Aboveground biomass of Pinus Halepensis Mill forests in the Kassandra Peninsula – Chalkidiki

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Abstract

Pinus halepensis occupies a large area of Mediterranean coastal forests. Kassandra Peninsula *Pinus halepensis* forests could be characterized as the representative forests in the Mediterranean. These forests are very important, due to their vicinity to urban and coastal areas. The knowledge of biomass distribution in these forests will help with the correct time and space planning, in order to fulfil the multifunctional management of ecosystems (wood production, water, forest protection, recreation etc.).

Key words: *Biomass, Pinus halepensis, forest management, forest protection, forest fire, recreation*

1. Introduction

Pinus halepensis is considered to be a widespread species in Mediterranean forest ecosystems. It occupies a larger area than the other Mediterranean xerothermic conifers. It's a species of the evergreen broadleaves zone that spreads mostly throughout the west part of the Mediterranean area. In Greece, it is found in Sterea Hellas, Peloponnisos, Pilio, Chalikidiki, Euboia, Skopelos, Skiathos, Skyros and on some other islands of the Aegean and Ionian seas. It appears in sites with mean annual rainfall of 350 – 1000 mm, mean summer rainfall not more than 40 mm, relative humidity of 47 - 60%, mean air temperature of 20 - 26^{0}C and tolerate temperature up to -17^{0}C. As stated by the soil conditions, it is a species that has great adaptability, low demands in moisture and nutrition elements and it grows in soils of different origin (limestones, marls, schists, granites etc.). *P. halepensis* forests occupy an area of 250000 ha in Greece with high temperatures and drought, usually found near urban and tourist areas. Under these circumstances, their value will become greater in the future. Biomass accumulation is observed in these forests due to the reduction of apiculture, resin, illegal logging, grazing etc. At the same time, there are prolonged summer drought periods with high temperatures. These facts, in combination with the absence of scientific methods of prevention and control of forest fires, increase the possibilities of forest fire disasters. The best way of prevention have the knowledge of the flammable material (biomass), and its vertical and horizontal distribution along with its quality and quantity. The aim of this research is to study *Pinus halepensis* biomass in Kassandra Chalkidiki, especially its quality and quantity distribution and to propose treatments in order to fulfil the multifunctional forest aims (economical, social and protectional).

2. Study area

This research took place in the Kassandra peninsula, Chalkidiki, in northern Greece. The soils in its extreme north belong to brown forests and to rendzinas, in its south, to red Mediterranean soils, while a small part in the northwest belong to the alluvial soils. (FAO, 1965). Kassandra has a Mediterranean type climate with dry, hot summers (Flokas, 1990).

The dry period lasts 5 months, from mid April to mid September. The vegetation in this area belongs to Quercetalia illicis (Dafis, 1973) and three site qualities are found (Tsitsoni, 1991).

3. Research method

In order to determine *Pinus halepensis* biomass, 46 trees were taken with a stratified random sampling method of all age classes (stands in 23, 48, 70 and over 100 years old). This way, there is a representation of all situations and biomass variation of this species. Trees were cut down at ground level (Alembay, 1980, Young et all, 1964) and their total height, base stem diameter and stem age were recorded. Total weight of each tree was measured in the field in the following categories:

- the weight of bole segment from the stump up to the crown base.
- the weight of bole segment from the live crown base to the point in which the diameter is 7.5cm.
- the weight of all branches (d<7,5cm).

Cross-sectional discs were taken along the bole at the height of 0.30 m, 1.30m, 2.0m and in intervals of 3.0m also in the base of the crown and at the point in which the diameter is 7.5 cm. At least 6 discs were taken along the bole up to the base of the live crown and 3 discs inside the crown.

A representative branch (in relation to needles density, vitality and number of cones) was taken and weighed with accuracy of 5 grams in the following categories :

- branches with diameter 2.5-7.5cm.
- branches with diameter 0.5-2.5cm.
- needles and branches with diameter <0.5cm.

The same process was used for the top of the crown. Representative samples were taken from all these bole and branch categories in each tree and carried to the laboratory for dry weight and determination. After the bark strip the bole samples were oven – dried for 48 hours at 8 5^{0}C.
Moisture content was estimated from the formula :
Y = (Fresh weight - Dry weight) / (Dry weight)
In order to calculate the biomass (fresh and dry weight) in each tree by their physical dimensions (height and diameter), several regression equations (linear and nonlinear), were examined to determine these relationships. With the equations and the structure analysis results, (Smiris, et al 1999) the dry biomass was determined.

4. Results

Weight rate for categories:
The percentage (%) between fresh and dry weights per categories of each representative sample is shown in figures 1 and 2.

