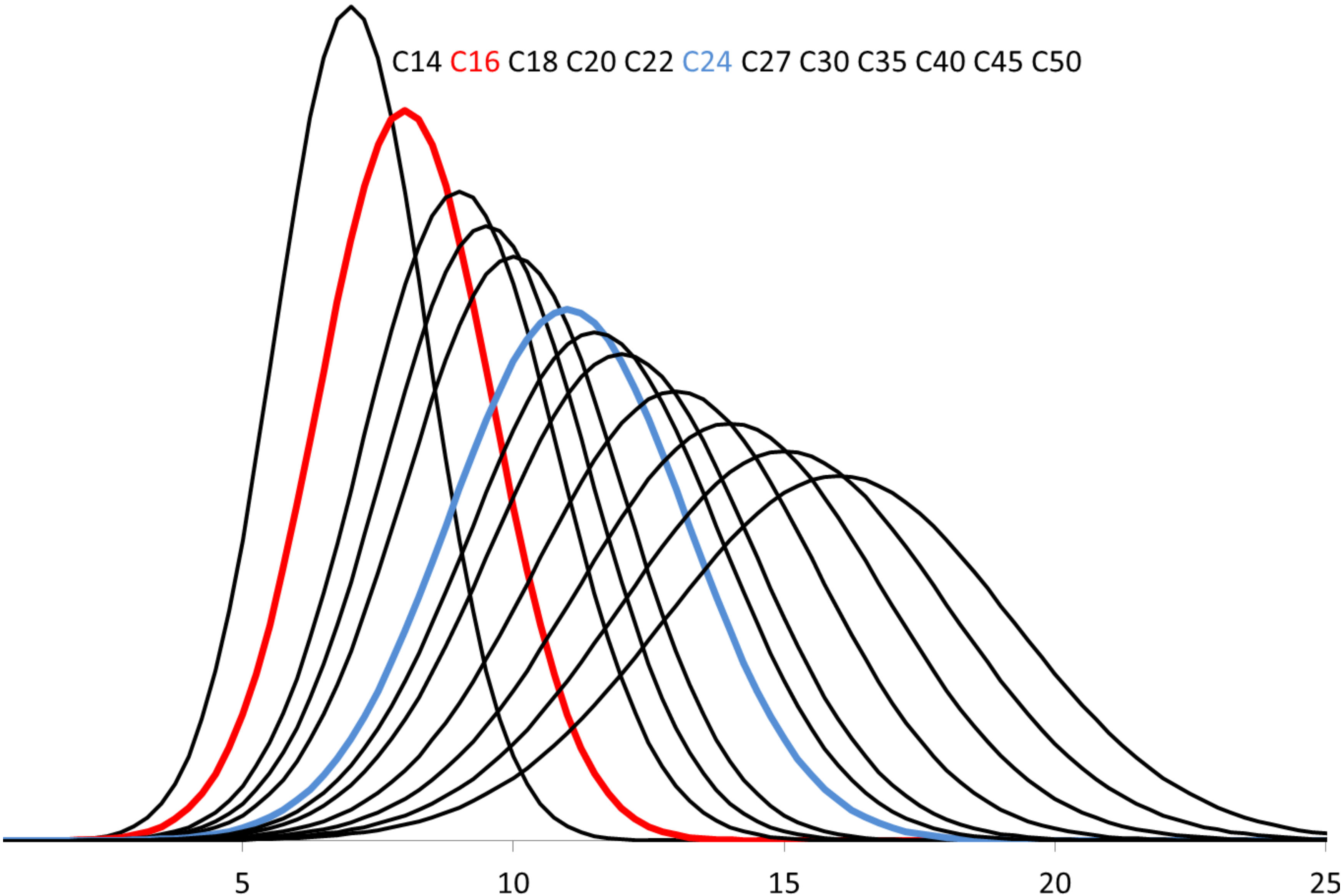


The strength classes are not totally different from each other

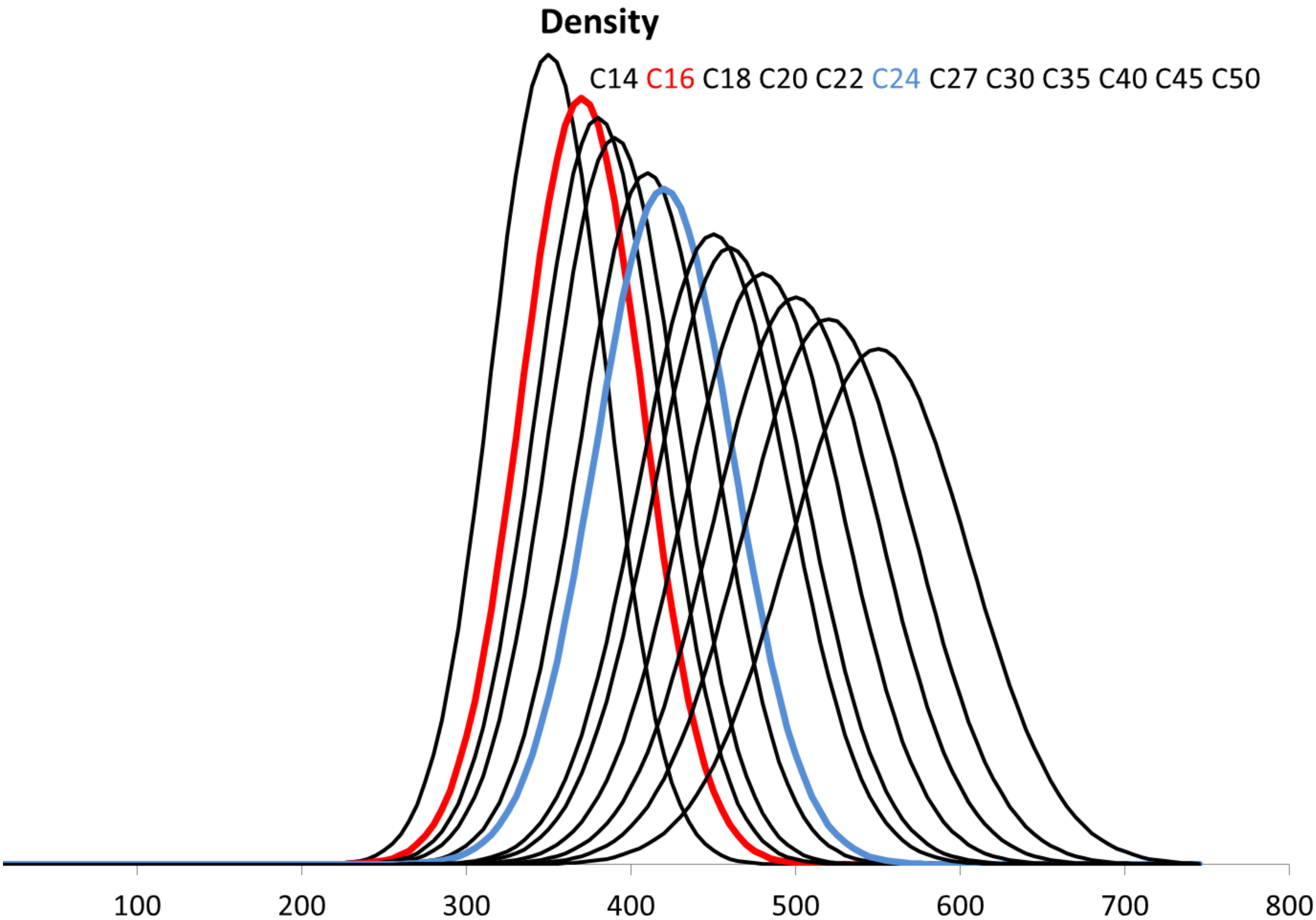
SIRT

Institute for Sustainable Construction

Bending stiffness



Institute for Sustainable Construction



SIRT

Institute for Sustainable Construction

Sources of the variation

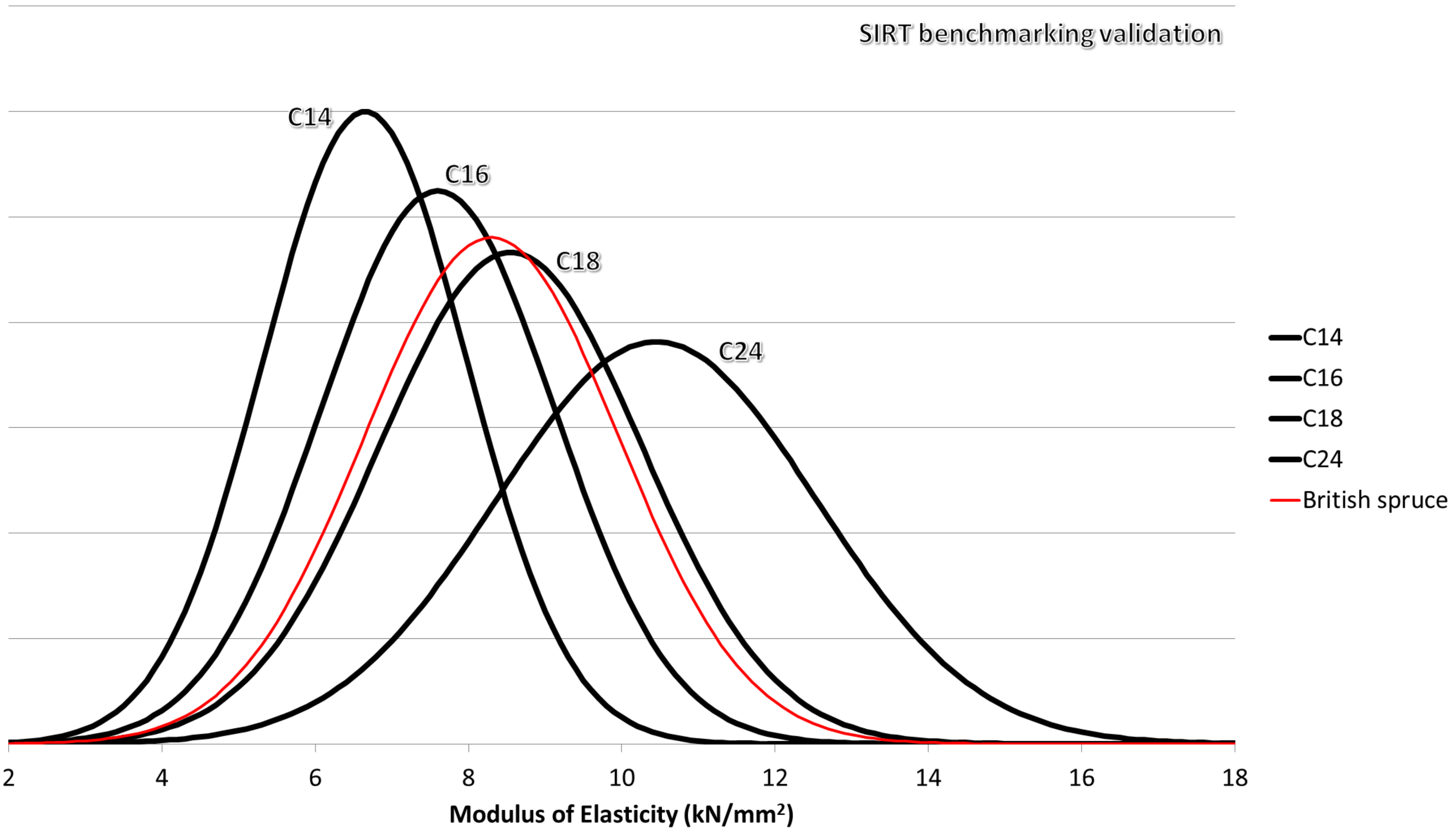
Source	Density	Strength	Stiffness
Between sites	23%	18%	26%
Between trees on a site	51%	25%	36%
Between logs in a tree	2%	5%	2%
Within log	25%	52%	35%

