Productivity studies of Bracke C16.c – Effects of boom-corridor thinning

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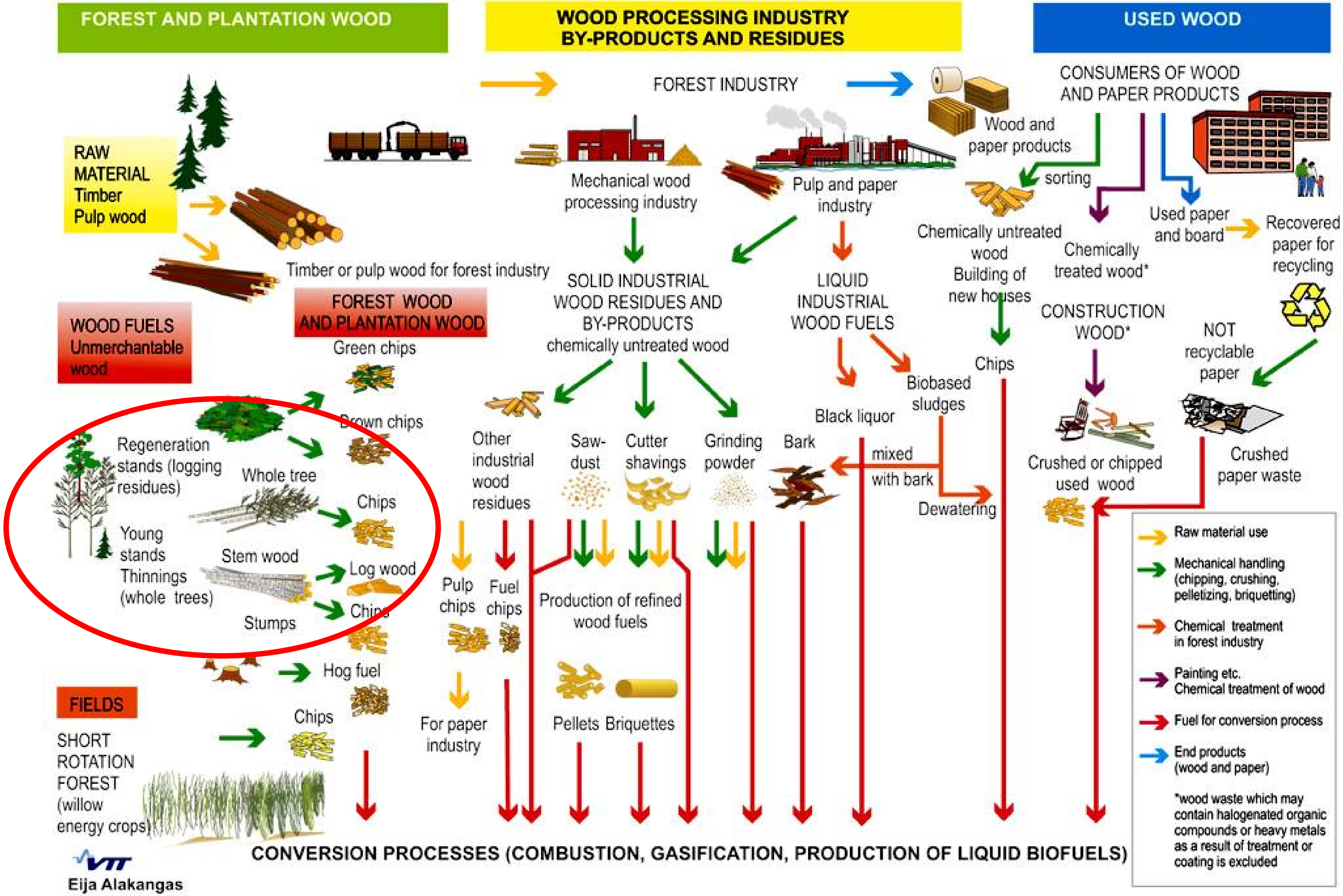
Background

- Increasing Industrial demand for biomass for biorefining and energy

- Small-diameter trees are currently underutilized

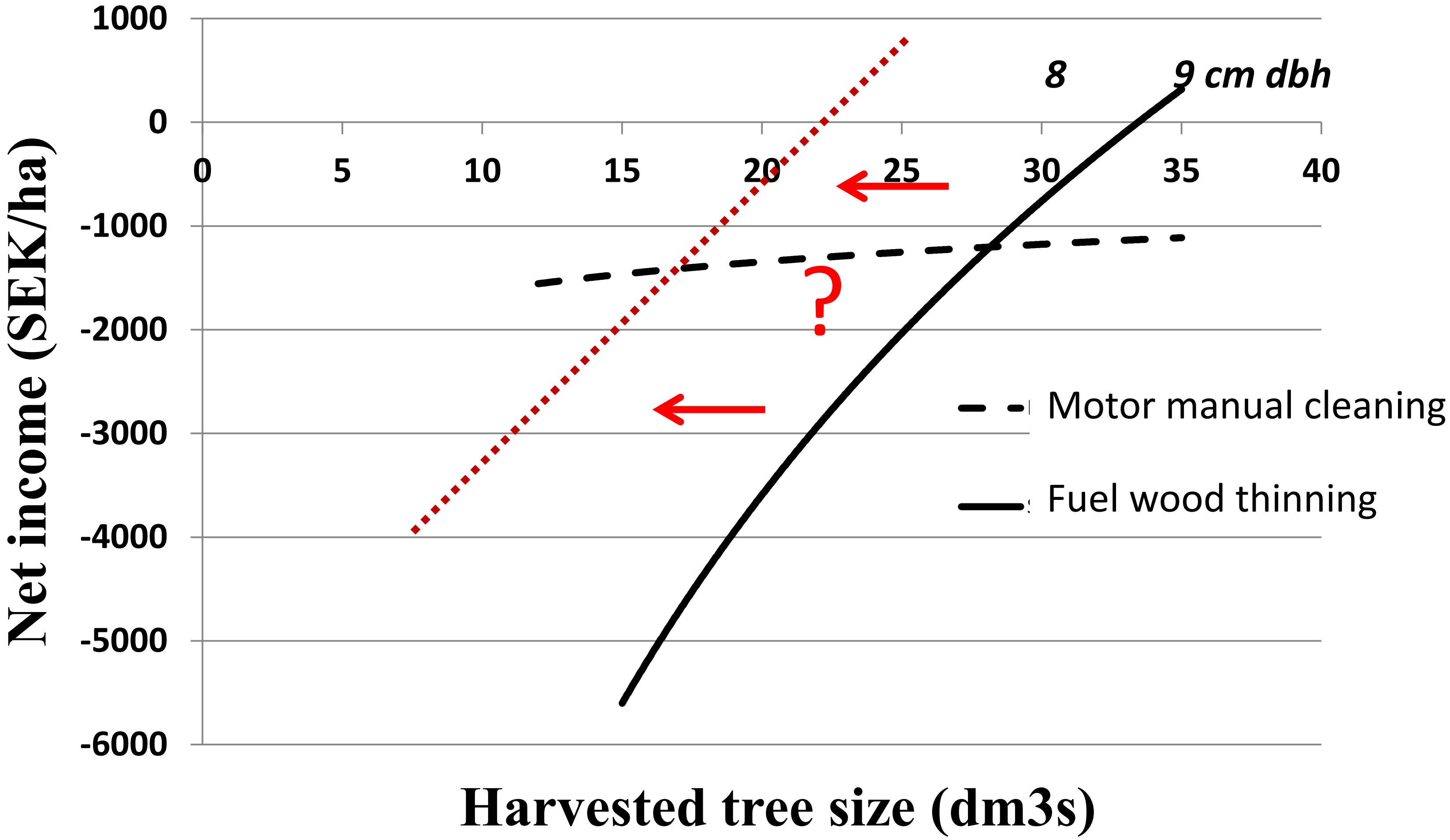
The material flows



Background

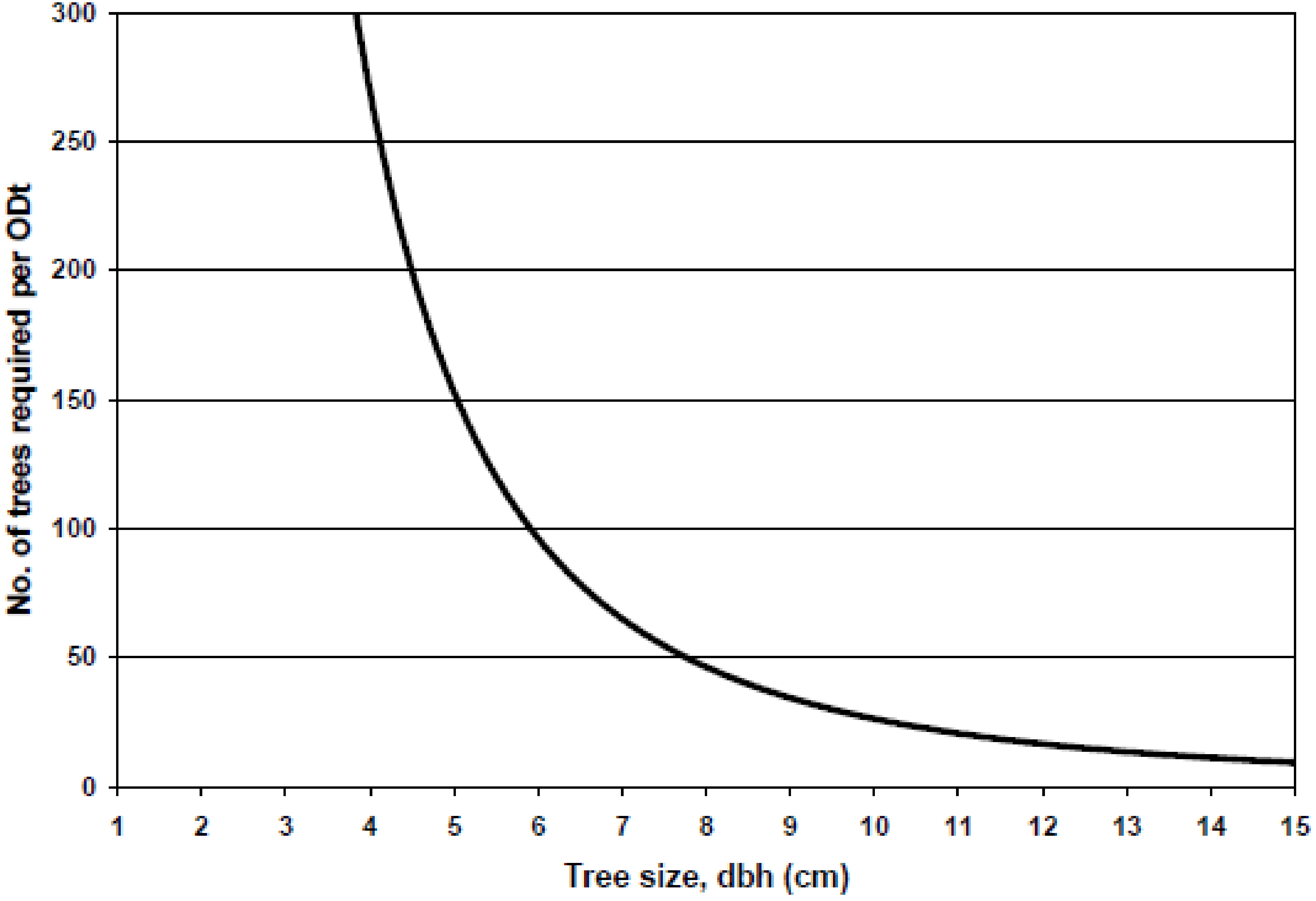
- Forest management practices – tending is common practice in European forest to promote high quality/value timber
- Cleaning cost…
- Problem: Small-diameter trees >> low harvesting productivity >> high supply cost

How can we reach higher cost efficiency in stands of small-diameter trees?!