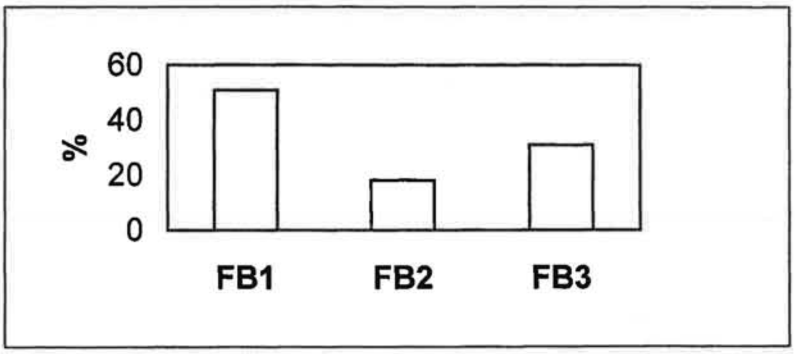

Figure 1. *The rate of fresh weights of representative part.*

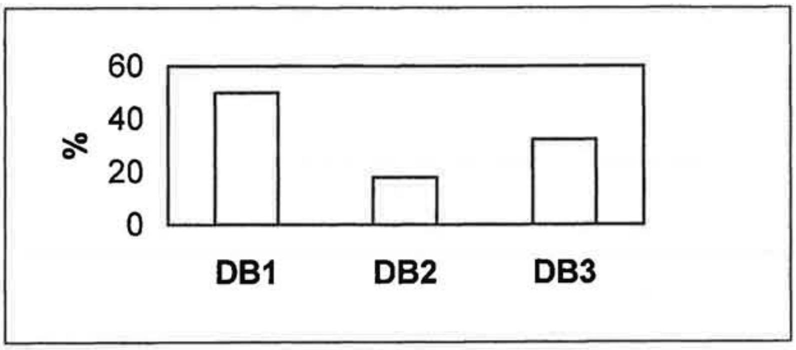

Figure 2. *The rate of dry weights of representative part.*

We observe that 50% of dry and fresh weight is occupied by needles and branches with a diameter of <0.5cm. The 18% of branches have diameter between 0.5 and 2.5 cm and the 32% of branches have a diameter between 2.5 and 7.5 cm. The statistical analysis gave us statistically significant differences for an important level of 5% between various categories in fresh and dry weights (Table 1 and 2).

Table 1. *Comparison between fresh weights of representative part*

$FB_1 - FB_2$ (d<0.5cm)	Statistical significant difference (a=5%)
$FB_2 - FB_3$ (0.5<d<2.5cm)	Statistical significant difference (a=5%)
$FB_1 - FB_3$ (2.5<d<7.5cm)	Statistical significant difference (a=5%)

Table 2. *Comparison between dry weights of representative part*

$DB_1 - DB_2$ (d<0.5cm)	Statistical significant difference (a=5%)
$DB_2 - DB_3$ (0.5<d<2.5cm)	Statistical significant difference (a=5%)
$DB_1 - DB_3$ (2.5<d<7.5cm)	Statistical significant difference (a=5%)

The percentage rate of fresh and dry weights of the top of the crown are given in figure 3 and figure 4.

