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Unit for Field-based Forest Research
Vindeln Experimental Forests

ISSN 1403-6398
ISBN 978-91-977896-4-6

This publication is available on http://pub-epsilon.slu.se:8080/perl/search/simple
Cover picture Sverker Lerheden
Layout Ulla Nylander, SLU

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Abstract

Jonsson, B. & Lerheden, S. Yield in a 30-year-old *Pinus contorta* stand in a harsh climate.

A 30-year-old *Pinus contorta* stand, growing on a mediocre site in a harsh climate, was studied with respect to the state and development of individual trees and of the stand as a whole. Competition for space in the crown stratum resulted in greater height increment, the denser was the stand (etiolation). Crown length was affected only to a small extent by stand density. The increase in height increment in dense stands was approximately equal to the decrease at the base of the live crown. This implies that *P. contorta* maintains a good crown length even in dense stands. In *P. contorta* stands, the trees can grow closely together, maintain a good crown length and exhibit good growth.

In the stand in question, stand volume and increment were directly proportional to the number of stems. A large number of stems resulted in good volume and increment.

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Yield in a 30-year-old *Pinus contorta* stand in a harsh climate

Background

A 36-ha stand of *Pinus contorta* Dougl., situated slightly more than 600 m a.s.l. in the southern part of Jämtland province, Sweden, is growing remarkably well, as are neighbouring stands of that species. The forest owner (Slottsvalvet) wished to have a yield estimate for the stand in question. An inventory, and subsequent statistical processing of the data, gave the results reported below.

Geographical location and climatic conditions of the stand

The stand is situated in Middle Sweden (62º21´N, 14º22´E, 600 m a.s.l.). The local climate is continental, and extremely cold compared to Swedish conditions generally (Hägglund & Lundmark, 1982).

The nearest meteorological station in a fairly similar climatic zone is Lofsdalen, 605 m a.s.l., *ca*. 65 km SW of the stand. For the period 1951–1980, the mean annual temperature at Lofsdalen was 1.1 ºC, and the mean monthly temperature in June, July and August was 10.7, 12.1 and 10.9 ºC, respectively (Eriksson, 1982). The mean annual precipitation was 663 mm during the same period, and the mean monthly precipitation in June, July and August was 76, 95 and 80 mm, respectively (uncorrected values); the corrected mean annual precipitation was 820 mm (Erikssson, 1983).

According to Odin *et al*. (1983), the duration of the growing season at the site is estimated at *ca*. 150 days (days with mean temperature >5 ºC). On average, the growing season begins around 5 May and ends around 5 October (threshold temperature +5 ºC). The temperature sum, derived by summing the diurnal mean temperatures for days with mean temperature >5 ºC, is *ca*. 700 units.

The soil moisture regime at the site is mesic and the soil is morainal. The stand also contains some Scots pine (*Pinus silvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.).

Field data collection

Ten sample points were laid out in the stand, in a square lattice. A circular plot, radius 7 m, was centred on each such point ('sample plots'). The following observations were made on each sample plot:

(1) All trees were numbered, diameter at breast-height (DBH, 1.3 m) was measured, tree species was recorded, as was any visible damage (which was uncommon; the timber was of good quality).

(2) Sample trees were measured with respect to current height and height five years previously, live crown base and bark thickness.

(3) An increment core was taken at breast height from every sample tree; the previous five years' radial increment was measured (±0.1 mm), and the number of growth rings to the pith was counted.

(4) On a circular plot, radius 10 m, around each sample point, two dominant-height trees were measured as described for the sample trees under point (3) above, for classification of site quality ('site index'), on the basis of dominant height on every such circular plot.

Processing and results

Site quality

The field-layer vegetation in the stand was abundant *Vaccinium myrtillus* (L.), with occasional occurrences of *Gymnocarpium dryopteris* (L.) and a few tall ferns.

According to the classification of Hägglund & Lundmark (1977, 1982), the site index is on average C19, *i.e.* the average dominant height for 50-year-old *P. contorta* is expected to be 19 m (SD 1.3 m).

