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Original article

A dendroecological study in a declining oak coppice stand

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Summary — The decline of a 30-year-old mixed oak coppice stand, with a prevalence of *Quercus cerris* L, located near Tolfa, Rome, Italy, was studied. The area is characterised by overgrazing and a lack of sylviculture. In order to better understand the importance of some disturbance factors resulting in decline, phytopathological conditions were compared with data provided by a dendroecological analysis. Stand structure, radial growth, decline symptoms observed at the stem and in the xylem, and the relationship between tree growth and meteorological data, were investigated. The increment series showed that dominant shoots classified as healthy have always had better growth than trees classified as declining. A multiple regression analysis performed between bi-monthly meteorological data and basal area increment showed spring climatic parameters to be those with the highest correlation to growth. These results confirm that several factors are associated to the observed oak decline. The biological implications of this process are discussed.

***Quercus cerris* / decline symptomatology / dendroecology / radial growth**

Résumé — Étude dendroécologique d'un taillis dépérissant de chêne. *L'étude a concerné un taillis mixte (*Quercus cerris *L prédominant), âgé de 30 ans, situé prés de Tolfa, Rome, Italie. La zone est marquée par un surpâturage de bovins et l'absence de toute intervention sylvicole. Pour évaluer l'importance des différents facteurs reliés au dépérissement, la situation phytopathologique du peuplement a été comparée avec les données dendroécologiques. L'étude a considéré : la structure du peuplement, la croissance radiale, les symptômes de dépérissement (sur la tige et dans le xylème), la relation entre croissance ligneuse et données météorologiques. Les séries d'accroissement radial montrent que les tiges dominantes considérées saines ont toujours présenté un rythme de croissance plus élevé que les tiges dépérissantes. Une régression multiple entre les données météorologiques bimensuelles et l'accroissement de la surface terrière montre que les paramètres climatiques printaniers sont les plus explicatifs. Les résultats confirment ainsi que plusieurs facteurs sont à l'origine du dépérissement observé sur le chêne chevelu.*

Quercus cerris ***/ symptôme de dépérissement / dendroécologie / accroissement radial***

INTRODUCTION

Pure and mixed coppices of *Quercus cerris* L are common in central and southern Italy, in a variety of different environments and site conditions. They characterise the forest cover from the mesophilous broadleaf layer to the mediterranean sclerophyllous stands (Fenaroli and Gambi, 1976). In the latter area, Turkey oak coppice management is complicated due to the long history of intensive human influence. A multipurpose management system producing fuelwood and coal and allowing grazing was largely carried out in these stands until a few decades ago. Following the social changes in mountain and hilly areas during the 1950s and 1960s, traditional management has not paid careful attention to the consequences of the functionality of the ecosystem with manifest consequences in the structural organisation of the stands, in the growth of woody biomass and in the health of individual trees.

In Italy, since the beginning of the 1980s, many oak stands have shown a general decline (Vannini and Luisi, 1990). Decline is a recurrent syndrome caused by concomitant action of multiple factors that can affect different tree species in many regions around the world (Houston, 1992). The symptoms for declining Turkey oak trees include smaller leaf size, transparency of the crown, increased production of epicormic sprouts and mucilaginous exudations on the trunk (Ragazzi et al, 1989). The dying trees frequently show black stromata of *Hypoxylon mediterraneum* (De Not) Mill breaking out of the bark. This fungus is a pathogen aggressive only on water-stressed hosts (Vannini and Scarascia Mugnozza, 1991).

The analysis of chronological series of annual wood production can be used to interpret the decline of forest stands (Tainter et al, 1990; Biocca et al, 1993). The annual radial growth of the trees provides a record of all exogenous and endogenous disturbance factors (Fritts, 1976; Schweingruber, 1988).

The aim of this work was to compare the phytopathological conditions, observed in the last 5 years in a mixed coppice dominated by *Q cerris*, with data provided by a dendroecological analysis, in order to indicate and quantify the disturbance factors which were acting on the ecosystem.