10 SEK~1 Euro

A basic fact to consider…



Background

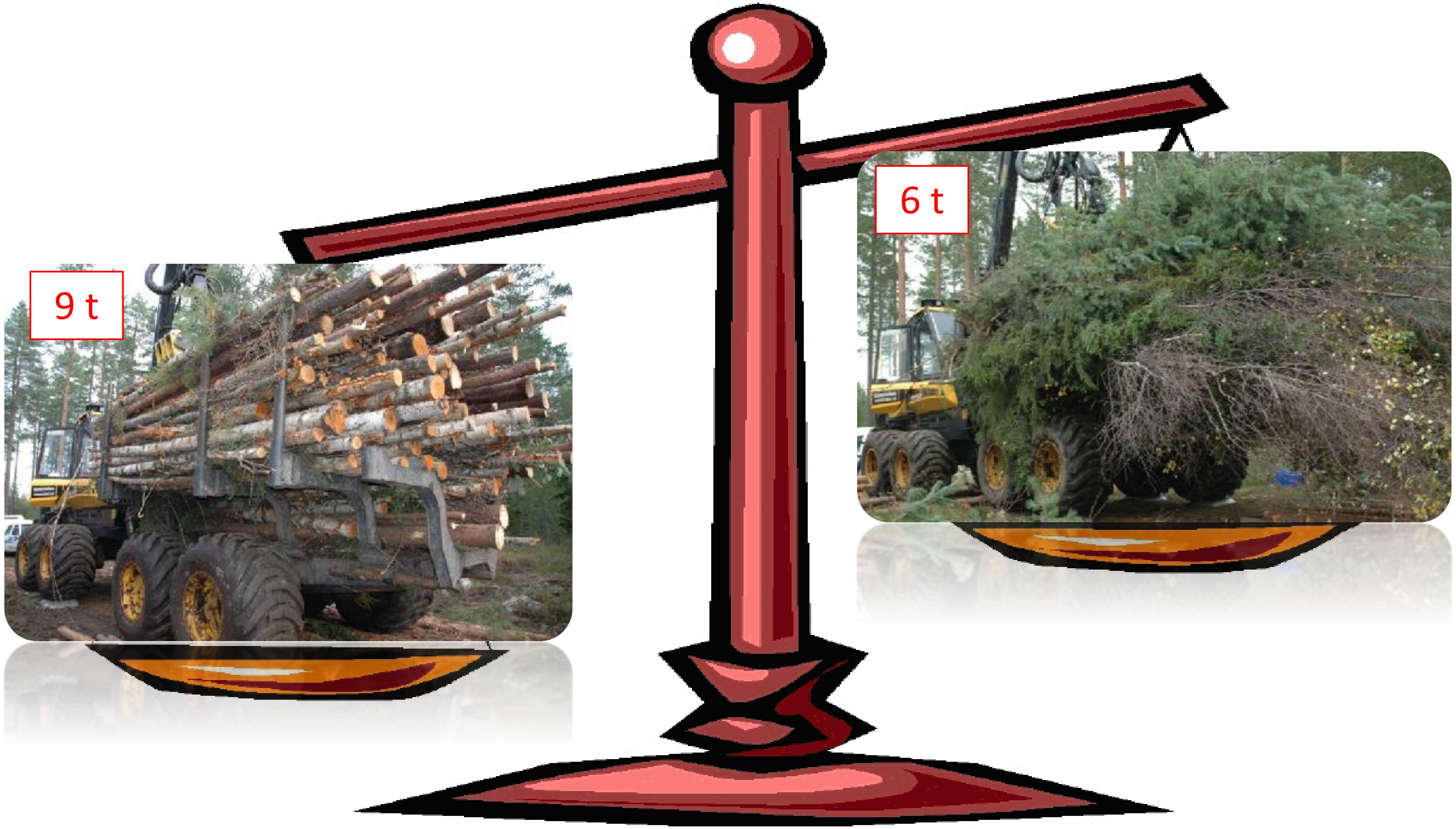
- Problem: Small-diameter trees >> bulky >> high transportation/supply cost

Ratio: Solid to Bulk volume

15-20 %　35-40 %　40 %　60-70%

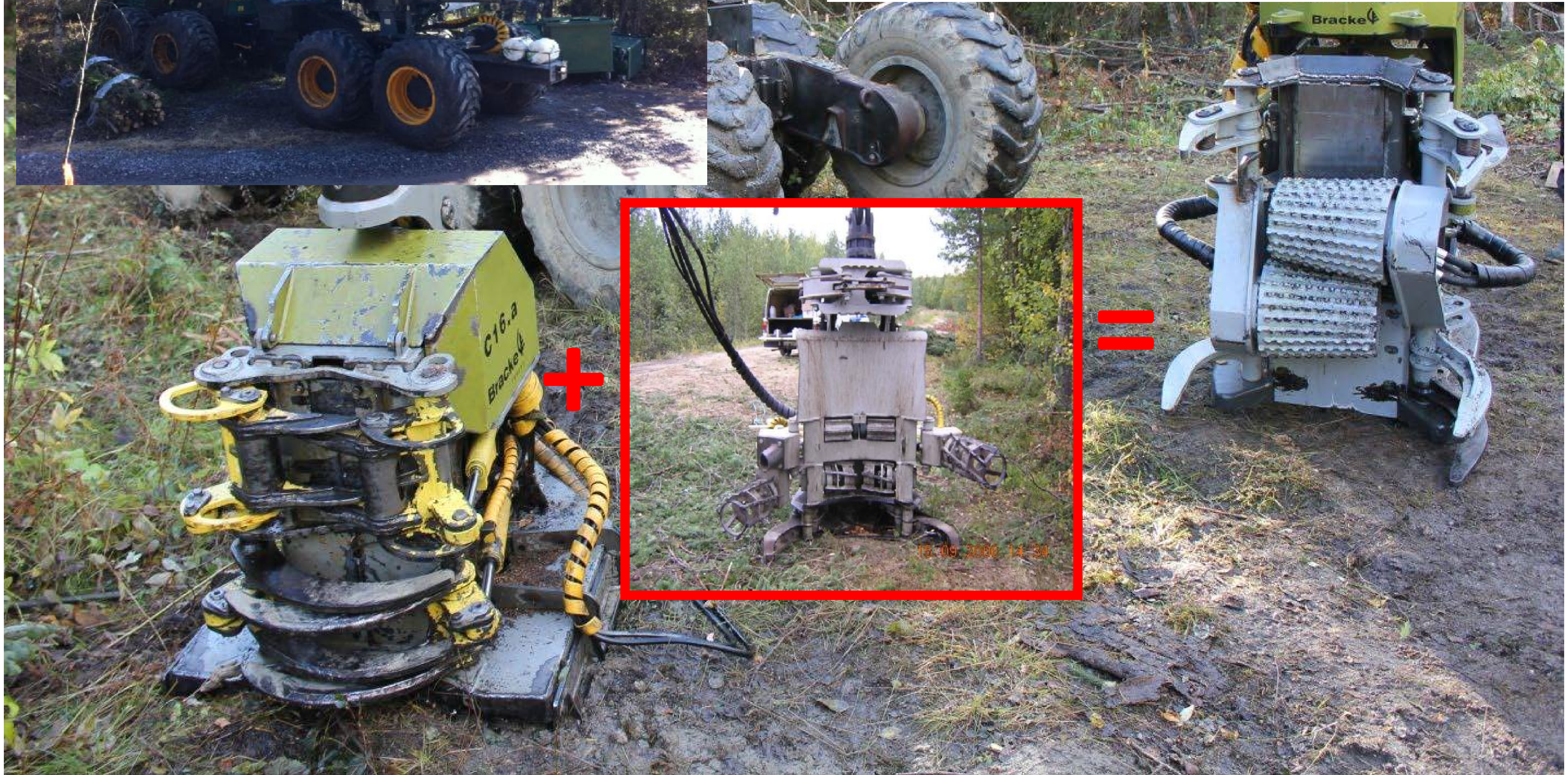
Small unprocessed trees are bulky:

- Piles of tree parts have a solid volume of ca 25-35%
- Only 30-60% of forwarders load capacity is then utilized



Increase payloads, possible solutions:

- Compression processing
- Bundling

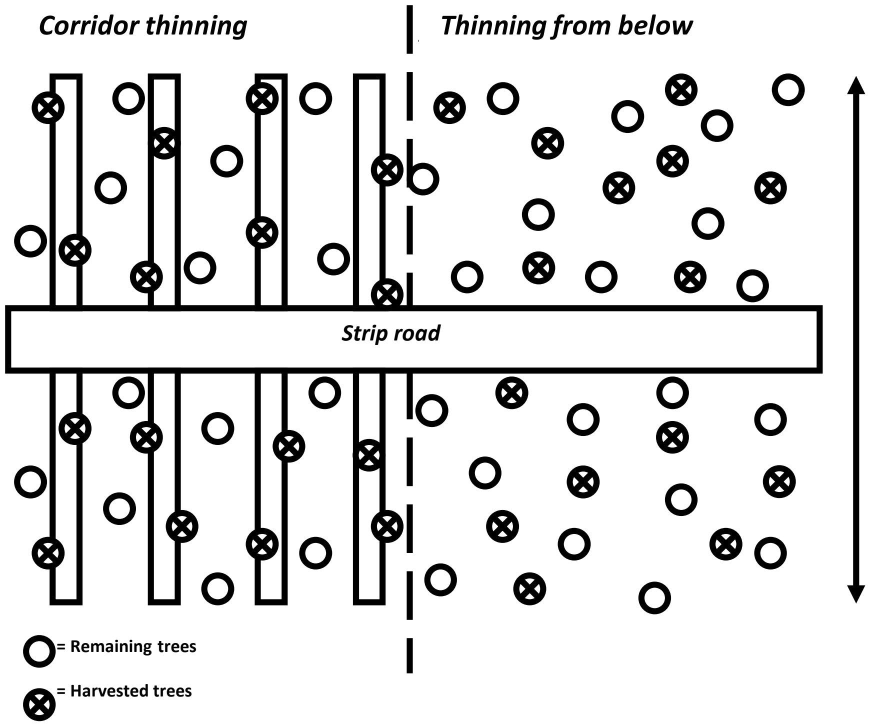


Background

- Identified prioritized measures to increase cost-efficiency:
    - *New methods, technology >> increase felling and bunching productivity*
    - *New methods, technology >> densification of biomass*

Basic research: Effect of work method on productivity

- First version of C16:
  - Boom-corridor thinning vs. Selective thinning (trials in 2007ish)
  - Bergström, D., Bergsten, U. & Nordfjell, T. 2010. Comparison of boom-corridor thinning and thinning from below harvesting methods in young dense Scots pine stands. Silva Fennica 44(4): 669-679.



→ 16% increased prod.!

Effect of new techn. + boom-corridor thinning

Conv. techn.
(sel och boom-corr.) ***vs.*** New techn. and boom-corr.