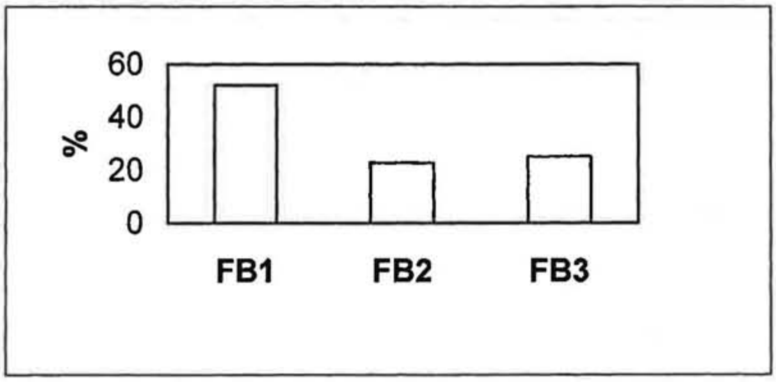

Figure 3. *The rate of fresh weight of the top of the crown.*

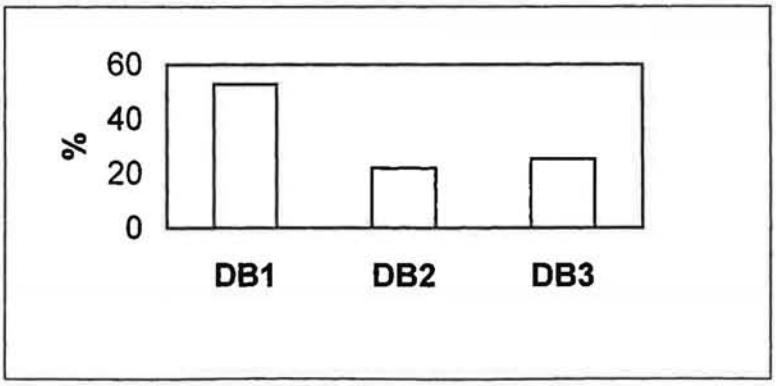

Figure 4. *The rate of dry weight of top of the crown.*

We observe that needles and small branches in fresh and dry weights are 52%, thin twigs with a diameter of 0.5 to 2.5 cm are 22% and branches with a diameter of 2.5 to 7.5cm are 25%. There is no difference between the rates of fresh and dry weights. The statistical analysis between fresh and dry weights in branch categories has presented statistically significant differences (Table 3 and 4).

Table 3. *Comparison between fresh weights of the top of the crown*

$FB_1 - FB_2$ (d<0.5cm)	Statistical significant difference (a=1%)
$FB_2 - FB_3$ (0.5<d<2.5cm)	Statistical significant difference (a=1%)
$FB_1 - FB_3$ (2.5<d<7.5cm)	Statistical significant difference (a=1%)

Table 4. *Comparison between dry weights of the top of the crown*

$DB_1 - DB_2$ (d<0.5cm)	Statistical significant difference (a=1%)
$DB_2 - DB_3$ (0.5<d<2.5cm)	Statistical significant difference (a=1%)
$DB_1 - DB_3$ (2.5<d<7.5cm)	Statistical significant difference (a=1%)

The percentage rates between fresh and dry weights of the top of the crown and the representative part are given in figures 3 and 4. We observe a small increase of needles and thin branches percentage and a reduction of thin branches percentage between 2.5 and 7.5 cm on the top of the crown. The statistical analysis between fresh and dry weights per categories of the top of the crown and the representative part presented statistically significant differences (Table 5 and 6).

Table 5. *Comparison of fresh weights between representative and top of the crown part*

Top of the crown part	Representative part		
	FB_1 (d<0.5cm)	FB_2 (0.5<d<2.5cm)	FB_3 (2.5<d<7.5cm)
FB_1 (d<0.5cm)	Statistical significant (a=5%)		
FB_2 (0.5<d<2.5cm)		Statistical significant (a=5%)	
FB_3 (2.5<d<7.5cm)			Statistical significant (a=5%)

Table 6. *Comparison of fresh and dry weights between representative and top of the crown part*

Top of the crown part	Representative part		
	DB_1 (d<0.5cm)	DB_2 (0.5<d<2.5cm)	DB_3 (2.5<d<7.5cm)
DB_1 (d<0.5cm)	Statistical significant (a=5%)		
DB_2 (0.5<d<2.5cm)		Statistical significant (a=5%)	
DB_3 (2.5<d<7.5cm)			Statistical significant (a=5%)

The percentage rate of fresh and dry weights in whole tree is given in figures 5 and 6.