MATERIALS AND METHODS

Site description

The experimental area is located in the Monti della Tolfa (Rome) at 230 m asl, latitude 42°3' N, longitude 11°58'E, 8% mean slope, south-southwest exposure. The forest cover is characterised by a 30-year-old mixed coppice with *Q cerris* prevailing over *Q pubescens* L and *Acer monspessulanum* L. The traditional silvicultural system included a cutting every 18 years, and the initiation of cattle grazing 5 years after coppicing. However, in the stand being studied, the last cutting was carried out in 1964; no subsidiary felling was carried out in the last rotation. Wild grazing is present throughout the year.

The soil is a brown soil with frequent outcrops, developed mainly on travertine parent material. The clay content is 31.5%, the texture ranges from loam to clayey-loam, the pH is 6.7 and C/N ratio is 15.0. It has a good water holding capacity, depending on physical characteristics and on the content of organic matter (6.8%). Humification degree (HD = 73.3%) and humification rate (HR = 50.0%) are satisfactory (Benedetti et al, 1994). However, the high potential fertility of the soil is reduced by the compaction caused by the intensive grazing.

The climate is Mediterranean and characterised by mild and rainy winters and dry summers. The annual rainfall is 560 mm, maximum in winter months (196 mm in total) and minimum in summer months (49 mm in total). The mean annual temperature is 16.7 °C; mean temperature of the coldest month (January) is 9.8 °C; mean temperature of the hottest month (August) is 24.6 °C (meteorological data recorded by "Ufficio Centrale di Ecologia Agraria" in Civitavecchia, Rome, for the period 1968–1992). The annual water deficit is 321 mm and lasts from May to October with maximum values in July and August; the surplus is only 111 mm and lasts from January to April (fig 1). In accordance with Thornthwaite and Mather (1957), the climatic type is subwet-dry with a moderate surplus in winter, mesothermic. According to Pavari's classification, this area can be attributed to 'cold *Lauretum*'.

The experimental area consisted of eight contiguous transects (2 500 m^2 in total) ranging along the longest diagonal of the plot (10 ha) (Motta et al, 1991).

Surveys and inventory

The experimental activity started in 1989: the Turkey oak stumps were numbered to identify individual populations, and the diameter at breast height (dbh) of all shoots of each species was measured. The stand was surveyed for phytopathological condition in June and October from 1989 to 1993. During the surveys, 299 shoots of Turkey oak were classified as showing either one or a combination of the following symptoms:

- class 'a': no symptoms;
- class 'b': presence of exudations on the stem;
- class 'c': presence of epicormic sprouts (more than 20 up to the first branch);
- class 'd': presence of stromata of *H mediterraneum*;
- class 'e': dead plant.

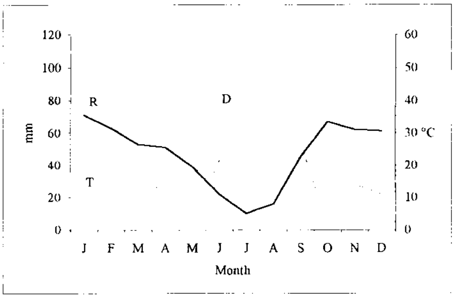

Fig 1. Diagram of monthly mean temperature (T), rainfall (R) and water deficit (D) in the site tested (Civitavecchia, Rome) calculated from 1968 to 1992.

Using the phytopathological data collected during 5 years, two groups of shoots were chosen and defined as healthy (always in class 'a' or with only occasional stem symptoms) or declining (always in class 'b' and/or 'c').

In February 1994, a second inventory was carried out, assessing the following stand parameters:

- dbh of all living shoots of each species and stump;
- social class of each shoot: dominant (D), intermediate (I), suppressed (S).

Dendroecology

Thirty-seven Turkey oak shoots belonging to the three social classes and the two phytopathological groups were chosen and felled (table I). After felling, the cross sections at 0.0, 0.5 and 1.3 m of each stem were collected. The age was determined from the basal cross section. Radial growth was measured on the 1.3 m cross section; the width of each annual ring was measured on four radii using the Measurement System SMIL3 with approximation of 0.01 mm (Amorini et al, 1988).