Moore, J. R., Lyon, A. J., Searles, G. J., Lehneke, S. A., Ridley-Ellis, D. J. Within- and between-stand variation in selected properties of Sitka spruce sawn timber in the United Kingdom: implications for segregation and grade recovery. Annals of Forest Science (February 2013)

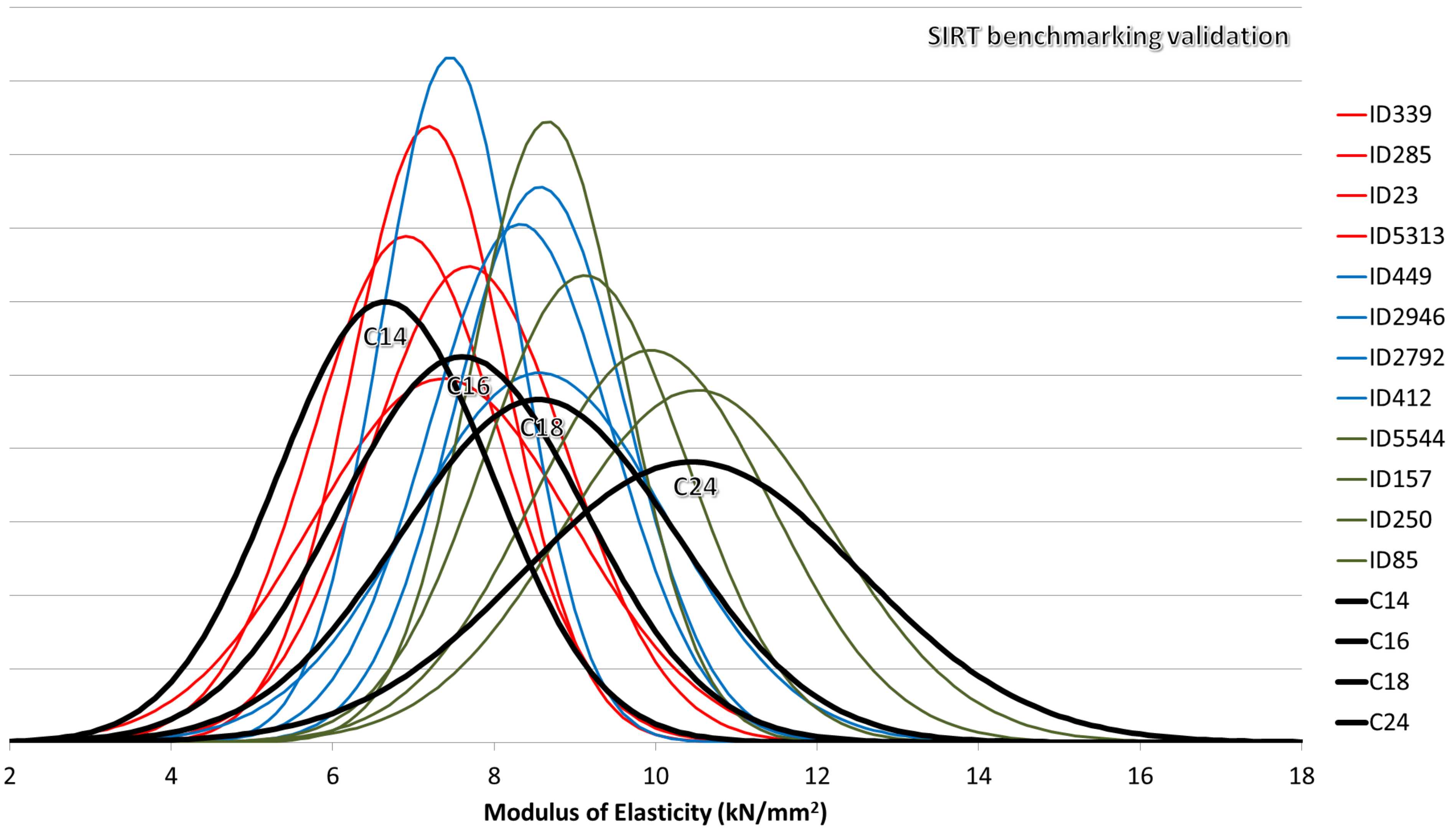
EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Edinburgh Napier UNIVERSITY

Variation in the resource



Variation in the resource



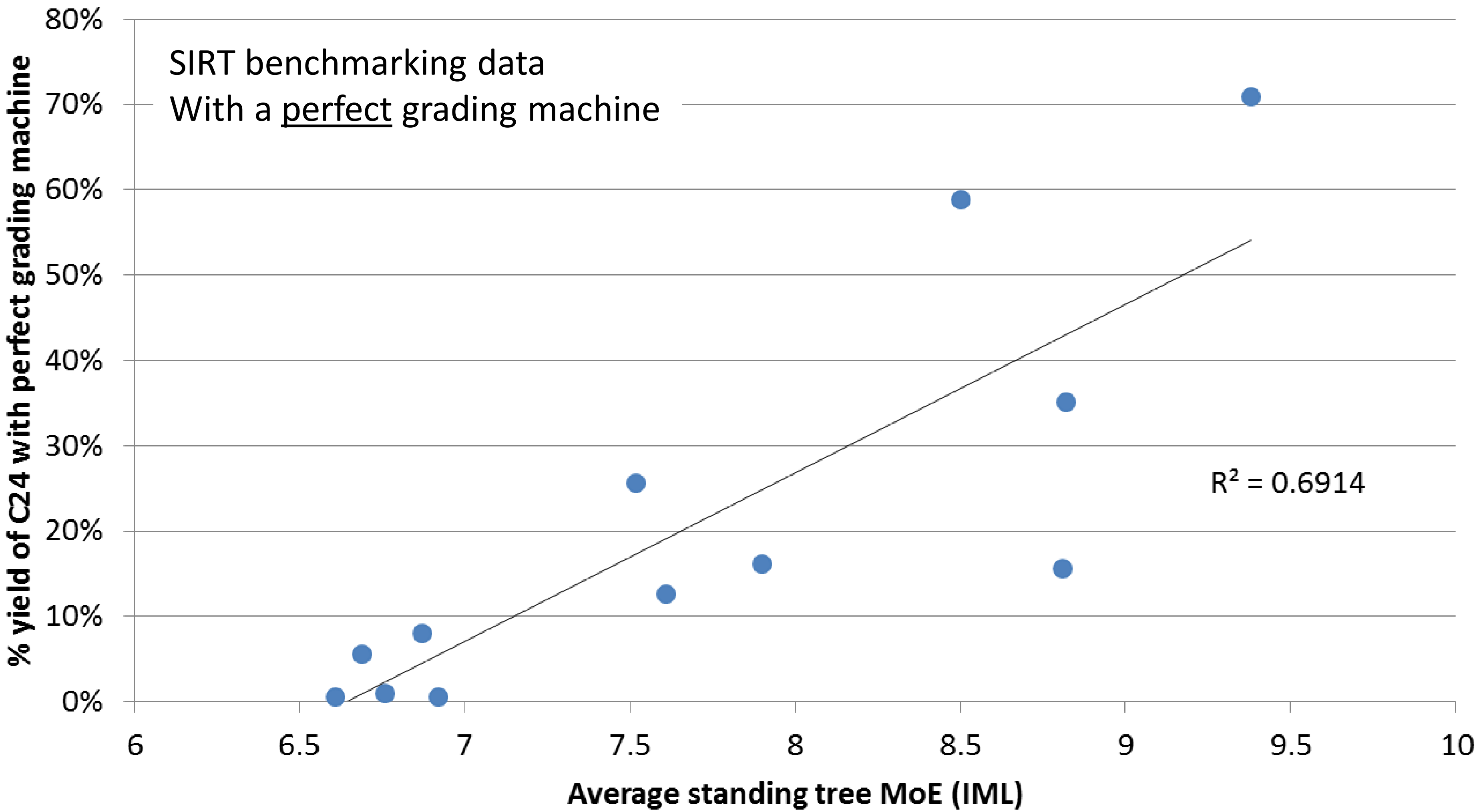
Grading simulation

Using a <u>perfect</u> grading machine
C16/C24/R threshold based on overall population

	Site		C16	C24	Reject	Graded timber % of required MoE	
						C16	C24
<7	**339**	**C14**	98%	1%	1%	91%	93%
<7	**285**	**C16**	94%	6%	0%	99%	96%
<7	**23**	**C14**	90%	8%	2%	94%	98%
<7	**5313**	**C14**	99%	1%	0%	94%	92%
7-9	**449**	**C14**	99%	1%	0%	98%	92%
7-9	**2946**	**C18**	84%	16%	0%	109%	97%
7-9	**2792**	**C18**	74%	26%	0%	104%	101%
7-9	**412**	**C16**	87%	13%	0%	106%	97%
>9	**5544**	**C18**	84%	16%	0%	111%	96%
>9	**157**	**C20**	65%	35%	0%	111%	100%
>9	**250**	**C22**	41%	59%	0%	112%	104%
>9	**85**	**C24**	29%	71%	0%	113%	108%