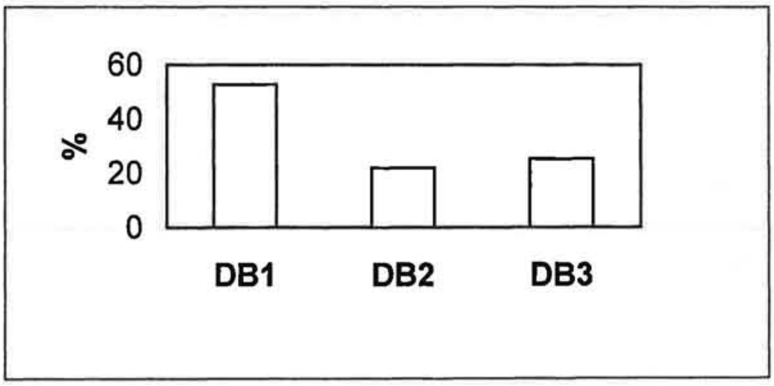

Figure 5. *The fresh weights rate of whole tree.*

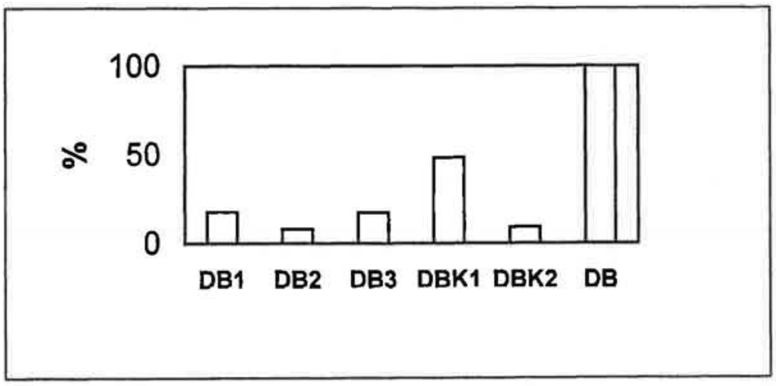

Figure 6. *The dry weights rate of whole tree.*

We observe that fresh and dry weights of the bole up to the live crown base holds 45% and 48% respectively of the total tree weights. Also, the bole inside the crown to the point with a diameter of 7.5cm is 9% of the total tree weight. Consequently, the bole holds 54% of fresh and 57% of dry weights of the total tree weight. Needles and thin twigs with a diameter of less than 0.5cm take up 20.2% of fresh and 17.5% of dry weights. Twigs with a diameter between 0.5 and 2.5 cm take up 8% and 8.34% respectively, while small branches with a diameter of 2.5 to 7.5 cm take up 17.31% and 17.22%. The statistical analysis between fresh and dry weights gave statistically significant differences for the various categories of the bole branches (Table 7).

Table 7. *Comparison between fresh and dry part of whole tree*

Fresh weights	Dry weights					
	DB_1	DB_2	DB_3	DBK_1	DBK_2	DB
FB_1 (d<0.5cm)	Statist. Signific. (a=1%)					
FB_2 (0.5<d<2.5cm)		Statist. Signific. (a=1%)				
FB_3 (2.5<d<7.5cm)			Statist. Signific. (a=1%)			
FBK_1 (d>7.5cm stem wood from stump to the live crown base)				Statist. Signific. (a=1%)		
FBK_2 (d>7.5cm stem wood to the live crown base)					Statist. Signific. (a=1%)	
FB (total tree)						Statist. Signific. (a=1%)

Moisture content percentage:

The moisture content percentage of the representative branch and the top of the crown part, per categories, are given in table 8.

Table 8. *Moisture content (% of dry weight)*

Crown component	representative branch	topwood
Foliage and branches diameter up to 0.5cm	117.8	110.7
Branches diameter 0.5 to 2.5cm	116.6	121.8
Branches diameter 2.5 to 7.5cm	102.2	112.8

We observe that the needles' moisture content percentage of the top of the crown part is 7% less than the needles' moisture content percentage of the representative branch, due to evaporation. The twigs and branches of the top of the crown part have 5% and 10% higher humidity percentages than the twigs and branches of the representative branch due to photosynthetic products (verbal explanation of Pr. Konstantinidou). Wood and bark moisture content percentages in various heights of trees are given in table 9.

Table 9. *Moisture content (% of dry weight)*

Discs height	Wood	Phleum
0.3m	52.5	63.6
1.3m	54.5	72.0
2.0m	59.8	78.0
5.0m	70.6	103.3
8.0m	72.8	123.1
11.0m	77.7	147.9
14.0m	86.9	158.1
17.0m	101.3	169.7
20.0m	106.0	245.0

We observe a continuous increase in wood moisture content percentage whose value is doubled, and in bark moisture content percentage whose value is quadrupled. The wood moisture content alteration with height graph is given in figure7. The former reasons explain this graph.

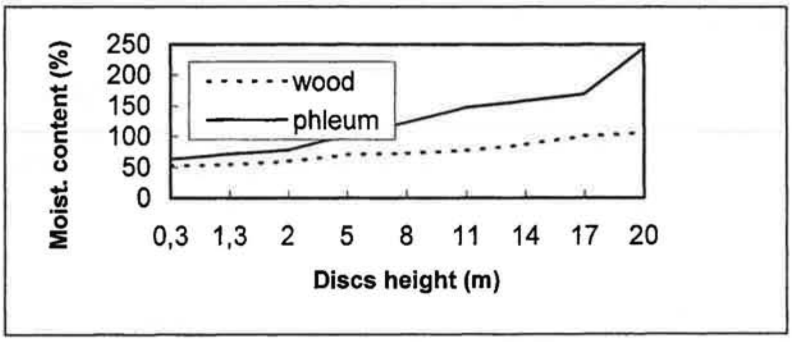

Figure 7. *Moisture content graph of Pinus halepensis wood and phleum.*

Biomass determination:

The regression equations for computing the biomass (fresh and dry weight) of each tree by their physical dimensions (height and diameter) are given in tables 10 and 11.

