GROWTH AND DEVELOPMENT OF STANDS OF CORSICAN PINE (PINUS NIGRA ARN. CALABRICA SCHN.) ON COARSE SANDS

P. Coppin[x] & N. Lust

[x]The field data of this study were collected and the results computed before the author P. Coppin entered FAO service.

1. Introduction and methodology

This study of stands of Corsican Pine (Pinus nigra Arn. calabrica Schn.) has a double aim :

- to gain an insight into the evolution of the stand density, diameter, basal area, height and crown development ;
- to formulate and discuss possibilities for silvicultural treatment and management, taking into consideration the present situation.

It should contribute to a better understanding of the growth and stand characteristics of the species, hence incorporating projections and estimates for the future.

The field data were collected in the state forest " Het Pijnven ", occupying a total area of 800 ha in the north of Belgium. Its three distinguishable soil types, podsols (P), shifting sands (S) and a transition phase (P/S), are all extremely poor. General site characteristics are a topsoil containing about 1 % of clay and 5 % of loam with a PH varying between 4.2 and 4.5, a groundwater-table fluctuating about a depth of 1 m., a mean annual temperature of 9.3°C, an average annual precipitation of 810 mm and an altitude above sea level between 50 and 58 m.

Afforestation activities in " Het Pijnven " date from the beginning of this century. Between 1913 and 1929, only Scotch Pine was planted. Today almost 50 % of the established plantations are pure stands of Corsican pine.

In this study, all stands of Corsican Pine have been grouped in age-classes, each covering a period of 10 years. Ten (or eventually less) trial plots were demarcated inside each class, scattered as good as possible. The individual areas of the plots so chosen are, according to age, 0.025 ha, 0,05 and 0.1 ha. They contain a minimum of 29, a maximum of 87 and a average number of 48 stems.

Each tree had its diameter measured and social position determined. The height and the projections of 2 crown diameters at right angles of at least 20 % of all trees from each stratum were also recorded. In addition, 250 samples, dispersed over all age classes and social strata, were taken with the Pressler-bore. (Table 1).

2. Analysis of the present situation

2.1. The evolution of the stand density

While actual stocking is liable to fluctuation within the age classes, its overall variation is rather uniform (S % = 25), except for the class 21/30, where all results are heavily influenced by the very densily stocked trial plot nr. 11 (Table 2).

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Table 1 : Principal characteristics of the stands of Corsican Pine

n°	age (y)	soil type	planting distance	stems/ha	$\bar{d}$ (cm)	basal area (m^2/ha)	mean height (m)	mean crown diameter (m)
1	11	P	1.25x1.25	6,000	4.2	9.5	2.5	1.2
2	13	P	1.25x1.25	4,800	5.1	11.1	3.4	1.2
3	14	P	1.25x1.25	4,500	6.5	16.5	4.3	1.7
4	15	P	sown	5,300	7.3	22.3	5.8	1.9
5	17	S	1.00x0.80 1.00x1.00	9,200	6.7	38.3	5.3	2.2
6	18	P/S	1.00x1.00	5,500	9.3	40.8	7.4	1.7
7	18	P/S	1.00x1.00	5,100	9.2	35.2	7.5	2.2
8	18	P/S	1.00x1.00	6,200	9.1	43.9	6.1	1.4
9	19	P	1.00x0.80	7,000	7.4	38.0	4.9	1.7
10	19	P	1.00x0.80	8,400	6.1	32.1	4.8	1.6
11	22	P/S	1.00x0.80	7,600	8.1	41.5	7.7	1.5
12	23	P	1.00x0.80	2,800	12.0	35.7	10.7	2.2
13	26	P	1.00x0.80	2,200	12.6	30.5	11.2	2.6
14	26	P	sown	4,350	9.7	34.2	10.7	1.6
15	27	P	1.00x0.80	1,900	14.4	32.6	12.7	2.5
16	27	S	1.00x0.80	2,750	10.9	28.6	9.1	2.1
17	29	P	1.00x0.80	2,000	13.2	29.1	11.7	2.8
18	29	P/S	1.00x0.80	2,250	12.2	28.5	12.2	2.0
19	29	P/S	1.00x0.80	1,950	13.6	31.4	12.6	1.7
20	29	P/S	1.00x0.80	1,700	15.1	32.1	11.6	2.3
21	31	P	1.00x0.80	2,550	13.3	37.6	11.5	3.0
22	34	P	1.00x0.80	1,650	15.3	33.0	12.6	2.7
23	34	P	1.00x0.80	2,200	13.9	35.5	11.7	2.9
24	34	P	1.00x0.80	1,950	15.0	35.3	11.3	3.4
25	34	P	1.00x0.80	1,600	15.7	32.5	11.6	3.3
26	34	P	1.00x0.80	2,100	13.4	32.3	11.4	3.0
27	36	P	1.00x0.80	2,150	14.8	39.8	12.5	3.0
28	37	P	1.00x0.70	2,350	14.0	38.8	12.3	3.1
29	39	P	1.00x0.80	1,650	15.0	32.5	11.6	3.2
30	39	P	1.00x0.80	1,040	19.7	34.2	13.7	3.2