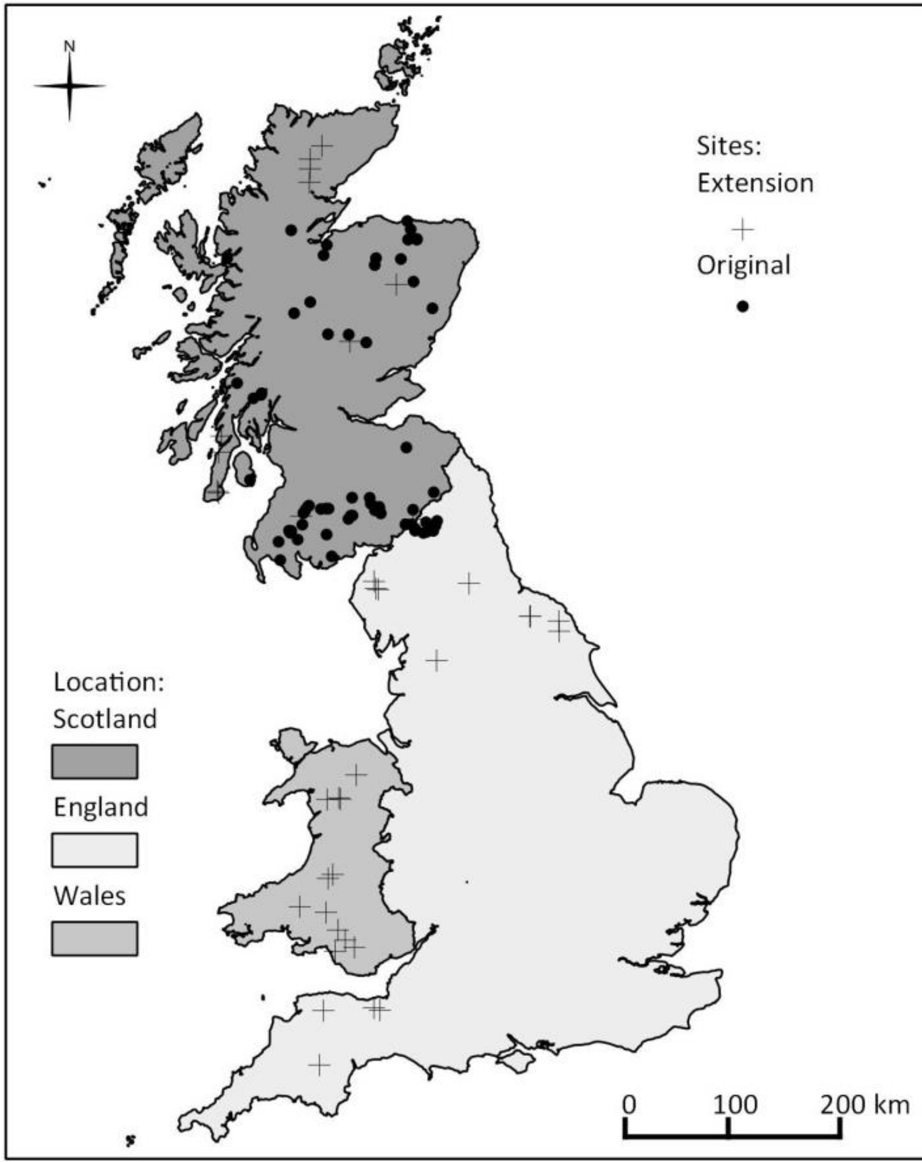
EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Tree MoE and C24 yield