Table 10. *Regression equations of physical dimension of trees on green weight*

a/a	Species	N	Regressions	r^2	SEE
1	FBA	46	$W = \exp(0.838+0.116d)$	0.89	0.50
2	FBB	46	$W = \exp(-0.066+0.117d)$	0.88	0.54
3	FBC	45	$W = \exp(0.823+0.099d)$	0.78	0.66
4	FCW	32	$W = 284.788-24.897d+0.608d^2$	0.81	45.65
5	FSW	37	$W = -17.9+0.032(d^2h)$	0.83	162.45
6	FT	46	$W = -5.428+0.051(d^2h)$	0.92	171.75
7	FTB	46	$W = \exp(1.74+0.112d)$	0.90	0.46
8	FTW	37	$W = -39.18+0.04(d^2h)$	0.88	164.73
9	FTC	32	$W = 19.6+0.012(d^2h)$	0.85	54.57
10	FB	46	$W=\exp(0.354+0.116d)$	0.89	0.50

Table 11. *Regression equations of physical dimension of trees on dry weight*

a/a	Species	N	Regressions	r^2	SEE
1	DBA	46	W= exp(-0.038+0.121d)	0.90	0.51
2	DBB	46	W= exp(-0.826+0.124d)	0.88	0.56
3	DBC	45	W= exp(-0.002+0.11d)	0.82	0.65
4	DCW	32	W= 174.495-15.099d+0.367d^2	0.70	36.89
5	DSW	37	W= -18.352+0.022(d^2h)	0.94	64.9
6	DT	46	W= -10.925+0.033(d^2h)	0.97	69.99
7	DTB	46	W= exp(0.957+0.116d)	0.91	0.45
8	DTW	37	W= -30.74+0.027(d^2h)	0.95	67.31
9	DTC	32	W= 16.942+0.006(d^2h)	0.81	28.72
10	DB	46	W=exp(-0.521+0.121d)	0.90	0.51

using

FBA, DBA	Needles and small branches (d<0.5cm)
FBB, DBB	Medium branches (0.5<d<2.5cm)
FBC, DBC	Large branches (2.5<d<7.5cm)
FCW, DCW	Stem wood with bark from live crown base to the top
FSW, DSW	Stem wood with bark from stump to the live crown base
FT, DT	Total tree, consisting of stem wood plus all branches
FTB, DTB	Total branches
FTW, DTW	Total stem wood with bark
FTC, FTC	Crown, consisting of all branches plus topwood
FB, DB	Needles
D	diameter (cm)
H	height (m)

Also the size of the sample and r^2 are given in the same tables. The dry biomass in several parts of tree categories and for each development stage is determined using the equations and structure analysis data (Smiris et al,1999). Biomass distribution in several categories and for each stand age class is given in figures 8, 9, 10, 11. At the age of 23 years the total biomass is 17.55 tn/ha. Needles and branches compose the greater part of this biomass. At the age of 48 years the total biomass is 764.86 tn/ha. At this age, the bole biomass is double the needles and twigs biomass. At the age of 70 years, the biomass is 1192.24 tn/ha. The bole biomass is triple the needles and twigs biomass. At the age of over 100 years, the total biomass is 1406.21 tn/ha.

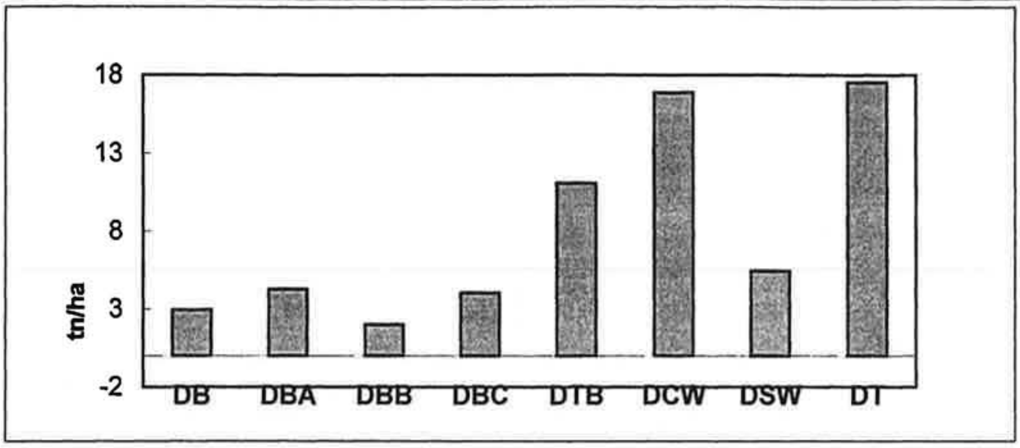

Figure 8. *Graph of species biomass distribution per ha of 23 years Pinus halepensis stand.*