Table 1 : continuation

n°	age (y)	soil type	planting distance	stems/ha	$\bar{d}$ (cm)	basal area (m^2/ha)	mean height (m)	mean crown diameter (m)
31	40	P	1.00x0.80	780	21.1	28.6	16.2	3.3
32	40	P	1.00x0.80	900	20.9	32.2	15.2	3.5
33	40	P	1.00x0.80	1,220	17.9	32.4	13.8	3.2
34	43	S	1.00x0.80	1,440	17.6	38.0	13.6	3.3
35	43	S	1.00x0.80	1,480	17.5	38.4	13.7	3.5
36	44	P	1.00x0.80	1,860	21.1	31.6	17.9	3.4
37	44	S	1.00x0.80	1,000	20.7	35.3	14.2	3.9
38	45	S	1.00x0.80	920	20.2	31.9	15.5	3.8
39	45	S	1.00x0.80	1,060	21.5	40.6	14.9	2.9
40	47	S	1.00x2.00	580	28.7	38.9	20.5	2.7
41	63	P	1.00x0.80	390	28.9	26.3	19.8	4.7
42	63	P	1.00x0.80	620	29.1	43.2	19.2	4.1
43	63	P	1.00x0.80	350	32.7	30.3	20.4	4.6
44	63	S	1.00x0.80	350	36.7	28.7	21.4	8.0
45	63	S	1.00x0.80	380	34.1	35.5	22.1	5.1
46	65	P	1.00x0.80	580	31.9	47.8	21.5	5.2

Table 2 : The evolution of the stand density

age class	mean age (y)	mean number of stems/ha	s	s%
11/20	16.2	6,200	1,559	25
21/30	26.7	2,950	1,803	61
31/40	35.2	1,924	443	23
41/50	43.1	1,024	285	28
61/70	63.3	445	122	27

The diversity in the class 11/20 is largely due to differences in establishment methods. In the plots 1,2 and 3 6,400 seedlings were planted per ha. After 11 to 14 year, before the first thinnings, respectively 84 %, 75 % and 70 % of them were still present,indicating a relatively low natural mortality percentage (20%). In plots 5 to 10, with a mean age of 18,2 years, and an average stocking of 6,900 trees/ha, actual density is high and demonstrates that first thinnings are carried out too late or are not sufficiently strong.

By age 35 the mean stocking still amounts to 1,900 trees/ha. This figure too appears extremely high and questions arise about the advisability to bring it down to about half. Plot 30 certainly points in that direction.

During the next 30 years stand density is reduced by 75% so that at age 63 an average of 445 trees remain. However, a few plots comprise only 350 specimens/ha.

Intensive thinning generally starts at age 35, which is demonstrated by the significant reduction in the number of stems between 35 and 43 years from 1,924 to 1,024: in 8 years 46 % of the standing stock is removed. This very high percentage reflects a negative thinning approach, principally clearing out the smallest, retarted and dominated specimens.

The correlation between age (x) and stocking (y) is normaly determined by the exponential function $y = a.e^{bx}$. With the densities observed in plots, the following frequency curve is obtained : $y = 143634.e^{-0.0583x}$ where $r = 0.93$. Compared with the yield class 12 curve, proposed by the U.K. Forestry Commission, the stocking of the trial plots is considerably higher for the first sixty years (fig. 1). The ratio between the actual number of stems and the stocking, calculated for yield class 12 of the Forestry Commission, is the following.

age	15	20	25	30	35	40	45	50	55	60
N/y.cl.12	1.48	1.62	1.99	2.11	2.05	1.90	1.69	1.46	1.22	1.00

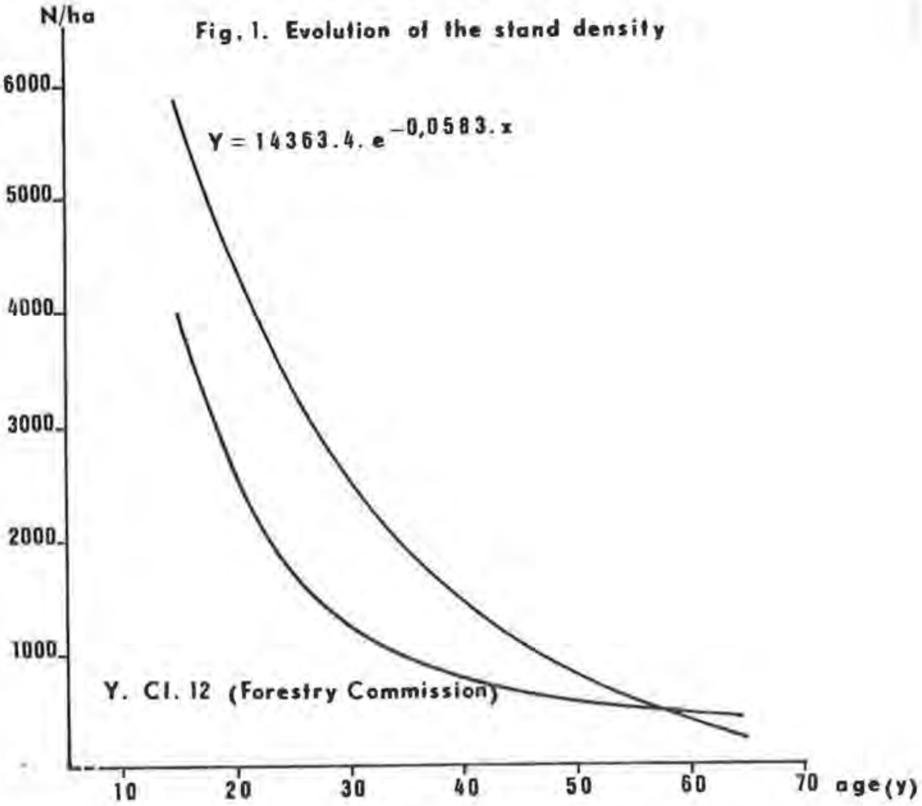
The maximal discrepancy between the two frequency curves occurs at age 30 : the stocking in the trial plots exceeds by 100 % the value obtained through the yield class 12 formula.