To estimate the influence of climate on *Q cerris* growth, only dominant shoots (20 trees) were considered. The dendroclimatic analysis was divided into four phases: i) determination of annual basal area increment for each dominant shoot; ii) visual comparison of 20 time series and determination of a mean curve; iii) indexation of current increment of basal area (real value and third degree moving average ratio) to remove the biological growth trend and to maximise the climatic component (Fritts, 1976); iv) multiple regression analysis between indexed values (dependent variable) and some climatic parameters (independent variables). The climatic variables used in the regression were the monthly and bi-monthly values of the current and the previous year of the following parameters: rainfall, mean minimum and maximum temperatures. All meteorological data refer to the period 1968– 1992. The data of the year 1989 were removed from the analysis because of a strong attack by *Lymantria dispar* L that greatly affected wood growth.

To detect xylem alterations and damages, all cross sections used for tree ring analysis were observed and the presence of such symptoms was related to the year in which the annual ring had been formed. To study the influence of cli-

Table I. Main dendrometric characteristics of the *Quercus cerris* shoots sampled for dendroecological analysis in a 30-year-old mixed coppice located in Monti della Tolfa (Civitavecchia, Rome).

	Dominant		*Intermediate*		*Suppressed*	
	Healthy	*Declining*	*Healthy*	*Declining*	*Healthy*	*Declining*
No of sampled shoot	10	10	2	6	4	5
No shoots/stump	2.7	2.7	2.5	2.7	5.7	2.6
dbh (cm)	16.2	14.5	10.9	9.8	8.4	8.4
Height (m)	12.3	12.2	11.3	11.2	8.5	8.3
Height first living branch (m)	5.8	5.9	4.3	6.5	3.6	4.2
Crown area (m^2)	13.59	13.00	7.29	4.69	5.82	6.26

dbh: diameter at breast height.

matic events on the formation of xylem alterations, a multiple regression analysis was carried out between the number of wood alterations (dependent variable) and the climatic variables just mentioned (independent variables).

All regression analyses were performed using the stepwise multiple linear regression procedure (backward selection) of Statgraphics® (version 6) software package. The stepwise regression procedure makes it possible to use a selection method to control the entry of variables into the model. With backward selection, the system begins with a model that contains many variables and eliminates them one at a time. At each stage, it verifies that previously removed variables are still not significant. The system reenters variables in the model if they become significant when other variables are removed.

RESULTS

Stand structure

The main parameters which characterised the stand are given in table II. The dominant layer contributed 75% of total basal area, while the intermediate and suppressed layers had similar values (13 and 12%, respectively). The suppressed storey included a higher number of trees. Almost all Turkey oak shoots were concentrated in the dominant layer, because of the light demanding character of the species which

Table II. Main parameters of the stand for each species by social position in a 30-year-old mixed coppice located in Monti della Tolfa (Civitavecchia, Rome).

	Shoot number				*Basal area (m^2/ha)*				*Mean diameter (cm)*			
	Qc	*Qp*	*Am*	*Total*	*Qc*	*Qp*	*Am*	*Total*	*Qc*	*Qp*	*Am*	*Total*
Dominant	776	132	36	944	15.19	2.14	0.25	17.58	15.8	14.4	9.4	15.4
Intermediate	180	92	44	316	1.90	0.83	0.39	3.12	11.6	10.7	10.6	11.2
Suppressed	156	148	520	824	1.01	0.67	1.16	2.84	9.1	7.6	5.3	6.6
Total	1 112	372	600	2 084	18.10	3.64	1.80	23.54	14.4	11.2	6.2	12.0

Qc: *Quercus cerris*; Qp: *Q pubescens*; Am: *Acer monspessulanum*.