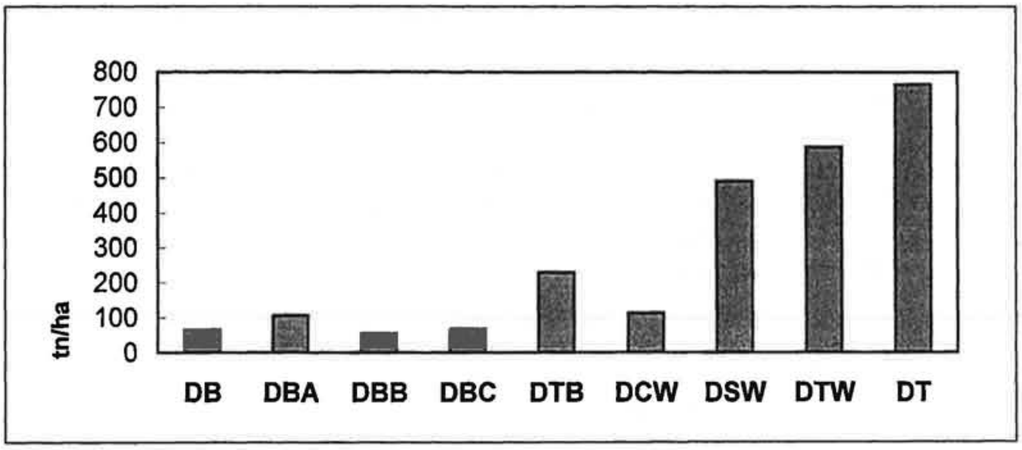

Figure 9. Graph of species biomass distribution per ha of 48 year *Pinus halepensis* stand.

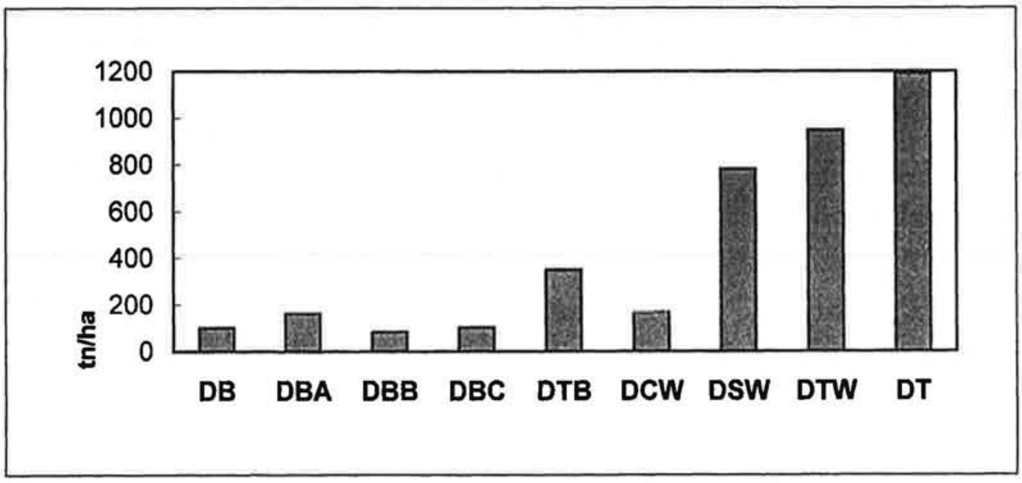

Figure 10. *Graph of species biomass distribution per ha of 70 years Pinus halepensis stand.*