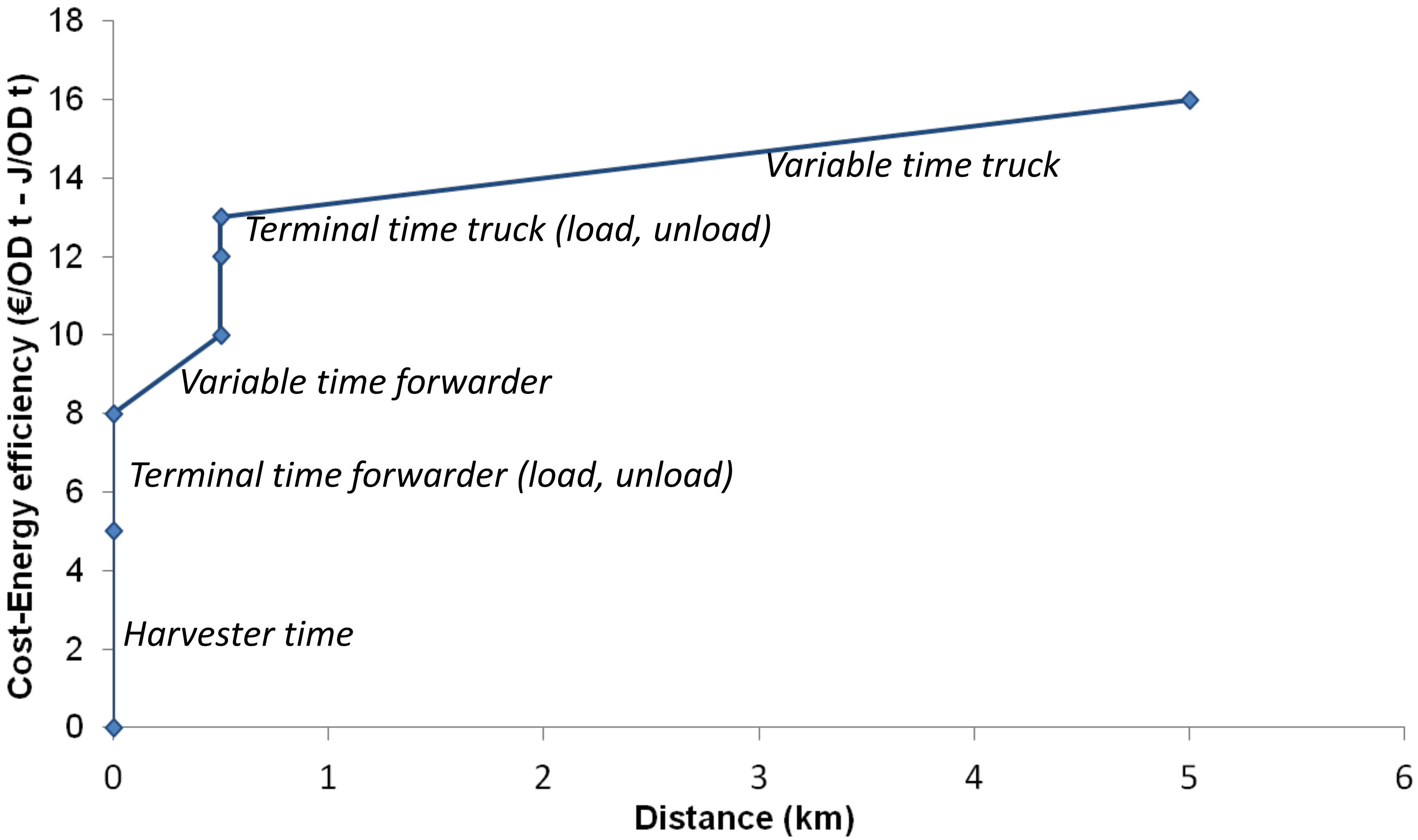
→ up to 200% increased prod.!!!

Example of analysis to decide future supply systems

"Study the effect of implementing new harvesting and handling technologies on the supply chain cost and energy efficiency for the early thinning of stands in comparison to conventional systems."

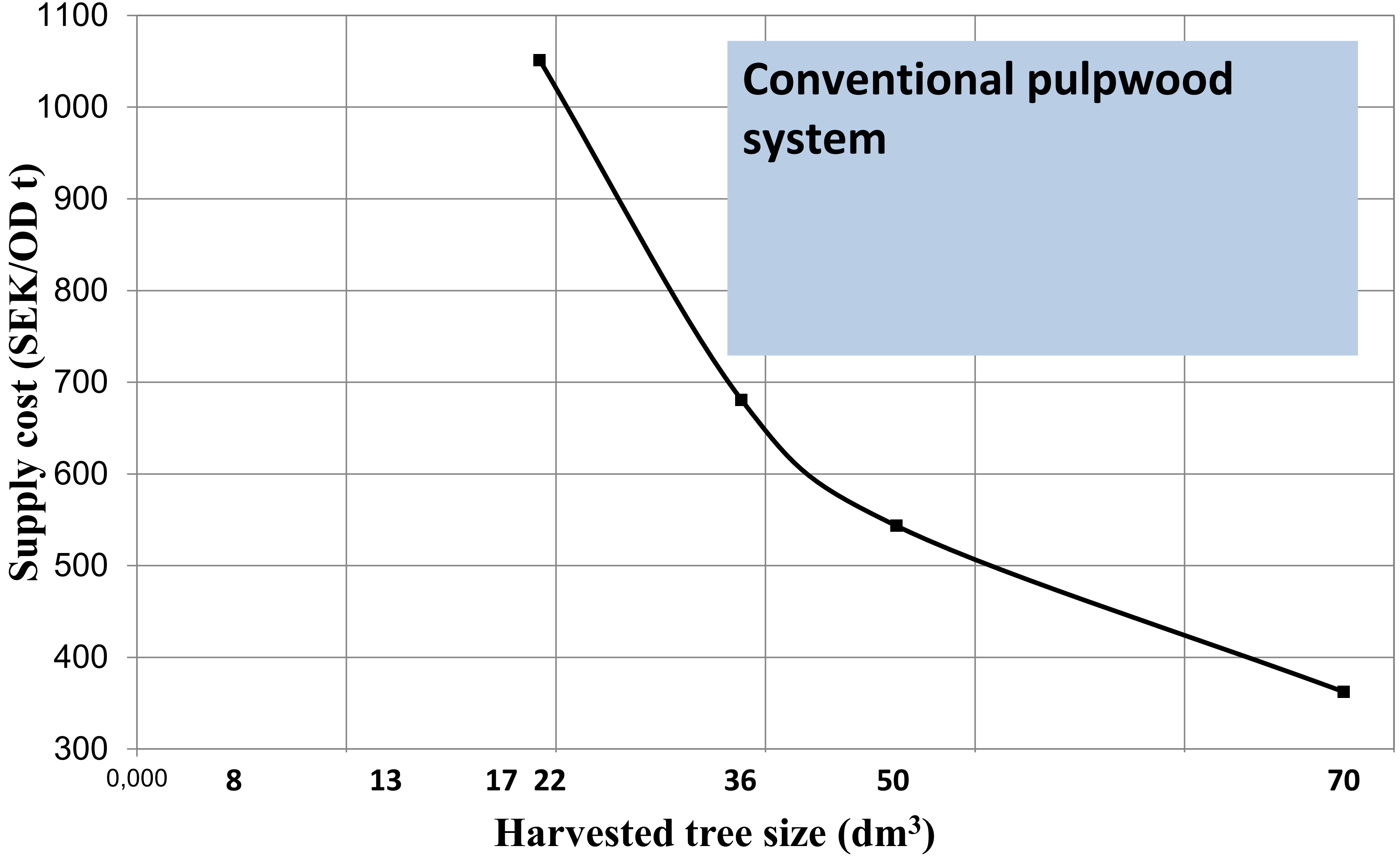
- ”Bergström, D. & Di Fulvio, D. 2014. Comparison of the cost and energy efficiencies of present and future biomass supply systems for young dense forests. Scandinavian Journal of Forest Research, DOI:10.1080/02827581.2014.976590”

Analysis

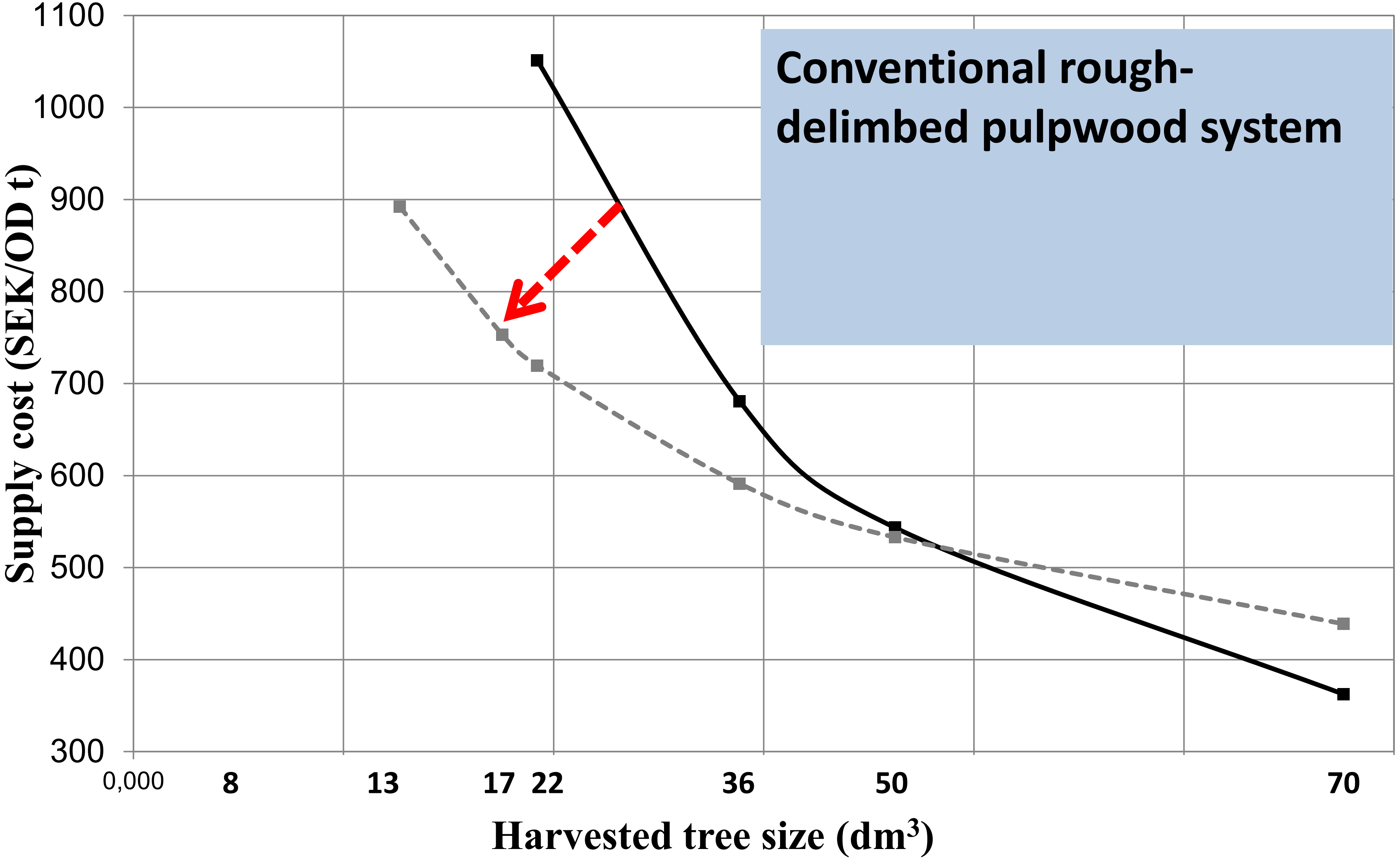


Cost-Energy efficiency (€/OD t - J/OD t)
18
16
14
12
10
8
6
4
2
0
Variable time truck
Terminal time truck (load, unload)
Variable time forwarder
Terminal time forwarder (load, unload)
Harvester time
0
1
2
3
4
5
6
Distance (km)