2.2. The diameter growth

Young stands of Corsican Pine are rather heterogeneous in growth and show big variances in diameter and height. The relationship betwee the mean diameter (d_m) and the age (y) can be summarized in a simple linear function (table 3 and fig. 2) :

Table 3 : The diameter growth

age class	mean age (y)	mean diameter (cm)	s	s%
11/20	16.2	7.1	1.7	24.6
21/30	26.7	12.2	2.1	17.6
31/40	35.2	15.1	1.8	12.2
41/50	43.1	20.7	3.2	15.5
61/70	63.3	32.2	3.0	9.3



Corsican Pine reaches a mean girth of 70 cm (which is the local minimum girth for industrial sawnwood production) after 46 years, of 90 cm (regular dimension for sawnwood production) at age 58 and the 120 cm girths limit for economically optimal conversion in sawnwood will be attained after about 76 years. Since thinning products have always inferior dimensions than those of the standing stock, the minimum age for the production of good quality sawnwood can be set at 50-55 years, while excellent lumber will be extracted from age 80 on.

The diameter increment is obviously strongly influenced by the social position of the trees :

$$d_{dominant} = 1.04 + 0.53\ x \quad \text{with } r = 0.97$$
$$d_{codominant} = 0.61 + 0.39\ x \quad \text{with } r = 0.97$$
$$d_{dominated} = 0.68 + 0.18\ x \quad \text{with } r = 0.86$$

Differentiation starts very early in Corsican Pine forests. At age 10, differences are already marked and 10 years later, at the moment of the first intervention, the strata are clearly defined. As a consequence, it is relatively easy to identify, at an early stage, which trees could presumedly be part of the final stand. Hence, a positive thinning method is required from the beginning. (high thinning).

A lower storey (dominated trees) is rare in stands older than 45 years, since most such specimens have already disapeared after 30 years. Although thinning activities were actually concentrated in the intermediate storey, the discrepancy in diameter between the codominating and dominating trees increases steadily at a yearly rate of 0.14 cm (0.53 - 0.39).

The relative ratio, however, remains quite stable over the age classes (table 4) : codominant trees have their mean diameter one third less than dominating companions.

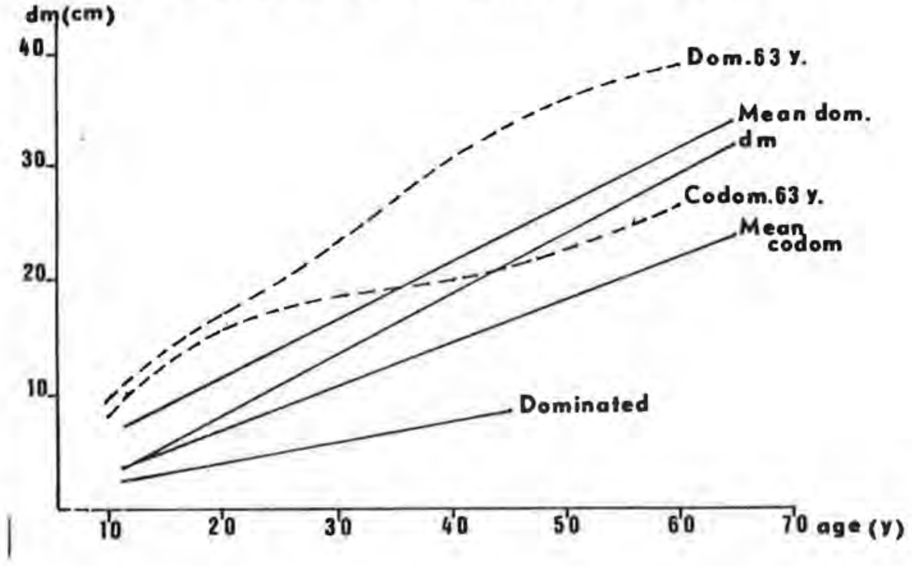
Table 4 : Diameter growth in the respective social strata

age class	average (cm)	mean diameter (cm) pro stratum			ratios between the strata	
		upper	medium	lower	m/u	l/u
11/20	7.1	9.1	6.1	3.5	0.67	0.38
21/30	12.2	14.2	9.2	5.7	0.65	0.40
31/40	15.1	19.8	12.9	6.2	0.65	0.31
41/50	20.7	24.9	17.0	7.9	0.68	0.31
61/70	32.2	35.5	24.6	-	0.69	-

Social promotion, or the passage of an individual from a lower stratum into a higher one, seems practically impossible in these homogeneous, man-made forests.

The diameter increment of the dominant and codominant trees has been analysed in five 63-years old trialplots (fig.2).

Fig 2 Relationship between age and diameter



It appears that, while the growth of the upper canopy has been rather regular, other trees, at the moment of the field investigations forming part of the middle storey, have matched this pace during the first 25 years, leading to the assumption that they belonged to the same upper canopy during that period. Social degradation resulted in a slowdown for about 20 years. Thereafter, from age 45, growth recovered to attain, after 53 years, about the same increment as the dominant specimens (3.3. - 3.9 cm).

These facts, together with the study of the periodic diameter incremant (table 5), allow for the following deductions :

Table 5 : Periodic (period = 2 years) diameter increment in cm.