increases the effect of natural competition among stumps and shoots. Pubescent oak made up 15% of the total basal area and can be considered to be codominant with Turkey oak, being present mainly in the upper storey. Montpellier maple was a secondary species: it was present almost exclusively in the overtopped storey. Stem frequency distribution (fig 2) highlights the different structure of the three layers; the shape of the distribution curve is similar in dominant and intermediate layers (positive skewness) because oak stems contribute to widen the dbh range towards the higher diameter value. Overtopped stems showed a reverse J shaped distribution, typical of the sec-

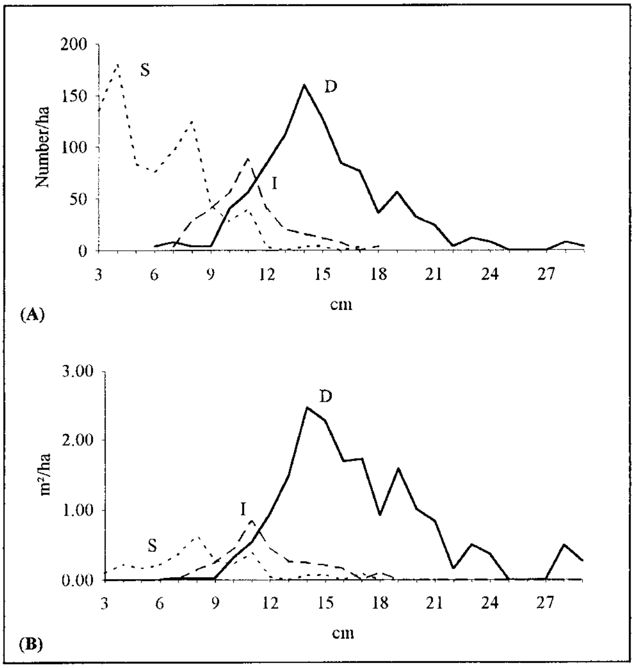

Fig 2. Frequency distributions of stem number per ha (**A**) and basal area per ha (**B**) by diameter at breast height (dbh) classes for the different layers (D: dominant, I: intermediate, S: suppressed) of a *Quercus cerris* coppice in Monti della Tolfa (Civitavecchia, Rome).

Table III. Phytopathological conditions of *Quercus cerris* shoots by social position in June 1989 and in October 1993, sampled in the stand of Tolfa (Civitavecchia, Rome).

	Dominant		*Intermediate*		*Suppressed*		*Total*	
	1989	*1993*	*1989*	*1993*	*1989*	*1993*	*1989*	*1993*
Class 'a'	65	49	4	3	4	3	73	55
Class 'b'	8	1	1	0	3	0	12	1
Class 'c'	100	126	32	28	30	18	162	172
Class 'b+c'	15	12	4	10	33	16	52	38
Class 'e'	-	0	-	0	-	16	-	16
Class 'd+e'	-	0	-	0	-	17	-	17
Total	188		41		70		299	

ondary species which find their optimum environment under the canopy. On the contrary, the distributions of basal area pointed out three curves with a similar shape.

Symptom surveys

The analysis of the phytopathological conditions of the stand (table III), surveyed in June 1989 only on the living shoots and in October 1993, shows that the dominant trees were generally healthier than the suppressed ones; however, in the last years, only a small percentage of dominants (26.1%) showed no symptoms of decline (class 'a') at all. During the 5 years, the observed mortality (11%) was concentrated on suppressed shoots. The presence of stromata of *H mediterraneum* (class 'd') was never recorded on living shoots.

Damage to the xylem was separated into two categories: i) well datable (present in a single ring) such as 'T' canker and vessel damage, respective results of a bark lesion healed by the plant and occlusion of few xylem cells by dark tannic material; ii) not datable (damage and discoloration extending over several rings). The incidence of both kinds of damage was similar during the observed period with peaks related to years of tree growth crisis and climatic stress conditions.