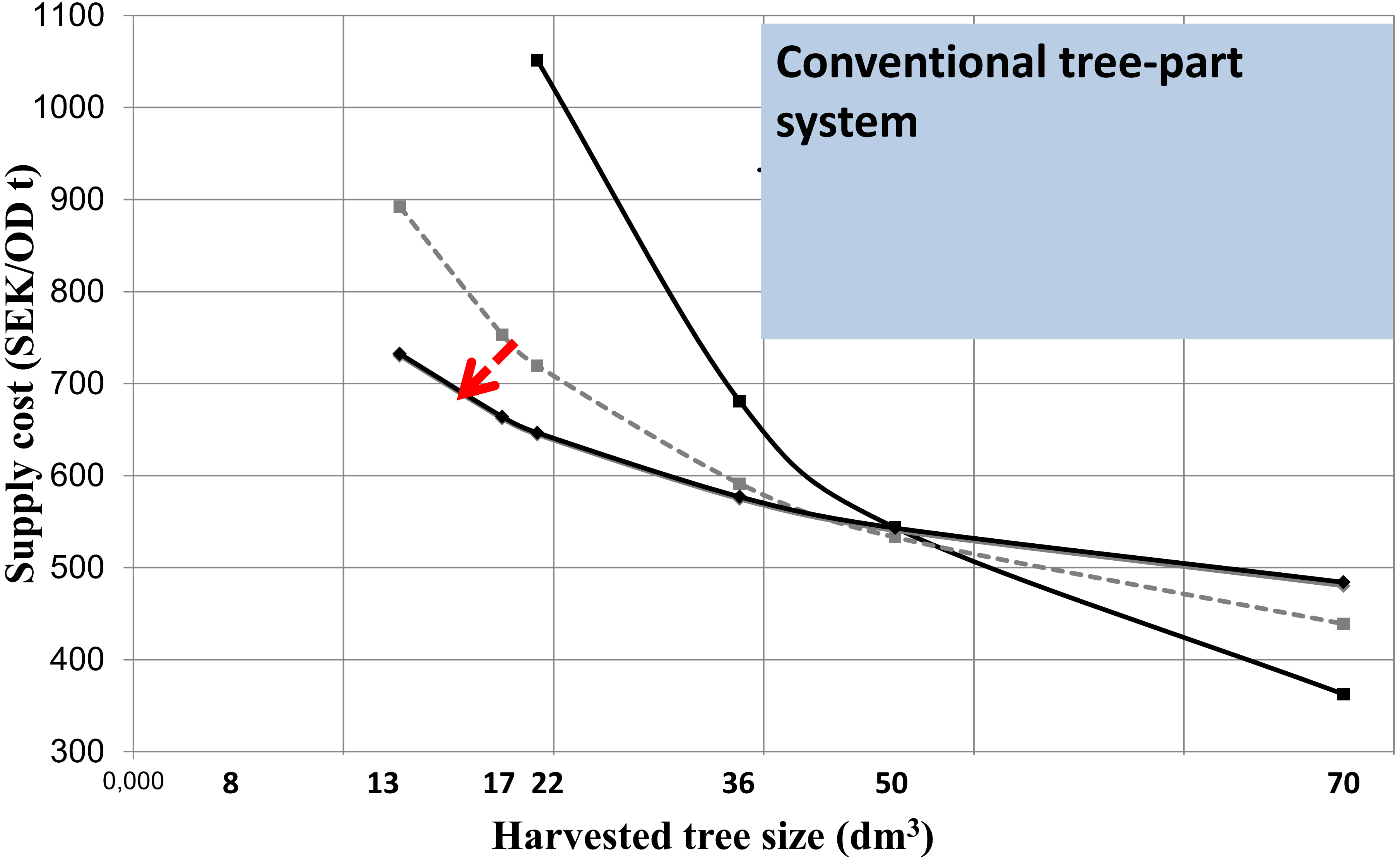
Main results: (Values are given for a forwarding distance of 300m and a trucking distance of 75km)



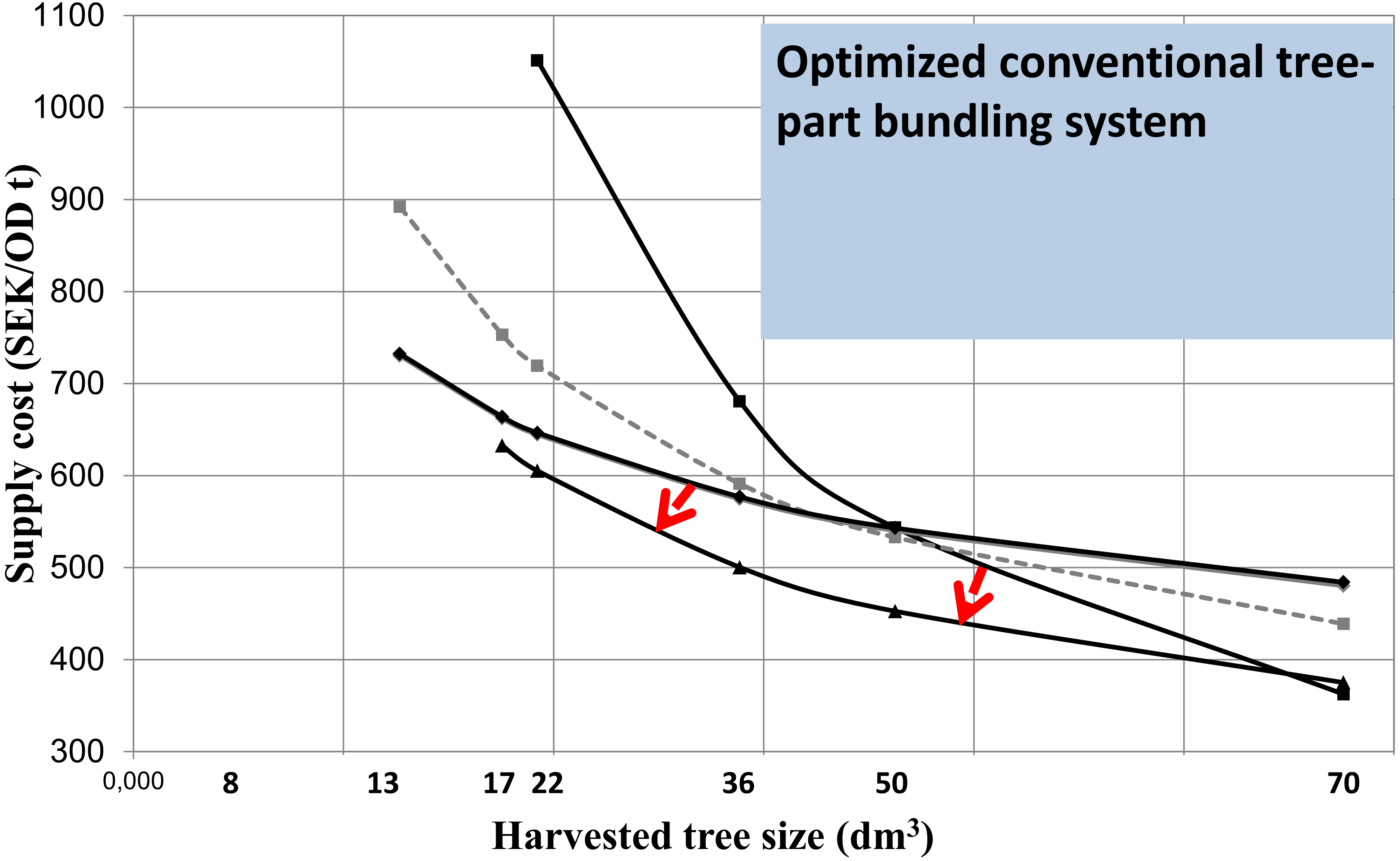
”Bending the curve”



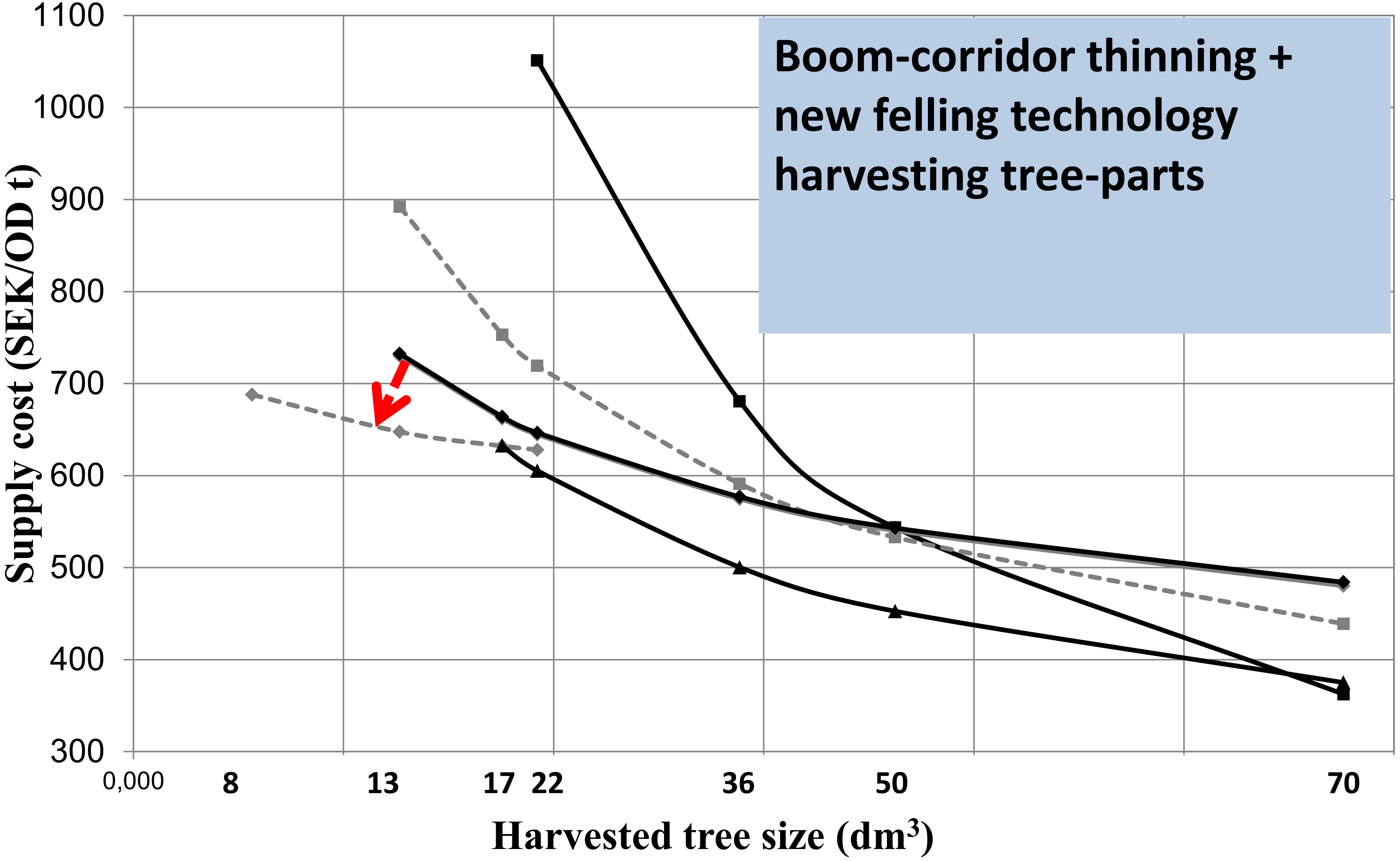
”Keep on bending”:



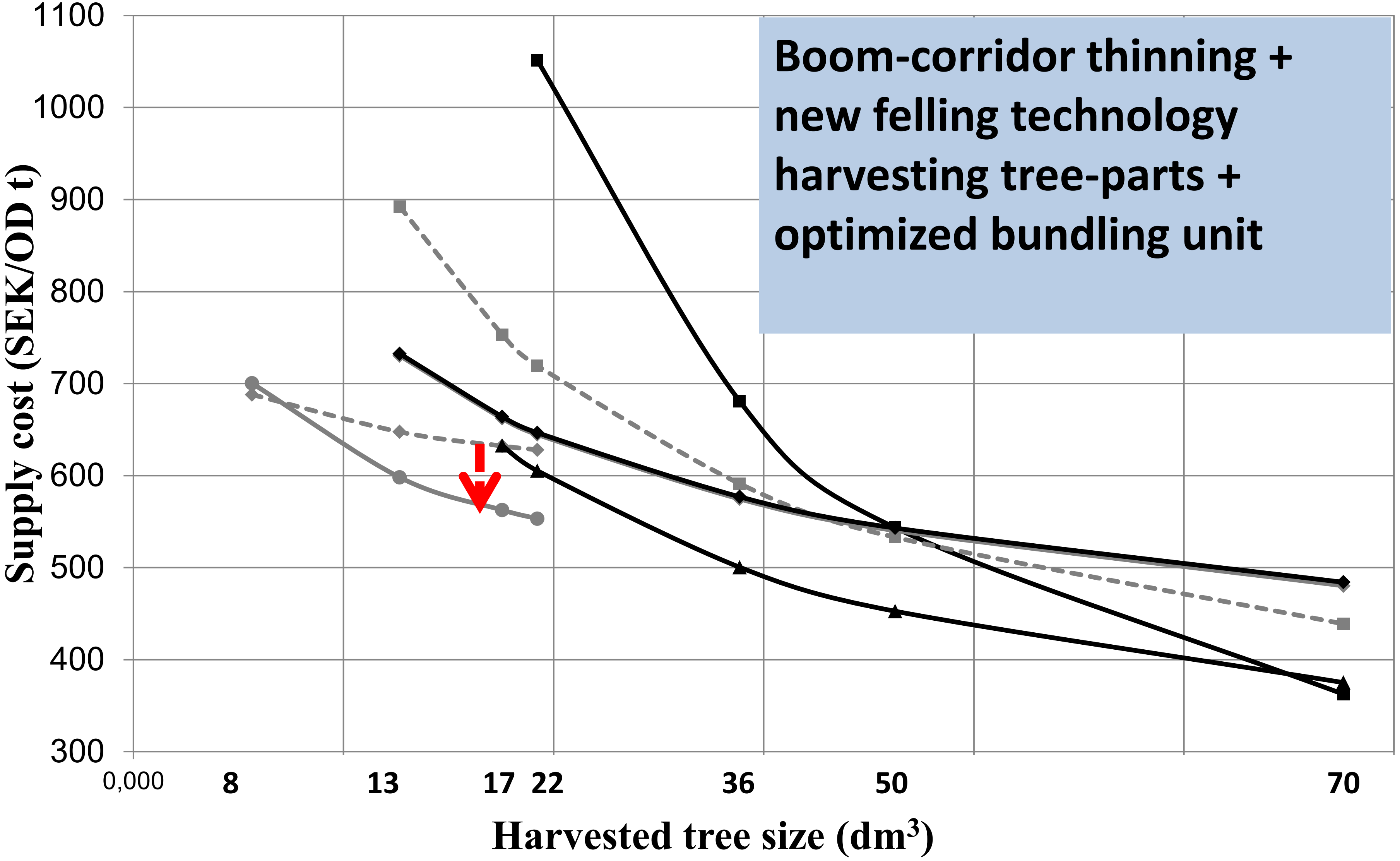
”Pushing down…”:



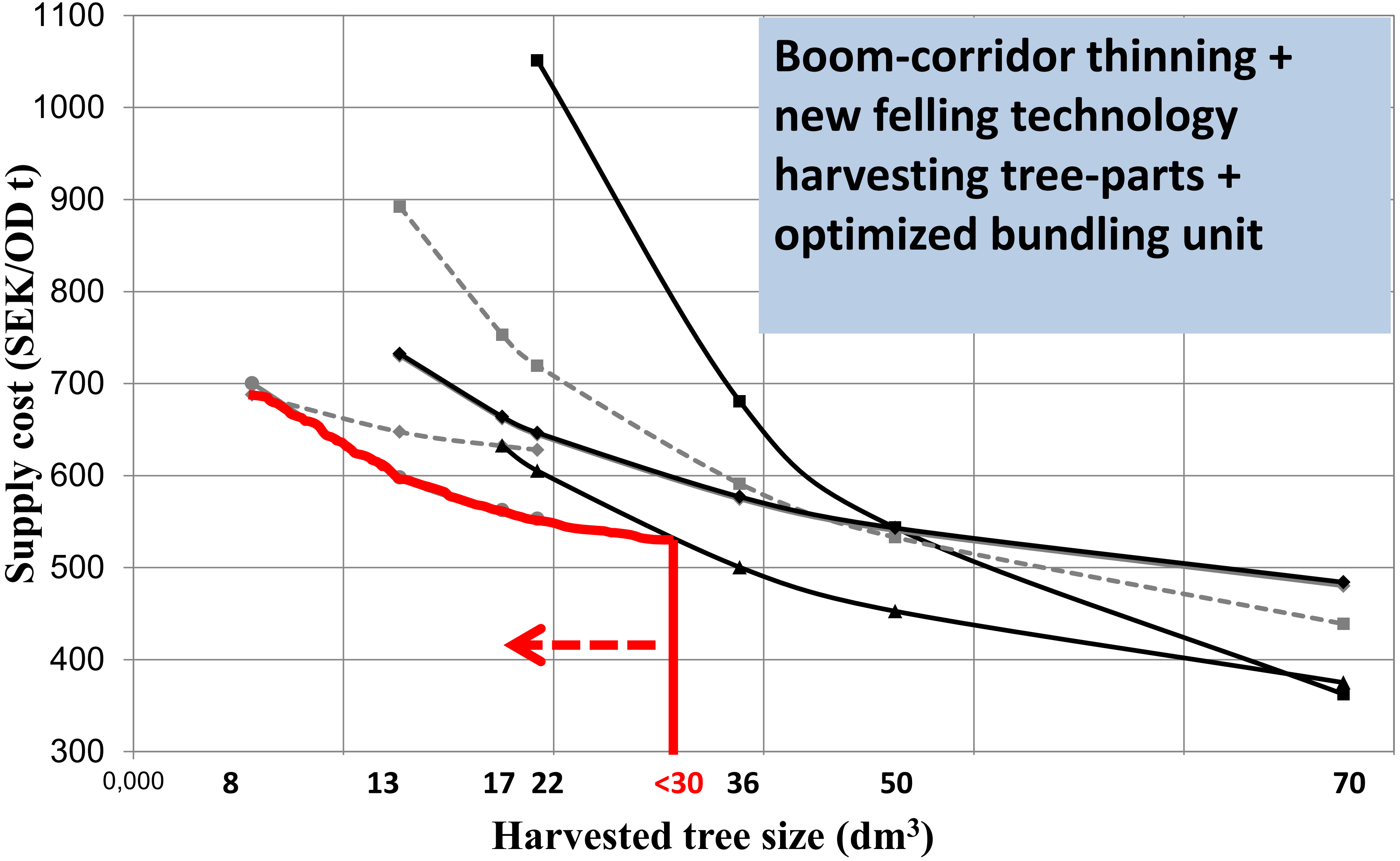
”Little bit more bending”:



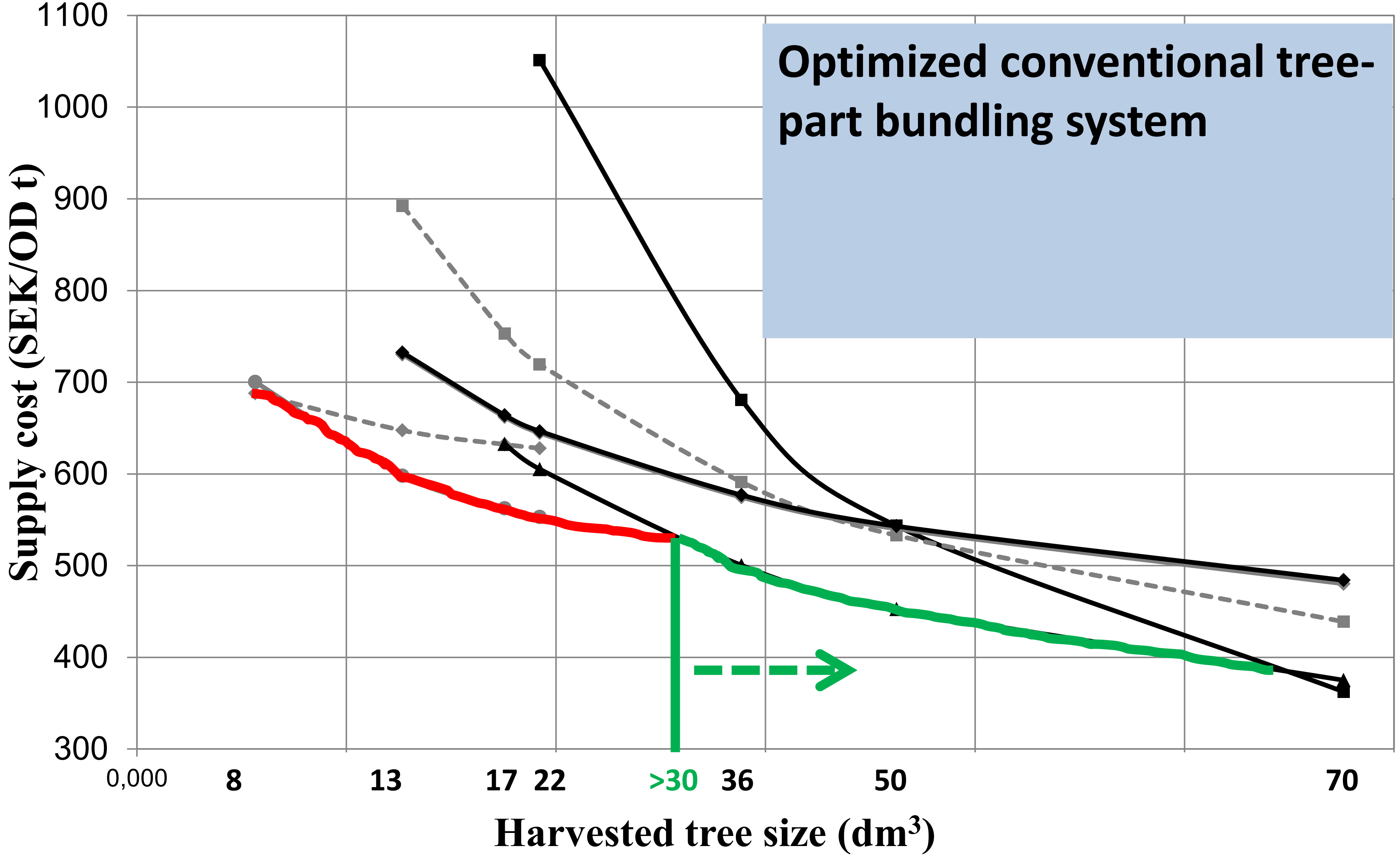
”And the final push”:



Trees below ca 30 dm3:



From ca 30 - 70 dm3”:



The justification of these systems for small diameter tree stands are however solely dependent on an <u>development of effective technology for cutting work!</u>

Felling and bunching technology development

Yesterday			Today	Tomorrow	
One-Tree per crane-cycle	**Multi-tree handling (MTH)**	**MTH + boom-corridor (BCT)**	**BCT-Develop. of current heads**	**BCT + new techn. (BTCN)**	**BCTN + two felling-cranes**
Ref.	**+40%**	**-**	**-**	**-**	**-**
-	**Ref.**	**16-40%**	**30-100%**	**200%**	**-**
-	**-**	**-**	**-**	**Ref.**	**+40%**

This is left to realize!!!