Period (y)	6-8	8-10	10-12	12-14	14-16	16-18	18-20
Incr.(cm)	1.22	1.67	1.62	1.28	1.18	1.15	0.95
Period (y)	20-22	22-24	24-26	26-28	28-30	30-32	32-34
Incr.(cm)	1.29	1.47	1.95	0.86	1.57	2.07	1.34
Period (y)	34-36	36-38	38-40	40-42	42-44	44-46	46-48
Incr.(cm)	1.24	1.39	1.22	0.71	1.12	1.15	0.97
Period (y)	48-50	50-52	52-54	54-56	56-58	58-60	60-62
Incr.(cm)	0.72	0.72	0.84	0.74	0.58	0.76	0.82

- The growth rate reaches a first maximum at age 10, immediately after the primary canopy closing (usual spacing 1.00 x 0.80 m).
- As a consequence of initial competition and the absence of any silvicultural treatment, the growth rate keeps diminishing during the following 10 years.
- A first moderate intervention results in a slight recovery, but soon (at age 28) a new minimum is attained, principally because of the very low intensity and the lack of effect of the subsequent low thinnings. It is in this period (from age 25 on) that the dominant trees differentiate and that the codominant tendencies of other specimens become apparent, the latter forming the middle canopy now present in 63 years old stands.
- Diameter growth culminates at age 32. This results not only from the inniate growth rhythm of the species, but also from the sudden heavy thinnings that were affected after 25 years. Corsican Pine generally reacts one to two years after the intervention by an increase in the diameter increment.
- The effect of the heavy thinnings is of short duration. Corsican Pine not only reacts to thinning but also to the reclosing of the canopy afterwards: diameter increment diminishes again.
- From the age of 50 years on the reaction of the Corsican Pine to liberation cuttings is very feeble.

The point of growth culmination has passed and the ability to recuperate has almost vanished. Internal competition diminishes, allowing almost normal growth for all trees, even these in the middle storey.

The relationship between diameter (d_m) and stand density (N) is mathematically approximated by the calculation of the coefficients :

$$\log N = 5.175 - 1.651 \log d_m \quad \text{with } r = 0{,}96$$

The density of the stand strongly influences its mean DBH. Since Corsican Pine forests are mainly destined for industrial sawnwood production, it is advantageous to strive for a large diameter on a short rotation period. Consequently dense stocking should be avoided.

2.3. The basal area

The value of the basal area in young Corsican Pine forests is quite high, with a maximum attained between age 30 and 40. From then on its level remains stationary at about 35 m^2 (table 6).

Table 6 : The evolution of the basal area

age class	mean age (y)	mean basal area (m2)	s	s%
11/20	16.2	28.8	12.8	44.5
21/30	26.7	32.4	4.0	12.3
31/40	35.2	35.2	2.8	7.9
41/50	43.1	34.8	4.0	11.5
61/70	63.3	35.3	8.6	24.3

In the age-class 11/20, the basal area is strongly determined by stand density. Those block with an original planting distance of 1.25 m x 1.25 m and a stocking of 4,500 trees/ha at age 14 attain a basal area of merely 16.5 m^2/ha. Plots 6 and 8, planted at 1.00 x 1.00 m and now 18 years old, with 5,500 respectively 6,200 trees per ha, have much larger basal areas, namely 40.8 m^2 and 43.9 m^2. These values lie even higher than those in plots 9 and 10, although the planting distance in the latter was only 1.00 x 0.80 m and the number of stems after 19 years is still very high : 7.000 and 8.400 trees/ha.

The relative reduction of the basal area in excessively dense stands results from the fact that under conditions of severe competitoin diameter increment falls more sharply than height growth.

The high values of the basal area indicate the density of stocking in the plantations before the first thinning. Individual growth-space is so restricted, that the stands as a whole lose their stability. Although serious reduction of numbers is required in such cases, action should not be taken too suddenly. First thinnings should thus necessarily be of a low intensity in spite of the above mentioned factors. Corsican Pine requires a 15 year period to adjust the wider spacing. At age 35, intensive thinnings can finally be carried out without risks.

Summarizing the situation it must be stressed that stocking is so dense between age 15 and 20, that at the outset only low intensity thinning may be applied. The initial high stand density results in still very dense 35 year old plantations and is, to a big extent, responsible for the instability of the stands and their sensitivity to windfall and storm-damage. The absence, because of its so-called non-profitable-character, of any silvicultural treatment between 1 and 20 years of age is to be considered extremely harmful for the further development of the forest.

It is necessary to intervene at an early stage, since it must be avoided that the basal area reaches a value of 30 m^2 too early. Prompt interventions render over-heavy thinnings unnecessary later on and strenghten the general stability of the plantations, whereby the risk of storm damage is considerably diminished.

Interesting in this aspect is the fact that in a nearly 70 year old plantation of Corsican Pine, to a small percentage (10 %) mixed with broadleaved trees, the stability is near perfect, while in the surrounding homogeneous stands substanstial windfall damage can be observed.

The presence of broadleaved trees alone certainly does not explain everything. It is also important that this particular forest, because of the explicitely required preservation of the broadleaved trees, necessarily had been thinned at a very early stage and that the stand density had always been kept at a low level. The broadleaved trees, by their presence, contribute, especially in winter, to the diversification of the forest cover. Particularly the alternation in the canopy between closed and open spaces increases the natural resistance against storm damage.