The results of regression analysis shows that the climatic parameters most significantly and negatively correlated with the presence of the alterations were the rainfalls of June (fig 3) and the minimum temperature of March of the current year (R^2 = 0.45) (table IV). The small number of xylem damages in 1991 was not consistent with the June precipitation value of the same

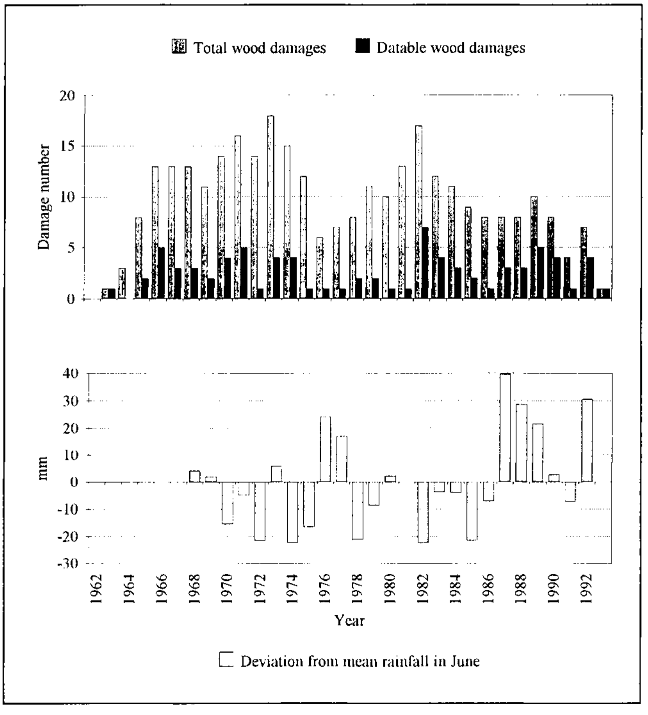

Fig 3. Number of total and datable wood damages in *Quercus cerris* shoots in the stand of Tolfa and deviations of each June rainfall value from the mean rainfall of June in the period 1968– 1992 (weather station of Civitavecchia, Rome).

Table IV. Meteorological parameters significantly correlated in a multiple regression analysis of total damages and meteorological data (monthly values of the current year).

Independent variables	*Coefficient*	*SE*	t-*value*	*Significance level*
Intercept	23.738	3.236	7.335	0.000
Rainfall of June	–0.111	0.032	–3.456	0.002
March minimum temp	–1.251	0.357	–3.505	0.002

R^2 adjusted = 0.45; standard error (SE) = 2.72; mean absolute error = 2.02.

year, but this is well explained by the rainfall surplus which occurred during May (138.6 mm).

Total wood damages are presented by social class (dominant and not dominant) in figure 4 (results are shown in percentage due to the different number of trees sampled in the two groups): it can be observed that dominant shoots recorded more damages than not dominant ones until 1981. To avoid interference of social class, in figure 5 only the data of wood damages in dominant shoots are presented by health condition of trees (healthy and declining dominant): it can be stated that healthy shoots had more damages than declining up to 1972, in 1976–1978 and 1981. The major presence of old wood damages in plants now classified as healthy or dominant may be explained supposing that all categories of plants suffered the same damages during the same years. However, only the stronger shoots could survive and therefore record the wood damages. On the other hand, declining and suppressed weak shoots are a surviving population which escaped these old damages that, otherwise, would have caused their death.

Growth pattern

The tree ring chronologies of the 37 sampled trees were compared and averaged for each social class and phytopathological category. The analysis of current (cai) and

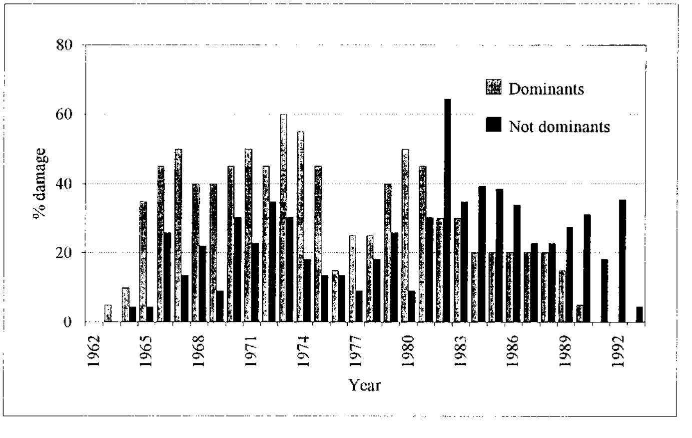

Fig 4. Total wood damages in dominant (20 shoots) and not dominant (intermediate and suppressed, 17 shoots) *Quercus cerris* shoots sampled in the stand of Tolfa.