Regression model for analysis of sample-tree characteristics

Since effects on tree growth may be expected to be multiplicative ('percentage'), a logarithmic regression model was chosen for the analysis, which implies that the dependent variable and the independent variables are expressed as natural logarithms. The following simple model was used:

ln(dependent sample-tree variable) = $\alpha + \beta_1$ ln(DBH) +
β_2 ln(basal area) + β_3 (CSI),

where
DBH is sample-tree diameter at breast height (cm),
Basal area is the sample plot stand's basal area in 2009 (m^2ha^{-1}),
CSI is the sample plot's site index (*i.e.* dominant height (m) for 50-year-old *P. contorta*).

Secondary volume functions

(1) For both sample trees and dominant height trees, DBH and height in 2009 and 2004 were available or were calculated. From this information, volume in 2009 and 2004 was calculated for every sample tree, from the (primary) volume function for *P. contorta* (PS-94); thus individual tree volumes (dm^3 o.b.) were obtained.

(2) From these estimated volumes, three secondary volume functions were derived, according to the following model (Jonsson 1978, 2001):

ln(single-tree volume, dm^3 o.b.) = $\alpha + \beta_1$ ln(DBH) + β_2 ln(basal area) + β_3 (CSI)

The three secondary volume functions are reported in Table 1. Note that in function 2, the dependent variable is estimated single-tree volume for 2004, and the independent variable is DBH for 2009. Figure 1 shows a comparison between estimated single-tree volume according to function 2, and the corresponding volume according to the volume function (PS-94).

The regression functions for the height curve, live crown base and crown length are shown in Table 1.

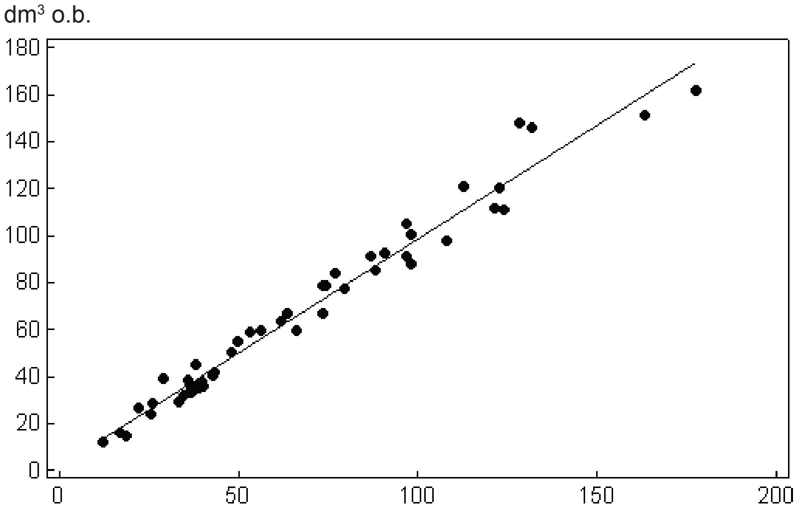

Figure 1. Tree volume in 2004 estimated by the PS-94 function, vs. tree volume in 2004 calculated from function 2.

Standing volume in 2009 and 2004

From the DBH of the calipered trees, sample plot basal area in 2009 and site index, the volume of every calipered tree in 2009 and 2004 was calculated by functions 1 and 2 in Table 1. In this way, the standing volume by sample plots in 2009 and 2004, and volume increment between the two years, was obtained.

Anomalous sample-plot values and adjusted volumes and volume increments

The sum of the sample-tree volumes according to the secondary volume functions, and volume according to the PS-94 volume function (quotient), is compared in Table 2. A deviation of the quotient from unity is regarded as a sample-plot anomaly. This is used to adjust the standing volume per sample plot as above. The adjusted volumes for 2009 and 2004, and the volume increment between these two years, are shown in Table 3 and Fig. 2 and 3. (The derivation and use of sample-plot anomalies was treated in detail by Jonsson (1995).)