Smallwood sub-objective

- Study the effects of thinning methods and stand conditions on felling and bunching productivity in small diameter tree European forest stands
- Why? >> We need more empiric data for various conditions to accept/reject previous findings!
- (OBS! Data and Results for Spanish trials is unpublished >> preliminary!)

Study layout

1
- Selection of stands
- Mark out time study units
- Pre-inventory

2
- Timing of felling and bunching work
- Scaling of cut biomass
- Post-inventory

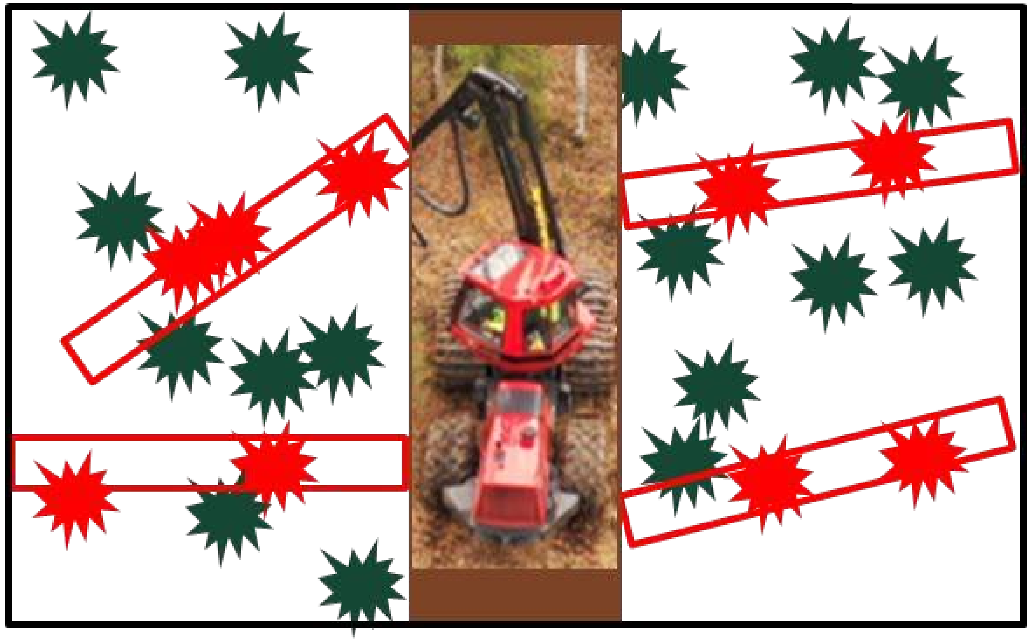
3
- Analysis

Harvester, felling and bunching technology

- Komatsu 901.3 thinning harvester, 14t
- Bracke C16.c felling and bunching head
- 1 experienced driver for all trials

Studied thinning methods

Novel boom-corridor thinning (BCT)



versus

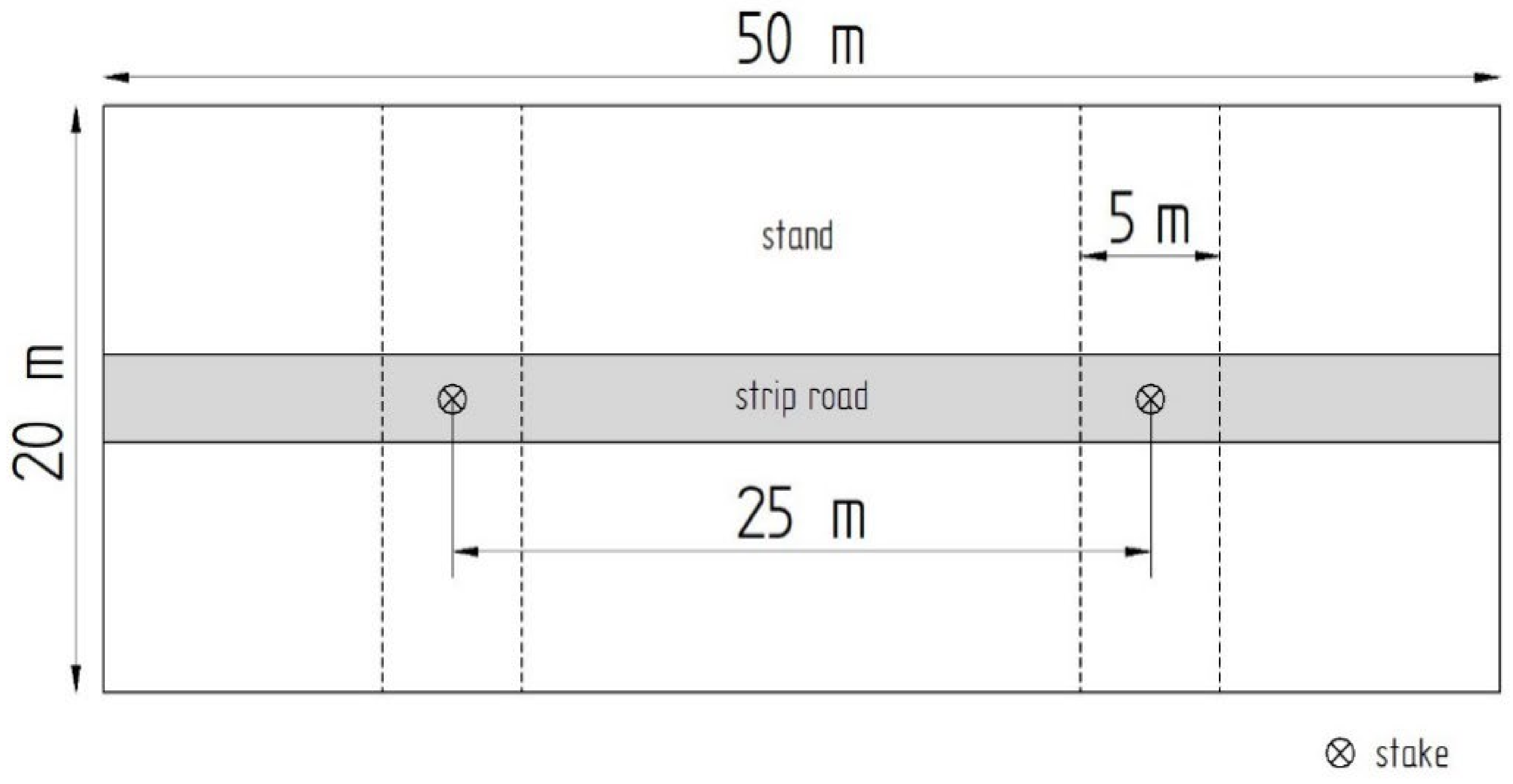
Conventional selective thinning (ST)

Instructions to operator: mimic ST targets (reference) as much as possible!

Stand types and locations

- Four countries ”Tour de Europé”
  - Sweden >> Finland >> Slovenia >> Spain
- 8 different stands
- 6 stand types
  - Pine, Birch, Spruce, Beech, Oak, mixed broadleaves
- 84 time study units in total

Time-study unit properties, same in all trials!



Sweden: Pine stands

Finland: Birch stands

Slovenia: Beech & Spruce stands

Stand conditions

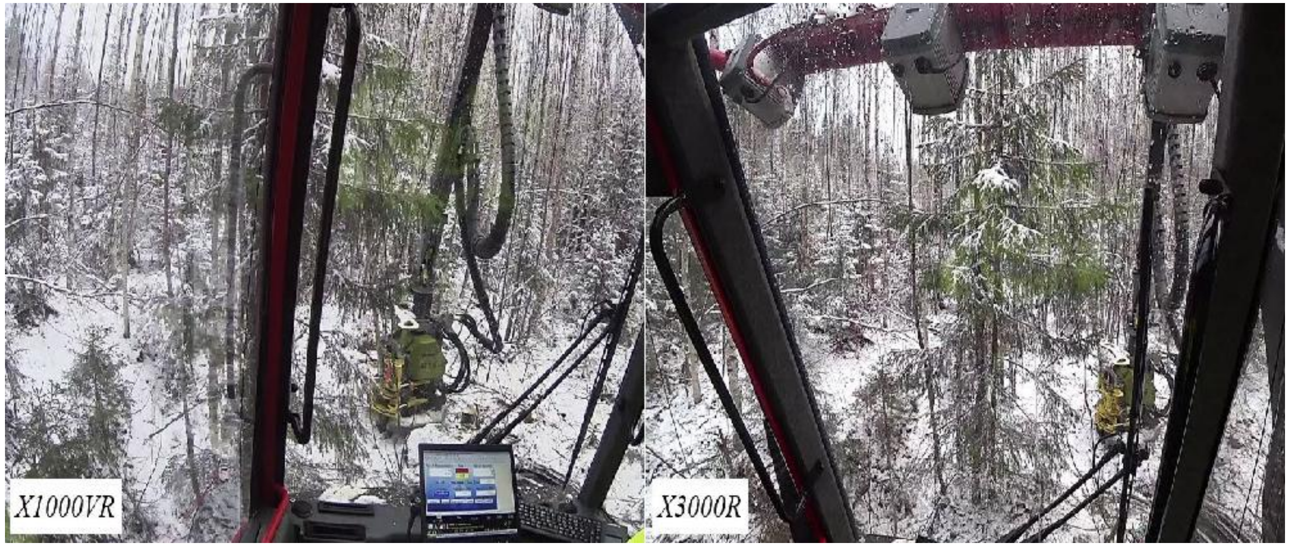
Block, country	Treatment	Species[1] (%)	DBH[2] (cm) arithmetic	DBH[2] (cm) baw[5]	Height (m) arithmetic	Height (m) baw[5]	Whole-tree volume[3] (dm^3) Arithmetic	Stand density (trees ha^{-1}) DBH[2] ≥1 cm	Stand density (trees ha^{-1}) DBH[2] ≥4 cm	Total biomass volume[4] (m^3 ha^{-1})	Basal area (m^2 ha^{-1})
1, Sweden	ST	Pine	4.3 (0.7)	11.4 (0.9)	5.8 (0.6)	10.3 (0.5)	22 (7)	10 590 (4 013)	3 360 (858)	212 (47)	27 (6)
	BCT	Pine	4.2 (0.6)	11.5 (1.2)	5.7 (0.5)	10.3 (0.6)	21 (7)	11 890 (3 914)	3 715 (1 213)	228 (57)	29 (7)
2, Finland	ST	Birch/spruce	4.3 (0.9)	8.1 (2.1)	**5.4 (1.3)**	**8.8 (2.6)**	15 (6)	6 817 (2 230)	3 383 (751)	**94 (21)**	**13 (3)**
	BCT	Birch/Spruce	4.8 (0.7)	8.8 (2.4)	6.1 (0.5)	9.6 (0.8)	19 (8)	8 717 (3 506)	4 783 (1 156)	152 (55)	22 (6)
3, Finland	ST	Birch	4.6 (0.2)	8.5 (0.4)	6.5 (0.5)	10.7 (0.2)	17 (1)	10 417 (1 361)	5 567 (751)	173 (13)	25 (2)
	BCT	Birch	4.4 (0.2)	8.1 (0.6)	6.4 (0.2)	10.3 (0.4)	15 (2)	10 700 (1 083)	5 750 (229)	162 (12)	23 (1)
4, Slovenia	ST	Mixed, main Hazel	5.6** (0.5)	11.4 (0.9)	8.0* (0.5)	11.7 (0.5)	24* (4)	10 350 (2 165)	5 544 (971)	241 (45)	**38 (7)**
	BCT	Mixed, main Hazel	4.9** (0.4)	10.9 (1.5)	7.5* (0.3)	11.2 (0.7)	19* (4)	11 817 (2 283)	**5 906 (1 345)**	221 (49)	35 (7)
5, Slovenia	ST	Beech	**3.3 (0.2)**	9.7 (2.6)	5.8 (0.2)	9.9 (0.9)	**10 (3)**	**11 920 (2 772)**	2 910 (765)	109 (14)	17 (2)
	BCT	Beech	4.0 (1.0)	**7.9 (1.2)**	6.6 (1.0)	9.7 (0.7)	11 (4)	11 210 (2 841)	3 950 (941)	111 (21)	20 (5)
6, Slovenia	ST	Spruce	**9.4 (0.3)**	14.3 (0.4)	**10.2 (0.1)**	13.7 (0.1)	**64 (6)**	**3 925 (106)**	2 900 (71)	252 (16)	37 (0)
	BCT	Spruce	8.1 (2.2)	**15.3 (2.3)**	9.1 (1.4)	**14.1 (1.2)**	63 (35)	5 025 (3 359)	**2 775 (1 167)**	**258 (37)**	35 (10)