mean (mai) increment of basal area (fig 6) shows that the stand was clearly differentiated in three well defined social classes: at the age of 30 years, the increment of dominants (cai = 4.17 m^2) was clearly different in comparison with values expressed by the other two classes (cai = 1.62 and 0.75 m^2). The mean increment reached its maximum in 1981 in suppressed shoots (mai = 1.58 m^2) and in 1989 in the intermediate social class (mai = 2.08 m^2). These 2 years may be considered as 'event years' in which disturbances, caused by a severe water deficiency (1981) and defoliation by *L dispar* (1989), determined the end of the positive growth trend. On the contrary, the mai of dominant shoots was still increasing (mai = 4.57 m^2) in 1993 and it was higher than the cai value at the same age, suggesting a continuation of the positive growth phase.

The subdivision of the incremental series according to the two pathological categories shows a correspondence between growth and health conditions in the dominant shoots; dominant shoots classified as healthy in the last 5 years have produced significantly higher basal area increment than declining dominants during their life span (fig 7). It is noteworthy that the absolute values are different in the years characterised by positive growth, whereas they are closer in the years of intense growth crisis.

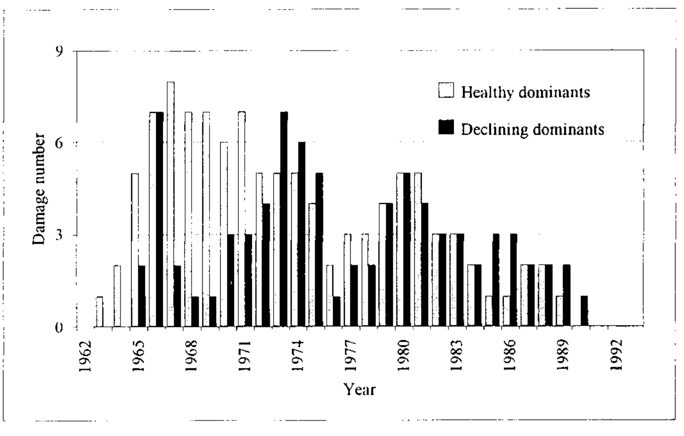

Fig 5. Number of total wood damages in ten healthy and in ten declining dominant *Quercus cerris* shoots sampled in the stand of Tolfa.

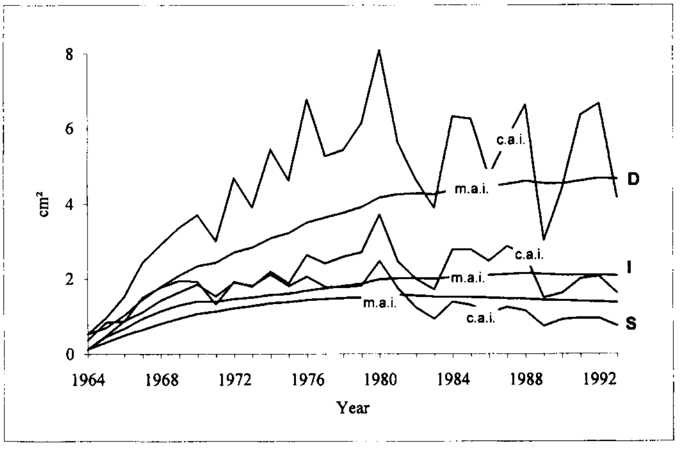

Fig 6. Current (cai) and mean (mai) annual increments of basal area of dominant (D), intermediate (I) and suppressed (S) shoots sampled in the stand of Tolfa during the life span of the coppice.