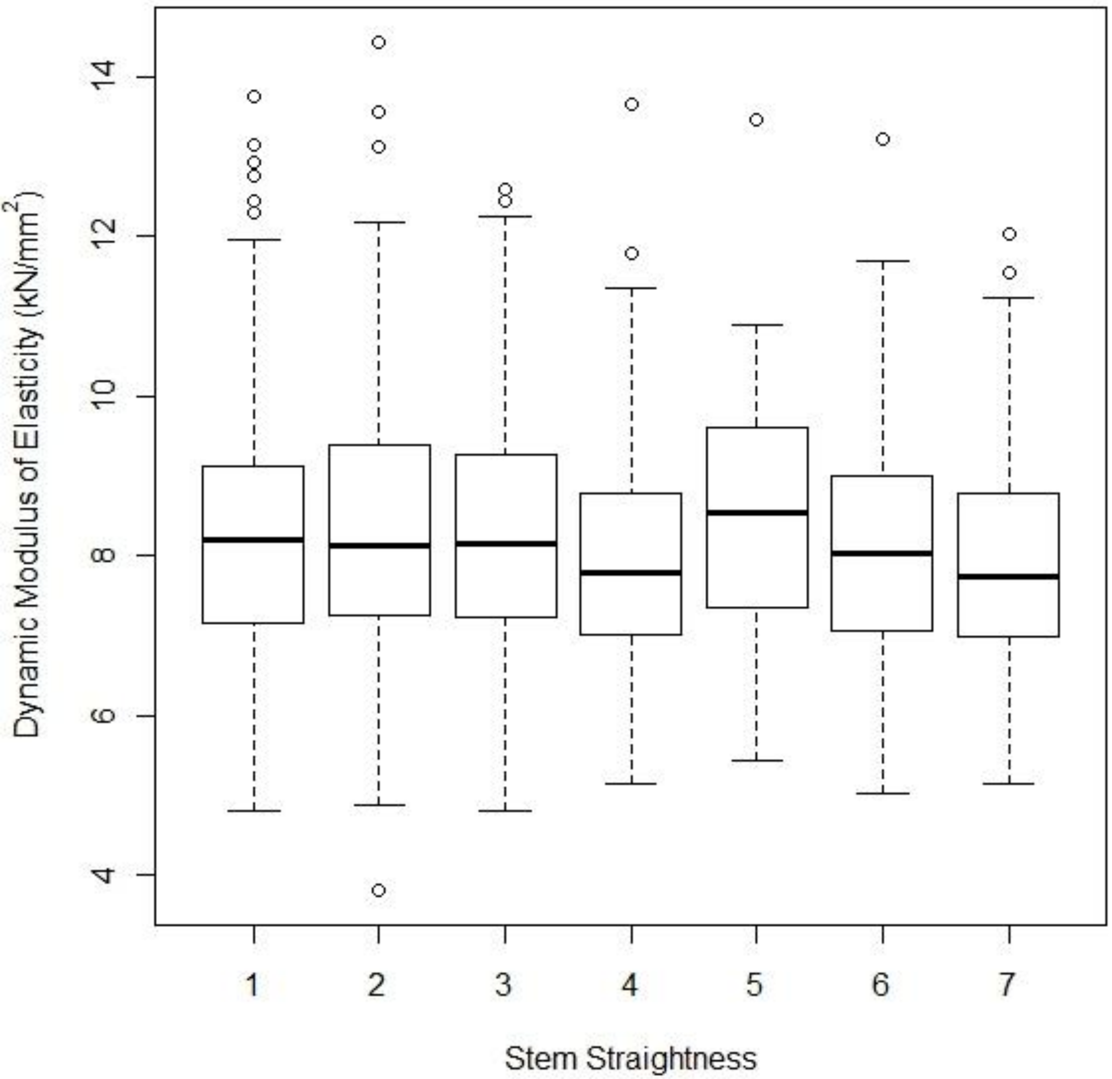


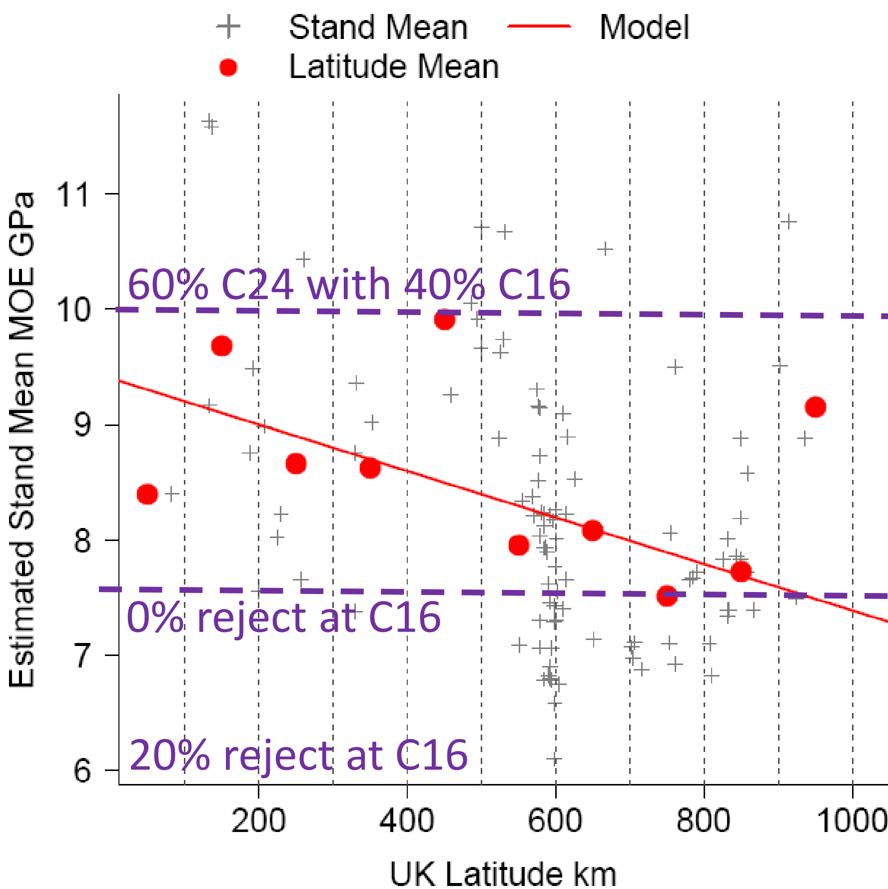
Benchmarking extension

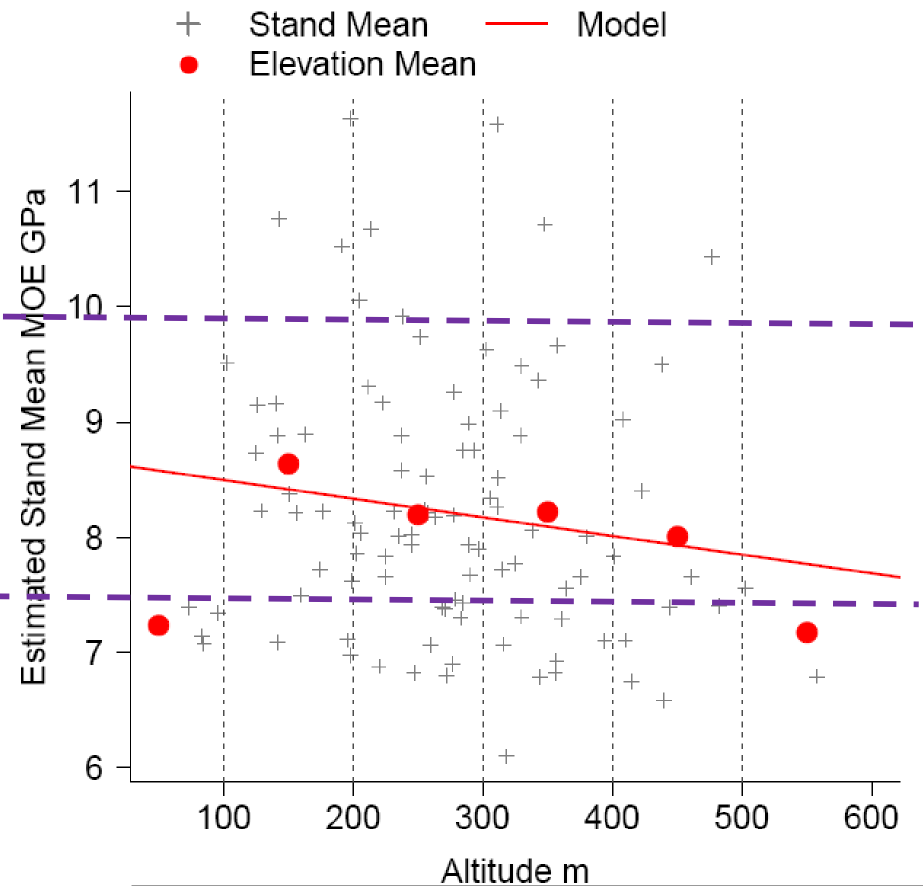
- 64 original sites
- 37 new sites
- Adding latitude

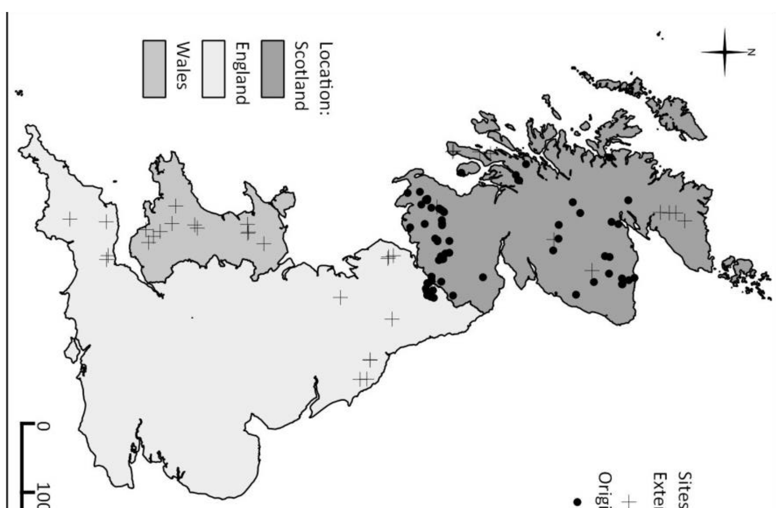


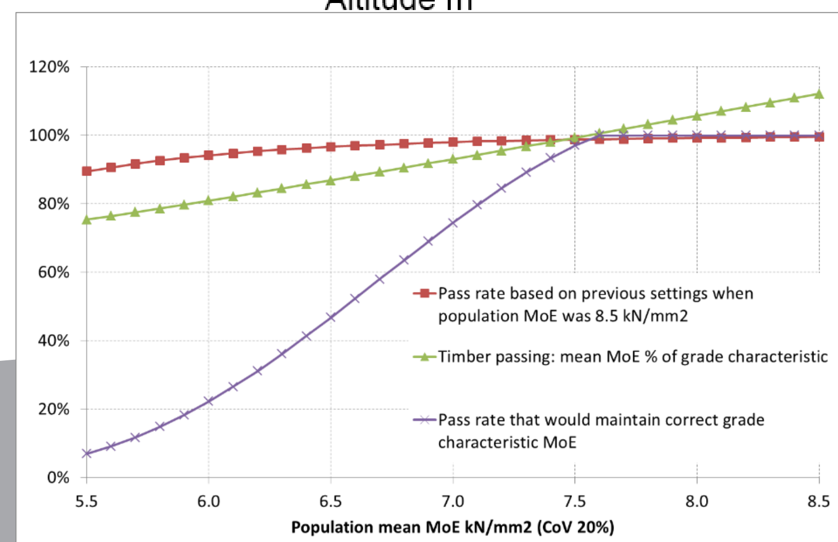
Stem straightness




Stand Mean
Model
Latitude Mean
60% C24 with 40% C16
0% reject at C16
20% reject at C16
Estimated Stand Mean MOE GPa
UK Latitude km
6
7
8
9
10
11
200
400
600
800
1000


Stand Mean
Model
Elevation Mean
Estimated Stand Mean MOE GPa
Altitude m
6
7
8
9
10
11
100
200
300
400
500
600


Location:
Scotland
England
Wales


Pass rate based on previous settings when population MoE was 8.5 kN/mm2
Timber passing: mean MoE % of grade characteristic
Pass rate that would maintain correct grade characteristic MoE
Population mean MoE kN/mm2 (CoV 20%)
0%
20%
40%
60%
80%
100%
120%
5.5
6.0
6.5
7.0
7.5
8.0
8.5

Variation (PROVISIONAL DATA)

- -0.13 kN/mm^2 for each 100 km north
- -0.28 kN/mm^2 for each 100 m elevation
- +0.72 kN/mm^2 for every 10 years age
- Although there is a *lot* of scatter

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

What else can this research tell us?

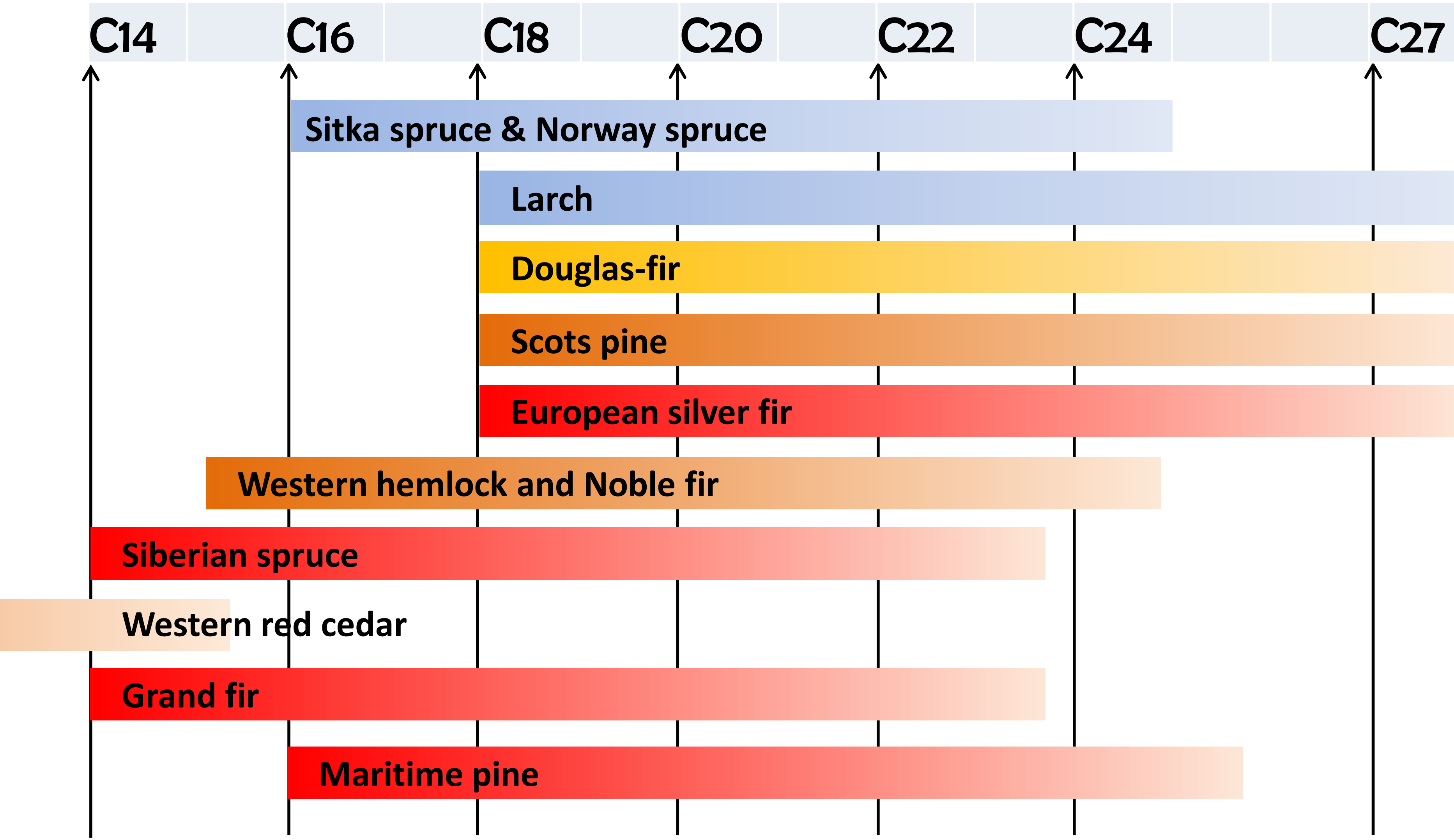
- If we know approximate relationships
  - Small clear properties to structural size
  - Log and tree measurements to structural size
- We can make estimates from limited data