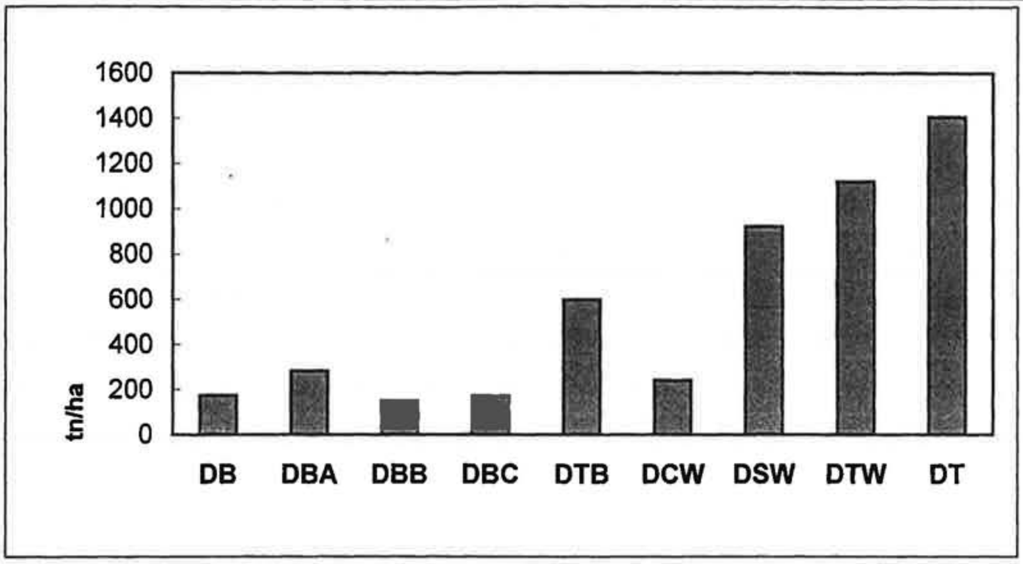

Figure 11. *Graph of species biomass distribution per ha over 100 years Aleppo pine stand.*

The bole biomass is double, the needles and twigs biomass. We observe that the best bole biomass rate in relation to the needles and twigs biomass is at the age of 70 years. Biomass distribution per diameter class at the ages of 23, 48, 70 and over 100 years is given in figure 12.

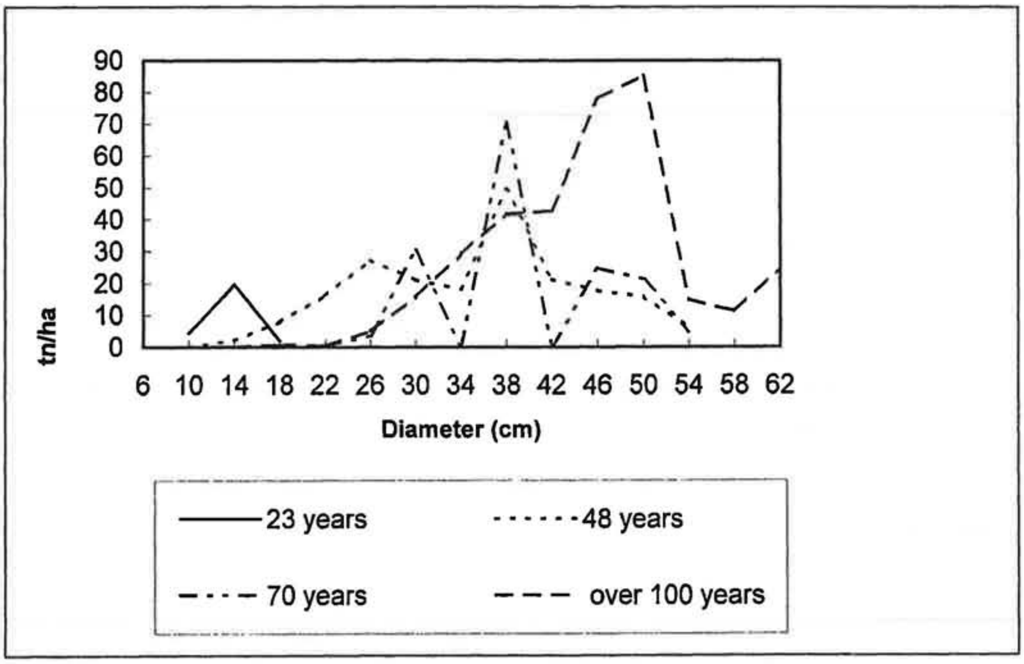

Figure 12. Biomass distribution in diameter classes per ha of 23, 48, 70 and over 100 years *P. halepensis* stand.

At the age of 23 years, biomass is accumulated in the 14 cm class. At the age of 48 years, it is accumulated in the 38 cm class with great dispersion. At the age of 70 years, we observe the greatest accumulation in the 38 cm class with small dispersion in the lower diameters. At the age of 100 years, we have the greatest accumulation in the 50 cm class with the same dispersion as that at the age of 70 years. Biomass distribution per height class at the various ages is given in figure 13.

At the age of 23 years, the biomass is accumulated in trees of 9 and 11m in height and it creates a one-storey stand. At the age of 48 years, the biomass is accumulated in trees of 19 and 21 min height. At the age of 70 years, the biomass is accumulated in trees of 21 and 23 m in height and it consists of one-storey stands suitable for hydronomical purposes. While at the age over 100 years, we observe a step - like biomass accumulation mostly in trees of heights of 17 m and it creates stands for aesthetic aims.