The increment series of intermediate and suppressed shoots do not show the same clear separation between healthy and declining plants seen in the dominants; this is probably due to a prevalent influence of endogenous factors (much higher selective pressure in the lower social classes) in comparison with the influence of external factors.

Dendroclimatology

The minimum growth rate of trees occurred in the years 1971, 1973, 1975, 1981–1983, 1986 and 1989; therefore, two periods of general growth crisis are discernible: the first one from 1971 to 1975, the second one from 1981 to 1989, corresponding to drought periods in the region. The years 1972, 1976, 1980, 1984, 1988 and 1992 were characterised by both a better growth of trees and a surplus rainfall in May and June (fig 8).

The regression analysis between annual indexed radial growth and meteorological data shows the main factors limiting the growth of *Q cerris* in the area. The meteorological data fitting best the radial growth are the bimonthly values of the current year (R^2 = 0.71): particularly, May and June rainfalls, May and June minimum temperatures, March and April maximum temperatures are positively correlated; March and April minimum temperatures, May and June maximum temperatures, July and August maximum temperatures are negatively correlated

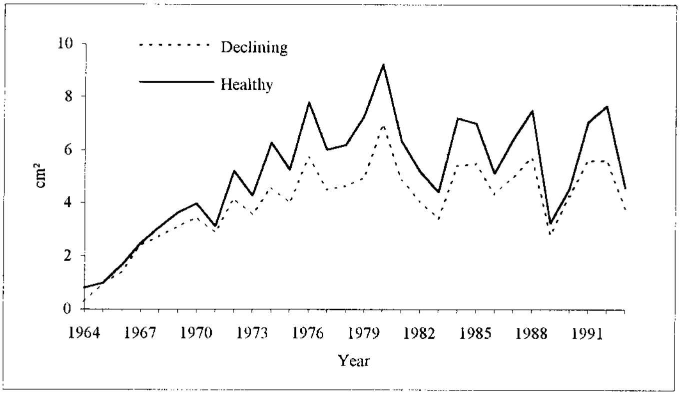

Fig 7. Annual basal area increments of healthy and declining *Quercus cerris* dominant shoots in the stand of Tolfa (means are different at significance level = 0.025; computed *t* statistic = −2.299).

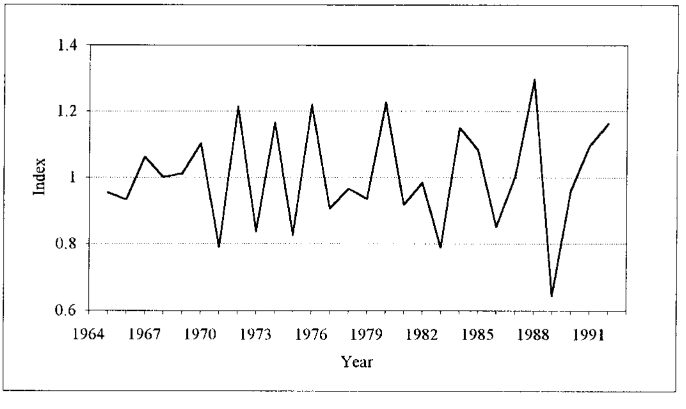

Fig 8. Indexed radial growth values of *Quercus cerris* dominant shoots sampled in the stand of Tolfa.

Table V. Meteorological parameters significantly correlated in a multiple regression analysis of indexed values of current increment of basal area and meteorological data (bi-monthly values of the current year).

Independent variables	*Coefficient*	*SE*	t-*value*	*Significance level*
Intercept	2.149	0.695	3.090	0.007
Rainfall May–June	0.004	0.001	3.876	0.001
March–April minimum temp	–0.137	0.032	–4.296	0.001
May–June minimum temp	0.186	0.041	4.534	0.000
March–April maximum temp	0.190	0.039	4.860	0.000
May–June maximum temp	–0.149	0.039	–3.767	0.002
July–August maximum temp	–0.093	0.020	–4.602	0.000

R^2 adjusted = 0.71; standard error (SE) = 0.076; mean absolute error = 0.051.