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

SIRT

Institute for Sustainable Construction

UK-grown timber



Distortion

- Ongoing …but no silver bullet (sadly)
- Measurement and description of distortion
- Compare models from literature
  - Spiral grain, ring slant, radial position, shrinkage, compression wood
- Determine true causes of distortion
- Prevention/avoidance …perhaps
- At least characterise


PULL to OPEN

Marie Johansson, Robert Kliger,
Sigurdur Ormarsson, Magnus Bäckströ
Chalmers University of Technology

Grading machine settings

- For TG1 meeting in 9-10 October 2014
- British spruce down to 20 mm thickness
  - Brookhuis MTG 920, 960, and MTG batch
    - Green and dry
  - MiCROTEC
    - GOLDENEYE 702 and 706
    - ViSCAN basic, plus, and compact
    - ViSCAN portable
- Also larch (separate project)

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future


Marshalls
01259 723548

Transforming trees

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

SIRT
Strategic Integrated Research in Timber

Institute for Sustainable Construction

Research into practice

Dan Ridley-Ellis

Edinburgh Napier UNIVERSITY

The core standards

EN 14081, Timber structures - Strength graded structural timber with rectangular cross section
Part 1: General requirements
Part 2: Machine grading, additional requirements for initial type testing
Part 3: Machine grading; additional requirements for factory production control
~~Part 4: Machine grading; grading machine settings for machine controlled systems~~

BS 4978, Visual strength grading of softwood. Specification
BS 5756, Visual strength grading of hardwood. Specification

EN 336, Structural timber - Sizes, permitted deviations
EN 338, Structural timber - Strength classes
EN 1912, Structural timber - Strength classes - Assignment of visual grades and species

EN 408, Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties
EN 384, Structural timber - Determination of characteristic values of mechanical properties and density
EN 14358, Timber structures - Calculation of characteristic 5-percentile values and acceptance criteria for a sample

The maintenance of standards

- The European Commission
- CEN TC124 “Timber Structures”
  - WG1 “Test Methods”
  - WG2 “Solid Timber”
    - TG1 “Grading”
      - Approves machine settings, and assignments in EN 1912
- BSI B/518 “Structural Timber”
- UKTGC “UK Timber Grading Committee”
- “Industry” and “Notified Bodies (SG18)

SIRT

Institute for Sustainable Construction

Process (simplified)

CEN committees draft or amend standard

↓

"Enquiry" Goes to National Standards Bodies for publication as draft for **public comment**

↓

Comments within countries are collated by National Standards Bodies.
A UK position is formulated by BSI B/518 and UKTGC

↓

Comments from all countries are reviewed by the CEN committee , debated and the standard changed (perhaps)

↓

Standard is sent to National Standards Bodies for Formal Vote

↓

Passed – Standard published
Failed – Standard goes back to CEN committee for more work / is dropped

Things that can go wrong

- Negative impact on yields (without reason)
- Expensive or impractical FPC requirements (without reason)
- Complicated or ambiguous standards – loss of confidence in structural timber
- Unsafe on unreliable standards – loss of confidence in structural timber

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Immediate issues

- EN 14081-1 (? pages of comments)
  - CE marking, DoP and FPC requirements
  - Notably moisture content & preservative treatment
- EN 338 (13 pages of comments)
  - Addition of CT (tension grades)
- EN 384 (21 pages of comments)
  - Global to shear free equation
  - Removal of kv
- EN 14358 (8 pages of comments)
  - Potential for lower yield from new settings

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Some related concerns

- Testing to EN 408 and EN 384
  - How MoE is measured
  - Location of the critical section
  - Conversion of global to shear free MoE

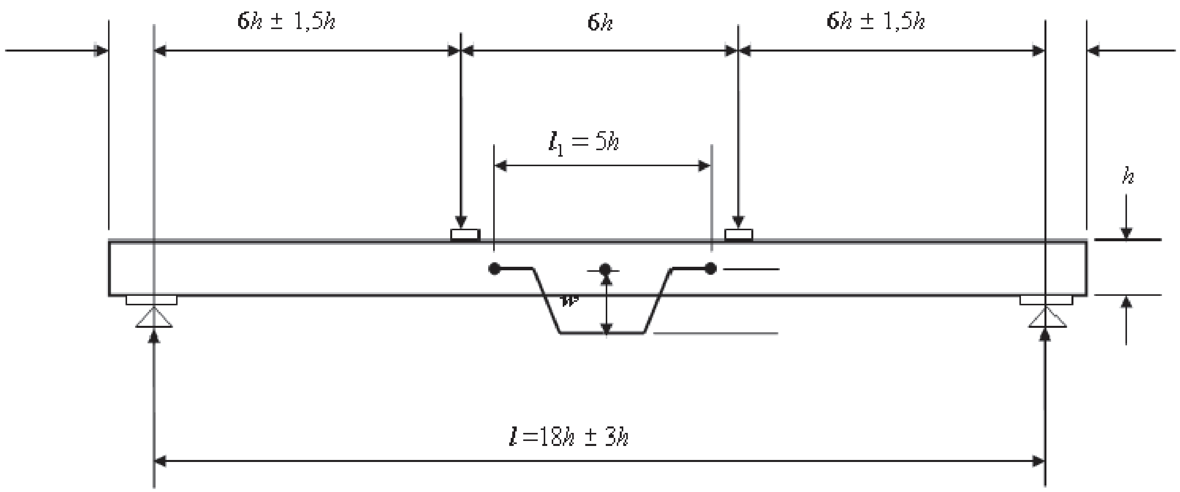
EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