Taking into consideration all trial plots, the following regression curve represents the relation between basal area (m^2/ha) and age :

$$g = 27.26 + 0.17\ x \text{ with } r = 0.34 \text{ and } F = 5.63$$

It has a low reliability margin because of the great variation of the basal area. It progresses in practically the same way as the one for yield class 12 (U.K. Forestry Commission), but generally on a higer level (+ 5m^2 and + 4 m^2 in older stands). As with all other species, the basal area increases steadily. It therefore is illogical, unfavorable and probably also impossible to keep the basal area at a prefixed level of p.e. 25, 30 or 35 m^2. A soo high basal area in young stands tends to increase their unstability. Keeping the basal area at a lower level necessitates early interventions, which secure a positive result, on stand stability, but do not guarantee the highest final yield as assimilation capacities are not exploited optimally.

2.4. Height growth

Corsican Pine is characterized by a very slow growth in its establishment period. After a few years it increases to remain at a high level for a considerable lapse of time.

(tables 1 and 7)

Table 7 : Evolution of the height

age class	mean age (y)	mein height (m)	s	s%
11/20	16.2	5.2	1.6	30.7
21/30	26.7	11.0	1.6	14.3
31/40	35.2	12.0	0.8	6.3
41/50	43.1	15.6	2.2	14.0
61/70	63.3	20.7	1.1	5.4

The average height of ten year old Corsican Pine stands attains 3 m. After 35 and 65 years the respective heights are 12.5 and 21 m.

In the age class 11/20, the height is quite variable. The 18 year old plots 6 and 7 reach an average of 7.4 m respectively 7.5 m, while the 19 year old plots 9 and 10 attain a height of only 4.9 and 4.8 m.

Normally discrepancies in height can be explained by differences in site quality. Plots 6 and 7 are located on P/S sites, while 9 and 10 are growing on P soils. Hence it might be deduced that P/S soils, and naturally S soils offer a better site quality than P soils. The comparison of representative plots however, shows that the height at one time is optimal on S soils, at another on P soils (plots 11-12, 15-16, 29-30, 35-36).

The hypothesis that height growth is initially better or less inhibited on S soils then on P soils, is very questionable.

The relation between height growth and number of stems is equally interesting. Although it is not possible to elaborate a uniform ratio between mean height and stand density (tables 1 and 8) in stands of the same age, an inferior number of stems generally results in a superior height growth.

Nevertheless, the evolution of height growth is rather complex. The influence of the site is not immediately clear. An extremely high stand density has a rather negative influence on its height. The relation between age (t) and height (y) can be calculated using the Backman growth-formula :

$$\log y = k_0 + k_1 \log t + k_2 \log^2 y$$

In this way the following equations have been elaborated for the mean height and the height of the upper and middle strata :

- mean $\log y = 1.018 + 1.171 \log. t - 0.533 \log_2^2 t$
- dominant $\log y = 0.905 + 1.130 \log. t - 0.558 \log_2^2 t$
- codominant $\log y = 1.266 + 1.551 \log. t - 0.690 \log^2 t$

The equations allow the deduction of growth curves with the following general aspects :

$$y = Co \int_{-\infty}^{x} e^{-x^2} dx \qquad \text{(fig.3)}$$

with y = height at a certain age
x = organical age = $C_1 + C_2$ log. t
t = age

the coefficient for the different curves are :

	Co	C_1	C_2
average	32.4602	1.1074	-2.2566
dominant	27.3237	1.1336	-2.1638
codominant	22.6423	1.2601	-2.3308

Table 8 : Relationship between number of stems and mean height

plot n°	soil	age (y)	number of stems/ha	mean height (m)	difference in m	difference %
6	P/S	18	5,500	7.4	2.1	40
5	S	17	9,200	5.3		
12	P	23	2,800	10.7	3.0	39
11	P/S	22	7,600	7.7		
15	P	27	1,900	12.7	2,0	19
14	P	26	4,350	10.7		
23	P	34	2,200	11.7	0,1	-
25	P	34	1,600	11.6		
30	S	39	1,040	13.7	2,1	18
29	P	39	1,650	11.6		
31	P	40	780	16.2	2,4	17
33	P	40	1,220	13.8		
36	P	44	860	17.9	4,2	31
35	S	43	1,480	13.7		
40	S	47	580	20.5	5.6	38
39	S	45	1,060	14.9		
43	P	63	350	20.4	1.2	6
42	P	63	620	19.2		

The logarithmic equations and the Backman formula permit the calculation of actual and mean annual height growth at different stages (table 9). The theoretically computed culmination points of the actual height growth as well as the corresponding bending points on the curve occur at the following

Table 9 : Actual and mean yearly h hgt growth

age (y)	actual yearly height growth (cm)			mean yearly height growth (cm)		
	domin.	average	codom.	domin.	average	codom.
5	0.41	0.35	0.30	0.25	0.21	0.16
10	0.47	0.42	0.39	0.35	0.30	0.26
15	0.45	0.42	0.40	0.30	0.34	0.31
20	0.42	0.40	0.38	0.40	0.36	0.33
25	0.38	0.38	0.36	0.40	0.36	0.34
30	0.35	0.35	0.33	0.39	0.36	0.34
35	0.32	0.33	0.31	0.39	0.37	0.34
40	0.30	0.31	0.28	0.38	0.36	0.33
45	0.27	0.29	0.26	0.37	0.35	0.32
50	0.25	0.27	-	0.36	0.34	-
55	0.24	0.25		0.35	0.33	
60	0.22	0.24		0.34	0.33	
65	0.20	0.23		0.33	0.32	
70	0.19	0.21		0.32	0.31	
75	0.18	0.20		0.31	0.31	
80	0.17	0.19		0.30	0.30	
85	0.16	0.18		0.29	0.29	
90	0.15	0.17		0.28	0.29	
95	0.14	0.16		0.28	0.28	
100	0.13	0.16		0.27	0.27	

moments and are of the following extent :

	first bending point		culmination point		second bending point	
	Extent	Age	Extent	Age	Extent	Age
dominant	0.07	0.6	0.47	10.3	0.41	21.5
mean	0.06	0.7	0.42	12.6	0.37	26.4
codominant	0.07	1.2	0.40	13.3	0.35	26.9

Corsican Pine with its initial very slow height growth reaches relatively rapidly the culmination point between the tenth and thirtienth year. At that moment the yearly shoots attain a lengt of 40 to 50 cm.