Spain: Oak stands

Stand properties	Stand 1	Stand 2
Total density (trees·ha^{-1})	11590[a] (8300 – 14550)	13185[a] (5200 – 17550)
Density (treesDBH>1 cm·ha^{-1})	9185[a] (6650 – 11150)	9220[a] (4350 – 13200)
Average DBH (cm)	5.18[a] (4.25 – 6.05)	5.39[a] (4.00– 9.00)
Total dry weight [Estimated] (odt·ha^{-1})	48.04[a] (35.77 – 58.29)	60.17[b] (44.82 – 76.85)
Basal area (m^2·ha^{-1})	22.36[a] (17.95 – 27.25)	26.24[b] (21.77 – 31.75)
Dry unit weight [Estimated] (kg·treeDBH>1^{-1})	5.36[a] (3.56 – 7.50)	7.38[a] (3.40 – 16.87)

Time-study and analysis

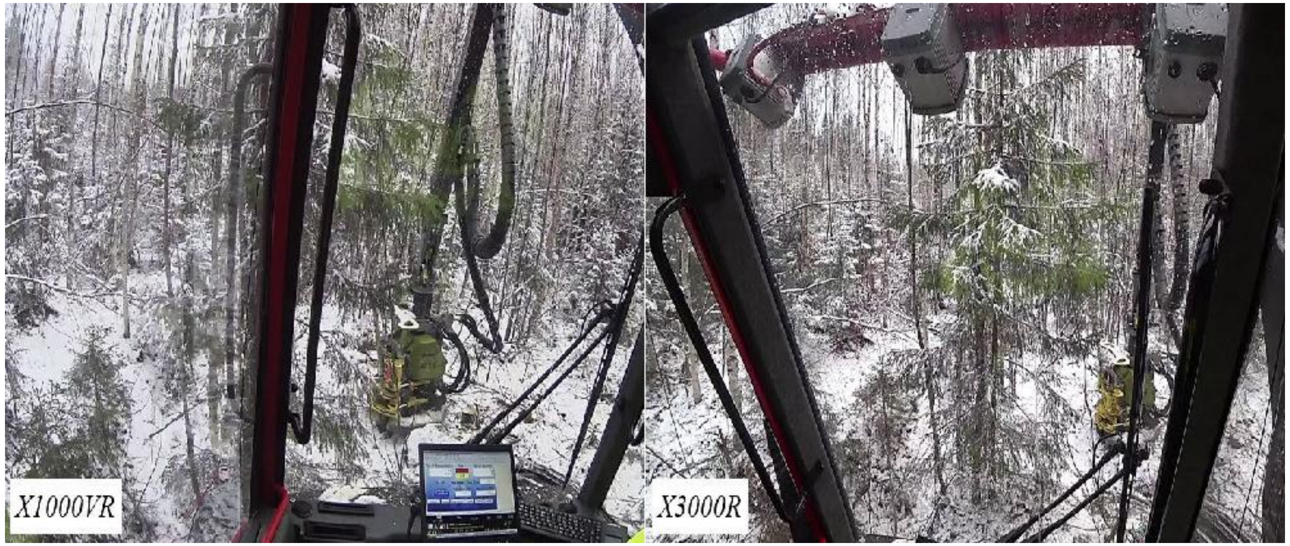
- *Cameras in cabing*
- *Continuos timing at office*
- *Standard separation of work elements*
  - *Incl. top-bucking*



Boom out	Boom out for felling or top bucking. Started when the empty boom moved out and ended when the boom slowed down for positioning the AFH on a tree.	1
Felling in the strip road	Felling of a tree in the strip road. Started when the boom slowed down for positioning the AFH on a tree and ended when the last tree in the crane cycle was cut and separated from the stump.	1
Felling in the stand	Felling of a tree in the stand (between strip roads). Started when the boom slowed down for positioning the AFH on a tree and ended when the last tree in the crane cycle was cut and separated from the stump.	1
Top bucking	Bucking of the standing tree at a height of ~4–5 m, in the stand or strip road. Started when the boom slowed down for positioning the AFH on a tree and ended when the last top bucking was done.	1
Boom in and bunching	Started when the AFH cut and separated the last tree in the crane cycle from the stump, and the boom was pulled against the machine, and ended when the AFH released the bunch.	1
Bucking of bunch	Started when the bunch was released on the ground and ended when the bucked part was put on the first part of the bunch.	1
Moving	Started when the harvester wheels turned and ended when the harvester wheels stopped.	2
Miscellaneous	Other activities such as trees being dropped and then picked up again, cutting roots of uprooted trees, etc.	1

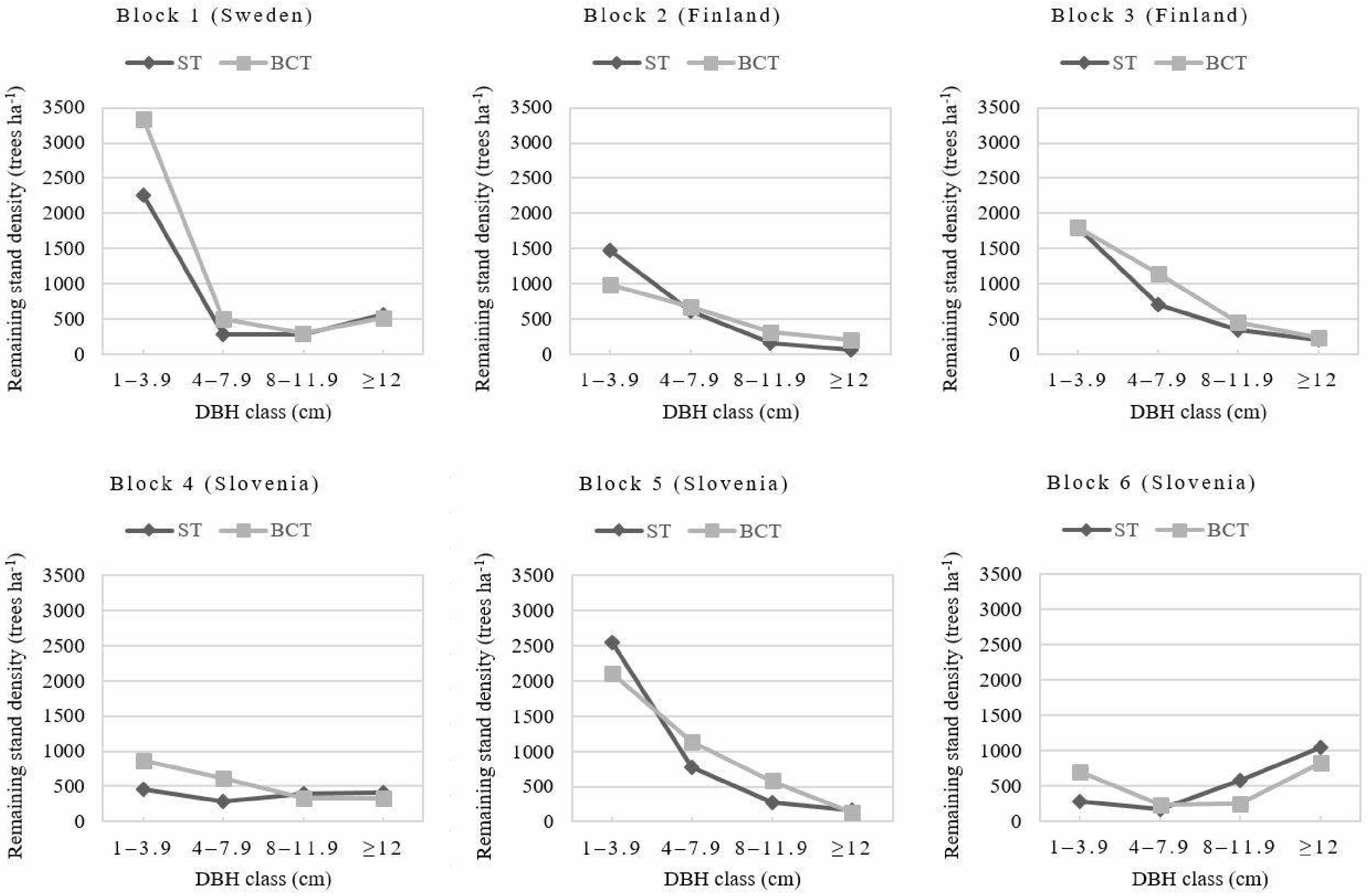
Time-study and analysis

- *Scaling of cut biomass and/or using biomass functions*
- *Effective time, no delays > 15min included*
- *Time consumption, s/tree*
- *Productivity, dry t/PMh*