SIRT

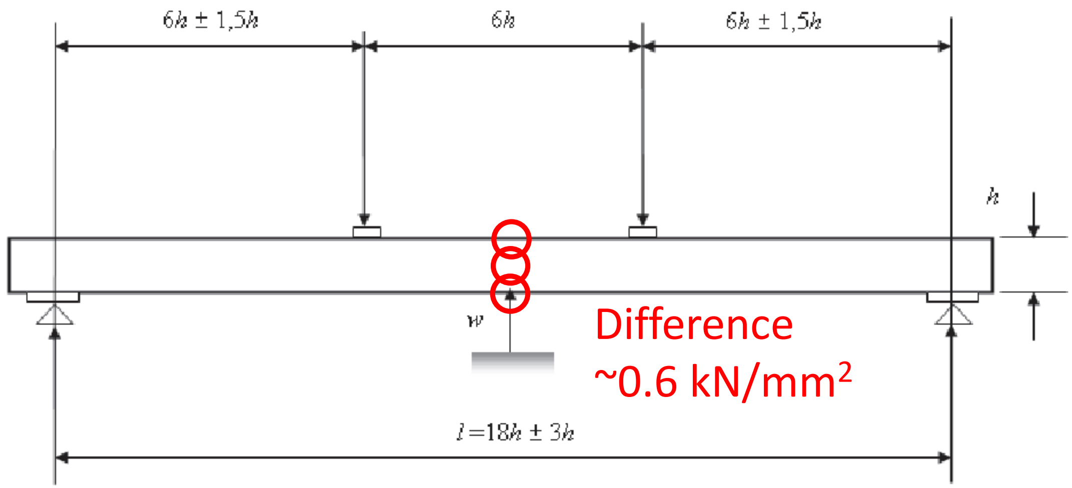
Institute for Sustainable Construction

Measurement of MoE

Local MoE



Global MoE

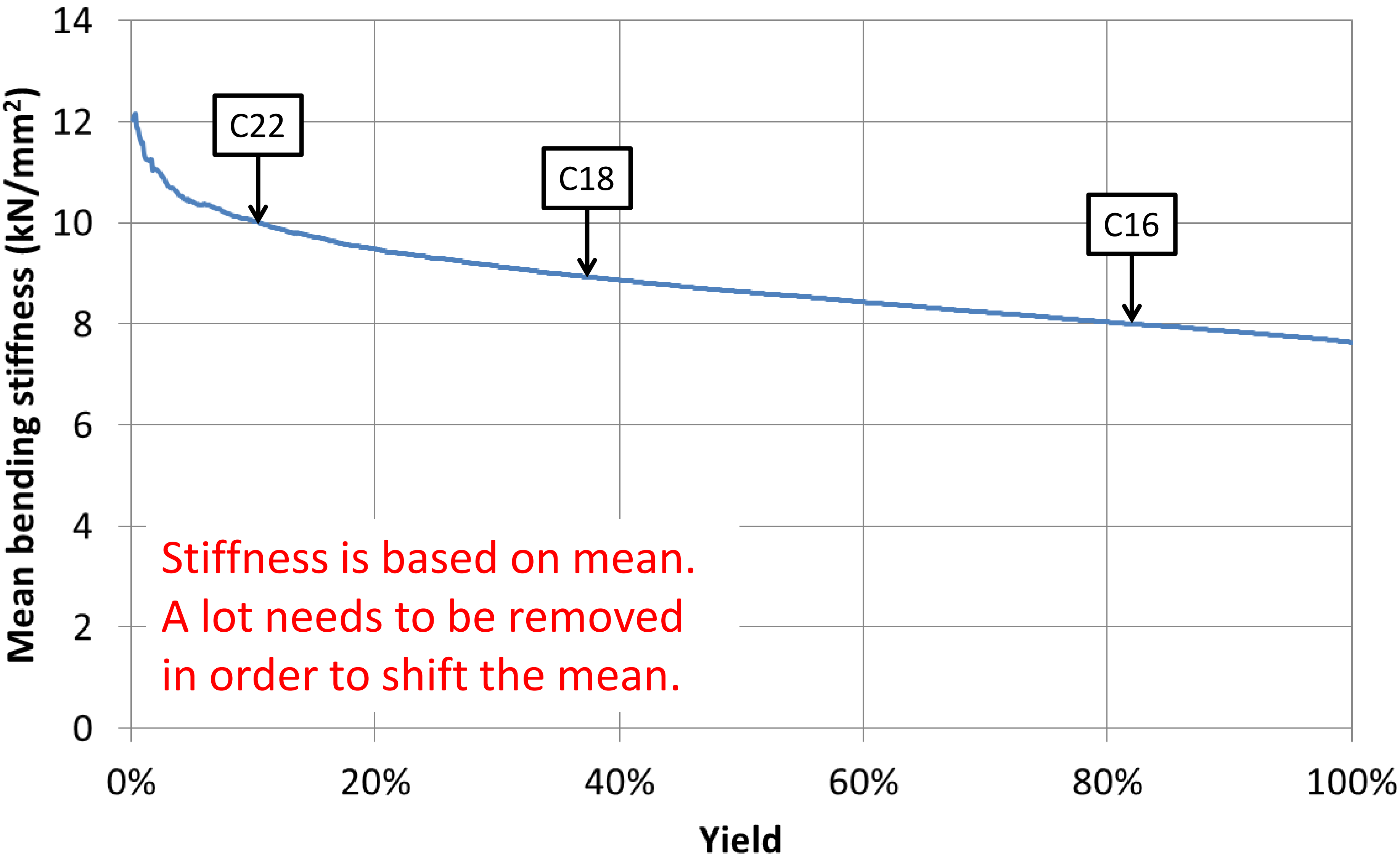


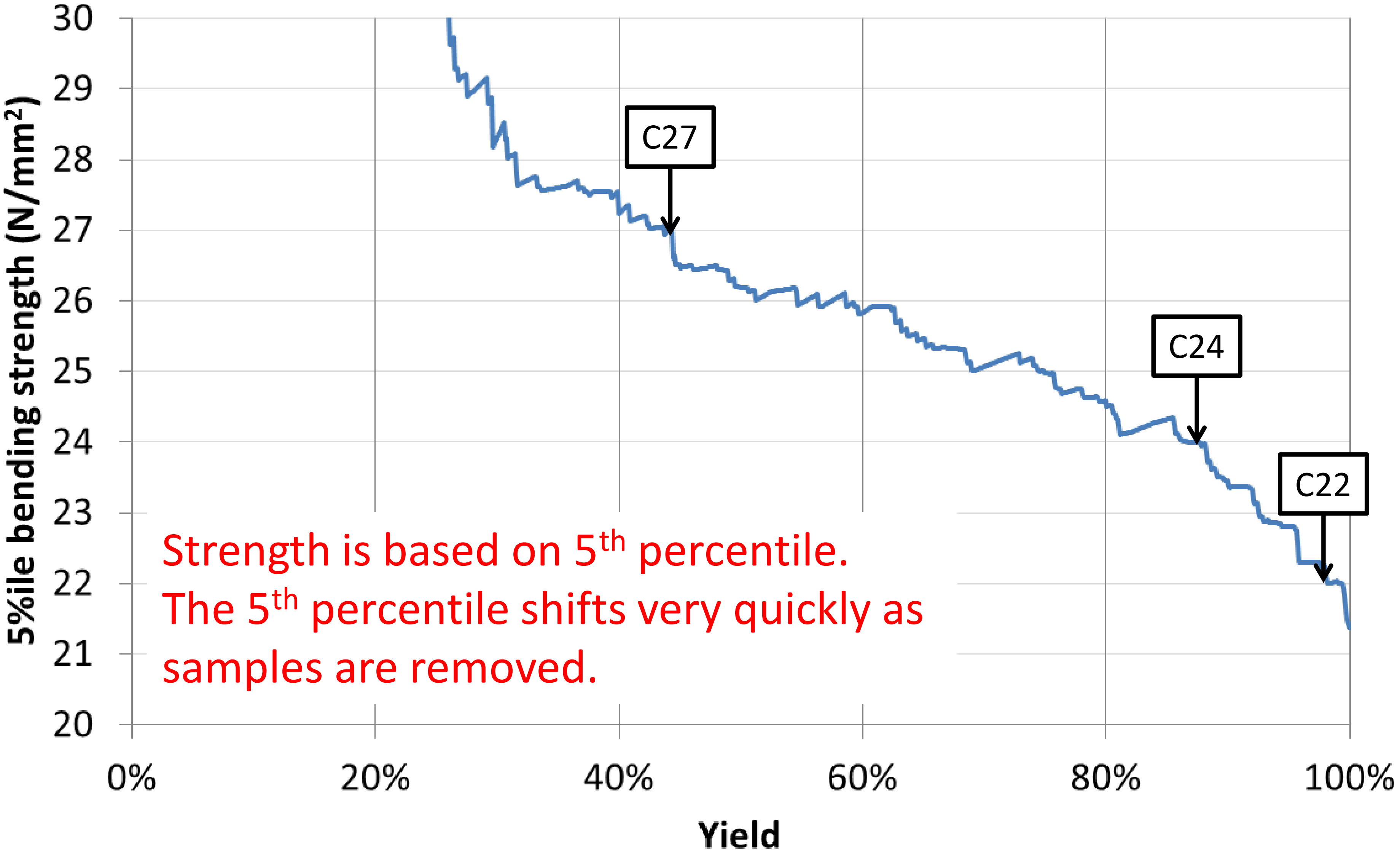
Treatment of MoE

BS EN 384:2010

EN 384:2010 (E)

$$E_0 = E_{m,g} * 1,3 - 2690$$


Mean bending stiffness (kN/mm²)
14
12
10
8
6
4
2
0
0%
20%
40%
60%
80%
100%
Yield
C22
C18
C16
Stiffness is based on mean.
A lot needs to be removed
in order to shift the mean.


5%ile bending strength (N/mm²)
30
29
28
27
26
25
24
23
22
21
20
0%
20%
40%
60%
80%
100%
Yield
C27
C24
C22
Strength is based on 5th percentile.
The 5th percentile shifts very quickly as samples are removed.

Yields with perfect grading machine

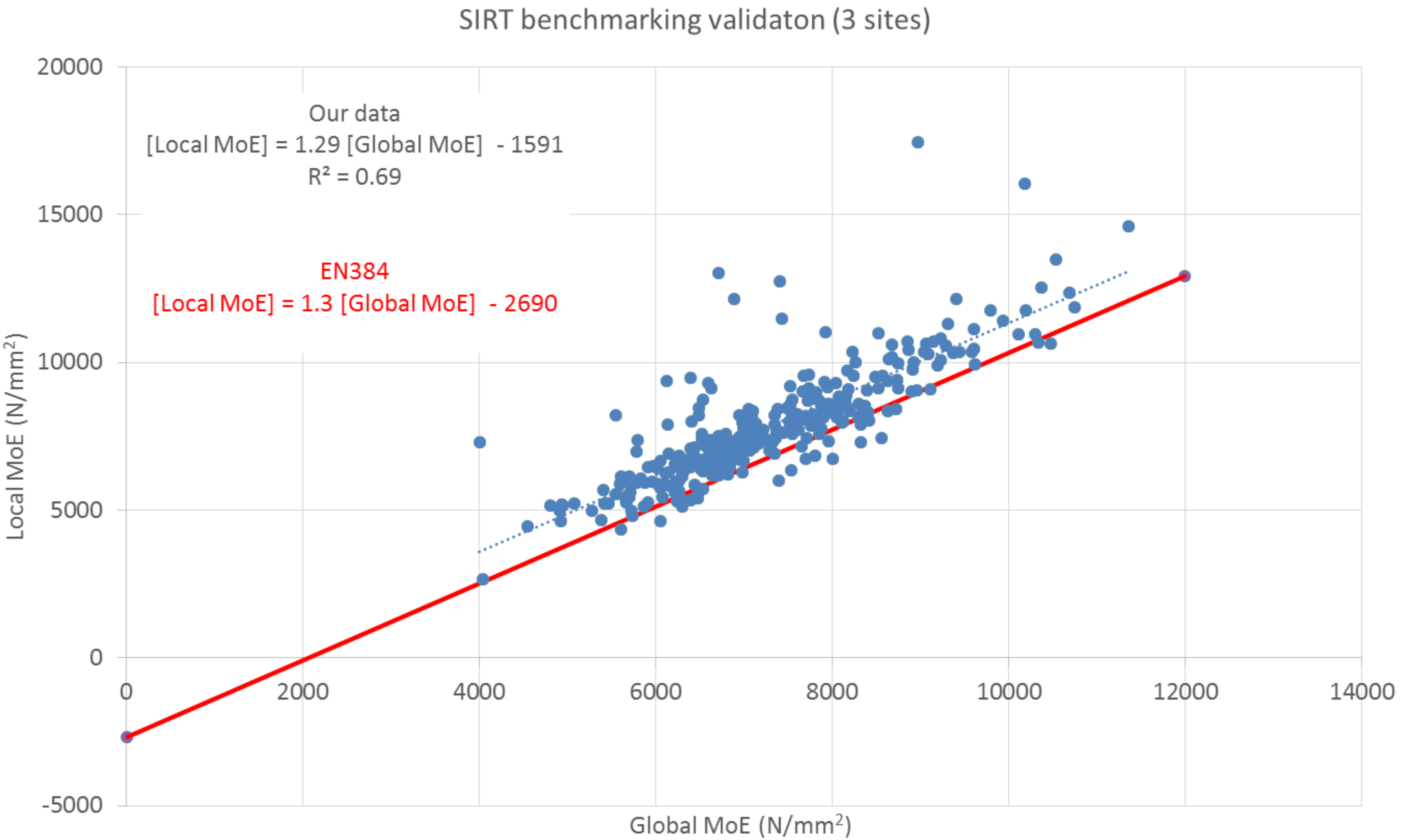
Mean MoE = 8 kN/mm2					
C14	C16	C18	C20	C22	C24
100%	100%	82%	64%	46%	20%
C27	C30	C35	C40	C45	C50
12%	6%	2%	0%	0%	0%

Mean MoE = 7.5 kN/mm2					
C14	C16	C18	C20	C22	C24
100%	97%	60%	42%	27%	9%
C27	C30	C35	C40	C45	C50
5%	2%	0%	0%	0%	0%

Mean MoE = 7 kN/mm2					
C14	C16	C18	C20	C22	C24
100%	77%	38%	23%	13%	3%
C27	C30	C35	C40	C45	C50
1%	0%	0%	0%	0%	0%