There remains the question which heihgt the trees will obtain at the moment of commercial maturity. The presently oldest plantation (age 65) reaches an average height of 21 m. The Backman formula calculates 27 m at age 100. The yearly vertical growth, which still amounts to 23 cm after 65 years, would then be decreased to 15 cm.

From another point of view it is a well known phenomen that differentiation is very marked in the Corsican Pine stands and, that it starts very early (Table 10).

Table 10 : The differentiation of the vertical growth

Age (years)	height (m) domin.	average	codom.	Differences between dom. and codom. trees m	%
5	1.27	1.04	0.81	0.46	57
15	5.81	5.10	4.61	1.20	26
25	9.99	9.10	8.44	1.55	18
35	13.53	12.64	11.76	1.77	15
45	16.51	15.73	14.57	1.94	13

The differentiation is, relatively, the most accentuated in younger stands. The limited shade tolerance of the species but especially the applied system of low thinning are the reasons of the diminishing differentiation later on. Already at age 50 the stand can be considered uniform, since height discrepancies are very limited and the number of codominant trees has been reduced drastically.

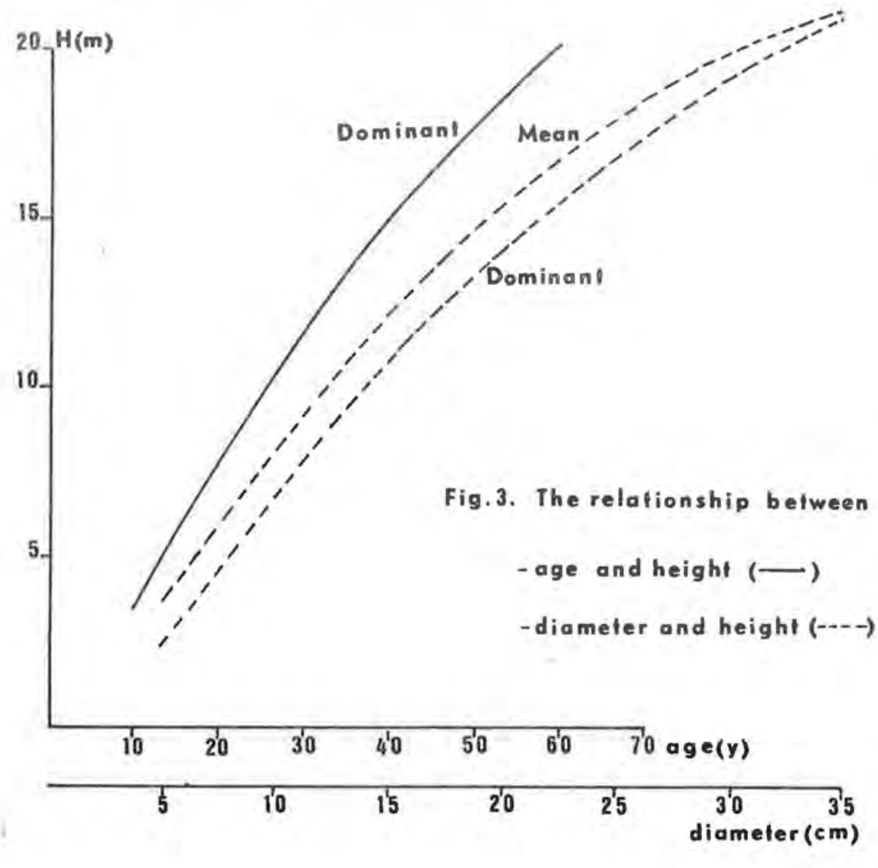


Fig.3. The relationship between
- age and height (——)
-diameter and height (----)

The relationship between diameter and height has been calculated on the basis of the values measured in all plots (fig. 3) :

average $y = 1.11259 + 1.080\ x - 0.01252\ x^2$
upper storey $y = 2.26383 + 1.023462 - 0.01016\ x^2$
with y = height and x = DBH (at 1.3 m).

The trees of the upper canopy have a lower height for a given diameter than the codominants. In the juvenile phase, when many of them are still present in the middle stratum, this is especially remarkable. This phenomenon explains the striking variability of the diameter growth : on the one side the codominant trees grow less high and have for a certain height only a small diameter and on the other side the dominating trees show naturally a superior height and a larger diameter for a certain height.

2.5. The development of the crown

2.5.1. The crown diameter

Although the plantations are certainly not examples of ideal structuration, crown dimensions have been measured in all of them.