Table 1. Regression functions for secondary tree volumes (functions 1–3), tree height, ('height curve', function 4), crown length (function 5) and height to live crown base (function 6) in 2009. Functions 1–4 are based on 48 observations (P. contorta sample trees); functions 5–6 on 43 observations

Dependent variable	Independent variable		β-value	p-value	SD	R^2
Function 1	Constant		−3.370	0.000***	0.072	
ln(PS-94 volume in 2009),	ln(DBH in 2009)	cm	2.241	0.000***		
dm^3o.b.	ln(basal area in 2009)	$m^2\ ha^{-1}$	0.062	0.035*		0.99
	ln(CSI)	m	0.584	0.004**		
Function 2	Constant		−3.651	0.000***	0.104	
ln(PS-94 volume in 2004),	ln(DBH in 2009)	cm	2.331	0.000***		
dm^3o.b.	ln(basal area in 2009)	$m^2\ ha^{-1}$	0.220	0.000***		0.97
	ln(CSI)	m	0.268	0.348		
Function 3	Constant		−3.533	0.000***	0.065	
ln(PS-94 volume in 2004),	ln(DBH in 2004)	cm	2.270	0.000***		
dm^3o.b.	ln(basal area in 2009)	$m^2\ ha^{-1}$	0.046	0.078		0.99
	ln(CSI)	m	0.573	0.002**		
Function 4	Constant		1.737	0.003**	0.075	
ln(tree height in 2009), dm	ln(DBH in 2009)	cm	0.322	0.000***		
	ln(basal area in 2009)	$m^2\ ha^{-1}$	0.067	0.028*		0.67
	ln(CSI)	m	0.633	0.003**		
Function 5	Constant		3.278	0.346	0.316	
ln(live crown base in 2009),	ln(DBH in 2009)	cm	−0.334	0.070		
dm	ln(basal area in 2009)	$m^2\ ha^{-1}$	0.516	0.000***		0.39
	ln(CSI)	m	−0.199	0.872		
Function 6	Constant		1.730	0.224	0.129	
ln(crown length in 2009), dm	ln(DBH in 2009)	cm	0.616	0.000***		
	ln(basal area in 2009)	$m^2\ ha^{-1}$	−0.090	0.095		0.64
	ln(CSI)	m	0.411	0.419		

Table 2. Plotwise comparison (quotient) between the sum of the volumes of sample trees according to the secondary volume function, and according to the PS-94 volume function

Sample plot No.	No. Sample trees	Year 2009	Year 2004
1	6	1.02	1.05
2	4	1.05	1.12
3	6	0.99	0.97
4	4	1.01	1.02
5	5	0.94	0.90
6	4	0.97	1.00
7	4	0.97	0.97
8	5	1.02	1.05
9	5	0.97	0.95
10	5	1.03	1.04
All	48	1.001	1.004

Table 3. No. stems, basal area, volume and increment in the stand

Plot No.	Species	No. stems 2009, ha^{-1}	Basal-area-weighted mean diameter 2009, mm	Basal area 2009, m^{2}ha^{-1}	Stand volume ha^{-1} and volume of mean stem, m^3 o.b.		Annual increment, m^{3}ha^{-1} o.b.
					Year 2009	Year 2004	
1	**Contorta**	**1884**	**155**	**31.3**	**185** **0.098**	**118** **0.063**	**13.4**
	Total	2144	152	33.7	198	127	14.2
2	**Contorta**	**1234**	**138**	**15.7**	**79** **0.064**	**45** **0.036**	**6.8**
	Total	1559	136	17.6	89	50	7.8
3	**Contorta**	**1949**	**145**	**29.3**	**180** **0.092**	**115** **0.059**	**13.0**
	Total	1949	145	29.3	180	115	13.0
4	**Contorta**	**325**	**150**	**5.6**	**29** **0.089**	**15** **0.046**	**2.8**
	Total	455	146	5.9	29	15	2.8
5	**Contorta**	**1819**	**132**	**21.4**	**122** **0.067**	**80** **0.044**	**8.4**
	Total	1949	134	23.7	135	90	9.0
6	**Contorta**	**974**	**133**	**12.2**	**67** **0.069**	**37** **0.038**	**6.0**
	Total	1234	132	13.8	76	42	6.8
7	**Contorta**	**780**	**145**	**11.3**	**57** **0.073**	**34** **0.044**	**4.6**
	Total	780	145	11.3	57	34	4.6
8	**Contorta**	**1559**	**151**	**24.4**	**136** **0.087**	**84** **0.054**	**10.4**
	Total	1624	150	24.6	137	85	10.4
9	**Contorta**	**844**	**166**	**16.5**	**97** **0.115**	**60** **0.071**	**7.4**
	Total	844	166	16.5	97	60	7.4
10	**Contorta**	**1429**	**121**	**15.0**	**77** **0.054**	**44** **0.031**	**6.6**
	Total	1494	121	15.1	78	44	6.8
All sample plots	**Contorta**	**1280**	**145**	**18.3**	**103** **0.080**	**63** **0.049**	**7.9**
	Scots pine	19	146	0.25	1.4	0.9	0.1
	Norway spruce	104	116	0.62	3.3	2.0	0.3
	Total	1403	144	19.1	108	66	8.3