(table V). The same analysis, performed separating healthy and declining trees, shows that the previously mentioned meteorological data are significantly correlated to both groups. It is noteworthy that the regression for the declining plants (R^2 = 0.67) is higher than for the healthy plants (R^2 = 0.56), suggesting declining plants are more sensitive to climatic extremes than healthy ones. No significant correlation was shown between radial growth and meteorological data of the previous year.

DISCUSSION

The analysis of climatic parameters suggests that, on the study site, *Q cerris* grows at its environmental limit. So far, the species has only been maintained due to the silvicultural system applied (repeated coppicing and agamic regeneration). The climatic parameters significantly correlated with radial growth are those expected for *Q cerris* in the Mediterranean area. In fact, the largest part of the annual wood increment of *Quercus* spp (especially Mediterranean oaks) is built during early spring (Zahner, 1968); all climatic factors acting in this short period are crucial in determining the annual ring width. Furthermore, summer maximum temperatures, combined with drought, induce such a water stress which reduces or prevents from any further radial wood increment.

Besides main climate characteristics, other factors have a strong influence on *Q cerris* growth, in particular disturbance factors such as coppicing, grazing and the presence of *H mediterraneum*, a fungus acting as pathogen in weakened oaks. Cattle grazing also has a strong impact, causing direct damage to the lower part of the trees, and indirect damage by compacting the soil. The action of these factors has strongly influenced the evolution of stand structure, determining the interruption of the cover in some microenvironments as a result of a highest competition between stumps and shoots. Therefore, the number of stumps is reduced in comparison with the average value measured in other stands of the same age and similar specific composition (Amorini and Fabbio, 1991).

The current increment trend follows the sequence of competition cycles already examined in other coppices under natural evolution (Amorini and Fabbio, 1987; Fabbio, 1994). A first selection phase is over at 18 years (1981), when a share of population lost its social rank (mai culminated in suppressed shoots). A second cycle is over at 25 years (1989), in correspondence with the culmination of intermediate shoots mean increment, age in which this social class regressed from the dominant storey. A third cycle is in course at present.

Relative health of Turkey oak trees in the study site was discernible by means of a simple observation of symptoms on the trunks. The observed correspondence between recent symptomatology and the growth during the entire period indicates that such symptoms are peculiar in plants characterised by a relatively low growth rate. It seems that the population was split into two groups, characterised by different growth rhythms, soon after coppicing. Healthy and declining trees showed the same increments in only 2 years with drastic growth reduction, probably because of the greater vigour of healthy plants which suffer like declining ones the drastic reduction of growth factors (event years), while they are able to optimise their full potentiality.

The correspondence between the incidence of wood damages and the growth crisis periods confirms that climatic stresses are factors inducing such decline symptoms. Some of the signs observed in the wood, in fact, are probably the effect of xylem cavitation induced by water stress (ie, vessel damage) or the residual trace of bark bleeding, a symptom not related to any biotic causal agent (Belisario et al, 1993).

A major consequence of the observed decline is to accentuate the mortality of suppressed shoots and to alter the vegetative conditions of those dominants which seem to be predestined to have a competitive disadvantage since the beginning of the rotation. In the natural evolution of the stand, it is likely that these declining shoots will be the ones to be eliminated in favour of the best individuals when severe environmental stress occurs. The observed decline fits well the Manion decline theory (1981). In particular, the case of coppice decline points out the natural action of decline in determining the even-aged stand evolution (Mueller-Dombois, 1992).

The natural disturbance factors are not controllable and are exalted by human interferences (Oliver and Larson, 1990). It is evident that the functional recovery of such areas needs a careful management strategy, to eliminate main human disturbance factors, such as grazing and repeated coppicing in a short rotation, in order to increase the resistance of these stands against other disturbances.

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