Table 11 : The evolution of the crown diameter

age class	mean age (y)	mean crown-diameter (m)	s	s%
11/20	16.2	1.70	0.3	19.4
21/30	26.7	2.13	0.4	20.5
31/40	35.2	3.08	0.2	6.6
41/50	43.1	3.35	0.4	10.9
61/70	63.3	5.28	1.4	26.3

As is the case with other characteristics of the Corsican Pine, the crown diameter varies considerably, as well in the young as in the older stands. It reaches a mean dimension of 1.57 m after 15 years, implying an annual growing rate of 10.5 cm. The figures corresponding to different ages (Table 12) show that the crown diameter is not the subject of a

Table 12 : The annual and periodical growth of the crown-diameter.

age (y)	crown diameter (m)	mean annual growth of the crown diameter (cm)	periodicial growth (cm)
15	1,57	10,5	4,0
25	1.97	7.9	11.0
35	3.08	8.8	4.7
45	3.55	7.9	9.5
64	5.44	8.4	

regular growth pattern under the given circumstances. Especially remarkable is the extremely slow growth between the 15th and the 25th year, due to the very high density in 20 years old stands.

The Corsican Pine reacts vigorously to the first thinnings. The maximum crown growth occurs at age 35. A slower increment between 40 and 50 years of age, on the other hand, reflects too high a number of stems at that moment. Even after two periods of slow development, crown growth increases again and even at age 65, the crown has not lost its vitality nor its potential for reaction to canopy thinning.

For all its uneven growth, it has still been possible to relate age (x) and crown diameter (y) in a regression formula :

$$y = 0{,}34 + 0.07\ x \text{ with } r = 0{,}88$$

The social position of the tree evidently influences its crown development (Table 13).

Table 13. The crown growth in different social strata

Age (y)	Dominants			Co-dominants		
	crownd. (m)	mean ann. growth (cm)	period. growth (cm)	crownd. (m)	mean ann. growth (cm)	period. growth (cm)
15	1.88	12.5		1.32	8.8	
			4.8			2.9
25	2.36	9.4		1.61	6.4	
			12.1			8.4
35	3.57	10.2		2.45	7.0	
			4.9			1.2
45	4.06	9.0		2.57	5.7	
			8.7			5.5
65	5.79	8.9		3.67	5.6	

The following regression curves are valid respectively for the upper and the middle storey :

dominant : $y = 0.75 + 0.08\ x$ with $r = 0.86$
co-dominant : $y = 0.34 + 0.07\ x$ with $r = 0.88$

While trying to calculate a similar mathematical relation between crown diameter and stand density, it has been found that none of the resulting correlation coëfficients allowed for an acceptable probability margin, and the same occurred inside each age-class separately.

On the other hand, crown diameter and stand density, permit the theoretical calculation of the forest cover rate (Tab. 14).

Table 14 : The cover-rate

age (years)	stand			upper storey			share of the middle and lower storeys (%)
	number of stems/ha	crown diam. (m)	cover rate (%)	number of stems/ha	crown diam. (m)	cover rate (%)	
15	5986	1.57	116	203	1.88	56	60
25	3339	1.97	102	1380	2.36	60	42
35	1863	3.08	139	857	3.57	86	53
45	1039	3.55	103	518	4.06	67	36
55	580	4.49	92	327	4.92	62	30
65	323	5.44	75	236	5.79	62	13

Theoretically, the canopy is totally closed for about 50 years. The maximum cover-rate (139 %) is reached at age 35, which indicates the accentuated interlacing of the crowns at that stage. The cover-rate then drops drastically to 75 % at age 65, when the stand canopy can be described as slightly to normally closed.

The share of the upper storey in the forest cover, apart from age class 35, characterized by an extremely dense canopy, remains constant at around 60 %. Later on the proportion of non-dominant trees diminishes considerably.

The high cover rate after 35 years again demonstrates the dense stocking of the stands. It is, however, remarkable that this does not disturb crown development. The non-parallel evolution of the crown growth and the cover-rate is a rather unexpected outcome of this study.

2.5.2. The ratio crown diameter-stem diameter (D/d)

The D/d factor is a valuable characteristic to describe density and stocking. It varies quite strongly between 9 and 32. Stands attain a mean D/d value of 25.7 in their youth when canopy closure has occurred. After 65 years, when they are slightly to normally closed, the figure drops to 15.9. (tab. 15).

Table 15 : The ratio crown diameter / stem diameter (D/d)

Age class	mean age (y)	mean D/d	D/d dom.	D/d codom.
11/20	16.2	25.7	20.9	24.0
21/30	26.7	17.6	16.4	18.6
31/40	35.2	20.6	19.7	21.2
41/50	43.1	16.4	17.4	16.4
61/70	63.3	15.9	15.5	16.0

An acceptable relation between the age (x) and the D/d value (y) exists for all plantations but this is not the case for the upper story separately :

whole stand	y = 15.42 + 0.001 x r = 0.89
upper storey	y = 15.62 + 0.02 x r = 0.44

The first regression leads to the following D/d values, which naturally are in accordance with the observed stand densities.

age (years)	15	25	35	45	55	65
D/d	21.4	18.8	17.3	16.5	16.0	15.7

3. Possibilities for the future

The analysis of the present situation leads to the following appreciations :

1. The stands are kept too dense for a long period. After 20 years, the number of stems still amounts to 4,471 trees per ha, the basal area mostly exceeds 30 m^2/ha and the forest cover rate reaches about 120 %. The density attains a maximum after 35 years : the cover rate goes up to 139 % and the number of stems totals 1.863 ha.

2. Only after 60 years the stands reach a normal stocking : 433 trees/ha and a cover rate of 75 %. The regulation of stand density begins only after 35 years as the high densities at 20 years or earlier make intensive thinnings impossible. Because of the precarious stability of the stands, the first interventions are necessarely restricted. It takes about 15 years more to reach the stability required for the application of intensive thinning methods.