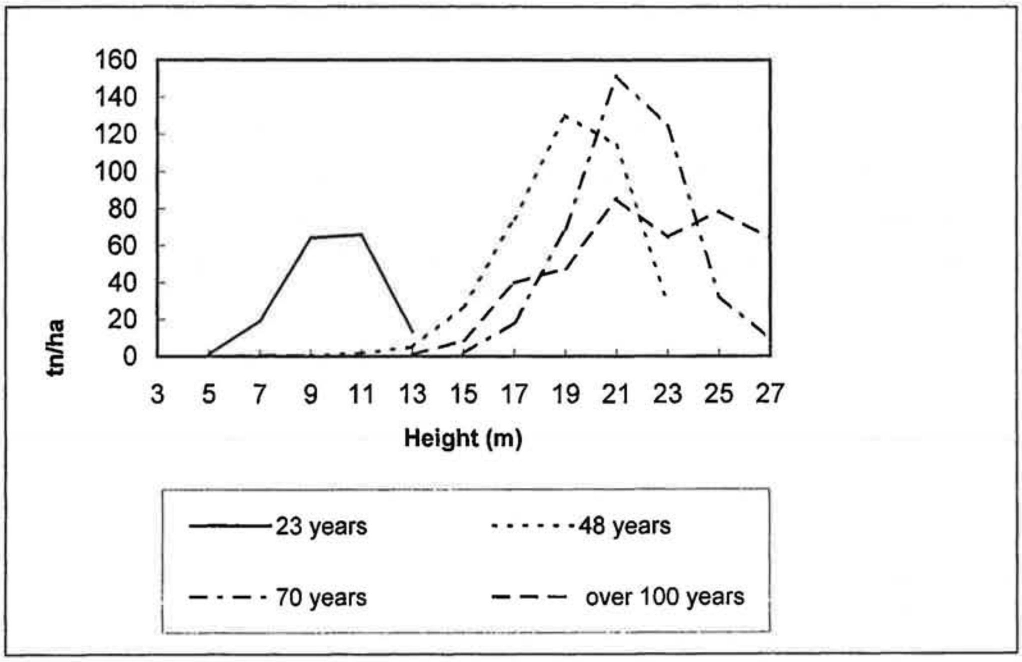

Figure 13. Biomass distribution in height classes per ha of 23, 48, 70 and over 100 years *P. halepensis* stand.

5. Conclusions

Weight distribution:

Fifty percent of the dry and fresh weight of the representative branch is in the needles and in the branches with a diameter of less than 0.5cm.

At the top of the crown, 52 % of the fresh and dry weight is in the needles and in the twigs with a diameter of less than 0.5 cm. In the whole tree the dry and fresh weights of the bole up to the live part of the crown are 45 % and 48 % respectively. The bole within the crown (d>7.5cm) is 9% of the total tree weight. In total, the bole contains 54 % of fresh and 57 % of dry weight of the entire tree.

Moisture content percentage:

The moisture content percentage of needles in the top of the crown part is 7 % lower than the humidity percentage of the representative branch needles. The twigs and branches of the top of the crown have higher moisture content percentages, 5 % and 10 % respectively. The wood and the bole bark moisture content percentage increases the tree height.

Biomass distribution:

At the age of 23 years, the total biomass is 17.55 tn/ha and mostly consists of needles and thin branches in the 14cm tree diameter class. At the age of 48 years, the biomass is 764.86 tn/ha. In a period of 25 years, we observe an increase of 744.31 tn/ha. The ratio between the bole biomass to the needles and the branches biomass is 2:1 and accumulates mostly in the 38 cm tree diameter class. At the age of 70 years, the biomass is 1192.24 tn/ha. In a period of 22 years we observe an increase of 3:1 of bole biomass to needles and branches biomass which accumulates mostly in the 38 cm tree diameter class. At the age of 100 years, the biomass is 1406.21 tn/ha. In a period greater than 30 years, we observe an increase of 213.97 tn/ha. The ratio between bole the biomass to the needles and branches biomass is 2:1 and accumulates in the 50 cm tree diameter class. The biomass distribution in diameter and height classes shows that over 100 year old stands are better than the other stands for aesthetic purposes. For wood production, hydronomical purposes and fire protection aims, the 70 year old stands are better than the other stands. Finally, in forest harvesting, the removal of needles and thin branches is not recommended because their participation in total biomass is 33 – 50 % and they contain a great number of nutrients.

6. Acknowledgements

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