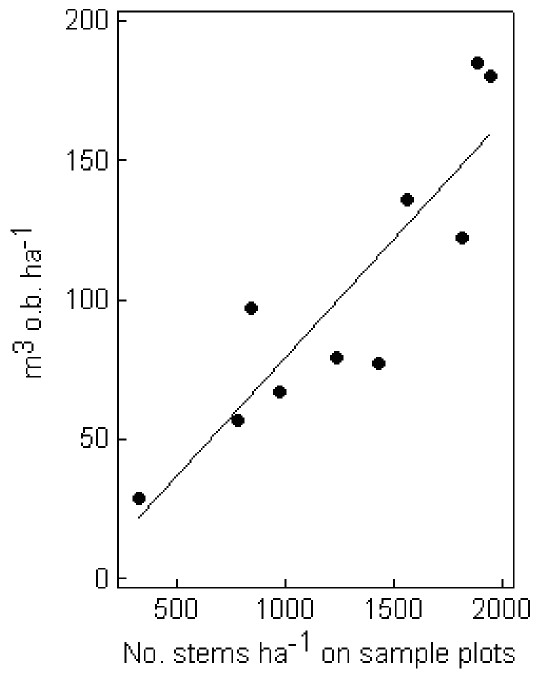

Figure 2. Standing volume of P. contorta in 2009.

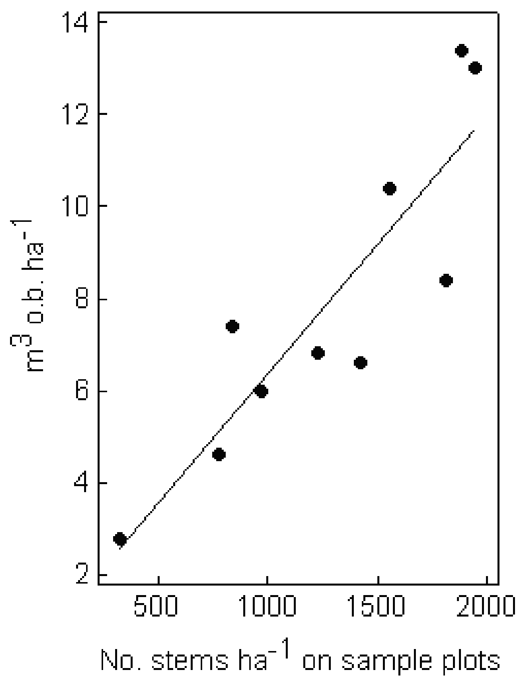

Figure 3. Annual volume increment in P. contorta.

Conclusions

At the same DBH, tree height in *P. contorta* is greater, the higher is stand basal area and site index. Competition for space in the crown layer in dense stands results in greater height growth (etiolation). This is in agreement with results for *P. silvestris* (Jonsson 2001, 2010).

Denser stands also lead to a higher live crown base, owing to lower light intensity in the lower part of the crown. Crown length, *i.e.* tree height minus height to live crown base, is affected only to a limited extent by stand density. Increased height increment in denser stands is about equal to the reduction of crown length in the lower crown. This implies that *P. contorta* maintains a good live crown length (and crown volume?) even in dense stands. In stands of *P. contorta*, trees can be closely spaced, achieve a good crown length and give good growth.

Table 3 shows yield figures which demonstrate that standing volume and increment in the stand in question were in direct proportion to the number of stems. A large number of stems gives a large standing volume and increment.

If the results from the present study can be generalised to similar sites, *i.e.* mediocre, high-level sites, then northern high-altitude sites in Sweden have a considerable yield potential.

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