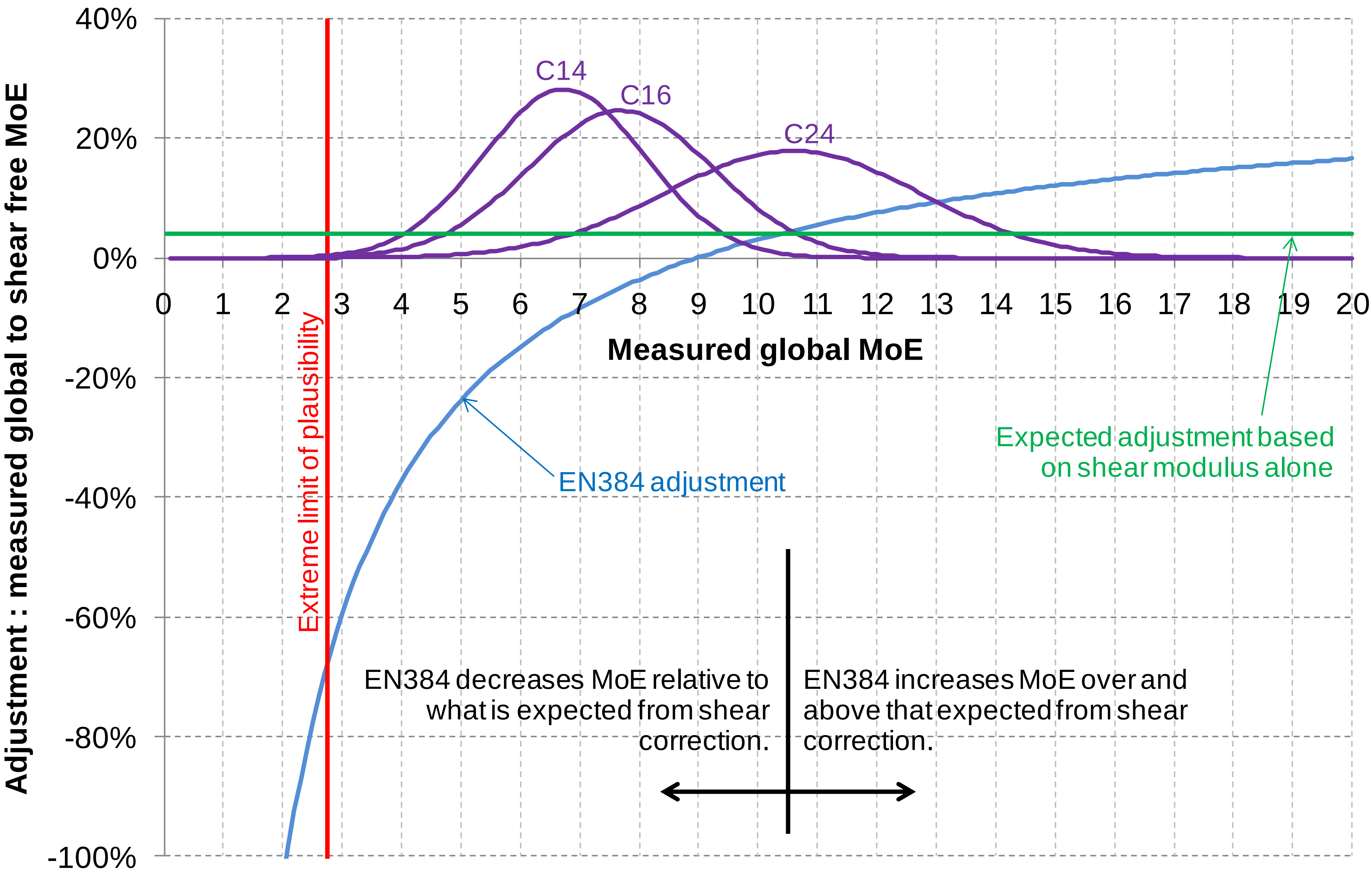
EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