Some Results, & Discussion

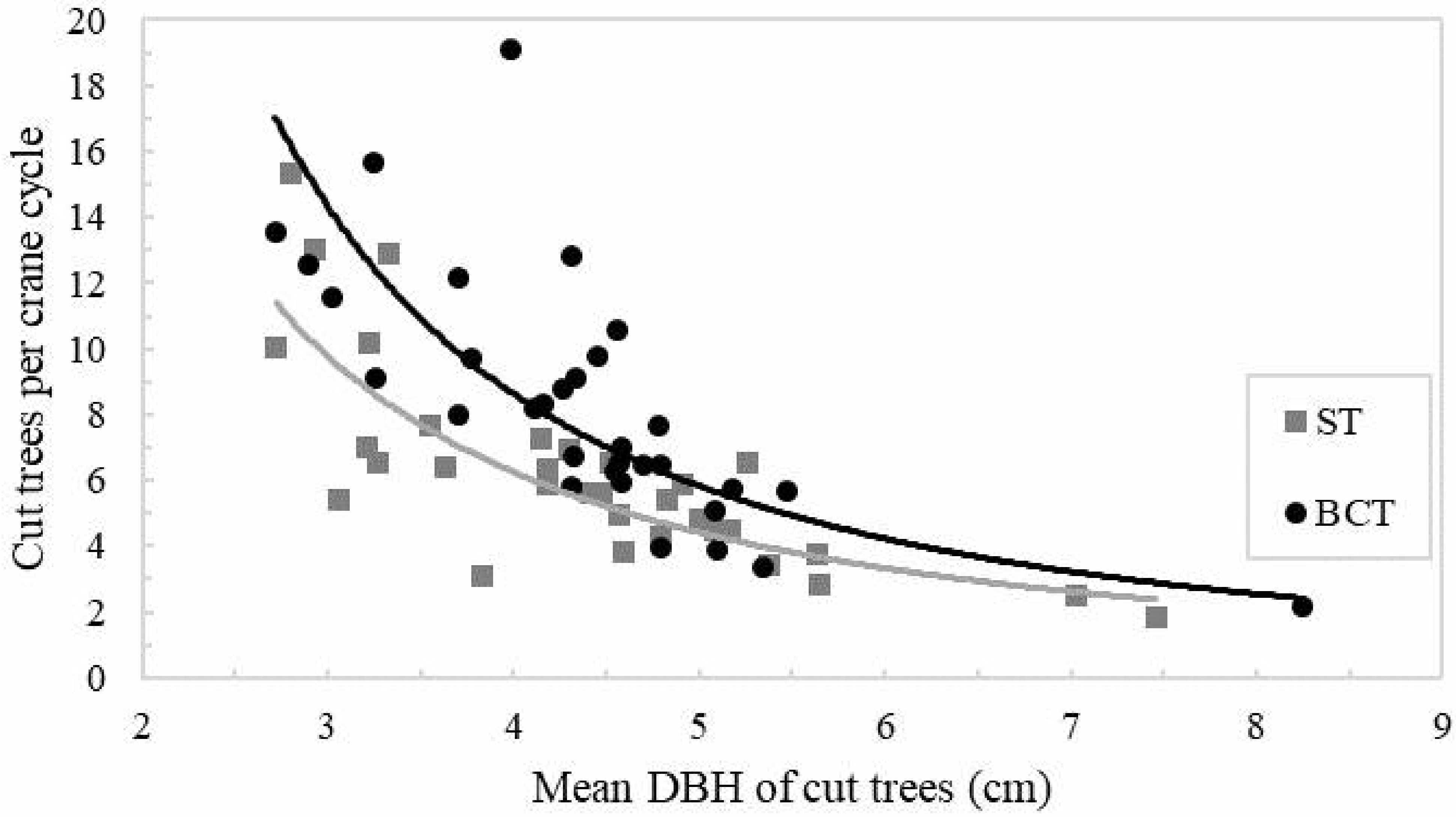
Thinning quality: Swe, Fin, Slo – no major diff.!



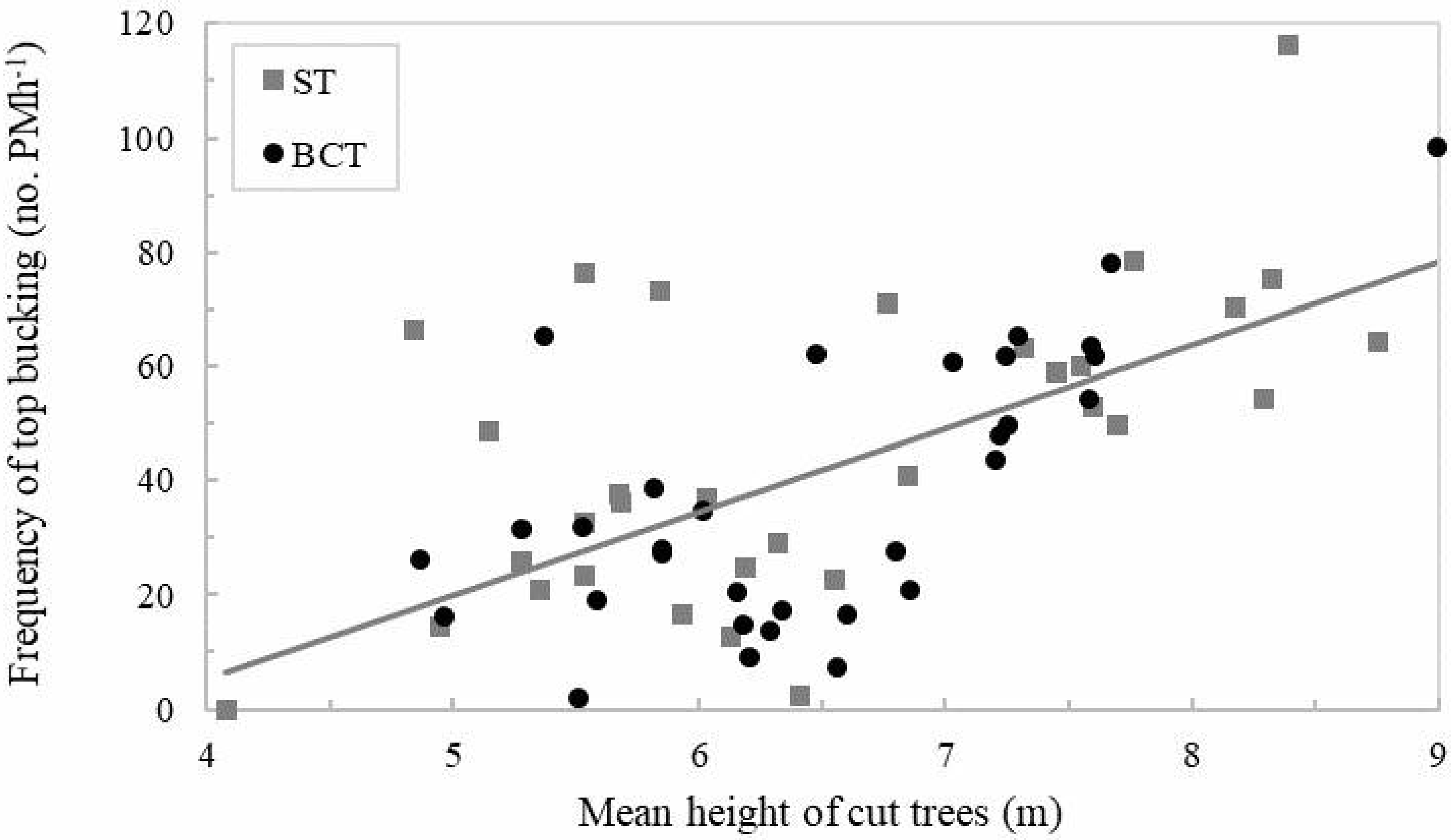
Time consumption: Swe, Fin, Slo – expected!

Work element	Treatment				
	ST (n=32)		BCT (n=32)		Diff.
	(sec $tree^{-1}$)	(%)	(sec $tree^{-1}$)	(%)	(%)
Boom out	**2.71****	**18.8**	**1.85****	**17.8**	**-32**
Felling in the strip road	2.03	14.1	1.78	17.0	-12
Felling in the stand	**4.23****	**29.4**	**2.98****	**28.6**	**-30**
Top bucking	**1.04***	**7.3**	**0.69***	**6.6**	**-34**
Boom in and bunching	**2.94****	**20.5**	**2.07****	**19.9**	**-30**
Bucking of bunch	0.43	3.0	0.34	3.2	-21
Moving	0.72	5.0	0.55	5.3	-29
Miscellaneous	0.28	1.9	0.17	1.6	-39
Total	**14.38****	**100**	**10.42****	**100**	**-28**

BCT promotes higher accumulation degree



Logic result...



Productivity: Swe, Fin, Slo

- On average 16% higher for BCT, P=0.054…
- Best fit model:

Table 9. Univariate linear regression models of harvester productivity (dry t PMh^{-1}), $y = \beta_0 + \beta_1 x$, where β_0 is a global intercept and β_1 is the slope for the covariate x. BAW = basal area weighted.

Model	R^2(adj)	Term	p-value	Coefficient			
				β_0			β_1
				Block	Treatment		
					ST	BCT	
1	0.676	Treatment	<0.0001				
		Block	0.090	1	2.5	3.5	
				2	2.5	3.5	
				3	0.9	1.9	
				4	1.3	2.3	
				5	1.3	2.3	
				6	2.4	3.4	
				1–6	1.8	2.8	
		Covariate: x = biomass removal (dry t ha^{-1})	<0.0001				0.0608

Discussion...

For BCT:

- In dense study units accumulation capacity was limited

- In study units with rel. large diameter trees (> ca 26 cm) selection were limited

Discussion...

In dense stands with tall trees >> “top bucking” was (almost) mandatory

Possible solution, feed-rollers for:

- Feeding & Bucking
- & (Compression processing)

Discussion...

Effects of the "horn-shaped" support plate:

- According to the machine operator we had in all countries (which worked with the standard C16 for several years), the handling of the stems was notably improved.

- (Additional technical tests to assess the "horns" are yet to be done)

C16 "SMALLWOOD version"

Conclusions

- **BCT render on average 16% higher felling and bunching productivity**
- **This difference is mainly due to:**
  - Effective crane movement
  - Slightly higher harvested tree sizes

- **No major differences between residual stands**
- **Further studies on current systems should focus on:**
  - Follow up studies
  - Forwarding with grapple-saw

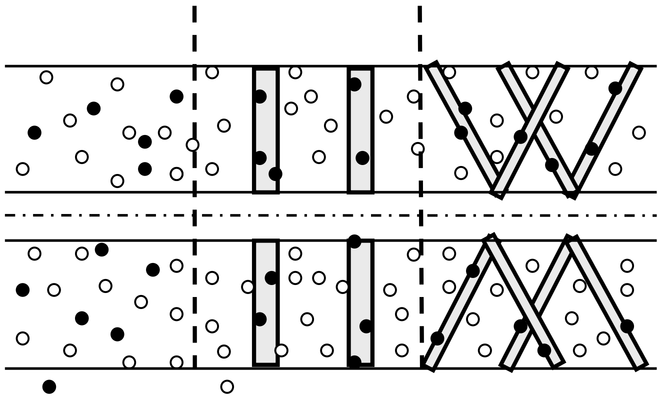
- …
- Supply cost analysis…

Conclusions

- New cutting technologies on the horizon..., requirements:
  - Continually cutting and accumulation in boom-corridors
  - Higher accumulation capacity
  - Bucking ability (alt forwarder with grapple-saw)
  - Compression processing
  - Selection of stands is crucial
  - E.g., too large trees in combination with “forced” selection >> wrong silvicultural goals!
  - ...

Conclusions

- **The technological development should firstly focus on systems intended for stands with an average tree size < ca 30 dm3**
  - **High share of the potential, no major competition, PCT is costly**
  - **Combination of new cutting techn. with bundling/compression**



Risupeto II felling head, capable of continuous cutting and accumulation. In time studies, the Risupeto II accumulating felling head was attached to the boom tip of the Kobelco SK140SRL-7 crawler excavator (see lower right-hand corner). Photos: J. Laitila and Reformet Oy

On the (Finnish) Horizon!

Matevz, how about harvesting cost-efficiency?

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