3. Silvicultural interventions start too late and are, moreover concentrated on the dominated and co-dominant trees. The former have practically disappeared from the stand after 30 years. The latter, on the contrary, remain present in reduced numbers even until age 65 (10 to 15 %). They differentiate continuously out of the upper canopy by failing to keep up with its height growth. The very light thinnings around 25 and 35 years, combined with the high stocking, result in a progressive social degradation of many trees, originally present in the upper layer.
   The absence of silvicultural treatment between the tenth and twentieth year have harmful results. Although these interventions have no direct financial benefit, they are very valuable indirectly.

4. The stem diameter increment reaches a first maximum after 10 years, but decreases subsequently. As a consequence of the thinnings and in accordance with the internal

growth rhythm of the species, it culminates at age 32. The effect of the interventions is, however, shortlived : because of the prompt reaction, the canopy closes quickly again, so that growth diminishes.

The crown development proves the fact that Corsican Pine reacts strongly to changes in its environment : there is almost no increment when the stand is totally closed and there is a quick respons to liberation cutting. The crown remains sensitive even at an older age (over 50 years). Corsican Pine is a species with excellent reactions, capable of renewal of the growth vigour after periods of extreme stand density.

5. Although height growth is rather slow during the first years, it culminates already after 10 to 13 years. Height growth of Corsican Pine is restricted on these poor sites. However, a total height of 27 m is estimated at 100 years of age. The relation between height growth and site class is quite complex : it is not clear which of the two principal soil types, podsols or shifting dune sands, give the best results.

6. Under present circumstances, the minimum girth for sawnwood is reached after 50 to 55 years. First class sawnwood, however, will probably only be obtained after 80 years.

It must be possible to advance all these target dates considerably through a reduction of the stand density early on by means of heavy thinnings, which will result in an important boost of the profitability.

The analysis of the present situation especially points to the fact that interventions are delayed for too long a period of time and that the first thinnings are not strong enough. It also allows certain proposals for the immediate future.

The continuing growth of the oldest stands leads to the presumption that a rotation period of 100 years is feasible. As indicated above, a mean height of 27 m may be expected at that age. The diameter naturally depends almost entirely on the silvicultural treatment applied. Estimates vary with the variable considered. Extrapolation of the calculated regression formula of the ' regular ' stand results in a final diameter of 50.8 cm, the upper storey having slightly thicker stems with 54 cm. Extrapolation of the diameter growth of the dominant trees found in the 63 year old stands, however, leads to a final diameter of 63.4 cm.

The following remakrs needs to be made :

The ' regular ' stand is representative for Corsican Pine forests that have been kept closed for a long time, while the 63 year old stands were originally mixed with Scots Pine and have always been subject to intensive thinnings.

The trees of the final crop will doubtless be the dominants of the present stand, with the understanding that the weekest of the latter will have fallen out before reaching the end of the rotation period.

More intensive thinnings in the future will eventually result in a DBH between 55 and 60 cm at the end of the proposed 100 year rotation. A final value of 57.5 cm is proposed for further calculations. The final s tand density is also determined by the silvicultural management, but can be approxilated theoretically in different ways.

Taking into account the D/d ratio, which should amount to about 15.5 after 100 years, on a felling diameter of 57.5, the following calculations can be made :

- area occupied by one tree = 62.39 m^2
- number of stems by a forest cover rate of 100 % = 160/ha
- number of stems by a forest cover rate of 85 % = 135/ha
- number of stems by a forest cover rate of 75 % = 120/ha

A basal area of 36 m^2 and a felling diameter of 57.5 cm lead to a final stand density of 138.6 trees/ha at age 100. It can thus be expected within reliable probability margins that the final stock ing will vary between 120 and 140 trees/ha with a mean value of 130.

Characteristics of an older Corsican Pine forest in Koekelare (Western Flanders) are given underneath in order to relate the calculated figures to reality

- planted in 1882
- situation in 1977 : 141 stems/ha, solid volum over bark of 607 m^2, mean height of 27 m, mean DBH of 65.15 cm.

It can be said that this particular stand is still considered quite dense.

The initial stocking not only has an economic, but also a silvicultural importance. The crown diameter increases with a mean 10.5 cm per annum during the first years, resulting in a value of 1.57 m after 15 years. This means that 5,133 trees are needed at that moment to have a theoretically 100 % closed forest cover and 4.206 specimens for a cover rate of 80 % or the realisation of the primary canopy closing.

The spacing of 1.25 m x 1.25 m in the recently established plantations, results in a stocking of 5,120 trees/ha, with a survival rate of 80 %. This is precisely the required number of stems to attain a 100 % forest cover rate after 15 years. Planting distances of 1.5 m x 1.5 m give 3,555 plants per ha with an identical survival percentage. A stand established under this spacing arrangement will take 18 years to attain full canopy closure.

In fact, the initial stocking is not that important, provided that a minimum number of plants are present and that the necessary interventions are effected.

4. General Conclusions

The most remarkable aspect of the Corsican Pine stands as they exist now is the very high stocking and forest cover rate between the 15th and the 35th years. This is the consequence of the lack of any silvicultural treatment between the 10th and the 20th year and also of the necessarely light character of the subsequent first thinnings. These dense stands are so unstable, that a period of light thinnings is unavadable before starting with heavy thinnings. It may be assumed that for the future a rotation period of 100 years is feasible. When the thinnings are carried out in the right way and at the right time (early on), the following stand characteristics may be expected

mean height : 27 m ; basal area : 36 m^2
felling density = 130 stems/ha; felling diameter = 57,5 cm.

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