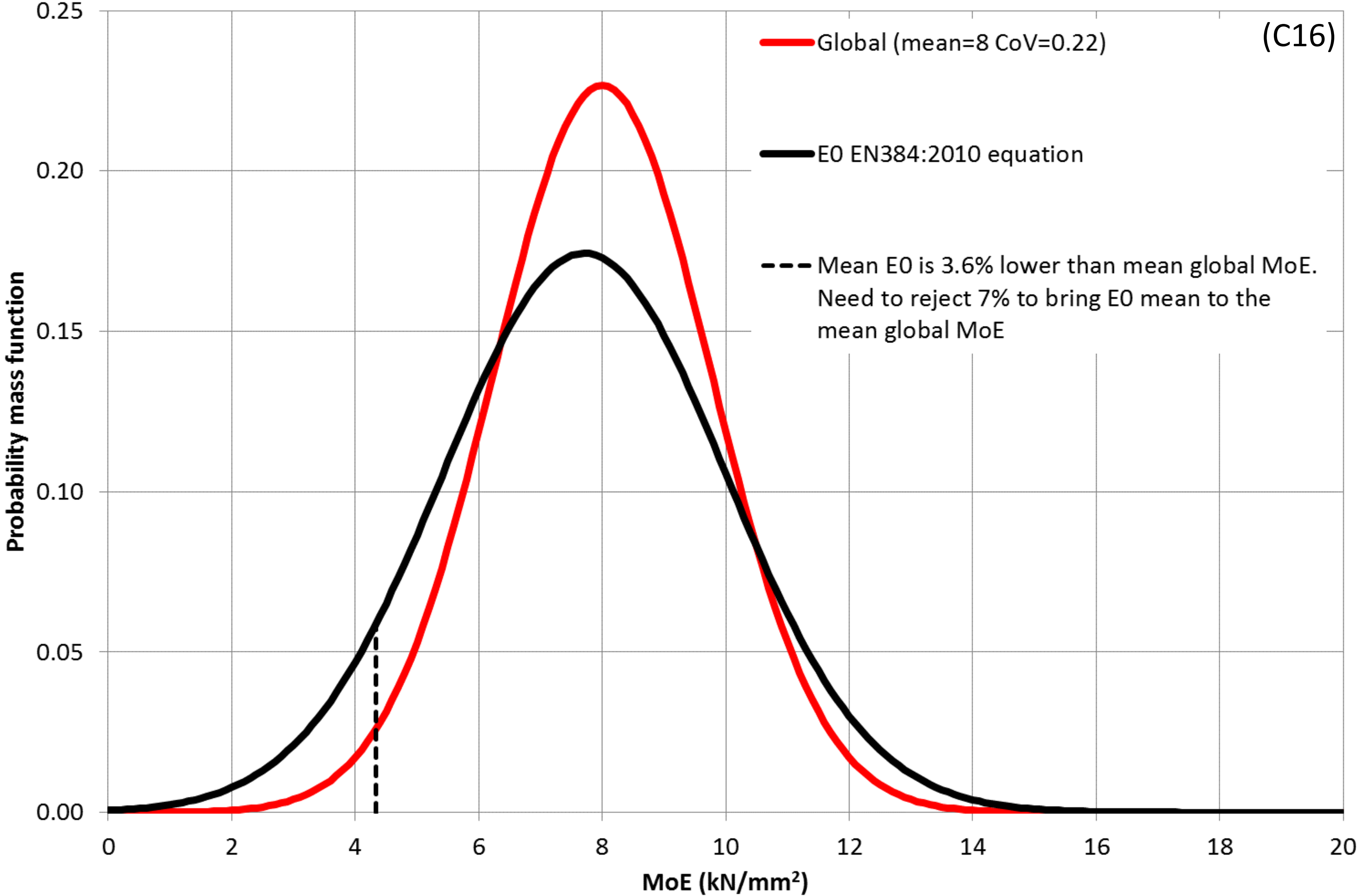
Treatment of MoE

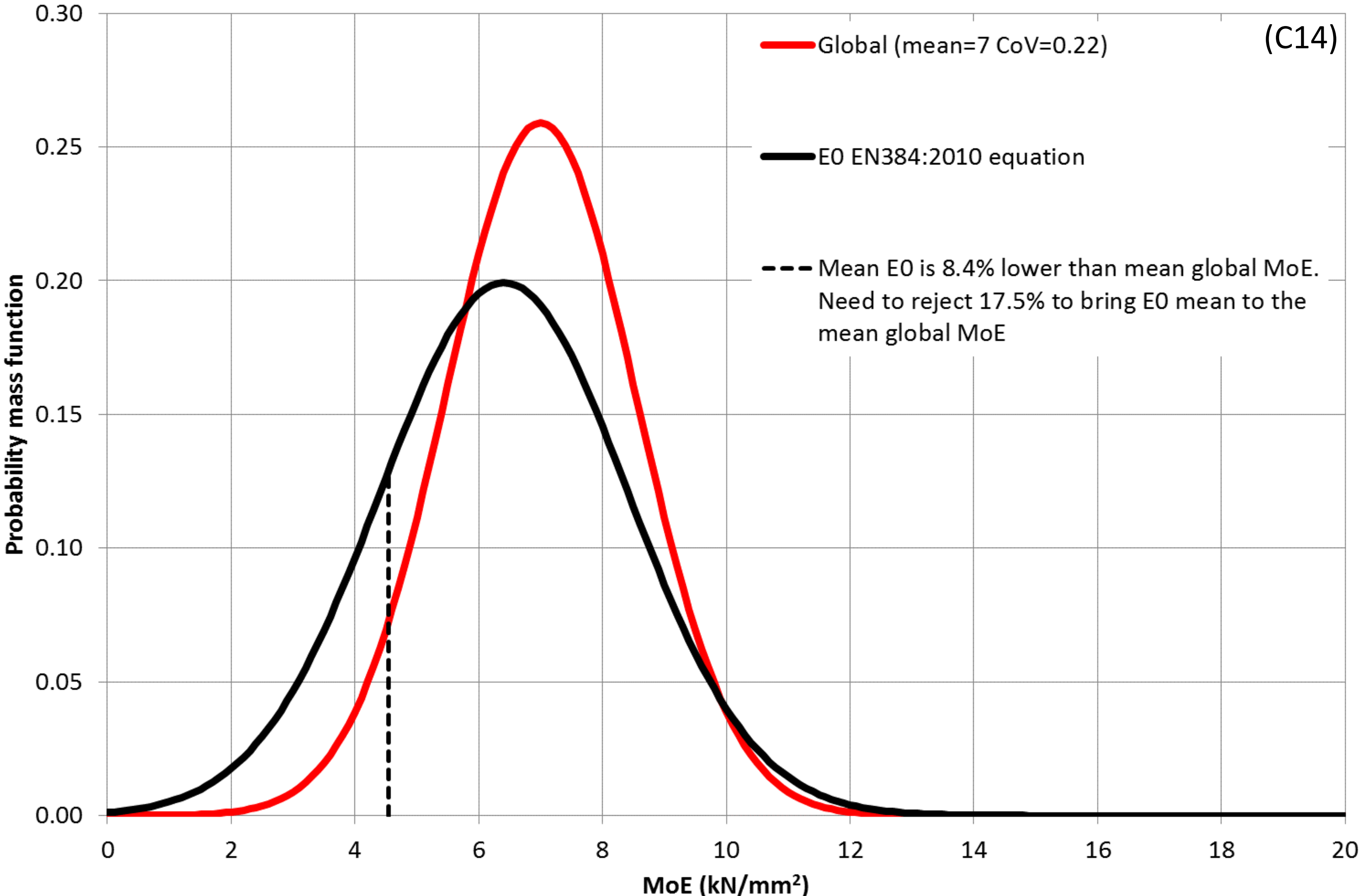


SIRT

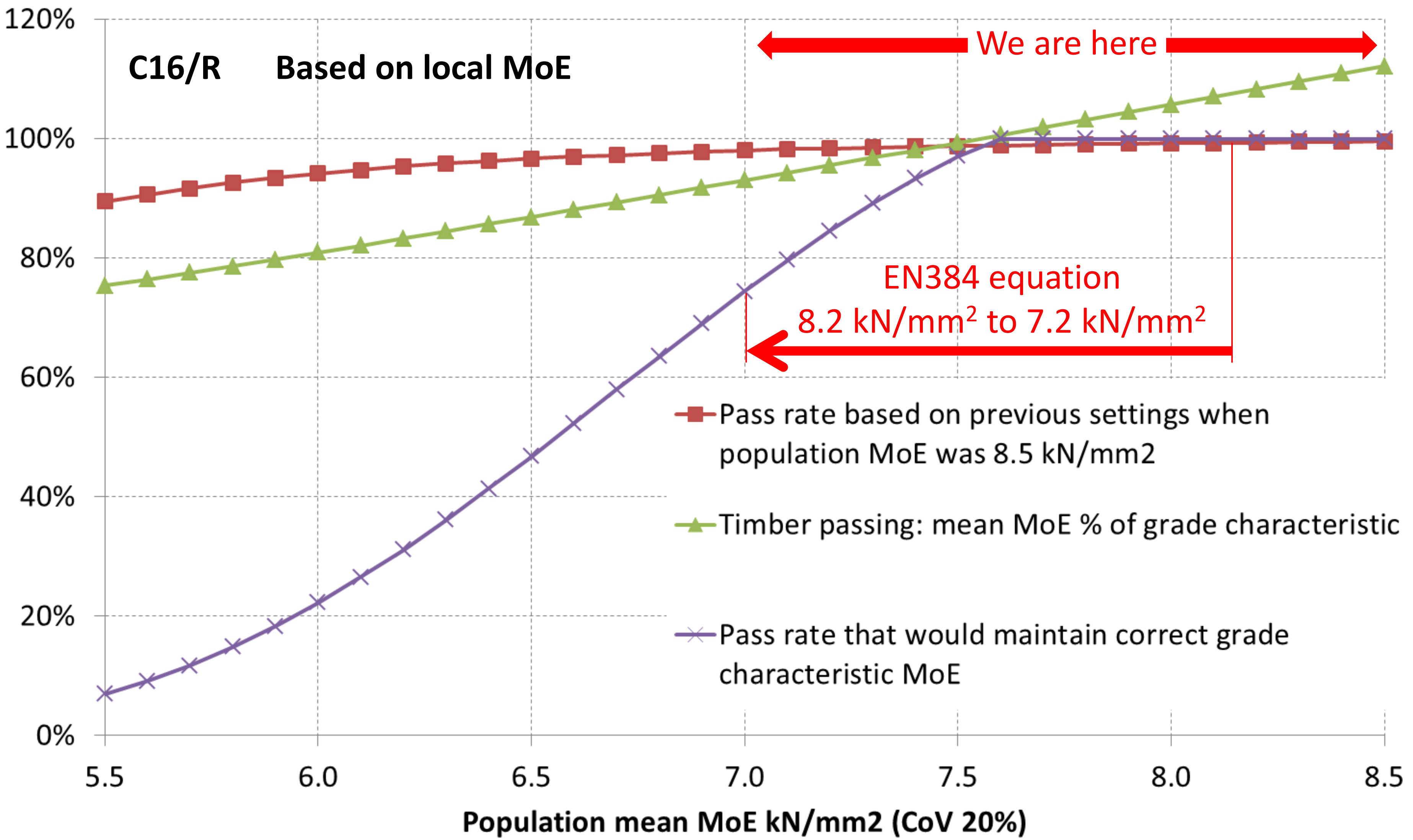
Institute for Sustainable Construction

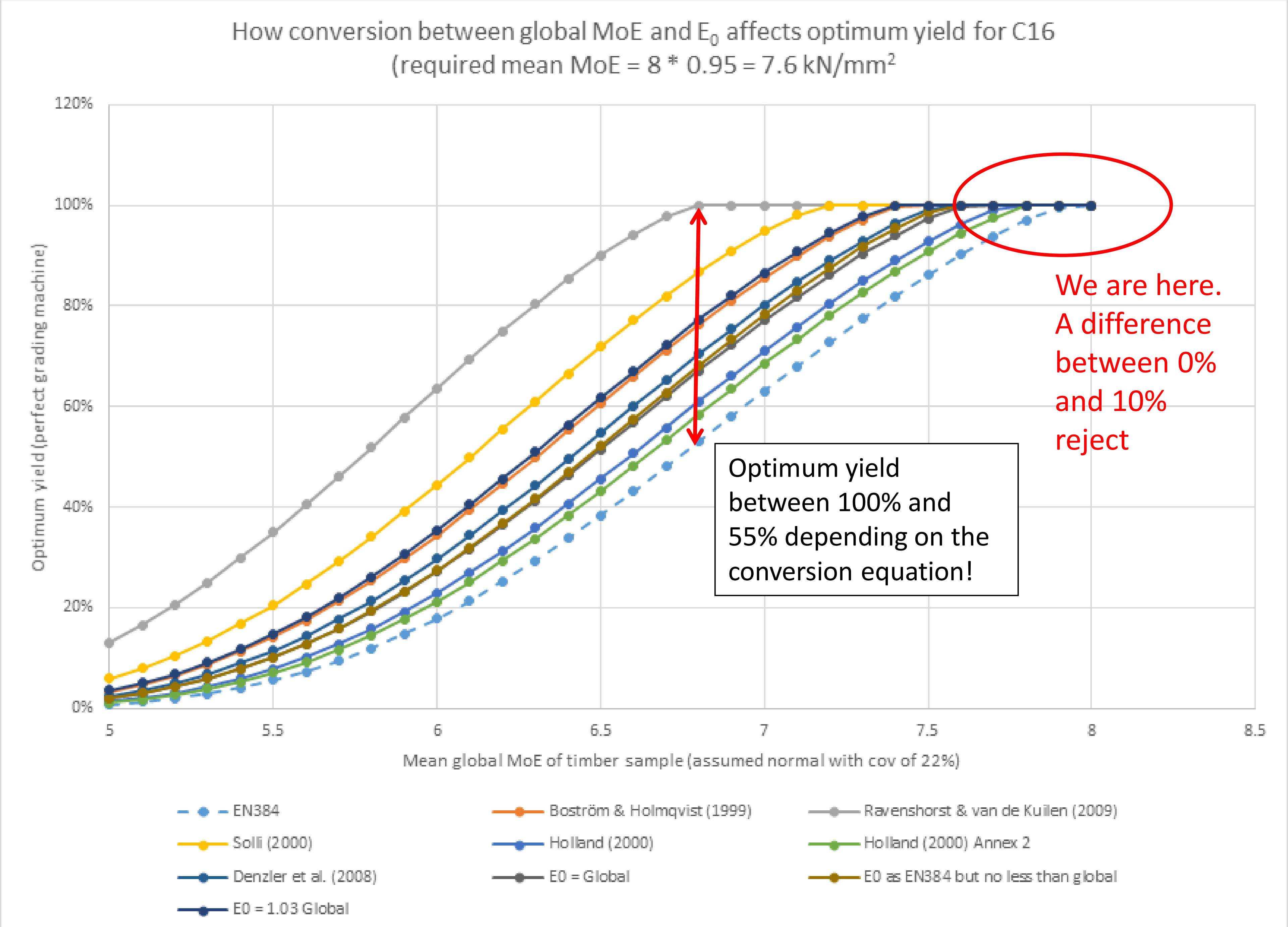



(C16)
Global (mean=8 CoV=0.22)
E0 EN384:2010 equation
Mean E0 is 3.6% lower than mean global MoE.
Need to reject 7% to bring E0 mean to the
mean global MoE
Probability mass function
0.25
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
10
12
14
16
18
20
MoE (kN/mm²)


(C14)
Global (mean=7 CoV=0.22)
E0 EN384:2010 equation
Mean E0 is 8.4% lower than mean global MoE. Need to reject 17.5% to bring E0 mean to the mean global MoE
Probability mass function
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
10
12
14
16
18
20
MoE (kN/mm²)

Stiffness of the resource




How conversion between global MoE and E0 affects optimum yield for C16
(required mean MoE = 8 * 0.95 = 7.6 kN/mm2
120%
100%
80%
60%
40%
20%
0%
Optimum yield (perfect grading machine)
5
5.5
6
6.5
7
7.5
8
8.5
Mean global MoE of timber sample (assumed normal with cov of 22%)
We are here.
A difference
between 0%
and 10%
reject
Optimum yield
between 100% and
55% depending on the
conversion equation!
EN384
Boström & Holmqvist (1999)
Ravenshorst & van de Kuilen (2009)
Solli (2000)
Holland (2000)
Holland (2000) Annex 2
Denzler et al. (2008)
E0 = Global
E0 as EN384 but no less than global
E0 = 1.03 Global

SIRT

Institute for Sustainable Construction

More general concerns

- Growth areas – and variability
  - Machine grading and visual grading
- Quality shifts
  - During production
  - Since settings were approved
  - Output control is too slow to adjust
- Complexity of the grading standards
- A European visual grading standard

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Looking further…

- Should settings have an expiry date?
- New approach
  - Prediction limit
  - Adaptive settings
- Need to know how timber properties vary!

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

Summary

- Development requires industry input
- And the underpinning of research
  - To see the problems
  - To convince the committees
- Small changes can have massive impact
  - Maybe for no good reason at all
- UK has a pretty unique situation
  - Sitka spruce, stiffness limited
- There are a lot of changes to come

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future